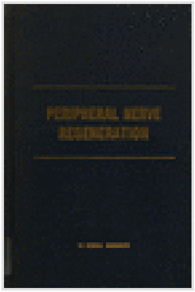


Peripheral Nerve Regeneration; a Follow-Up Study of 3,656 World War II Injuries. Editors: Barnes Woodhall and Gilbert W. Beebe. 26 June 1956 (1957)

Pages
699

Size
5 x 8

ISBN
0309292212

Barnes Woodhall and Gilbert W. Beebe, Editors; Division of Medical Sciences; National Research Council

VA Medical Monograph

PERIPHERAL NERVE REGENERATION

A Follow-up Study of 3,656 World War II Injuries

Editors

BARNES WOODHALL, M. D.
Professor of Neurosurgery
Duke University Medical School
Durham, North Carolina

and

GILBERT W. BEEBE, Ph. D.
Statistician, Follow-up Agency
Division of Medical Sciences
National Research Council
Washington, D. C.

26 JUNE 1956

The work reported herein is part of the program of studies of the Follow-up Agency of the National Research Council developed by the Committee on Veterans Medical Problems in cooperation with the Veterans Administration, the Army, and the Navy.

This investigation was supported by the Veterans Administration upon the specific advice of the Committee on Veterans Medical Problems of the National Research Council and was conducted as a collaborative effort under contracts with the medical schools of Duke University, Columbia University, Northwestern University, the University of Pennsylvania, and the University of California, with the Massachusetts General Hospital, and with the National Academy of Sciences.

LIST OF VA MEDICAL MONOGRAPHS

In Print

A Follow-up Study of World War II Prisoners of War
Tuberculosis in the Army of the U. S. in World War II
A Follow-up Study of War Neuroses
Peripheral Nerve Regeneration: A Follow-up Study of 3,656 World War II Injuries

In Preparation

Sequelae of Acute Viral Hepatitis
Late Effects of Arterial Interruption in Battle Casualties of World War II
The After-Effects of Head Injuries Sustained in World War II
Late Effects of Cold Injuries (Ground Type) Sustained in World War II

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C.

Foreword

To the Series of Monographs on Medical Follow-up Studies

It may have been said by the casual reader that this series of monographs arose from war and owed its interest to the aftermath of war, but this would be less than half truth. It is true that those who saw and mended the wounds of combat took immediate steps to learn in peace the medical cost and errors of war. But the studies which these monographs report are not limited to war injury, and by design are applicable to all patients and all medicine, and to the improvement of medical education wherever practiced or needed. They grew from a concept that was then expressed in part as follows:

"During the period beginning with the mobilization of the Army in 1940 and continuing to date an enormous amount of material of great clinical value has accumulated in the records kept in * * * medical installations * * * of the Armed Forces. It can fairly be said that no similar amount of material has ever been accumulated, and it is doubtful whether a similar amount will ever again be available." * * *

"It is suggested that this accumulation of material should be turned to practical use by the establishment of a clinical research program, including a follow-up system to determine the natural and post-treatment history of such diseases and conditions as might be selected for the study." * * *

"At the clinical research level it furnishes an opportunity to provide an investigative program in which the entire medical profession would participate and from which all would profit." (Memorandum of 5 March 1946 from Dr. Michael E. DeBakey, then Colonel, Director of Surgical Consultants Division, to The Surgeon General of the Army Norman T. Kirk.)

Undoubtedly there were other such generous suggestions during World War II, and indeed DeBakey cited the Army experience with several, such as the registry on peripheral nerve injuries, but this one was well placed and pursued with energy.

General Kirk transmitted the plan to the National Academy of Sciences—National Research Council (NAS–NRC), and Dr. Lewis H. Weed, Chairman of its Division of Medical Sciences, invited an ad hoc committee to consider the feasibility of the proposal. This committee, with Dr. Edward D. Churchill as chairman, in the course of three meetings, April to June 1946, in approving the plan, recommended a standing Committee on Veterans Medical Problems to guide the studies and an operating agency to conduct them. With the stout backing of General Paul R. Hawley, Chief Medical Director, Dr. Paul B. Magnuson, Assistant Medical Director for Research and Education, promised the support of the Veterans Administration, and the Surgeons General of the Army, Navy, and the U. S. Public

Health Service expressed their approval. Thus the Committee on Veterans Medical Problems came into being in August 1946 under the chairmanship of Dr. O. H. Perry Pepper, and the Follow-up Agency was constituted under Dr. Gilbert W. Beebe.

In the intervening 10 years natural changes have occurred in committee and staff personnel with one exception, and it is to this exception that we owe the continuity, the excellence of experimental design and analysis, the high quality, and even the actual production of the reports of these studies. That exception is the stability of the senior group in the Follow-up Agency: Dr. Gilbert W. Beebe, Dr. Bernard M. Cohen, and Mr. Seymour Jablon.

This group foresaw and its successors found a panorama of opportunities largely neglected after previous wars: a reservoir of pathological material (now in the Armed Forces Institute of Pathology) common to the military and the succeeding veteran; a punchcard index of episodes of illness in a large segment of our population; a verteran population more easily located and more readily motivated to participate in specific studies than any other large population group; and an integrated system of medical care with emphasis upon war-connected illness or injury administered by 173 hospitals and 69 regional offices, so located that some experience all extremes of climate and altitude that exist in our nation, supplemented by the hospitals' close association with medical faculties through the Deans Committees of 73 medical schools with a like geographic distribution. In all these resources there is a continuing record of stress, trauma, and disease in which illness or injury, from induction in the Armed Forces to death of the veteran, generates a permanent record available for study.

To take full advantage of these obvious opportunities the Committee on Veterans Medical Problems was charged with the broad responsibility for initiating and fostering a general program of medical follow-up studies based on experience with the military and veteran population. Under this committee was organized the Follow-up Agency of the National Research Council to carry out the staff functions associated with the planning and organization of research projects, arranging access to medical records, and providing statistical analysis.

The program is a general one, its unity arising out of the availability of a research tool of broad applicability in clinical medicine, especially in the area of the natural history of disease. Some studies have been based entirely on existing records (military, clinical, pathological, mortality, disability) while in others the recorded information has been supplemented by intensive current laboratory and clinical observations.

Much of the product of the program will be found in medical periodicals appropriate to the subjects of investigation. However, some of the studies are of such magnitude as to require reporting at greater length than would be possible even in a series of journal articles. The Veterans Administration, therefore, has inaugurated this series of monographs as the most effective means of presenting the results of these larger studies.

The Veterans Administration has provided the direct financial support for the majority of the studies in this program and the Armed Forces have provided strategic support in the form of access to necessary records and ancillary services. Many Federal, State, and private agencies have also given generous assistance to the work as required. Field installations of the Veterans Administration—hospitals, regional offices, and record repositories—have joined with the Central Office in extending needed assistance to the NRC and the investigators responsible for the direction of these studies. While the commitments were made by the Chief Medical Director, most of the VA resources essential to the success of such a program lie under the administrative control of groups other than the Department of Medicine and Surgery, and yet the necessary aid always has been promptly, efficiently, and cheerfully given.

We of the present staff of the Veterans Administration are much indebted to the initial group of planners and to their successors on the Committee on Veterans Medical Problems, to many officers and civilians on duty in the offices of the Surgeons General of the Armed Forces and in the record repositories of the Armed Forces, to our own predecessors in the Veterans Administration, to the editors and contributors of each volume, and to the officers, staff, and members of National Academy—Research Council, but most particularly to the continuing staff of the statistical Follow-up Agency. We wish also to emphasize here the peculiar distinction of the National Research Council in bringing together in one effort the research talents of our Nation—those of universities, professional societies, various governmental agencies, and private physicians.

The Veterans Administration is proud of its privilege in presenting this series of monographs in the belief that each volume is a contribution to all medicine, but most particularly in the conviction that its conception in cooperation is a peculiar contribution of and by a free American Medicine.

JOHN B. BARNWELL, M. D.
Assistant Chief Medical Director
for Research and Education.

PARTICIPANTS IN VETERAN FOLLOW-UP PROGRAM AT THE LEVEL OF THE NAS-NRC

Chairman, Division of Medical Sciences

Dr. Lewis H. Weed, 1939–49
Dr. Milton C. Winternitz, 1949–53
Dr. R. Keith Cannan, 1953–

Members and Staff, Committee on Veterans Medical Problems

Members:

- Dr. H. Glenn Bell, 1950
- Dr. David A. Boyd, Jr., 1956–
- Dr. Francis J. Braceland, 1946–48
- Dr. W. Edward Chamberlain, 1956–
- Dr. Edward D. Churchill, 1946–1948
- Dr. Winchell McK. Craig, 1946–1949
- Dr. Wilburt C. Davison, chairman, 1950–55; member, 1956–
- Dr. Michael E. DeBakey, 1946–
- Dr. Louis I. Dublin, 1946–47
- Dr. Jacob E. Finesinger, 1952–
- Dr. Morris Fishbein, 1946–51
- Dr. A. McGehee Harvey, 1953–
- Dr. A. LeRoy Johnson, 1951–53
- Dr. Chester Scott Keefer, 1949–1950
- Dr. Esmond R. Long, chairman, 1956–; member 1952–55
- Dr. Perrin H. Long, 1946–53
- Dr. Currier McEwen, 1956–
- Dr. Donald Mainland, 1953 and 1956–
- Dr. Herbert H. Marks, 1948–53
- Dr. William C. Menninger, 1946–1948
- Dr. H. Houston Merritt, 1952–53
- Dr. J. Roscoe Miller, 1946–53
- Dr. Hugh J. Morgan, 1946–48
- Dr. O. H. Perry Pepper, chairman, 1946–49; member 1950
- Dr. I. S. Ravdin, 1949–50
- Dr. C. P. Rhoads, 1946
- Dr. William S. Stone, 1956–
- Dr. Roy H. Turner, 1951
- Dr. John C. Whitehorn, 1949–50
- Dr. Milton C. Winternitz, 1946–1949
- Dr. Stewart G. Wolf, 1951
- Dr. Harold G. Wolff, 1949–50
- Dr. Barnes Woodhall, 1951

Staff:

- Dr. John C. Ransmeier, 1946–48
- Dr. Thomas Bradley, 1953–56
- Dr. Theodore S. Moise, 1948–53
- Dr. Gilbert W. Beebe, 1946–

Follow-Up Agency Professional Staff

Senior Statisticians:

Dr. Gilbert W. Beebe, 1946–

Dr. Bernard M. Cohen, 1948–

Mr. Seymour Jablon, 1948–

Operations:

Miss Regina Loewenstein, 1948–1954

Miss Nona-Murray Lucke, 1947–1951

Mr. A. Hiram Simon, 1949–

Mr. Sidney Wald, 1951–54

PERSONNEL OF DEPARTMENT OF MEDICINE AND SURGERY, VETERANS ADMINISTRATION, RESPONSIBLE FOR INITIATION AND CONTINUED SUPPORT OF PROGRAM OF VETERAN FOLLOW-UP STUDIES

Chief Medical Director

Dr. Paul R. Hawley, 1946–47
Dr. Paul B. Magnuson, 1948–51
Dr. Joel T. Boone, 1951–55
Dr. William S. Middleton, 1955–

Assistant Chief Medical Director for Research and Education

Dr. Paul B. Magnuson, 1946–47
Dr. E. H. Cushing, 1948–52
Dr. George M. Lyon, 1952–56
Dr. John B. Barnwell, 1956–

Director, Research Service

Dr. E. H. Cushing, 1946–47
Dr. Louis Welt, 1947–48
Dr. Alfred H. Lawton, 1948–51
Dr. John C. Nunemaker, 1952
Dr. Arthur F. Abt, 1952–53
Dr. Martin M. Cummings, 1953–

Chief, Contractual Division, Research Service

Dr. Marjorie Price Wilson, 1952–53
Dr. Theodore S. Moise, 1953–

Special Assistant to Assistant Chief Medical Director for Research and Education

Mr. Robert A. Kevan, 1946–48
Mr. Ralph T. Casteel, 1948–55

COLLABORATORS IN THE FOLLOW-UP STUDY OF PERIPHERAL NERVE INJURIES

The present study constitutes a large collaborative effort on the part of many investigators representing several disciplines and eight institutions. In addition to the contributors of the individual chapters, many others have shared in the planning and organization of the work, including development of the standard protocol for the examination, and in the examinations of patients.

Membership in the study group is listed below; composition of the teams at the respective centers is indicated in the footnotes.

Barnes Woodhall, M. D., Chairman
Professor of Neurosurgery
Duke University
School of Medicine
Durham, N. C.

Gilbert W. Beebe, Ph. D.
Statistician, Division of Medical Sciences
National Research Council
Washington, D. C.

Loyal Davis, M. D.[1]
Professor of Surgery
Northwestern University
Medical School
Chicago, Ill.

Thomas L. DeLorme, M. D.[2]
Instructor in Orthopedics
Massachusetts General Hospital
Boston, Mass.

S. Malvern Dorinson, M. D.[3]
Director, Physical Medicine
Maimonides Hospital
San Francisco, Calif.

Harry Grundfest, Ph. D.[3]
Associate Professor of Neurology
Columbia University
College of Physicians and Surgeons
New York, N. Y.

Ernst Herz, M. D.[3]
Assistant Professor of Clinical Neurology
Columbia University
College of Physicians and Surgeons
New York, N. Y.

Frederic H. Lewey, M. D. (deceased)[4]
Associate Professor of Neuropathology
University of Pennsylvania
School of Medicine
Philadelphia, Pa.

William R. Lyons, Ph. D., M. D.
Professor of Anatomy
University of California
Medical School
Berkeley, Calif.

Joseph Moldaver, M. D.[3]
Associate in Neurology
Columbia University
College of Physicians and Surgeons
New York, N. Y.

Howard C. Naffziger, M. D.[5]
Professor of Surgery
University of California
School of Medicine
San Francisco, Calif.

Frank E. Nulsen, M. D.[4]
Professor of Neurosurgery
Western Reserve University
School of Medicine
Cleveland, Ohio

Y. T. Oester, M. D.[1]
Associate Professor of Pharmacology
Stritch School of Medicine
Loyola University
Chicago, Ill.

See footnotes on page x.

Lewis J. Pollock, M. D.[1]
Professor of Neurology
Northwestern University
Medical School
Chicago, Ill.

Robert S. Schwab, M. D.[2]
Assistant Clinical Professor of Neurology
Harvard University Medical School
Boston, Mass.

Bertram Selverstone, M. D.[2]
Professor of Neurosurgery
Tufts College Medical School
Boston, Mass.

Eugene B. Spitz, M. D.[4]
Assistant Professor of Neurosurgery
University of Pennsylvania
School of Medicine
Philadelphia, Pa.

Arthur L. Watkins, M. D.[2]
Assistant Clinical Professor of Medicine
Harvard University
Medical School
Boston, Mass.

Eugene M. Webb, M. D.[5]
Assistant Clinical Professor of Neurosurgery
University of California
School of Medicine
San Francisco, Calif.

James C. White, M. D.[2]
Professor of Surgery
Harvard University
Medical School
Boston, Mass.

Melvin D. Yahr, M. D.[3]
Assistant Professor of Clinical Neurology
Columbia University
College of Physicians and Surgeons
New York, N. Y.

Korea intervened before the work of the original study group could be completed and provided an opportunity for the further study of early peripheral nerve injuries. Dr. Frank E. Nulsen organized a team of investigators which included William J. Erdman, II, M. D., Instructor, Physical Medicine and Rehabilitation, University of Pennsylvania Medical School, and Harry W. Slade, M. D., Instructor in Neurosurgery, Western Reserve University School of Medicine. This work was done on Army patients at Valley Forge General Hospital, under a contract between the Army and the University of Pennsylvania.

[1] Member of the Chicago team, headed by Dr. Davis.
[2] Member of the Boston team, headed by Dr. White.
[3] Member of the New York team, headed by Dr. Grundfest.
[4] Member of the Philadelphia team, headed by Dr. Lewey.
[5] Member of the San Francisco team, headed by Dr. Naffziger.

Foreword

The publication of this study of peripheral nerve regeneration after battle-incurred injury marks the end of a huge clinical research program that began in 1943, in the course of World War II. The program was participated in by more than a hundred of the neurosurgeons who served in the Medical Corps, as well as by many neurologists, neuroanatomists, neurophysiologists, neuropathologists, physical therapists, statisticians, and representatives of the administrative personnel of every echelon of command in the Army Medical Corps. Later the program was also participated in by representatives of the Veterans Administration and the National Research Council.

A clinical research program of such magnitude has probably never before been attempted by Federal agencies concerned with the care and rehabilitation of military personnel. That enthusiasm for its completion should have extended over the 11 postwar years is in itself a remarkable fact. It is also a lasting tribute to the foresight and tenacity of the man who conceived this project and brought it to fruition, Dr. Barnes Woodhall, now Professor of Neurosurgery at the Duke University School of Medicine and formerly Lieutenant Colonel, Medical Corps, A.U.S.

This investigation does not, of course, provide all the answers to all the unsolved problems of peripheral nerve surgery. For one thing, it was not possible, as is true in all clinical research programs, to set up ideal control conditions for all phases of the study. In wartime the pressure of routine work in the operating room and out of it left surgeons with little time, strength, or enthusiasm to keep accurate records of all the details essential in a research investigation. Furthermore, as the editors point out, when this study was conceived, the investigators themselves did not know exactly what information regarding the early care of patients with peripheral nerve injuries would prove to be of the greatest importance.

In spite of these deficiencies, many basic problems have been answered by this investigation, and to the satisfaction, it seems certain, of the most critical observer. We now know, for instance, the optimum time for nerve suture and the value of physical therapy during the period of regeneration. We can accept the validity of the concept that one must be radical in the exploration of every case of nerve injury with total loss of function but extremely conservative before one substitutes end-to-end suture for neurolysis when continuity of the nerve has not been interrupted. We also know now that the degree of functional recovery can be prophesied with reasonable precision by estimating the distance of the lesion from the area of principal innervation. These examples are only a few of the basic concepts established, with irrefutable evidence, by this study. The answers to certain technical problems concerned with peripheral nerve repair are somewhat less conclusive.

When this manuscript, which contains about 900 pages of text, tables, charts, and graphs, came to my office with the request that I write the foreword, I am afraid I groaned at the prospect of giving my leisure for the next month to digesting the contents. To my surprise and pleasure, I found the material of so much interest that within a week, during which I gave more than my leisure to it on some days, I had completed the first reading of the entire manuscript. The text is well organized and is presented in a remarkably lucid manner, which is not always true of a manuscript that has multiple authors. Some of the statistical material, particularly the tables and graphs, were not easy going for a neurosurgeon who is not a statistician at heart, but even these, with the proper application, became readily understandable. Now, after another reading, I can say, with complete truthfulness, that this is a most remarkable document, and one that is well worth the full attention of any physician who is interested in neurosurgery or in battle-incurred injuries.

In peacetime, the busiest civilian clinics do not see enough peripheral nerve injuries to permit authoritative conclusions to be drawn about their management. In World War I, large numbers of these injuries were skillfully cared for by a small group of pioneer neurosurgeons, but there was no comprehensive follow-up and the opportunity to use the experience to the fullest possible extent was lost. It is gratifying that after World War II the same splendid opportunity was not lost again.

Every man, woman, or child who has seen war and its aftermath will hope prayerfully that the opportunity to study such large masses of battle casualties as are represented in this volume will never again occur. But, should future generations be faced by a similar catastrophe, this monumental work on peripheral nerve regeneration will ease the task of those who must care for these injuries and will assure the victims of another war better functional results than our generation of neurosurgeons has been able to achieve.

R. Glen Spurling, M. D.

Table of Contents

Introduction

Barnes Woodhall

More than 10 years have elapsed since the first casualties of the African invasion arrived at the Walter Reed General Hospital for continuing treatment of their war wounds. In this initial convoy of 94 casualties, the harbinger of many others, were 10 peripheral nerve injuries. They were the first of 25,000 peripheral nerve injuries that were subsequently distributed among 19 neurosurgical centers established by the Army Medical Corps. Many of these patients had already received definitive peripheral nerve surgery in specialized neurosurgical facilities in general hospitals in England and in the North African theater. The responsibility for their treatment rested upon a small group of young neurosurgeons who had been largely recruited under the leadership of Colonel R. Glen Spurling of Louisville, Ky., and upon others who were in turn stimulated to initiate a similar program among injured personnel of the Navy and Marine Corps. To this nidus of neurosurgically trained individuals was added a larger group, both here and overseas, of general surgeons who had been trained under civilian, Army, and Navy auspices in the specific demands of military neurosurgery. In this respect, particular mention should be made of schools established at Columbia University and at the University of Pennsylvania under, respectively, Tracy Putnam and Francis Grant, where general surgeons were indoctrinated in neuroanatomy and neurophysiology. These were experimental ventures at the time but they proved exceedingly worthwhile.

The tradition of peripheral nerve surgery of war had been in large part dimmed by the passage of time since World War I, not only in this country but in the whole world. The 3,500 nerve casualties of that conflict had been absorbed in the veteran population, and the care of similar injuries, incurred in the growing industrial life of the United States, was spread widely among any and all surgeons. Only in our medical schools could the student of surgery encounter this tradition and this contact was but a casual one. The Friday morning surgical clinics of Professor Dean Lewis at the Hopkins were too rarely highlighted by the laborious progress of a fourth-year medical student around the circular highway of the anatomical structures of the wrist, with particular attention being directed to the nerve supply of the intrinsic hand muscles. Such grueling episodes might have been repeated with Loyal Davis in Chicago, the late Claude C. Coleman in Richmond, the late Charles Elsberg in Philadelphia, or with Byron Stookey in New York City. Lewis Pollock, with Loyal Davis and also Byron Stookey, published textbooks devoted to this subject. There undoubtedly were others who endeavored to sustain interest in a subject which often was delegated to the attention of the surgical intern on call in the emergency room. The Medical History of World War I concerned with neurosurgery weighed 8 pounds and, on the back shelves of the medical libraries, appeared lost to many observers. It contained the neuropathological research studies of Carl Huber and his associates and a very complete clinical section by K. Winfield Ney, both as valid at the start of World War II as they had been when written.

The Neurosurgical Centers of World War I, at Cape May and elsewhere, had registered some 3,000 peripheral nerve injuries, with the hope that some type of follow-up program might be instituted in the postwar years. Registers of 3,129 peripheral nerve injuries were completed. The examinations of 400 cases of nerve suture by physicians of the Veterans Administration in the postwar period were only reported in terms of good, mediocre, or negative. An analysis of 470 cases by a single neurosurgical observer yielded 34 percent "good" results, 36 percent "mediocre," and 26 percent "failures." No objective definition of these terms was published.

The situation was little better in the other countries that had been engaged in the battles of World War I. In England, Sir Robert Jones had assembled a distinguished group of surgeons, anatomists, and neurophysiologists with the knowledge and skill to study and treat nerve injuries, and their casualties too were segregated in specialized centers. The members of this group might be termed the opposite numbers of the surgeons, who, for a shorter period, served in a similar capacity in the United States Army. No arrangements were made, however, for the analysis of the vast amount of data assembled by these observers and the report on nerve injuries published by the Medical Research Council in Great Britain was an inconclusive one. Again the only surgeons who evinced interest in this matter in the postwar years were those few who had participated directly in nerve surgery during World War I. No follow-up studies were available from the other major combatant powers, France and Germany, although the infrequently read observations made by Tinel and Foerster in this field were of the highest order.

In October 1944, The Surgeon General of the United States Army, Major General Norman T. Kirk, directed the establishment of a Peripheral Nerve Registry for the dual purpose of evaluating the existing program of nerve surgery and laying a foundation for postwar studies. Registry forms were devised, sent to all neurosurgical hospitals, and the completed initial and 3-months' assessment reports were forwarded to the Surgeon General's Office. In consultation with Army representatives, the neurosurgical services of the naval hospitals at St. Albans (New York) and Oak Knoll (San Francisco) agreed to collect similar data on their nerve injuries in sailors and marines. These reports were coded and filed under the statistical guidance of the Medical Statistics Division of the Surgeon General's Office. By September 1945, a total of 7,050 nerve sutures and

67 nerve grafts had been registered. As this basic roster was being compiled, identical efforts on a more circumscribed scale were being initiated by individual observers, the most comprehensive of these being that assembled under the direction of the late Frederic H. Lewey at the Cushing General Hospital. It was clearly manifest during the war period that the data recorded on the individual patient's history varied greatly in detail and accuracy, due presumably to lack of planning in the prewar period. It is a historical fact, however, that such planning proceeded at a rapid pace during the war years and, as the fighting in the Western theater came to its end, postwar study centers were envisaged. The time hiatus between discharge from military hospital and the functioning of these study centers interdicted the study of many longitudinal data. On the other hand, the large rosters which are mandatory in the study of such a many-faceted injury were available, and the essential information upon which a follow-up study of late peripheral nerve regeneration largely depends, was at hand, both in the hospital records and registry forms. These were indisputable advantages which favored any proposed postwar study.

The lack of good longitudinal data in the original study project has been alleviated in large part through a meticulous survey of early peripheral nerve injuries in casualties from the Korean campaign hospitalized in the Valley Forge General Hospital. This project, initiated and carried on by Frank E. Nulsen, under an Army contract recommended by the National Research Council, represents an early and very valuable dividend from these basic studies. They represent some foretaste of what this monograph may establish on a firm foundation for the future.

The study centers and their organization responsible for this report are described in the early part of this monograph. Their objectives could be visualized but were not to be readily attained. The elaborate patterns of synergistic muscle activity and sensory synthesis that are damaged when a peripheral nerve is divided are not easy to study, either as an initial and relatively static injury or during the course of spontaneous or acquired nerve regeneration. Statistical data may be provided by the measurement of the return of voluntary power in muscle and the return of sensibility in skin and deeper tissues. The physiological changes that occur in denervated and reinnervated muscle in electrical excitability and electromyographical activity are also susceptible of statistical analysis. From such data, some of the factors, both biological and technical, that influence peripheral nerve regeneration may be assessed. The average expectation of anatomic regeneration may be plotted with reasonable certainty, and in relation to the varying factors of time interval, height of lesion, specific neuropathology, and a host of others, but in the aggregate such factors as these do not so closely determine the end result as to enable prognoses to be made with confidence about individual cases. The variables having to do with retrograde neuronal reaction, delayed recovery, incomplete recovery and persistent transsynaptic effects are beyond the skill of a surgeon to influence and may largely contribute to the fact that recovery after nerve division is never complete, even under the most favorable circumstances.

A considerable mass of statistical material has been collected and studied. It is valid, difficult to read, and represents the source data from which certain clinical conclusions have been expressed. It must be emphasized that in 92 percent of the cases the follow-up data were secured 3 or more years after suture (or, for lyses, after injury), and that the median length of follow-up is 52 months. They do not, therefore, reflect the different findings that may be seen immediately after nerve injury or suture and in the early period of neural regeneration.

From the whole complex functional result must be abstracted, for purposes of statistical analysis, those components which somehow seem more important or which are more reliably measured, with the realization that the status of functional regeneration is more than the sum of these components and reflects in part influences which extend far beyond mere anatomic reinnervation. These factors become increasingly evident years after injury when the results of treatment may be studied in terms of function of the entire extremity rather than its component parts. During this time, the patient has become adjusted to his residual disability both mentally and physically, and the extent of his readjustment may be defined as functional regeneration. The neural basis of skilled movement, involving motor and sensory neurons and central integration, must be reestablished on the basis of either diminished stimuli and effectors or reeducated in terms of new patterns introduced through the medium of tendon transfer. The patient himself has a profound influence upon the extent of his own functional regeneration, both from the point of view of his personal reaction to injury and the demands of his occupational training. An effort has been made to analyze functional regeneration in this report, although any type of truly scientific expression of this faculty is lacking.

The primary purpose of this study of postwar nerve regeneration has been that of providing for the surgeon of the future a body of information upon which he may guide repair of injured peripheral nerves and initiate needed orthopedic rehabilitation. In particular, a clear knowledge of the regeneration which can be expected from a given nerve suture in a given location will allow an intelligent choice between the alternatives of such surgical treatment as opposed to preservation of a nerve lesion permitting partial function. The more accurate early anticipation of end results will also delineate more promptly the indicated orthopedic measures. Prolonged hospitalization can be curtailed far short of an end point for nerve regeneration when it is clear that all applicable rehabilitative measures have been utilized. In the closing chapter an attempt has been made to draw from the material, supplemented by extensive clinical experience with the problem, its implications for the management of lesions in the future. Finally, not the least of the aims of this investigation has been that of procuring for the Armed Forces adequate information on the time spent in hospital by men with well-defined peripheral nerve injuries and of securing specific information on residual disabilities.

This work is a classical example of cooperative clinical research, subject to the strengths and weaknesses of such an endeavor. The investigators concerned with sifting this huge mass of material were individuals of proved talent, working under certain handicaps characteristic of the veteran population, pioneering in a new field and possessed of strong personal interests in the total area of peripheral nerve injury. They were permitted full freedom of research interest since they were eminently qualified as responsible investigators. The exigencies of the problem of evaluating peripheral nerve regeneration required the use of diverse talents, largely outside the domain of clinical or operative neurosurgery. To these neurophysiologists, the seeming lack of surgical direction and the apparent failure early to establish questions to be answered or denied, beyond those designated in the initial code design, must have been a continuing source of irritation. In retrospect, their criticisms may be valid. On the other hand, by this technique objective data of great variety and detail, unprejudiced by previous thinking, have been laboriously collected and this is the major contribution of this inquiry.

This monograph is not a textbook of peripheral nerve surgery. During the longtime period encompassed by this study of neural regeneration, a number of clinical contributions have been published that have stemmed from this identical material. These include studies on peripheral nerve diagnosis, the neuropathology of peripheral nerve injuries and critical evaluations of electrodiagnostic techniques. From the data presented in the body of the monograph, certain surgical conclusions have been reached or, when necessary, restated so that the informed surgeon can treat a new peripheral nerve injury with a firm concept of the result that he will attain under the diverse and many factors that influence such an injury. The wide clinical spectrum of peripheral nerve injury has been reviewed in fresh format and meticulous insight in the newly published British peripheral nerve report in which chapter VIII alone is devoted to the results of peripheral nerve suture.

From the technical point of view of defining the source of data, the assembling and presentation of data, the discussion of ancillary or specialized topics, and the marshalling of pertinent conclusions, this monograph stands as a study in continuity. No facile or superficial method has been found to substitute for the rather painstaking recording of factual data although considerable effort has been expended to formulate conclusions in a readable form. The casual reader should lay aside this report; the reader who commences his task in the middle of this monograph will make a grave error. To this should be added the observation that the reader who completes the monograph is a brave disciple of our art.

Many individuals and agencies have contributed to this effort to salvage from the surgical experience of World War II basic information on the

Chapter I

ORGANIZATION AND CONDUCT OF STUDY

Gilbert W. Beebe and *Barnes Woodhall*

A. INTRODUCTION

At the time of the Conference on Postwar Research called by the National Research Council (NRC) (56) in 1946, prominent reference was made to the desirability of a study of peripheral nerve injuries based on the Army Registry, and, when the NRC accepted from the Armed Forces and the Veterans Administration (VA) a mandate to develop the means for exploiting the medical experience of World War II, it was inevitable that the present study be among the first proposed. A preliminary plan was circulated by Dr. Woodhall in the fall of 1946 and at the request of the VA the NRC called, in January 1947, a Peripheral Nerve Conference [a] to review objectives, prepare specific plans, and settle upon the centers where necessary work might be performed. The resulting research protocol, further refined by those who were to take the lead in the conduct of the subsequent work, was submitted to the VA through the Committee on Veterans Medical Problems of the NRC and recommended for financing in March 1947 in the first group of projects under the new program. As one of the first studies sponsored by the Committee, the peripheral nerve study was begun without having the benefit of any prior experience in medical follow-up studies on veterans, or of existing procedures for insuring access to veterans and their records. It was, in fact, in large part through the peripheral nerve project that the procedures necessary to the success of the entire VA–NRC follow-up program were evolved.

The research plan was a very general one, concerned chiefly with the specification of the follow-up observations to be made and of the university

[a] Those attending were:

Conference Members—Drs. Loyal Davis (Chairman in Dr. Woodhall's unavoidable absence), Harry Grundfest, Thomas Hoen, Frederic H. Lewey, W. K. Livingston, Lewis J. Pollock, Curt P. Richter, R. G. Spurling, W. P. Van Wagenen, Arthur J. Watkins, Paul W. Weiss, and James C. White.

U. S. Army—Lt. Col. R. P. Mason, M. C., War Department General Staff. Major S. J. Vogel, Jr., M. C., Office of The Surgeon General. Mr. J. J. Ozog, Medical Statistics Division, Office of The Surgeon General.

U. S. Navy—Captain George B. Dowling (MC), Bureau of Medicine and Surgery. Commander R. A. Phillips (MC), Bureau of Medicine and Surgery. Lt. (j. g.) E. N. Weaver (MC), Naval Hospital, Bethesda, Md.

Veterans Administration—Drs. E. H. Cushing and C. Harrison.

National Research Council—Drs. Lewis H. Weed, S. D. Aberle, Gilbert W. Beebe, and John C. Ransmeier.

centers where the patients would be seen Before actual work could begin it was necessary for the investigators to engage in more definitive planning both with respect to the observations to be made and the selection of cases for study, and for the Committee and the VA to work out procedures for facilitating access to both records and patients. It was also necessary to develop an administrative pattern for the organization of the work as a cooperative endeavor of the investigators on the one hand and the Committee, through its Follow-up Agency,[7] on the other. Specific planning along these lines proceeded only slowly and it was a year before any real beginning could be made on the work.

Beginning in the January 1947 Peripheral Nerve Conference and continuing thereafter, great emphasis was placed upon the prospective value of detailed, largely quantitative studies of specific modalities in contrast to broad, functional assessments, and the observations eventually decided upon at a final planning conference at Hot Springs, Va., in November 1947 reflect the former point of view. Also, since greatest emphasis was placed upon complete lesions, the Army Registry was visualized as the chief source of case material, but sufficient interest was expressed in neurolysed lesions and certain other groups of special interest to require the acquisition of other rosters as well.

From the outset, and continuing throughout the life of the project, financial support has come entirely from the VA and has been generous in its extent. The Armed Forces have furnished the rosters and basic clinical data upon which the entire study rests, as well as strategic aid of other kinds. Support by the VA has not been confined to the financing of the project, but has extended on the provision of information essential to the location and follow-up of the individuals to be studied, and to many other services.

B. ORGANIZATION OF STUDY

There are three elements in the organization of the actual work of the project: (1) The chairman, Dr. Barnes Woodhall; (2) the 5 follow-up centers headed by Dr. James C. White of Boston, Dr. Loyal Davis of Chicago Dr. Harry Grundfest of New York, Dr. Frederic H. Lewey (deceased) of Philadelphia, and Dr. Howard C. Naffziger of San Francisco; and (3) the NRC Follow-up Agency. The association was a loose, voluntary one, each center and the NRC Follow-up Agency being financed by means of an independent research contract with the VA. The chairman, at the same time Peripheral Nerve Consultant to the VA, assumed responsibility for the sampling plan, the allocation of patients for study, the development of procedures for facilitating access to patients, the provision of medical records covering the original injury and its treatment, assisting the centers in establishing a standard protocol for the follow-up examination, and for the final collection, analysis, and publication of the basic data obtained.

[7] Under the Committee there was established the Follow-up Agency as a records and statistical organization to provide operating assistance to investigators participating in the entire VA–NRC follow-up program.

In most of these functions the chairman had the assistance of the NRC Follow-up Agency established under the Committee on Veterans Medical Problems to assist investigators in obtaining necessary access to patients and their records, and in processing their observations, not merely for the peripheral nerve project but for any which might be sponsored by the Committee. The senior author of the present chapter, a statistician, was assigned to the project to assist the chairman and directors of follow-up centers in these aspects of the study.

Selection of the follow-up centers was the major step taken in organizing the study. It reflects in part the organization of clinical work in the Army during World War II with its emphasis upon centers for specialized care, and wartime support of research directed toward the better diagnosis of peripheral nerve lesions. Even prior to the Peripheral Nerve Conference in January 1947, four investigators in appropriately large urban centers (Boston, Chicago, New York, and Philadelphia) had indicated to Dr. Woodhall their desire to participate in a precise and detailed assessment of the final level of regeneration and functional return following injury of known extent. The desirability of a West Coast center was stressed at the January meeting, and a fifth investigator, Dr. Naffziger, was invited to participate in the planning of the project with a view to establishing a center in San Francisco. Dr. Naffziger accepted the invitation and the final recommendation of the Conference on Peripheral Nerve Injuries was that there be five centers located as mentioned. This recommendation was based on no specific consideration of sample size required by the objectives of the investigation, but the present investigation was entirely too complex for an optimum sample size to be calculated on the basis of purely statistical considerations. The consensus of the conference was that an adequate study would require perhaps several thousand cases.

Each follow-up center was organized somewhat differently in terms of the number and variety of professional personnel assisting the responsible investigator in the work. At the January 1947 conference a beginning was made on the drafting of a protocol governing the follow-up examinations, and in their formal applications to the VA for research contracts, the investigators bound themselves to develop and observe such a protocol. In addition, it was expected that each investigator would supplement the standard observations with others, relevant to the project, in which his group had special interest and competence. Also, the great emphasis upon detailed and objective observations, as distinguished from summary ratings of functional return, tended to shape the organization in terms of specialists in several of the centers. At the Chicago center, for instance, where most patients were hospitalized for 4 or 5 days while their studies were being made, primary responsibility for different elements of the examination was assigned in terms of sensory examination, motor examination, electrical studies, sympathetic function studies, photography, and a final surgical evaluation and interpretation of regeneration by the responsible investigator. In other centers patients were examined on an ambulatory basis, usually over a 2-day period, but the same concept of specialized examinations prevailed, although specific interests might vary from center to center.

Neuropathological studies were done under a separate contract with Duke University, where Dr. William R. Lyons worked with the chairman on the classification of nerve ends for eventual correlation with the results of the clinical follow-up studies.

Allocations of patients for study were made by the chairman through the NRC Follow-up Agency, and at the same time photostatic copies of all relevant medical records were provided to all but the Chicago center, where necessary data were abstracted from original records in VA claims folders. Allocations were made on standard NRC forms bearing the latest address obtainable by the Follow-up Agency, usually through the local VA office. It then became the responsibility of the center to arrange for the examination and to record the results on special forms worked out in conference by representatives of all centers. About midway through the study a statistical code was developed to cover all the data in the standard protocol. The code was divided into two parts, corresponding to the military and civilian periods. Coding based on the first part, dealing with the injury and its management, was performed centrally by personnel of the Follow-up Agency trained and supervised by the chairman and the project statistician. The second part of the coding, covering the interim history and the follow-up examination, was done in each center under the direction of the responsible investigator. All eligible cases were coded, whether examined or not, and the coded information deposited with the NRC Follow-up Agency for editing, tabulation, and statistical analysis in accordance with plans developed by the investigator responsible for the particular subject, assisted by the project statistician. The latter functions, and that of preparing manuscript, were divided among the investigators in November 1950 in accordance with a working outline, as follows:

Chapter and subject	*Responsibility* — *Primary*	*Responsibility* — *Secondary*
I. Introduction	Woodhall.	
II. Organization and conduct of study.	Beebe	Woodhall.
III. Characteristics of the sample	Woodhall	Beebe.
IV. Motor recovery	Yahr	Nulsen, Herz.
V. Electrodiagnosis	Grundfest	Davis, Moldaver, Webb.
VI. Sensory recovery	Davis	White (pain), Nulsen, Herz.
VII. Autonomic regeneration	White	Herz.
VIII. Pathology	Lyons	Woodhall.
IX. Summary		
A. Correlation of modalities	Yahr.	
B. Anatomic regeneration	Davis, Grundfest, Yahr, White.	
C. Brachial plexus cases	Nulsen	Davis.
D. Functional return	Nulsen.	

Chapter and subject	Responsibility: Primary	Responsibility: Secondary
IX. Summary—Continuet		
E. Symptoms, treatment, and adjustment.	Nulsen.	
X. Neurosurgical implications.....	Woodhall.........	Davis, White.
XI. Program for management of peripheral nerve injuries.	Woodhall.........	Nulsen, Davis, White.

The final table of contents bears only an approximate relationship to this original working outline.

C. SAMPLING PLAN AND ALLOCATION OF CASES FOR STUDY

The research protocol leading to acceptance of the study by the Committee and the VA contains only a general statement of objectives:

> "The primary purpose of this study is that of evaluating the results of peripheral nerve injuries sustained in World War II, with the hope of standardizing such treatment for future wars and, where possible, for similar injuries of civilian life. The secondary purpose of this study, and one of considerable immediate value, is that of discovering nerve injuries among veterans of all services that still require remedial measures."

The specific objectives which dictated the sampling plan, however, may be listed as follows:

1. To describe the final level of regeneration in representative cases of complete suture, neurolysis, and nerve graft.
2. To ascertain the apparent influence of gross characteristics of the lesion, and of associated injuries, upon final result.
3. To ascertain the apparent influence of numerous aspects of management upon final result.
4. To evaluate predictions of final recovery based on gross and histologic study of tissue removed at operation.

Many other objectives, of course, moved the investigators to undertake the present study but exert no influence on the sampling plan. The minutes of the various conferences and lesser meetings reveal expressions of interest in the following: case-finding, correlation of careful research examinations with VA disability ratings, improvement in accuracy of VA disability ratings, correlation between different modalities, e. g., motor and sensory, evaluation of techniques of assessing recovery, evaluation of military disposition policy, evaluation of rehabilitative measures undertaken on World War II cases, and study of psychological factors interfering with return of function commensurate with level of nerve regeneration.

No interest was expressed in the population of perhaps 40,000 World War II peripheral nerve injuries as a whole, certainly a most difficult one to specify and, by that token, to sample. The uncertainty extends not merely to lesions with spontaneous recovery but also to those treated by neurolysis because of their nonspecific character. Some care was exercised, therefore, in acquiring rosters of neurolyses. Also, only certain major peripheral nerves and the brachial plexus were of real interest, namely, the median, ulnar, radial, peroneal, tibial, and sciatic. Further, each nerve was viewed as a distinct entity requiring some separate study, with the result that special efforts were required to insure adequate numbers of each. A minor consequence of such sampling, of course, is that the distribution of lesions by nerve provides no real estimate of that in the general population of peripheral nerve injuries. There were also certain factors of special interest because of possible paucity of cases in a representative sample, and it was thought necessary to take special precautions to obtain adequate numbers of cases, e. g., those involving arterial injury, normal bone resection, bulb suture, nerve graft, pathological study of nerve ends by Dr. Lyons and Dr. Woodhall, early suture overseas, and sutures done by the plasma glue technique. In summary, then, the objectives of the study require both adequate, representative samples and groups of cases of special interest for particular comparisons.

Rosters of *bona fide* peripheral nerve injuries were acquired on the basis of the above interests and these merit careful description.

Rosters of Complete Lesions Primarily

Roster #39, contributed by James C. White, M. D., of Boston, Mass., and consisting of 31 peripheral nerve injuries treated by him at St. Albans Naval Hospital.

Roster #48, contributed by Thomas I. Hoen, M. D., of New York City, and representing every nerve repair he did at St. Albans Naval Hospital from July 1943 to June 1946, a series of 143 consecutive cases, all repaired by the plasma glue technique.

Roster #68, contributed by The Surgeon General, U. S. Army, and consisting of 375 1944 Army wounded who were coded as having wounds or fractures with nerve involvement. This roster was used in estimating the incidence and variety of peripheral nerve injuries and particularly in the tests of the completeness of the Army Peripheral Nerve Registry which are described below.

Roster #69, the Army Peripheral Nerve Registry, established by the chairman during World War II and contributed to the study by The Surgeon General, U. S. Army. In November 1944, Z/I neurosurgical centers were directed (*82*) to register all peripheral nerve injuries requiring suture or graft, or under study following such treatment, and to file reports on the completion of any repair and on reassessment at 3-month intervals and at disposition. As received from The Surgeon General, the roster consists of 7,720 men with one or more nerve injuries, and undoubtedly represents the bulk of the sutured cases in the World War II Army experience.

Roster #86, contributed by Donald H. Wrork, M. D., of Rockford, Ill., and consisting primarily of peripheral nerve injuries with early suture which he performed at the 15th Evacuation Hospital in the Mediterranean Theater of Operations. The total roster numbers 102 men.

Roster #88, contributed by Barnes Woodhall, M. D., of Durham, N. C., and William R. Lyons, M. D., of San Francisco, Calif., and consisting of 555 peripheral nerve injuries, treated at Walter Reed and Halloran General Hospitals, for which pathological material was available at the Armed Forces Institute of Pathology (Accession No. 110822). Most of these cases are duplicated on the Army Peripheral Nerve Registry.

Rosters Obtained as Sources of Incomplete Lesions

Roster #40, contributed by W. K. Livingston, M. D., of Portland, Oreg., and consisting of 1,278 Navy and Marine Corps wounded men with peripheral nerve injuries of all kinds managed by Dr. Livingston. Only incomplete lesions were used in the allocations.

Roster #47, contributed by Everett G. Grantham, M. D., of Louisville, Ky., and consisting of 619 men with peripheral nerve injuries treated by himself and Claude Pollard, M. D., at Tilton and England General Hospitals. Only incomplete lesions were used.

Roster #90, contributed by the late Frederic H. Lewey, M. D., of Philadelphia, Pa., and consisting of 1,220 men with peripheral nerve injuries seen by him at Cushing General Hospital. The roster was used primarily as a source of incomplete lesions.

Roster #92, contributed by Harry Grundfest, Ph. D., of New York City, and consisting of 305 men with incomplete peripheral nerve injuries treated at Halloran General Hospital.

Once acquired, the various rosters were processed to yield essentially two samples, which may be termed "representative" and "extended" in order to distinguish them, each of which was further subdivided into sutures and grafts on the one hand and neurolyses on the other. The distinction between the representative and the extended samples was made on the basis of geographic areas surrounding the follow-up centers and applies only to the Army Registry. Each man appearing on the Registry was located geographically, and for each center appropriate geographic limits were stipulated for each nerve, varying somewhat inversely in size with the relative frequency of injury to the particular nerves. The specific geographic limits adopted are as follows, by center and by nerve:

Boston:

Brachial plexus	Massachusetts, Rhode Island, Connecticut, New Hampshire, and Maine.
Median	70 mile area around Boston.
Peroneal	125 mile area around Boston.
Radial	100 mile area around Boston.
Sciatic	120 mile area around Boston.
Tibial	125 mile area around Boston.
Ulnar	Massachusetts, 125 miles to the west of Boston, plus Rhode Island.

Chicago:

Brachial plexus	320 mile area around Chicago.
Median	Cook County.
Peroneal	Cook and DuPage counties in Illinois, plus the southern part of Michigan.
Radial	Cook County.
Sciatic	Cook County.
Tibial	Most of Illinois, the northern part of Indiana, and the southern halves of Wisconsin and Michigan.
Ulnar	Cook County.

New York:

Brachial plexus	All of New York, plus 1 case in New Jersey.
Median	The 5 boroughs of New York City, plus Essex, Middlesex, and Union counties in New Jersey.
Peroneal	New York City, plus northern New Jersey and Orange, Putnam, Westchester, and Rockland counties in New York.
Radial	The 5 boroughs of New York City, plus Hudson County in New Jersey.
Sciatic	The 5 boroughs of New York City, plus Bergen and Hudson counties in New Jersey.
Tibial	60 mile area around New York City.
Ulnar	The 5 boroughs of New York City.

Philadelphia:

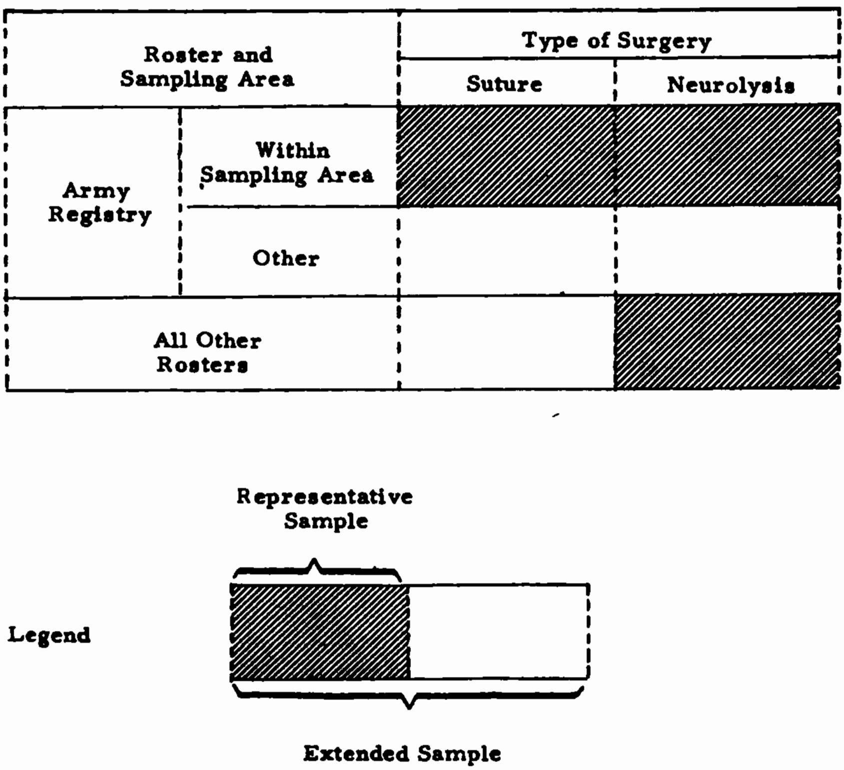
Brachial plexus	Pennsylvania, Maryland, Virginia, and West Virginia.
Median	The eastern part of Pennsylvania and that part of Maryland and Delaware most accessible to Philadelphia.
Peroneal	Eastern Pennsylvania and part of Maryland.
Radial	140 mile area around Philadelphia.
Sciatic	140 mile area around Philadelphia.
Tibial	130 mile area around Philadelphia.
Ulnar	145 mile area around Philadelphia.

San Francisco:

Brachial plexus	California.
Median	California.
Peroneal	California.
Radial	California.
Sciatic	California.
Tibial	California.
Ulnar	California, plus 1 case in Washoe County, Nev.

It will be noted that men back in service are excluded under this plan, and although few they are of some special interest. Accordingly, the chairman made a separate study of 18 men who were in service at the time the allocations were being made; Army surgeons generously undertook to examine these men according to the general specifications sent them under this plan. All the men from the Registry residing in the above areas were allocated as part of the representative sample, and all the sutures (both complete and partial) included in the representative sample were thus obtained. Special efforts were then made to augment the allocation with men living outside these areas but having a particular interest in connection with one or another of the special topics listed above, and such men are not included in the representative sample, either for sutures or for neurolyses. Men from other rosters were allocated solely on the basis of propinquity to the nearest center and do not contribute sutures to the representative sample; they do, however, contribute neurolyses to the representative sample. Figure 1 provides a rough diagram of these various interrelations. The shaded areas taken together constitute the representative sample, the total area the extended or total sample. All sutures not from the Registry were acquired with special interests in mind, and, therefore, are possibly atypical, and this is also true of all Registry cases outside the sampling area.

Figure 1. *Relation Between Representative and Extended Samples*



Two groups of cases were added locally. Dr. Lewey was especially interested in long-gap cases and those with incomplete lesions, and he conducted some reexaminations at Cushing in connection with these special interests. Any such Cushing cases which appeared on the Army

Registry were placed in the basic sample or outside it, depending entirely upon geographical considerations. The other special group consisted of men with plasma glue sutures (roster 48), who were seen only at the New York center. These cases are excluded from the representative sample of sutures but are used at most points in the analysis.

Men were allocated on the basis of a single nerve injury, and if a man had more than a single injured nerve the interest in him depended upon the roster to which he belonged. When a man was examined, of course, all his injured nerves were taken into account. Thus, the final allocation of 2,714 men had on the order of 3,800 lesions worthy of study, as such lesions are counted here. By center, the allocation of men was as follows:

Boston	378
Chicago	389
New York	849
Philadelphia	746
San Francisco	352
Total	2,714

Table 1 indicates the use made of each roster in preparing the allocations.

Table 1.—*Distribution of Final Allocations by Roster*

Roster number and source	Number of men allocated
39 (White)	31
40 (Livingston)	52
47 (Grantham and Pollard)	74
48 (Hoen)	127
61 (Miscellaneous local cases)	12
68 (SGO)	....
69 (Army Registry)	1,987
86 (Wrork)	33
88 (Woodhall and Lyons) [1]	193
90 (Lewey)	183
92 (Grundfest)	22
Total	2,714

[1] In addition there were 163 men allocated from roster 69, so that the pathological roster is represented by a total of 356 men in the entire allocation.

Two chief assumptions underlie the sampling plan: (1) that the Registry would produce representative cases within any definitive-operation group; and (2) that sampling based on residence is unbiased as to nerve regeneration. Only the first of these has seemed worthy of investigation. In view of the care attending the framing of the Army directives establishing the Registry, and the efficient concentration of Army cases in Z/I neurosurgical centers, there could be little doubt about the representativeness of sutures drawn from the Registry, but, nevertheless, a limited test was made on the 1944 material, using roster 68 as the basis of expectation. The procedure consisted of, first, identifying all roster 68 cases having peripheral nerve lesions treated by suture or graft, and second, collating this list against the Registry. There were in all 42 roster 68 men with such sutures or grafts, of which 18 were found on the Registry. The 24 cases excluded from the Registry were then compared with the 18 overlapping cases, the points of comparison being rank, month of injury, place of injury, place of final treatment, evacuation home, coding of first, second, and third diagnoses, location of first diagnosis, operations performed, final result of injury, disposition from hospital, and total time spent in hospital. In none of these comparisons was a statistically significant ($P<.05$) difference found. As far as this very limited exploration goes, therefore, it suggests that: (1) about half of the 1944 sutures and grafts appear on the Registry; and (2) there are no very considerable differences between cases included and excluded from the Registry. The bulk of the Registry cases, of course, are of 1945 origin and it was not thought necessary to carry the exploration of representativeness and completeness into the 1945 material. In one minor respect the lysed cases from the Registry are surely atypical: of necessity, each involves a man with at least one other nerve injury, usually on the same limb, treated by suture or graft. Any such bias assumes importance to the extent that the presence of associated nerve lesions might affect recovery, but, fortunately, this is of no real consequence except in assessing practical function, where the influence of associated lesions must be controlled in any event. The lysed cases from the Registry may also be unrepresentative of the generality of neurolyses in the same way in which the rosters of incomplete lesions are probably atypical, i. e., in that the lesions were more carefully evaluated, more skillfully handled, and more surely involved truly denervated muscles. But in this instance one is not interested in the generality of so-called neurolyses but in only the well-studied, well-documented incomplete lesions which these rosters represent.

After the reexaminations had been completed, during the coding of the details of injury and management, additional criteria of eligibility were introduced which led to the exclusion of 62 men on the following grounds:

Injury occurred before entry into service.
Defect not caused by trauma.
Injury caused only sensory deficit.
Spinal injury.

In addition, card-punching of follow-up material coded by the several centers was scheduled against a deadline and two examined cases were received too late for inclusion in the analysis. Finally, there were 96 men whose only injury was at the level of the brachial plexus and 12 cases with C_5 and C_6 involvement, and since a hand analysis seemed necessary for these very complex cases, cards were not punched for them. There were, however, 17 additional men with *bona fide* lesions below the brachial plexus who also had brachial plexus lesions on the same extremity or another extremity, and for these men cards were punched for lesions below the brachial plexus. The final utilization of the 2,714 allocated men, then, stands as follows:

Total allocated		2,714
Deleted from study entirely		
Received too late for coding	2	
Ineligible	50	
Used in final analysis		2,662
Brachial plexus cases only, including C_5 and C_6 cases		108
Others		2,554

With the exclusion of the brachial plexus cases, the analysis reported here is based on 2,554 men of whom 1,920 or 75 percent were reexamined and 207 were studied on the basis of existing records. Among the 2,554 men on whom the main analysis was done, there were 17 with median, radial, or ulnar lesions and associated injuries to the brachial plexus, so that there were in all 125 brachial plexus cases available for study. Table 2 provides a recapitulation of the handling of the rosters after they were unduplicated and shorn of civilians, men who had died, and members of foreign military groups.

Table 2.—*Summary of Use Made of Peripheral Nerve Rosters*

Total men available, all rosters except #68, after unduplication, etc				10,170
Initial deletions				277
Identification unsatisfactory			201	
Peripheral nerve injury in question			20	
Adequate base-line records unavailable			56	
Dropped on geographical basis (see text for details)				7,179
Final allocation to all five centers				2,714
Later dropped from study			52	
Ineligible		50		
Follow-up data received too late		2		
Used in final study			2,662	
Brachial plexus or C_5 or C_6		108		
Other injuries		2,554		
Examined	1,920			
Record follow-up	207			
No follow-up	427			

The 2,554 men had, in all, 3,656 peripheral nerve injuries, and table 3 provides a summary of their distribution by nerve, definitive reparative procedure, and role in the analysis. A table classifying lesions as to character of the first operation would differ from table 3, especially in showing larger numbers of grafts and neurolyses.

It will be noted that the sciatic is shown separately in two components, tibial and peroneal. Although most lesions do involve both branches, this very fact makes for a wide spectrum of injury, e. g., as seen in the pattern of affected muscles, and it was believed that the analysis would be facilitated by considering each component separately. Thus, each was separately described as to nature and completeness of lesion, and the precise type of surgery performed upon it, so that any affected muscle, for example, could be specifically associated with a defined lesion treated in a specific way. Battle casualties account for 92 percent of the lesions, gunshot wounds for 95, and gunshot wounds in combat for 91 percent.

Table 3.—*Composition of the Study Sample by Nerve, Definitive Operation, and Role in Analysis, Brachial Plexus Lesions Omitted*

Nerve	Suture		Neurolysis	Graft	Other or none	Total
	Partial	Complete				
Representative sample						
Median	32	319	134	....	....	485
Ulnar	15	576	148	....	....	739
Radial	19	270	46	....	....	335
Peroneal	36	190	30	....	....	256
Tibial	15	126	37	....	....	178
Sciatic-peroneal	9	225	57	....	....	291
Sciatic-tibial	21	180	78	....	....	279
Other	....	....	....	....	....	.....
Total	147	1, 886	530	....	....	2, 563
Extended sample						
Median	49	464	146	6	42	707
Ulnar	25	752	162	6	55	1, 000
Radial	24	365	50	6	71	516
Peroneal	46	240	33	1	21	341
Tibial	21	155	39	5	15	235
Sciatic-peroneal	14	311	65	2	12	404
Sciatic-tibial	32	241	95	4	22	394
Other	2	28	15	....	14	59
Total	213	2, 556	605	30	252	3, 656

D. FOLLOW-UP PROCEDURES

Until the Hot Springs Conference in November 1947 there was every indication that the follow-up process would be facilitated by the VA use of its prerogative to request compensated men to appear for examination. In this study, where so many of the observations are objective in nature, the interference of compensation considerations would have been minimal. The British follow-up studies on peripheral nerves have been accomplished with the aid of the Ministry of Pensions, it may be noted. However, when the peripheral nerve investigators met in November, they were informed by the VA representative that they should assume the entire responsibility for the follow-up process, and request additional funds for any necessary travel and per diem. Subsequently, the Committee took the position that research examinations should not be used for adjudication purposes, and a ruling was obtained from the VA Solicitor that examinees might be so assured provided that certain precautions were taken in the handling and identification of the case material.

For each man allocated, a current address was obtained by the Follow-up Agency, chiefly from the VA, and provided to the director of the follow-up center at the time of allocation, together with photostatic copies of the Army or Navy clinical records of the case. It then became the responsibility of the director of the center to interest the subject in the examination, schedule his appearance, and obtain the follow-up observations on which agreement had been reached. The initial approach was made by mail, and a copy of the form letter used by one center (New York) for this purpose is reproduced as figure 2. Examiners did not wish to arouse anxiety, but yet it was necessary to take advantage of the real concern these men had about their condition. It was also felt that the examinee was being offered something quite positive by way of a meticulous assessment of his condition and an opportunity to learn of any rehabilitative or other measures which might offer some prospect for future improvement. The letters of most centers also made the point that whatever was learned from the study would be incorporated in the management of future injuries. Although many of the allocated men reported for examination in response to the first letter, it was usually necessary to make more intensive efforts via mail, telephone, and telegraph to schedule the men for examination. Using these devices, the centers brought in the bulk of the final allocation of 2,554 men who represent the entire sample less brachial plexus cases. If a man did not respond, the center sent a registered letter in order to verify the address, and with a surely correct address continued until three letters had been sent. At that point the center was considered to have exhausted its power of appeal and the man was referred to the American Red Cross, through its national headquarters, for help under a cooperative arrangement worked out with the Follow-up Agency. Red Cross representatives were provided with a statement about the project and visited each center to learn something of the nature of the examination and of the essential medical interests of the investigators. There were 771 men referred to the American Red Cross under this arrangement and 274, or 36 percent, were eventually brought in for examination. As a final step, a few VA regional offices were asked to write to a fraction of the men who refused even under urging by Red Cross workers, and their response was rather favorable. The aggregate yield of all these efforts was 75 percent of the allocation. By center there was considerable variation associated with density of population, the effort made, and the extent of the sacrifice required of the examinee; the percentages examined range from 68 to 85.

An immediate benefit of Red Cross participation in the follow-up work was the information it provided about the apparent motivation of men who refused to participate and about the interaction between subjects and personnel of the follow-up center. The Philadelphia chapter especially was most helpful in providing detailed reports by social workers on a sample of cases, and analysis of this material shows refusal to have been based on a variety of personal reactions to the proposal, e. g., fear that the examiners

Figure 2. *Letter From Columbia University College of Physicians and Surgeons, Peripheral Nerve Study Center*

Columbia University
College of Physicians and Surgeons
PERIPHERAL NERVE STUDY CENTER
[illegible]
[illegible]
NEUROLOGICAL INSTITUTE

Columbia University is making a medical survey of peripheral nerve injuries, such as you received during the war. We are interested in finding out how well you are doing following your injury and treatment and how the treatment of your injury worked out.

For this purpose, we are asking you and some other men who had these injuries to come in for an examination. You will get a thorough check-up completely free of charge and advice about any future treatment which might benefit you. By taking part in this survey you will enable doctors to give the best possible treatment to other cases like yours.

The examination will take one day. We will pay for your travel, meals, and if necessary, for your lodging. Although our work is being supported by the Veterans Administration, the Veterans Administration is interested only in the broad conclusions so that it can continue to give the best medical care to veteran patients. We are authorized by the Veterans Administration to state that:

> "The results of this examination will not be made available to the Veterans Administration for the purpose of adjudicating or reviewing the compensation or pension claim of the veteran."

We hope that you have recovered entirely, or if not, that we may be able to recommend something which will help you. If you wish, we will give you a written report or send it to your doctor.

We would appreciate your filling in the enclosed card and mailing it to us so that we can schedule your examination.

Very sincerely yours,

Harry Grundfest
Director, Peripheral Nerve
Study Center

HG:DL
Enclosure

would urge further surgery, fear of pain associated with the examination, loss of time from work, belief that nothing beneficial could be done for oneself, feeling that any necessary information could be obtained from the VA regional office to which the man had returned periodically, concern about possibly adverse effect upon compensation status, and generalized aversion to "guinea-pig" role. Often such interviews suggested that a social worker might prove helpful to a man in further efforts to obtain compensation or treatment from the VA. The interviews also suggested that great flexibility is required of center personnel in terms of adaptation to the requirements of the individual subject, most obviously in scheduling examinations, but also in communicating with the examinee.

Although examiners assured the men in their allocation that the results of the examination would not be available to the VA for purposes of adjudication, they were, of course, willing to provide examinees with summaries of their findings when requested to do so. None of the examiners found himself embroiled in any controversy over the merits of any claims for compensation. All are convinced, however, that anxiety over interference with VA compensation payments was not entirely allayed by assurances that the research examination would not be used in adjudication.

E. OBSERVATIONAL PROCESS

The observations required in the study pertain to the original injury and its treatment, available only from the clinical and laboratory records prepared at the time, and to the follow-up examination. The availability of the underlying records proved to be complete and very satisfactory. They were located and reproduced by the Follow-up Agency for four centers; in Chicago the follow-up work was done at Hines VA Hospital and it was possible for the VA to transfer necessary records there for review and abstracting by center personnel. A standard abstracting form was devised in conference and used by most centers, partly as an adjunct to the examination of the individual subject and partly in anticipation of subsequent coding preparatory to statistical analysis.

By far the more important observations are those obtained at follow-up. Specific concepts, instrumentation, and other technical details of methodology are discussed in the chapters which follow. For the most part agreement on the content of the follow-up examination was reached at Hot Springs in November 1947 and standard forms were issued early in 1948 to facilitate its uniform recording. Eventually, however, all such information was coded for tabulation on IBM equipment, and it is in the final code [8] that one finds the characteristics and categories which finally prevailed. It may be useful here, by way of orientation, to cite the rubrics of

[8] Evolution of a satisfactory code proved to be a difficult and time-consuming task, but was greatly facilitated by the prior existence of an analogous code prepared by Dr. Lewey and by the skillful analysis of sample cases by Miss Jane T. Johnson of the staff of the Follow-up Agency.

the code as indicative of the chief observations made. Apart from identification and the like the coded information may be described as follows:

1. The Injury. Including the identity of each injured nerve, the type of injury, evidence for injury, site of lesion, causative agent, degree of paralysis and sensory deficit at time of operation (for incomplete lesions only), pattern of associated orthopedic and vascular injuries, evidence of delay in repair because of chronic infection, presence of plastic repair at site of nerve injury, age of patient at injury, and handedness (for upper extremity injuries).
2. Its Treatment. Including total number of operations and, for each, the calendar date, the interval from injury to operation, hospital echelon, type of operation performed, tension noted by operator at time of repair, such special operative features as prior bulb suture and transposition (for sutures and grafts), suture materials used, type of lysis, type of cuff and stay suture (for sutures and grafts), length of surgical defect after any surgical resection, level of training of surgeon, response to electrical stimulation at operation, operator's evaluation of nerve ends just prior to anastomosis, apparent indication for any subsequent operation, reason for any obvious failure of this operation (for sutures and grafts), subsequent operative procedures (other than peripheral nerve surgery) before separation from service, duration of hospitalization, and disposition from hospital.
3. Follow-up Information. Including effort necessary to bring man under study, the distance he traveled, source of follow-up information (examination or other record) available, any treatment (for nerve injury) following separation from service, place of treatment, duration of follow-up interval, complaints presented by patient and classified as to (a) pain and sensation, (b) motor function, and (c) autonomic function, sensory recovery as determined by (1) pain threshold, (2) touch threshold, (3) position sense, (4) localization, and (5) as summarized in the British code, skin resistance and sweating, assessment of specific functional capabilities of injured extremity, assessment of overall functional evaluation of injured extremity, presence of residuals of associated orthopedic, vascular, and other lesions, occupational history and any handicap found, need of patient for further treatment, attitudes of patient toward his result and toward further treatment, electrodiagnostic tests on individual muscles (chronaxie, results of electrical stimulation of muscle and of nerve), tetanus ratio, electromyography, and EMG response to stimulation of nerve, voluntary contraction of individual muscles, measured strength of movement for individual muscles, number of muscles originally affected by injury and number exhibiting voluntary contraction at follow-up, and overall motor recovery as summarized in the British code. In addition, certain centers, notably Chicago, made other observations routinely, especially in the area of sensory recovery.
4. Assessments of Nerve Ends. From pathological material removed at surgery and subjected to detailed study by Dr. Lyons, these being in the form of forecasts of eventual regeneration.

The information listed under items 1 and 2 was coded centrally under the supervision of the chairman, and that under item 3 by each center under the supervision of the responsible investigator. Dr. Lyons made and coded his own assessments independently of any knowledge of end results.

Although the November 1947 meeting resulted in agreement on the bulk of the observations to be made, preparation of a statistical code presented an opportunity for some changes and even such a fundamental pattern as the standard list of muscles changed slightly on the basis of experience and the preferences of investigators at particular centers.

Standardization of concepts was attempted on the basis of conference discussion, including one at the Hines VA Hospital arranged by Dr. Davis

F. STATISTICAL PROCESSING

Preparations for the final tabulation plan were begun in 1947 as part of the process of elucidating the design of the project, and consisted chiefly in the identification of the major variables and the specification of the approximate form of the statistical comparisons. Early in 1950 the chairman distributed a suggested outline for a comprehensive report on the study and asked for comments and alternative suggestions from the entire working group preparatory to the next meeting which was held in Boston in October 1950. In July the investigators were requested by the VA to review their material in connection with the military problems which burgeoned with the invasion of South Korea. Preparation of the interim report (88), entailed by this request, which presented an integrated plan for the management of peripheral nerve injuries, served further to stimulate specific thinking about the content of any final report on the fruits of the study as a whole. Since all centers were submitting coded follow-up data in the spring and summer of 1950, it was possible to develop some preliminary tables in advance of the Boston meeting. A working outline for the report (p. 4) was agreed upon at that meeting, and specific assignments accepted for the analysis of the various parts of the material.

Once the responsibility for each chapter had been fixed, it became possible to plan the tabulations required for a full exploitation of the material, and, for the most part, such plans were ready by the summer of 1951. A real difficulty arose out of the fact that it was administratively possible for the Follow-up Agency to cope with the huge volume of tabulation requested only by scheduling it as a whole for a solid period in the tabulating room during which the work could be arranged in the most efficient fashion for the available equipment. This requirement limited the amount of experimentation which could be done in advance. The preparation of systematic, advance plans for the statistical reduction of their data placed a very heavy load upon the investigators, most of whom had little or no prior experience in a large-scale study of this type, and of course there was a difficult problem of communication between the investigator, who had not previously participated in a large-scale study requiring statistical reduction of data, and the statistician, who had little technical knowledge of the subject of the investigation. However, the situation was greatly relieved by two circumstances: (1) The acquisition of an IBM electronic statistical machine; and (2) the development of a basic classification of the case material permitting, in effect, many tables to be run simultaneously. In the opinion of the investigators, certain variables were almost sure to account for much of any variation observed in recovery, and any analysis would need to be controlled on them. These dominant factors are:

1. The anatomic identity of the injured nerve.
2. The nature of the original lesion.
3. The gross site of the lesion.
4. The type of reparative surgery.

These factors were organized in a classification which may be illustrated for the median nerve as follows:

Injury-operation group number	*Set of cases*
1	Complete suture, complete division, high
2	Complete suture, complete division, low
3	Complete suture, complete division, total
4	Complete suture, partial division, total
5	Complete suture, neuroma, high
6	Complete suture, neuroma, low
7	Complete suture, neuroma, total
9	Complete suture, all, high
10	Complete suture, all, low
11	Complete suture, all, total
12	Partial suture, all, total
15	Neurolysis, incomplete lesion, high
16	Neurolysis, incomplete lesion, low
17	Neurolysis, incomplete lesion, total

Other nerves were classified in more or less detail, and, in all, 60 groupings were made covering all 7 major nerves, abbreviated as follows, M, U, R, P, T, SP, and ST.

The general nature of the tabulation plan may be illustrated with reference to the motor chapter, which has the following parts:

1. For the representative sample only, each motor index was tabulated for each of the 60 injury-operation groups.
2. For the extended sample, each of 2 motor indices was run against each of the following characteristics of injury, again for each of the 60 injury-operation groups:
   - Associated bone or joint injury, including type of healing.
   - Associated arterial injury.
   - Presence of chronic infection delaying repair.
   - Presence of plastic repair at site of nerve lesion.
   - Age.
   - Specific site of lesion.
3. For the extended sample, each of 2 motor indices was run against each of the following details of management, again for each of the 60 injury-operation groups:
   - Number of operations.
   - Days from injury to definitive repair.
   - Date of definitive repair.
   - Hospital echelon of definitive repair.
   - Tension on suture line reported by surgeon at definitive repair.
   - Special operative features characteristic of definitive repair (e. g., bulb suture, transposition, etc.).
   - Type of suture material, definitive suture.
   - Type of neurolysis, definitive neurolysis.
   - Type of cuff used at definitive operation.
   - Use of stay suture at definitive suture.
   - Length of surgical defect at definitive suture.
   - Training of surgeon performing definitive operation.
   - Motor response to electrical stimulation at definitive operation.
   - Quality of nerve ends reported by surgeon at definitive repair.

The above plan was embarked upon in systematic fashion in the expectation that a limited number of problems would be attacked later with more attention to the interrelations among variables, once these first tables had been studied, and such proved to be the case.

An early problem requiring solution even before the tables could be run was that of center variation. The magnitude of the tabulation task, and of associated computing, forbade any plan whereby all tables might be run separately for each center, and yet it was plain that certain observations might well have to be so handled, and there was no disposition to combine essentially unlike observations. Accordingly, once the punched cards had been made ready for use, the first task of the statistician was to investigate some of the more important observations from this standpoint. In the interests of homogeneity the analysis was confined to examined cases in which there was a single lesion of complete severance treated by complete suture. The follow-up observations chosen for study follow:

Complaints as to pain and sensation.
Complaints as to motor function.
Complaints as to autonomic function.
Pain threshold.
Touch threshold.
Position sense.
Localization.
Skin resistance and sweating.
Functional status.
Overall functional evaluation.
Has occupation changed because of nerve injury?
Handicap in present occupation.
Need of patient for further treatment.
Evidence for anatomic regeneration.
Chronaxie.
Tetanus ratio.
Voluntary contraction.
Strength of movement.
Assessment of motor recovery.

Although discrepancies among centers were observed, they were rarely of such a nature as to require, in the opinion of the statistician, a separate analysis of the material contributed by each center. The exceptions are as follows:

1. Complaints of all kinds (motor, sensory, and autonomic) were reported with quite variable frequency by center, and were analyzed by center.
2. Hyperpathia and dysesthesia, which were to be noted at the time of determining the pain threshold, did not have the same meanings for all centers, and were quite variably reported. Their analysis was done by center.
3. Chronaxie values of the several centers varied in a way suggestive of differences in calibration, and were studied by center.
4. Such marked variation was found in the observation of position sense and localization among the centers, and these modalities were studied in so few cases, that very little use of the data could be made.

The center variation found in the British motor and sensory assessments is discussed in connection with the presentation of appropriate data. There are, of course, two dangers associated with center variation. At the very least such variation will represent the introduction of an error which will be independent of other characteristics of the lesion and serve only to obscure relationships which might otherwise appear plain. Should center errors *not* be independent of other characteristics of the lesion, however, or should one correlate two follow-up observations both affected by the errors of a particular center, then the door is opened wide to spurious relationships. Fortunately, the allocations are quite homogeneous from center to center, and the characteristics of injury and treatment were centrally coded, so that there is little room for the confounding of, say, a particular type of case with an erroneous follow-up observation in a particular center. In the correlation of one follow-up observation with another, however, there is ample room for such confounding and we hope we have been sufficiently alert to it.

The design of the punchcards also contributed greatly to the efficient handling of the data, especially in view of the multiplicity of observations on the various muscles; a single radial lesion, for example, might have dynamometer readings on 8 muscles. The key to simplicity proved to be the fact that the projected analysis would never require that the readings on one muscle be tabulated against those on another. This allowed the design of a single card carrying information about the injury, the definitive operation, and all the follow-up data *except* that only such follow-up data as pertained to a single muscle could be placed on a single card. Data of the latter type occupied columns 58–79 of the card, and any lesion would require 3 to 8 cards depending upon the number of muscles the examiners had agreed to include in their standard examination. If there were, as in the radial, 8 such muscles, then 8 muscle cards were prepared by reproducing into all of them the data of columns 1 to 57 in the basic design, and then adding in columns 58–79 of each the information for the particular muscle which was in turn identified by the card (and muscle) identification placed in column 80. Other intermediate and supplementary cards were required, but the bulk of the work was done on the muscle cards. Figures 3 and 4 contain the card number and show exactly how the material was placed on the final cards.

Another methodological problem assigned to the statistician was to determine whether important bias had entered the material via incomplete follow-up. This problem was explored in three ways. First, on the basis of evidence that certain elements of injury and management were exercising the role of determinants of end results, the examined and not examined cases were compared directly as to these elements. Second, on the assumption that the bias of nonresponse is progressively eliminated as one exerts increasing efforts to bring men under study, a comparison was made of men who reported for study without urging and of men who cooperated only after much persuasion. Third, the chairman reviewed and coded, on the basis of VA rating examinations, representative examined and nonexamined cases of one center (New York) to permit comparison on key points.

The complex nature of the sampling plan made it desirable to restrict the study of bias to the most homogeneous, representative cases. Accordingly, the tables on characteristics of injury and treatment were confined to lesions treated by complete suture, of men drawn from the Army Peripheral Nerve Registry, and of men resident within the sampling area defined for the representative sample. Nine characteristics of injury and treatment were chosen as the basis for comparisons of examined and nonexamined cases, as follows:

Identity of injured nerve.
Site of lesion.
Presence of chronic infection sufficient to delay definitive suture.
Presence of associated arterial injury.
Number of operations of definitive intent.
Days from injury to definitive suture.
Length of surgical gap at definitive operation.
Use of cuff at definitive operation.
Use of stay suture at definitive operation.

The comparison as to identity of the injured nerve was done separately for high (elbow or knee and above) and for lower sites of injury, and in both instances only small, statistically insignificant differences were found. The study of site of lesion was confined to median, ulnar, peroneal, and tibial lesions and showed that follow-up was definitely better for the higher lesions, and especially so in the ulnar (table 4). Although the discrepancy seems quite clear, in that the combined probability is below .01 under the hypothesis of homogeneity of high and low lesions, it is not large in amount and has seemed of no great practical concern.

Table 4.—*Gross Site of Lesion and Percentage Examined at Follow-up, by Nerve, Completely Sutured Lesions in Representative Sample*

Nerve	Percentage examined		P
	High lesions	Low lesions	
Median	86.9	82.3	>.05
Ulnar	86.1	77.7	.02
Peroneal	81.1	78.1	>.05
Tibial	87.9	82.7	>.05
All four combined at probability level			<.01

Chronic infection was scrutinized on the basis of all nerves combined. The percentage not examined was found to be 25 for lesions accompanied by such infection and 17 for lesions without; this discrepancy has a probability of about .02 under the null hypothesis. Associated arterial injury, number of operations, days from injury to operation, surgical gap, and use of cuff were all found to be unrelated to the chance of follow-up examination. However, in the lower extremity, lesions for which the treatment included the use of a stay suture had a significantly higher follow-up percentage than lesions not so treated (90 v. 78 percent, which differ by an amount with a probability well below .01).

Of the 9 characteristics employed in the comparisons on examined and nonexamined cases, only 3 (site of lesion, chronic infection, and use of stay suture) are associated with the chance of follow-up. To appreciate the import of these findings it is necessary to anticipate the results of the follow-up study by noting the relationship between the bias of follow-up and the apparent effect of each characteristic upon end result, as follows:

	Follow-up percentage	*Performance at follow-up*
Low lesions	Low	High.
Lesions with chronic infection	Low	Low.
Lesions with stay suture	High	Low.

Even these three evidences of bias, that is, fail to suggest any general tendency for either the poorer or the better results to have been more frequently examined at follow-up.

The second approach to follow-up bias made use of a classification of the effort required to bring the man in for examination. Three effort groups were contrasted: (1) men who came in response to a personal letter; (2) men who required more than one letter, but not as much as a personal visit by the Red Cross; and (3) men who required a personal visit by the Red Cross or intervention by the VA regional office. These three effort groups were then compared as to each of the following observations made at follow-up:

Pain threshold.
British summary of sensory regeneration.
Skin resistance.
Overall function of injured extremity.
British summary of motor regeneration.

In each instance, the comparisons were made by nerve, i. e., separately for median, ulnar, etc. In each instance except 1 the 3 effort groups differed by no more than chance. The exception was found in the peroneal nerve when overall function was made the basis of the comparison (table 5). However, no such relationship is seen in the other nerves, and in view of the large number of comparisons which were made on the five follow-up observations, to find one apparently striking discrepancy is not itself remarkable.

Although the first two studies of follow-up bias provide an insufficient basis for denying the existence of such bias, they do suggest very strongly that follow-up bias is not an important problem in the study.

Table 5.—*Percentage of Limbs With at Least 70 Percent of Overall Functional Capacity,*[1] *by Extent of Follow-up Effort, Limbs With Complete Peroneal Sutures, Representative Sample Only*

Effort	Number of cases	Percentage rated 70 percent or better as to overall functional recovery
Single letter	90	32.2
Two or more letters	31	51.6
Personal visit, or regional office intervention	17	94.1
Total	138	44.2

[1] The scale of overall functional capacity is described on pp. 351–353.

The third study of follow-up bias rests upon a comparison of examined and nonexamined men from the standpoint of data found in VA claims folders. The New York allocation of complete lesions on the ulnar nerve, falling within the representative cross section and having no associated nerve lesions, was sampled at random to provide 31 nonexamined men and 26 examined. The VA claims folders contain all examinations made by VA examiners in connection with the adjudication of claims for compensation, and the chairman of the study group undertook to assess each case on the basis of two of the most summary scales employed in the follow-up study: (1) Dr. Lewey's scale of functional recovery (pp. 351–353); and (2) the British scale of motor recovery (p. 75). For the examined cases these supplementary ratings were accomplished in ignorance of the actual judgments reached by the New York group on the basis of its detailed follow-up examinations, and it was of more than passing interest to compare the two independent ratings. Since Dr. Lewey's scale is a quantitative one, it seemed natural to correlate the two ratings; the correlation coefficient is +.80. The British motor ratings agree even more closely; in 18 of the 26 cases the same rating was assigned and in 6 the ratings were but one step apart on the British scale. Although the samples are small, the agreement inspires confidence in the use of the ratings based on the VA claims folder to compare the examined and nonexamined cases.

For both motor recovery and overall functional recovery the sample of examined men presents a significantly more favorable picture than the nonexamined. Table 6 presents the data on the British scale of motor recovery; the two samples differ by an amount which has a probability below .01. Table 7 provides the parallel data on Dr. Lewey's scale of functional recovery; the two samples differ significantly ($P = .04$). Since the testimony of this experiment is clearly in favor of the notion that the follow-up sample is somewhat biased in the direction of more favorable results, it is important to estimate at least roughly the magnitude of the error of estimation arising out of use of data on only those men who could be brought in for examination. This may be done easily, although the samples are too small to permit it to be done very reliably, by weighting the sample of examined men by 75 percent and the sample of nonexamined by 25 percent. This process leads to the estimates presented in table 8 for the British scale of motor recovery and in table 9 for Dr. Lewey's scale of overall functional recovery. In each table the biased estimate is derived from the men who were examined, and the unbiased estimate was obtained from both samples by the weighting procedure described. Although the evidence of tables 6 and 7 is clearly to the effect that the examined men made the better recovery, the percentage of men actually brought under examination is so high that the actual bias does not seem very large.

Table 6.—*Comparison of Examined and Unexamined Pure Ulnar Lesions as to British Classification of Motor Recovery Evaluated From VA Claims Folders, Representative Sutures From New York Allocation*

British motor classification	Examined	Not examined	Total
	Number of lesions		
At most proximal muscles acting against gravity, no return of power in intrinsics	4	20	24
Proximal muscles against gravity, and perceptible contraction in intrinsics	13	8	21
Return of function in both proximal and distal muscles such that all important muscles act against resistance, or better	9	3	12
Total	26	31	57

Table 7.—*Comparison of Examined and Unexamined Pure Ulnar Nerve Lesions as to Overall Functional Recovery Evaluated From VA Claims Folders, Representative Sutures From New York Allocation*

Overall functional recovery (percent)	Examined	Not examined	Total
	Number of lesions		
60 or less	8	17	25
70	7	10	17
80 or more	11	4	15
Total	26	31	57

As a prelude to the coding experiment on the VA claims folders the VA numerical disability ratings in effect at the time of the follow-up study were obtained for fairly large samples of men in the New York allocation, both the examined and the unexamined. The two groups proved to be indistinguishable in their VA disability ratings.

Table 8.—*Comparison of Biased and Unbiased Estimates of Motor Recovery Following Ulnar Nerve Suture, Based on Study of VA Claims Folders*

Motor recovery (British scale)	Biased (examined men only)	Unbiased (all men)
	Percent	*Percent*
No contraction	0	3.7
Perceptible contraction, proximal only	0	4.6
Proximal against gravity, no power in intrinsics	15.0	21.1
Proximal against gravity, perceptible contraction in intrinsics	50.0	43.1
Proximal and distal against resistance	35.0	27.5
As above, plus some synergic and isolated movements	0	0
Complete recovery	0	0
Total	100.0	100.0
Number of men studied	26	57

Table 9.—*Comparison of Biased and Unbiased Estimates of Overall Functional Recovery Following Ulnar Nerve Suture, Based on Study of VA Claims Folders*

Functional recovery (percent)	Biased (examined men)	Unbiased (all men)
	Percent	*Percent*
0	0	0
10	0	0
20	0	0
30	3.8	3.7
40	0	0
50	0	0
60	27.0	33.9
70	27.0	28.4
80	30.8	23.8
90	11.5	10.1
100	0	0
Total	100.1	99.9
Number of men studied	26	57

In summary, several separate studies have been made on the possible extent of any bias arising out of incomplete follow-up, and only one provides convincing evidence of bias. Moreover, when account is taken of the fact that 75 percent of the allocated men were examined, the suggestion is strong that any bias is not very extensive.

Once the tables for a given chapter had been run, it fell to the statistician to analyze them from the point of view which dictated the original plan, and to prepare a written summary of both the tabular data and his analysis of them. Methods of analysis have been those generally used in testing hypotheses and need not be elaborated upon here; acknowledgment is made, however, to Mr. Seymour Jablon of the Follow-up Agency who served as mathematical consultant on numerous points in the analysis and effected great savings in the processing costs. Several statistical problems which must be confronted in the analysis deserve mention here also. In seeking to determine whether a factor, e. g., presence of associated bone injury, has some influence upon, say, motor recovery, one may approach the analysis via seven separate nerves, asking the same question about each, and being content to learn, for example, that there seems to be evidence of an effect in certain nerves but not in others. Or one may utilize the data on the different anatomic structures in seeking to learn if there be an effect of a general nature, applicable to all nerves. It is from the latter point of view that most of the analysis has been done, and exceptions are noted in the text. Another statistical problem concerns the use of data on several muscles innervated by the same nerve to enable conclusions to be reached about that nerve. The observations on one muscle are not independent of those on another in the same man, and the data provided by the several muscles cannot be combined on the basis of the assumption of independence without doing violence to the facts. Although alternative statistical techniques are helpful in this situation, a great deal of judgment is called for in the interpretation of the data, and this is one reason why, especially in the motor chapter, so much of the information is presented in the form in which it was obtained, i. e., by muscle.

A third statistical problem, by no means unique to these data but especially troublesome in evaluating the influence of factors associated with management, arises out of the association of one factor with another, e. g., time and surgical gap, so that apparent effects may disappear when analyzed in more detail or, what is worse, may actually be confounded to such an extent that their independent existence cannot be demonstrated by the data. One cannot, of course, be sanguine about an *ex post facto* study of treatment effects in routine clinical material, but must expect continually to be misled and mistaken by apparent relationships which are in fact based upon the factors governing selection of treatment in a clinical (not experimental) situation in which the physician undertakes to do what seems best for the particular patient. The interest in the details of treatment, however, will not allow their neglect even though the prospects for definitive conclusions may be poor. One can hardly experiment with peripheral nerve lesions in the human.

G. PREPARATION OF THE FINAL REPORT

The plan developed at the Boston conference has been followed in its general outline. A first draft of each chapter has been prepared by the investigator responsible for the subject, and then reviewed and edited by the chairman with the assistance of the statistician. The statistician, in turn, has reviewed all the text from the statistical point of view and verified the statistical accuracy of such data and conclusions as are presented. Finally, the entire investigative group has reviewed the manuscript as a whole.

H. SOME DEFICIENCIES SEEN IN RETROSPECT

No cooperative study of such magnitude as the present one can be viewed in retrospect without regrets being felt over what now seem to be deficiencies, and to review a study from this standpoint may seem folly. However, we have done so, in a limited way, not to persuade ourselves of the inevitability of what has been done but for whatever value it may have for other clinical investigators who must embark upon large enterprises where advance planning is of especial importance. Had the many important purposes of the study been made more explicit at the beginning, all subsequent planning would have been easier and more effective, and the study a less expensive and time-consuming one to complete.

Early pilot work on the content of the follow-up examination, with more recognition of the need for uniformity of concepts and examining procedures, would have permitted the drafting of the statistical code before the main series of examinations began and would have otherwise hastened and facilitated the successful conclusion of the study. More adequate advance planning would undoubtedly have enabled the investigators to approach their objectives on the basis of a smaller volume of observations per case, and to enter upon the final analysis in a leisurely and experimental fashion more in keeping with the complex interrelations among the variables under study. A major deficiency, in the opinion of all the investigators, was the necessity for each center to expend a major portion of its total resource on inducing and scheduling men to report for examination. The final score of 75 percent examined is a high one, but it was attained at great cost and delay in the entire undertaking; men drawing compensation from the Federal Government should be more accessible to government-sponsored investigation.

In a cooperative clinical study of such magnitude, it would be desirable, after preparation of a preliminary scheme for examination and coding, for a pilot group of patients at each center to be studied under the personal direction of the permanent director who would be responsible for the training of its professional and technical personnel. The pertinent results of the pilot study should then be subjected to a searching analysis by the intended author of each chapter of the final report, who, after consultation with the statistician, would prepare the examination procedure and coding system to be adopted. Another improvement would be the provision of a full-time deputy, working closely with the chairman, who could make frequent visits of several days to each center, during which he would participate actively in the examination and coding of patients. The preparation and correlation of the final manuscripts would also be greatly aided by regular conferences between the traveling full-time deputy and each author.

Chapter II

THE INJURY AND ITS MANAGEMENT

Barnes Woodhall and *Gilbert W. Beebe*

Before any follow-up data can be presented it is essential that the reader be familiar with the characteristics of the acute lesion which has been chosen for study here, and with its management. The selection of various aspects of the injury and its treatment was, of course, limited by *à priori* concepts of the significance of individual factors in peripheral nerve regeneration and, even more important, by the quality and detail of the average military record. This chapter serves to introduce the different classifications of injury and treatment upon which the later analysis of regeneration depends. It includes definitions and discussions of the problems which were encountered in creating the many classifications and in adapting them to the individual case. At the same time, the structure of the entire sample is revealed in terms of these classifications, and the implications of the sampling plan are explored.

Since the abstracting of service medical records necessarily extended to all active treatment received in military hospitals, the pattern of surgical management reveals important information on such points as the probability of reoperation and the practice of cuff removal. In the belief that they provide rough measures of the cost of peripheral nerve injuries to the Armed Forces, duration in hospital and disposition were also abstracted and the resulting data appear in this chapter.

A. CHARACTERISTICS OF THE NERVE INJURY

The information included under this general heading pertains to the origin of the case in terms of the sampling plan, identity of the injured nerve, presence of associated nerve injury, presence of other associated injuries of importance, presence of serious infection, type of nerve injury, site of injury, agent of injury, and presence of plastic repair at site of nerve injury. Information on age at injury is also included here. Omitted from this list as an aspect of management is the length of any surgical defect. Each of these characteristics is discussed briefly, together with certain in-interrelations among them, especially those involving site of injury and identity of nerve injured. All 3,656 injured nerves, or the involved injured extremities, of 2,554 injured men are used in the tables from which these observations are drawn. In any particular table, however, a smaller total may appear because of lack of information concerning one or more of the factors involved.

Three main groups of cases were established from the 10 rosters that were available and from scattered local cases that were added to this study. Group A consists entirely of cases from the large Army Peripheral Nerve Registry and within the geographical sampling areas defined for the five follow-up centers. It includes both sutures and lyses and is the most representative material in the sample except, of course, with respect to the ratio of sutures to lyses and, for the lyses, the presence of associated nerve lesions. Group B, on the other hand, was formed from the five lysis rosters chosen, it will be recalled, on the basis of the care with which the incomplete lesions had been assessed. Group C contains cases from the Army Peripheral Nerve Registry which fell outside the respective sampling areas, and from the other rosters of complete lesions (except roster 68) described on pages 6–7, i. e., cases of special interest because of some particular characteristic of injury or treatment. Thus, here are to be found Hoen's plasma glue sutures, Wrork's overseas sutures, the Lyons-Woodhall series with special pathological studies, and cases from the Registry allocated for study only because of arterial injury, normal bone resection, bulb suture, or nerve graft. Both sutures and lyses are represented in group C, but the factors of selection apply chiefly to sutures.

The cases in group C, being of special interest for one reason or another, could not be accepted in advance as typical of peripheral nerve injuries or as homogeneous with the lesions in groups A and B. Accordingly, the several roster groups were compared on several major characteristics of injury. Most of the expected differences were found, although many of them are not as large as anticipated and seem of doubtful practical importance despite their statistical reliability. Nevertheless, since group A contained 2,501 lesions, group B 280 lesions, and group C 875 lesions, it was decided that the descriptive analysis of each modality of recovery should be confined to group A insofar as it pertains to sutures. It was believed that the lyses should be drawn from all three groups, except that lyses from the Army Registry should also be confined to the sampling areas surrounding the five centers.

In tables 10, 11, and 12 the sample is described in terms of the nerve involved, the presence of associated nerve injury to the same limb, and the number of lesions in the same nerve. As has been noted in previous studies, and despite the effort made in this study to secure adequate samples of the less frequently injured nerves, upper extremity nerve injuries were twice as numerous as lower extremity injuries. In the upper extremity, the ulnar nerve was the most frequently represented of the three major nerve segments, followed in turn by the median and the radial. In the lower extremity, thigh injuries involving some component of the sciatic nerve were more common than injuries in the foreleg. The sampling plan was geared to a study of the seven major peripheral nerves; occasionally, however, associated injuries involving other nerves were encountered. Regeneration studies were conducted upon these latter nerves where motor function was involved but no analysis has been made of the data.

Table 10.—*Identity of Nerve Affected, Total Sample*

Part of body	Nerve	Number of lesions	Percentage distribution: All nerves	Percentage distribution: Nerves in this part of body
Upper extremity	Median	707	19.3	31.1
	Radial	516	14.1	22.7
	Ulnar	1,000	27.4	43.9
	Musculocutaneous	44	1.2	1.9
	Axillary	9	.2	.4
	Total	2,276	62.3	100.0
Lower extremity	Femoral	6	0.2	0.4
	Peroneal	341	9.3	24.7
	Sciatic-peroneal	404	11.1	29.3
	Tibial	235	6.4	17.0
	Sciatic-tibial	394	10.8	28.6
	Total	1,380	37.7	100.0
Grand total		3,656	100.0	

Table 11.—*Associated Nerve Lesions* [1] *on the Same Limb, by Nerve*

Nerve	Total lesions	Percentage with other nerve lesions, same limb
Median	707	58.0
Radial	516	32.8
Ulnar	1,000	40.2
Peroneal	341	24.9
Sciatic-peroneal	404	94.3
Tibial	235	35.7
Sciatic-tibial	394	97.0

[1] In addition to the major nerves only the following were included in counting associated nerve lesions: musculocutaneous, axillary, and femoral.

A high percentage of patients with nerve injury had an associated nerve injury, and multiple injuries tended to be concentrated in a single limb. The very high percentage of associated nerve injury indicated for the

Table 12.—*Number of Lesions Per Injured Nerve, Total Sample*

Number of lesions per nerve	Injured nerves	
	Number	Percent
One	3, 615	98. 88
Two	40	1. 09
Three	1	. 03
Total	3, 656	100. 00

sciatic-peroneal and sciatic-tibial lesions is a consequence of regarding these two sciatic branches as individual nerves for the purpose of the regeneration studies.

When the multiplicity of peripheral nerves injured in the same extremity was analysed in terms of various aspects of the clinical history, the following conclusions emerged: A high injury in the arm more often involved other nerves than a low injury, and the same phenomenon was present in the lower extremity; strangely enough, the more nerves injured in a limb, the less likely was concomitant bone or joint injury; there was a tendency for infection to be more common in the presence of multiple nerve injuries; associated vascular injuries were rare in the lower extremity but they were common in the upper extremity and were strongly associated with the presence of additional nerve injuries; for the radial nerve, there was a marked tendency for a major plastic surgical procedure to be associated with other nerve injuries.

In table 13 appears the summary classification adopted for the type of injury to the nerve, as well as the frequency with which each type was found in the entire sample. The finer nuances of this classification are presented in another publication (46), but the criteria for its application

Table 13.—*Type of Injury to Nerve, Total Sample*

Type of injury	Number	Percent
Normal nerve	22	0. 6
Normal nerve, compressed by scar tissue	386	11. 1
Complete nerve division	1, 795	51. 7
Partial nerve division	449	12. 9
Neuroma in continuity	776	22. 3
Contusion	43	1. 2
Stretch injury	2	0. 1
Total known	3, 473	99. 9

to the military records are of interest here. The purpose of the classification was to describe the extent of the lesion as it appeared to the operator. Thus no attention was paid to the evidence of electrical testing or of microscopic pathological study, although both types of observation were included elsewhere in the abstract of the case for statistical purposes. The following notes guided the classification of individual cases:

NORMAL NERVE COMPRESSED BY SCAR TISSUE. This is rarely found. Nerve is bound down in scar tissue but it is not itself scarred or neuromatous. No suture is done in these cases.

COMPLETE NERVE DIVISION. This means there is or has been a complete separation of the nerve. Include here cases with only connecting strand of fibrosed tissue or few nonfunctioning fibers between two ends of the nerve—also cases where there is continuity but the operator sections the scarred area or "neuroma" and finds no fibers going through. In absence of operation report, if summary speaks of severance and suture overseas, this classification may be used. Bulb sutures indicate complete nerve division.

PARTIAL NERVE DIVISION. Partial separation implies that the unsevered portion of the nerve contains functioning nerve fibers. When there is partial division and the rest is neuromatous, it should be coded as a neuroma, not a partial division. When the only continuity is scarred connective tissue, code complete rather than partial severance. There can be cases of partial division with a neuroma at one end and glioma at the other, but there must be some functioning fibers going through.

NEUROMA IN CONTINUITY. Neuroma is more than external scar; there must be growth in the nerve itself. This classification is not compatible with a statement that any normal fibers are going through. If part of the cross section is neuromatous, and part normal, classify as partial division. There must be positive evidence of neuroma in continuity before it can be coded here. (See complete division.) If nerve is described as densely scarred or extensively scarred it is in most cases a neuroma in continuity. If nerve appears grossly normal, but on palpation at operation nerve is described as lumpy, hard, irregular, or with fusiform thickening, or otherwise abnormal, it can be considered a neuroma in continuity. Where there is partial division and the rest neuromatous code as neuroma in continuity.

STRETCH INJURY. Will also be called a traction injury.

The classification as to specific site is exhibited in table 14. Like those of table 10, and despite the sampling plan, these data reflect the concentration of nerve injuries in the upper extremity and demonstrate once more the higher percentage of wounds in that part of the extremity adjacent to the trunk. Of greater import is the implication that the high and low nerve injuries will be adequate to permit comparisons as to nerve regeneration. Indeed, if indicated, good regeneration studies appear possible for injuries received in any part of either extremity.

An analysis of the agent causing injury, among other matters, has been presented in an earlier statistical review of the Army Registry material (87). For the purposes of the regeneration study, it appears sufficient to note that 92 percent of the nerve injuries were sustained in combat.

In large numbers of peripheral nerve injuries the extremity is involved in one or another grave concomitant injury to other tissues. As defined in this analysis, an associated injury is one that would be expected to bear a direct and significant relationship to the treatment and anatomical regeneration of the injured nerve. The relation between site of nerve injury and associated injury was studied separately for injuries in the upper and lower extremity. In both sets of cases there was an intimate association between the location of the nerve lesion and the probability of a bone or joint injury. Bone or joint injury was defined as a significant gunshot or other wound of such structures causing open fracture or destruction of tissue demanding specific orthopedic care. The probability was low for injuries above the elbow and in the upper two-thirds of the thigh, and high for injuries below these points. Also, if a bone or joint injury were incurred its chance of normal healing varied significantly in relation to site of injury in the upper extremity. These figures are shown in table 15.

Table 14.—*Specific Site of Lesion, Total Sample* [1]

Part of body	Specific site	Number of lesions	Percentage distribution	
			All lesions	Lesions in this part of body
Upper extremity	Shoulder	32	0.9	1.4
	Arm, upper third	422	11.8	18.9
	Arm, middle third	402	11.2	18.1
	Arm, lower third	358	10.0	16.1
	Elbow	216	6.0	9.7
	Forearm, upper third	217	6.0	9.7
	Forearm, middle third	224	6.2	10.1
	Forearm, lower third	208	5.8	9.3
	Wrist	136	3.8	6.1
	Hand	12	0.3	0.5
	Total	2,227	62.1	99.9
Lower extremity	Thigh, upper third	433	12.1	31.8
	Thigh, middle third	259	7.2	19.0
	Thigh, lower third	184	5.1	13.5
	Knee	256	7.1	18.8
	Leg, upper third	108	3.0	7.9
	Leg, middle third	49	1.4	3.6
	Leg, lower third	46	1.3	3.4
	Ankle	16	0.4	1.2
	Foot	9	0.3	0.7
	Total	1,360	37.9	99.9
Grand total		3,587	99.9	

[1] Omitted are 49 upper and 20 lower extremity cases for which site was not specified in sufficient detail for this classification.

In the upper extremity, associated arterial injury varied quite significantly with site of injury, being especially common in the upper arm. An associated arterial injury was further defined as one implicating a major vessel supplying an extremity, i. e., the subclavian, axillary, brachial, radial, and ulnar in the upper extremity, and the iliac, femoral, popliteal, and tibial in the lower. Tables 16 and 17 show the variable frequency of such arterial injuries in association with the particular nerve affected and the specific site of the nerve lesion.

Table 15.—*Percentage of Nerve Injuries With Associated Bone or Joint Injury, and Percentage of Bone or Joint Injuries in Which Normal Healing Occurred, by Site of Injury and Part of Body*

Site of nerve injury	Percentage of nerve lesions with bone or joint injury	Percentage of bone or joint injuries with normal healing
Upper extremity		
Shoulder, arm upper third	27.1	77.2
Arm, middle third	44.3	67.4
Arm, lower third	40.3	48.6
Forearm, upper third	65.0	58.9
Forearm, middle third	58.0	61.5
Forearm, lower third	63.8	69.7
Elbow	64.7	67.6
Wrist, hand	45.3	76.1
All sites	47.4	65.0
Lower extremity		
Thigh, upper third	28.9	73.6
Thigh, middle third	21.6	67.9
Thigh, lower third	21.2	69.2
Leg, upper third	49.1	79.2
Leg, middle third	57.1	71.4
Leg, lower third	52.2	75.0
Knee	28.1	79.2
Ankle, foot	52.0	92.3
All sites	30.1	74.6

Table 16.—*Associated Arterial Injury, by Nerve*

Nerve	Percentage with associated arterial injury	Nerve	Percentage with associated arterial injury
Median	32.0	Tibial	3.9
Ulnar	23.4	Sciatic-peroneal	3.0
Radial	15.1	Sciatic-tibial	3.0
Peroneal	1.5		

Table 17.—*Associated Arterial Injury, by Site of Nerve Lesion*

Site of nerve injury	Percentage with associated arterial injury	Site of nerve injury	Percentage with associated arterial injury
Upper extremity		Lower extremity	
Shoulder, arm, upper third	42.4	Thigh, upper third	2.5
Arm, middle third	27.8	Thigh, middle third	3.9
Arm, lower third	16.2	Thigh, lower third	3.3
Forearm, upper third	15.7	Knee	2.4
Forearm, middle third	15.2	Leg, upper third	0.9
Forearm, lower third	26.8	Leg, middle third	6.1
Elbow	12.3	Leg, lower third	0
Wrist, hand	21.2	Ankle	6.3
		Foot	0
All sites	24.4		
		All sites	2.8

The frequency of major plastic repair at the site of the nerve lesion also varied significantly by location of the nerve injury. Among injuries in the upper extremity, plastic repair was more common in the forearm than in the arm. A parallel situation existed among injuries to the lower extremity (table 18).

The agent of injury was moderately related to the probability of associated bone or joint injury and also to the chance of an infection sufficient to delay nerve operation. It was entirely unrelated to the likelihood of arterial injury or plastic repair. The percentages with bone or joint injury, and the parallel percentages with infection, appear in table 19.

In a series of military battle casualties one does not expect to find sufficient variation in age to have biological significance, but since the follow-up

Table 18.—*Plastic Repair at Site of Nerve Injury, by Site of Nerve Injury, and by Body Part*

Site of nerve injury	Percentage with plastic repair	Site of nerve injury	Percentage with plastic repair
Upper extremity		Lower extremity	
Shoulder, arm, upper third..	4.3	Thigh, upper third.........	3.2
Arm, middle third.........	7.6	Thigh, middle and lower thirds..................	7.2
Arm, lower third...........	8.1	Knee......................	16.5
Forearm, upper third.......	18.9	Leg, ankle and foot........	14.2
Forearm, middle third......	21.1	All sites..............	8.8
Forearm, lower third.......	20.5		
Elbow....................	14.7		
Wrist, hand...............	14.4		
All sites..............	11.8		

Table 19.—*Associated Bone or Joint Injury and Infection, by Agent of Injury, All Peripheral Nerve Lesions Combined*

Agent	Percentage of nerve lesions with associated bone or joint injury	Percentage of nerve lesions with associated infection
Combat gunshot wounds.........................	41.5	9.3
Noncombat gunshot wounds......................	47.0	2.3
Cutting instruments and closed wounds............	27.1	6.4
All agents................................	40.9	8.9

results pertain to a particular series of men, their age should be recorded here (table 20).

In summary, the foregoing data serve to define the nerve injury in terms of distribution, associated nerve injury, type of nerve injury, the specific site of the nerve injury, the agent causing the injury, and the presence of associated injury to bone, vessel, and soft tissue. It is evident that any adequate number of individual nerve injuries is available for study at an site in the extremity. Furthermore, such injuries may be found with related nerve injury, an association that may not impair the study of anatomical regeneration but certainly may adversely implicate function of the extremity. This is of even greater import when it may be noted that a single limb is involved in multiple nerve lesions in a high percentage of such instances.

As would be suspected from the nature of the rosters and the origin of the wounds, this material shows a high percentage of completely severed nerves incurred in combat. Of real interest to the military surgeon is the pronounced incidence of concomitant tissue injury with the specific nerve lesions and, in particular, the association of bone injury.

Table 20.—*Age of Patient at Injury, Total Sample*

Age, in completed years	Nerve lesions		Age, in completed years	Nerve lesions	
	Number	Percent		Number	Percent
Under 20	348	10.6	32–33	162	4.9
20–21	661	20.1	34–35	126	3.8
22–23	550	16.7	36–37	58	1.8
24–25	497	15.1	38 or over	25	0.8
26–27	389	11.8			
28–29	258	7.8	Total known	3,296	100.1
30–31	222	6.7			

B. MANAGEMENT OF THE NERVE INJURY

Just as the preceding section is focussed upon the nerve injury, the present section has to do with its management and is designed to furnish background for the subsequent chapters rather than to provide generalizations about peripheral nerve injuries as a whole. The definitive operation is here defined as the last operation undertaken to treat the injury with an anticipated good result, and no lysis may be called the definitive operation if it follows a suture or graft. All subsequent tables on management refer to it. A cuff removal following a suture or graft is not classified as a definitive operation; a suture done after an unsuccessful graft is, however, classified as a definitive operation. In the analysis of the effect of number of operations upon nerve regeneration, bulb suture was not counted as a separate operation but considered to be the first stage of an anticipated definitive suture, but explorations, transpositions, and other operations following more definitive procedures were counted. Neurolysis, removal of a tantalum cuff thought to act as a barrier to nerve regeneration, and unsuccessful suture were defined as operations. An approximation suture, usually performed at the time of wound toilet, was not defined as an operation. Since it is the definitive operation which appears on the follow-up card, the subsequent portions of this report revolve around it, and whatever is learned from the tables in this section will provide useful background data. It should be noted that subsequent tables will embrace a total of 3,416 injured nerves with definitive operation rather than the total of 3,656 injured nerves used heretofore. The sequence of operations terminated by the definitive operation will be discussed in a subsequent section.

The features of the definitive operation which were abstracted from the military records are as follows:

Number of operations.
Interval from injury to operation.
Calendar date of operation.
Medical echelon of repair.
Training of surgeon.
Type of surgery performed.
Special features of operation, e. g., bulb suture, mobilization.
Length of surgical defect after resection.
Other operative procedures prior to separation, e. g., tendon transplant, arthrodesis.
Suture materials employed.
Use of cuff.
Placement of stay suture.
Technique of neurolysis.
Tension on suture-line.
Results of electrical stimulation.
Condition of nerve ends just prior to anastomosis.

At the outset a study was made of the lesions derived from the three main roster groups as to their comparability in respect to treatment. These groups are, it may be recalled:

A. Army Peripheral Nerve Registry cases within the sampling areas.
B. Lysis rosters (rosters 40, 47, 90, 92 described on p. 7).
C. Other rosters (rosters 39, 48, 61, 86, 88) and Registry cases outside the sampling areas.

The rosters, of course, consist of men, so that the lesions contributed by each roster group may be both complete and incomplete. This is especially true of groups A and C.

From the comparisons which were made, it seemed evident that the Registry cross section (group A) differed significantly from group C in a number of respects. These differences were not always striking but were sufficient to support the decision to limit the descriptive parts of the main chapters to sutures of the group A rosters and to lyses from any source except Registry cases outside the sampling area. A typical study table which is of interest in terms of the probability of more than one operation, regardless of type, is table 21.

In summary form, the points on which the roster groups were compared and the results are as follows:

1. Registry cases within the sampling area (group A) were operated upon somewhat less often than group C cases.
2. The definitive operation on group A cases occurred somewhat sooner after injury than is true of group C cases.
3. The average calendar date of the definitive operation is 1 to 3 months earlier for group A than group C cases.
4. Group A cases were operated upon more often overseas than group C.
5. Groups A and C do not differ as to special operative features.
6. Group A sutures were less often done with tantalum than group C sutures.
7. The use of a cuff does not vary between groups A and C.
8. A stay suture was more often used in group C sutures than in group A.

9. Group C cases were more often done by surgeons without known neurosurgical training.

10. Groups A and C do not differ as to such ancillary operative procedures as cuff removal, tendon transplants, arthrodesis, sympathectomy for pain, etc.

Table 21.—*Percentage of Lesions Requiring More than One Operation, by Type of Injury, and by Roster Group*

Type of injury	Roster group		
	Army Registry, within sampling area (A)	Lysis rosters (B)	Other (C)
Normal nerve	5.7	11.8	14.1
Complete division	19.4	30.4	25.0
Partial division	17.1	28.2	22.5
Neuroma in continuity	13.9	34.5	19.7
Other	4.8	5.6	9.1

Differences among the nerves in respect to the number of operations are not remarkable and are statistically significant at only two points:

1. Among normal nerves, the median much less often (3.3 percent) required more than one operation than other nerves (12.0 percent).

2. Among complete divisions, those on the tibial nerve were much less often operated upon more than once (7.5 percent) than was true of other nerves (table 22).

Table 22.—*Percentage of Nerves Completely Divided at Injury Requiring More Than One Operation, by Nerve*

Nerve	Percentage	Nerve	Percentage
Median	22.3	Tibial	7.5
Radial	15.9	Sciatic-tibial	23.3
Ulnar	22.9		
Peroneal	28.9	All	21.2
Sciatic-peroneal	22.4		

For the entire series as a whole, table 23 indicates the time interval from injury to definitive operation, as this procedure has already been defined. After the first 30 days, the number of cases available for study rises rapidly, in all probability reflecting the World War II emphasis upon "early" nerve suture (75). An adequate number of cases operated upon after 365 days is likewise available for study of regeneration after the assumed interval for optimal recovery. Examination of the interval from injury to definitive operation in terms of the character of the operation and the type of injury suggests the following:

1. On the average a definitive suture was accomplished most promptly if the lesion was one of complete division and with the greatest delay if the operator was presented with a neuroma in continuity; partial lesions occupy a middle ground.
2. Definitive lyses on nerves of normal appearance were accomplished more expeditiously than definitive lyses on neuromas.
3. The definitive repair of a neuroma by means of suture was generally done well before a definitive lysis on a neuroma.

Table 23.—*Interval From Injury to Definitive Operation, Total Sample*[1]

Interval, in days	Nerve lesions		Interval, in days	Nerve lesions	
	Number	Percent		Number	Percent
Under 10	100	2.9	360–419	90	2.6
10–29	44	1.3	420–479	60	1.8
30–59	252	7.4	480–539	40	1.2
60–89	381	11.2	540–599	41	1.2
90–119	495	14.5	600–659	20	0.6
120–149	488	14.3	660–719	9	0.3
150–179	382	11.2	720–779	11	0.3
180–209	313	9.2	780–839	8	0.2
210–239	212	6.2	840–899	4	0.1
240–269	188	5.5	900 or more	11	0.3
270–299	116	3.4			
300–359	150	4.4	Total	3,415	100.1

[1] One case excluded for unknown date of definitive repair, others for lack of any definitive operation.

Table 24 shows that most definitive operations were performed in 1945, by which time the neurosurgical centers and acceptable methods of repair had been fully developed.

Echelon of repair of an injured nerve is obviously related to the time-interval from injury to repair. Under the stimulus of the principle of "early" nerve suture, many definitive repairs of uncomplicated nerve divisions were made in neurosurgical centers in overseas hospitals. In this sample, 84.2 percent received their definitive operation in hospitals of the Zone of Interior. Medical echelon of repair was originally abstracted in terms of the following general classification, based on Army terminology: field hospital overseas, evacuation hospital overseas, general hospital overseas, and general hospital in the continental United States. When the lesions with definitive operation were first distributed according to this classification, however, it was found that only 0.3 percent had been performed in field hospitals, 1.4 percent in evacuation hospitals, and 14.1 percent in general hospitals overseas. Consequently, only the overseas-Z/I aspect of the classification was employed in later analyses.

Table 24.—*Calendar Period of Definitive Operation, Total Sample*

Calendar period	Nerve lesions		Calendar period	Nerve lesions	
	Number	Percent		Number	Percent
1942 or earlier	1	0.0	1945, July–Sept	635	18.6
1943	38	1.1	1945, Oct.–Dec	163	4.8
1944, Jan.–Mar	41	1.2	1946	144	4.2
1944, Apr.–June	70	2.0	1947	16	0.5
1944, July–Sept	237	6.9	1948	7	0.2
1944, Oct.–Dec	382	11.2			
1945, Jan.–Mar	797	23.3	Total	3,416	99.9
1945, Apr.–June	885	25.9			

When the abstracting was being planned it was agreed by all members of the group that the training or experience of the surgeon should be a determining variable of importance in the end result. Opinions differed, however, as to just which features of training and/or experience might be significant. No such characteristic could be employed unless the classification of any individual surgeon could be reduced to a simple task, for hundreds of different operators were involved in the series as a whole. It was finally decided, therefore, to attempt no more than the following classification of neurosurgical training:

Trained neurosurgeon.
General surgeon trained to do neurosurgery.
Essentially untrained in neurosurgery.
Training unknown.

The trained neurosurgeons were most easily identified as the products of the various neurosurgical centers in the United States. The general surgeons with supplementary training in neurosurgery were identified largely on the basis of lists of graduates of the special courses instituted for the purpose at Columbia and the University of Pennsylvania. When the definitive operations were classified in this way it was of interest to observe that 44.4 percent had been done by trained neurosurgeons, 33.4 percent by general surgeons with supplementary training in neurosurgery, 0.4 percent by surgeons with essentially no training in neurosurgery and 21.8 percent by surgeons whose training was unknown. Many of the last group, of course, may have had considerable wartime experience in the surgery of peripheral nerve lesions. Also, in each neurosurgical, center a fully trained Chief of Neurosurgery was in charge of all cases. Surgeons with little background in peripheral nerve surgery were rigorously and intensively trained by the chief before they were permitted to operate.

Their performance of the essential operative steps was ordinarily supervised in detail by the chief before they were permitted to proceed independently. It seems probable, under these circumstances, that the policies and degree of supervision exercised by the Chief of Neurosurgery in each center may have been of more importance than the formal training of the operating surgeon.

The neurosurgical training of the operator exhibited some variation in relation to identity of nerve, type of injury, and type of operation. The most probable finding showed that, in completely divided nerves, there was a tendency for the better-trained operators to suture the sciatic and tibial nerves and for the less well-trained to handle the ulnar nerve more often than other nerves.

The definitive operation has been defined earlier (p. 40). It will be recalled that a final lysis could be regarded as the definitive operation only if not preceded by a suture or graft. Table 25 presents the basic counts as to type of surgery performed at the definitive operation. It will be noted that there were 605 cases in which only lysis was performed. In 42 cases the initial operation was a graft, and additional grafts were done at the second operation. However, the final count of table 25 gives only 30 lesions with definitive operation graft, many grafts having been removed in favor of anastomosis of the nerve ends themselves. The 11 operations in the "other" category of table 25 represent reroutings, intrafascicular sutures, etc.

Table 25.—*Type of Definitive Operation, Total Sample* [1]

Type of definitive operation	Nerve lesions	
	Number	Percent
Partial suture	213	6.2
Complete suture	2,556	74.8
Lysis	605	17.7
Graft	30	0.9
Other	11	0.3
Total	3,415	99.9

[1] Excluding one case in which the record was unclear as to type of definitive operation, and lesions not operated upon.

Of more specific interest is table 26 where are presented the several special operative features that might be associated with the definitive suture or graft. The separate classifications are self-explanatory but note should be made of the large number of nerve-segment transpositions and mobilizations that were deemed necessary to carry out technically good nerve suture. The cases with antecedent bulb suture will also be a source

Table 26.—*Special Operative Features at Definitive Graft or Suture, Total Sample*

Special features	Number	Percent
None	1,353	39.6
Bulb suture prior to operation	51	1.5
Transposition of nerve segment	607	17.8
Normal bone resection	21	0.6
Pathological bone resection	26	0.8
Nerve shunt	2	0.1
More than one lesion on this nerve repaired	15	0.4
Bulb suture prior to this operation and extensive mobilization of nerve preparatory to suture or graft	50	1.5
Bulb suture and transposition of nerve segment	49	1.4
Extensive mobilization of nerve preparatory to suture	567	16.6
Other, including other combinations	62	1.8
Not suture or graft	613	17.9
Total	3,416	100.0

Table 27.—*Percentage of Completely Sutured Lesions in which Transposition* [1] *or Mobilization* [1] *Was Performed at the Definitive Suture, by Nerve and by Type of Injury*

Nerve	Type of injury			
	Complete division		Neuroma	
	Transposition only	Mobilization only	Transposition only	Mobilization only
Median	15.4	24.6	9.8	27.7
Radial	6.6	16.2	4.0	12.0
Ulnar	62.9	4.6	65.2	7.7
Peroneal	4.6	25.5	3.0	17.9
Sciatic-peroneal	1.5	42.4	0	27.3
Tibial	16.3	35.6	13.2	21.1
Sciatic-tibial	1.9	43.9	1.5	30.3
All nerves	24.7	21.8	22.3	18.8

[1] Omitted from the counts are a small number of both transpositions and mobilizations associated with bulb suture as a first stage in the repair, addition of which does not materially affect the pattern of variation.

of further review. The special operative features of transposition and extensive mobilization showed a great deal of variation among individual nerves (table 27). In general, transposition was rather common in the ulnar and rare in the radial, sciatic, and peroneal nerves. Extensive mobilization was, on the other hand, common in the sciatic but rare in the ulnar nerve.

The length of surgical defect, i. e., that following removal of all pathological tissue, was coded to the nearest cm. (centimeter), and the resulting distribution appears in table 28. In about 5 percent of the cases the operator merely recorded that the gap was in excess of some stated number of cm., and these appear in the table at whatever number was so stated. An attempt was made to cope with the special problem presented by bulb sutures so that the estimates would reflect, not the gap at any particular operation, but the total length of the nerve excised or otherwise lost at injury and all subsequent operations. This assumes that, by the time a second stage suture is done, the first gap will have been made up, so that any second gap may be added to the first as an estimate of the total length of nerve lost. However, if two sutures were done the respective gaps were not added together in this way.

Length of surgical defect is quite reliably associated with specific type of injury and the gross anatomical location of nerves. In general, complete nerve divisions were followed by longer surgical defects and, among individual nerves, injuries of the sciatic nerve gave rise to longer surgical defects (table 29).

Table 28.—*Length of Surgical Defect at Definitive Repair, by Complete Suture or Graft, Total Sample* [1]

Length of defect, cm.	Nerve lesions		Length of defect, cm.	Nerve lesions	
	Number	Percent		Number	Percent
Under 0.4	12	0.5	13.5–14.4	27	1.1
0.4–1.4	49	1.9	14.5–15.4	17	0.7
1.5–2.4	169	6.6	15.5–16.4	7	0.3
2.5–3.4	375	14.7	16.5–17.4	3	0.1
3.5–4.4	387	15.1	17.5–18.4	4	0.2
4.5–5.4	399	15.6	18.5–19.4	....	....
5.5–6.4	305	11.9	19.5–20.4	3	0.1
6.5–7.4	249	9.7	20.5–21.4	....	....
7.5–8.4	218	8.5	21.5–22.4	....	....
8.5–9.4	113	4.4	22.5–23.4	3	0.1
9.5–10.4	95	3.7	31.5–32.4	1	0.0
10.5–11.4	48	1.9			
11.5–12.4	48	1.9	Total	2,558	100.0
12.5–13.4	26	1.0			

[1] Excluding 213 partial sutures and 32 unknown for length of defect; also, 131 cases are classified as X cm. for which the record merely shows gap to have been at least X.

Table 29.—*Mean Length of Surgical Defect in Centimeters, Sutures and Grafts, by Nerve and by Type of Injury*

Nerve	Type of injury			
	Complete division	Partial division	Neuroma	All types
	cm.	*cm.*	*cm.*	*cm.*
Median	6.3	4.1	4.1	5.4
Radial	5.3	3.5	4.2	4.9
Ulnar	6.1	3.4	4.2	5.5
Peroneal	6.4	4.2	5.5	5.8
Sciatic-peroneal	7.7	5.6	5.6	6.9
Tibial	7.2	4.3	5.2	6.2
Sciatic-tibial	8.2	5.3	5.9	7.1
All nerves	6.5	4.2	4.8	5.8

In a study of special operative features (bulb suture and transposition and extreme mobilization procedures) and the length of the surgical defect overcome at the definitive operation, these conclusions were reached:

1. Bulb suture is associated with a gap 2 to 3 times that observed in cases with no special operative procedures, as noted in table 30. This difference amounts to 6.43 cm. in the median nerve, 7.40 cm. in the ulnar nerve, 4.35 cm. in the radial nerve, and an overall average of 6.25 cm. for all nerves.
2. Transposition and extreme mobilization procedures are associated with smaller differences in length of gap, about 1.55 cm. for both complete and incomplete lesions on all nerves combined.

Before they were separated from service many patients had ancillary surgical procedures of an orthopedic or neurosurgical variety, especially cuff removals, tendon transplants, sympathectomies for pain, and arthrodeses. The list of procedures abstracted from the records appears in table 31 together with the total counts observed in the entire series. Table 32 shows how often each procedure was carried out in connection with lesions treated by suture (complete or partial) or graft, separately for each major nerve. It may be noted that such procedures were abstracted with the material for each nerve only as they related to the nerve in question, and tendon transplants only if they were done because of deficiencies in nerve regeneration. Cuff removals were noted without regard to the intent of the operator; in some instances removal was routine, and in others motivated by a desire to further the process of regeneration. Of all the supplementary procedures tendon transplants proved to be the most variable in relation to the nerve injured, as table 32 shows. Only for the median, radial, ulnar, and peroneal was this procedure at all frequent. Amputation for nerve injury was, of course, quite rare in this series of treated nerve lesions and was usually confined to digits of the upper extremities.

In the upper extremity cuff removal was done in about 8.9 percent of cases, in the lower extremity in about 7.5 percent. In the upper extremity, arthrodesis was done in 3.2 percent of the cases.

Table 30.—*Mean Length of Gap in Relation to Special Operative Features, by Nerve and Type of Injury, Completely Divided Nerves Treated by Suture or Graft*

Nerve	Special operative features					
	None		Bulb suture		Transposition-mobilization	
	Number of lesions	Mean gap	Number of lesions	Mean gap	Number of lesions	Mean gap
		cm.		*cm.*		*cm.*
Median	126	*4.93*	28	*11.36*	120	*6.26*
Ulnar	91	*3.63*	29	*11.03*	337	*6.35*
Radial	124	*4.22*	28	*8.57*	62	*5.65*
Peroneal	93	*5.72*	....	....	45	*6.84*
Tibial	33	*5.85*	....	....	54	*7.22*
Sciatic-peroneal	90	*6.74*	....	....	88	*8.01*
Sciatic-tibial	67	*7.28*	....	....	70	*8.39*

Table 31.—*Relevant Operative Procedures Other Than Nerve Repair Performed Prior to Separation From Service, Total Series*

Operative procedure	Lesions associated with such procedures	
	Number	Percent
None	2,991	81.9
Tendon transplant	252	6.9
Amputation (for nerve injury)	16	0.4
Capsulotomy	53	1.5
Arthrodesis	103	2.8
Sympathectomy for pain	105	2.9
Removal of cuff or wrapping	259	7.1
Total known [1]	3,651	100.0

[1] Frequencies do not add to totals shown because of multiple procedures per lesion.

The abstracting of operation reports was extended to several technical features of the operative procedure itself, namely, the type of suture material, the use of a nerve suture cuff, the choice of a stay suture, and the method of performing a neurolysis. Sutures were chiefly (71 percent) done with tantalum wire; in addition 5 percent were performed according to the plasma glue technique, and in 24 percent other materials, mainly silk, were used.

Table 32.—*Relevant Operative Procedures Other Than Nerve Repair Performed Prior to Separation From Service, Lesions Treated by Suture or Graft Only, by Nerve*

Nerve	Total lesions	Percentage of lesions associated with stated procedures						
		None	Tendon transplant	Amputation	Capsulotomy	Arthrodesis	Sympathectomy	Cuff removal
Median..........	518	73.4	13.7	0.4	3.1	5.2	2.5	8.9
Radial...........	395	78.7	14.7	0.3	0.8	1.5	1.3	6.8
Ulnar............	780	80.9	5.9	0.6	2.1	2.7	1.7	10.0
Peroneal..........	287	86.4	8.4	0	0	3.5	1.0	3.5
Sciatic-peroneal....	327	84.1	1.5	0	0	1.2	3.1	11.0
Tibial............	180	86.7	0.6	0	1.7	0.6	5.6	5.6
Sciatic-tibial......	277	86.6	0	0	0.4	1.1	3.6	8.7

The various nerves were compared as to the use of a cuff at the time of definitive suture, and for neither partial divisions nor neuromas were significant variations noted. Among complete nerve divisions, however, the cuff was least often used in peroneal lesions. Among all nerves, 37.2 percent were treated by a suture-line cuff at the time of definitive suture. Practically all cuffs were made of tantalum foil.

Stay sutures were most commonly used in complete divisions of the sciatic branches. Otherwise, the nerves appeared fairly homogeneous in this respect; 24.7 percent of all definitive sutures were accomplished with the aid of a stay suture.

The so-called external lysis, a poorly defined procedure, appeared to be the method of choice in lysis cases, being done in 70 percent of such cases. In 25 percent the lysis extended to the internal injection of saline, and in 5 percent to fascicular dissection.

Certain subjective observations were often recorded by the peripheral nerve surgeon, especially his opinion of the degree of tension upon the two nerve segments at the time of suture, his evaluation of the nerve ends to be approximated, and the response to electrical stimulation prior to suture. In 46 percent of the definitive sutures and grafts the operator failed to mention the subject of tension, but in 43 percent he explicitly stated that tension was absent or, in effect, within normal limits. In 9 percent tension was noted as moderate in degree, and in only 2 percent was it called marked or severe. The nature of the material on electrical stimulation was fragmentary and did not lend itself well to review; although it was initially abstracted no use is made of it in the subsequent analysis. Since the operator's estimation of the pathologic changes in nerve ends may be of practical significance, the available data are presented for review in table 33. The reliability of these observations, of course, is in sharp contrast with that of the neuropathological assessments analysed in chapter XI.

Several associated injuries, and complications of injury, are thought to influence the normal course of neural regeneration. The most common of these are injuries to major arteries, bones, and soft tissue if severe, and chronic wound infection. Their influence is generally reflected in an increase in the injury-operation interval, and in other facets of management. On the other hand, the necessity of repairing an injury to an important vessel may actually shorten the interval between injury and nerve operation.

Table 33.—*Operator's Evaluation of Nerve Ends at Definitive Repair by Suture or Graft, Total Sample* [1]

Evaluation of nerve ends by operator	Nerve lesions	
	Number	Percent
1. Both distal and proximal described as having normal fascicles or as being good or excellent	1,328	72.0
2. Both distal and proximal described as having some, but not considerable, scarring and some normal fascicles, or as being fair	259	14.0
3. Either distal or proximal described as having considerable scarring, and with some normal fascicles, or as being poor or very poor	117	6.3
4. Distal code 1, proximal code 2	47	2.5
5. Distal code 2, proximal code 1	93	5.0
Total	1,844	99.8

[1] Excluding 959 for which ends were not sufficiently well described as well as those not treated by suture or graft.

Associated bone and joint injury was studied in relation to two features of the definitive operation, i. e., days from injury and other operative procedures. Quite uniformly, there was a significant delay in the final operation for cases with associated bone and joint injury. For complete nerve division with suture the delay amounted to 52 days, and even for lyses the effect was a general one. Table 34 gives the supporting data. Operative procedures other than surgery upon the nerve injury itself were similarly analyzed in relation to associated bone and joint injury with particular reference to orthopedic rehabilitation measures and to sympathectomy for pain. The following conclusions were suggested by this study:

1. The presence of associated bone and joint injury had little effect upon the frequency of other operations if the neurosurgical operation was that of lysis. Exceptions were noted in the median nerve where capsulotomy and arthrodesis, and possibly sympathectomy for pain, were done more frequently upon cases with bone and joint injury.
2. In complete nerve division, and also in incomplete lesions requiring complete suture, the number of tendon transfers was notably increased in radial and median nerve cases when the nerve lesion was associated with bone or joint injury. In the median nerve, the percentage of cases with arthrodesis and capsulotomy was also increased. Sympathectomy for pain seems unrelated to associated bone and joint injury.

Table 34.—*Mean Days From Injury to Definitive Suture, by Presence of Associated Bone or Joint Injury, by Nerve, and by Type of Injury, Complete Sutures Only*

Nerve sutured	Complete nerve divisions, by presence of associated bone or joint injury		Neuromas in continuity, by presence of associated bone or joint injury	
	Absent	Present	Absent	Present
	Mean days			
Median	191	236	135	170
Ulnar	153	198	152	287
Radial	116	200	101	179
Peroneal	218	221	190	193
Tibial	184	260	145	208
Sciatic-peroneal	160	272	138	196
Sciatic-tibial	165	261	135	150
All nerves	168	220	143	192

The interval from injury to operation and the need for ancillary surgical procedures were also studied in relation to chronic infection. A quite considerable delay was found to be associated with chronic infection, amounting to 3 to 4 months on the average (table 35). Chronic infection also increased the need for tendon transplants and other orthopedic procedures.

The presence of an associated arterial injury was next studied in relation to the interval between injury and definitive repair, and to the need for ancillary surgical procedures. For cases of complete nerve division and suture, there was a significant difference between cases with and without arterial injury, those with an associated arterial injury being operated upon about 1 month earlier. No suggestion of this appears in the other injury-operation groups but the difference is not judged to be an artifact.

Cases with arterial injury more often had other operative procedures such as tendon transplants.

In cases requiring suture, it was evident that a major soft tissue defect needing plastic surgery considerably delayed the definitive suture. The effect was quite marked, averaging about 60 days for complete divisions treated by complete suture (table 36). Tendon transplants, capsulotomies, and arthrodeses were about twice as frequent in cases with soft-tissue defects.

Table 35.—*Mean Days From Injury to Definitive Operation, by Chronic Infection Deferring Definitive Operation, by Nature of Nerve Operation, and by Type of Injury*

Nature of nerve operation and type of injury to nerve	Chronic infection: Present	Chronic infection: Absent
	Mean days	
Complete suture:		
Complete division	281	181
Other	256	161
Lysis: Normal appearing nerve	270	154

Table 36.—*Mean Days From Injury to Definitive Operation, by Presence of Soft Tissue Defect, Type of Operation, and Type of Injury*

Nature of nerve operation and type of injury to nerve	Soft tissue defect: Present	Soft tissue defect: Absent
	Mean days	
Complete suture:		
Complete division	247	184
Other	188	163
Lysis: Normal appearing nerve	168	166

C. PROBABILITY OF REOPERATION

A brief discussion must be devoted to the probability of reoperation and its relation to various characteristics of the injury and first operation itself. The analysis takes as its criterion of failure of the first operation the fact of a subsequent, and applies this criterion to those characteristics of the injury and its treatment which might be thought to influence the result. It might be regarded as a miniature follow-up study, based on a fairly weak index of success or failure. Not all subsequent operations, of course, constitute equally valid evidence of failure of the initial operation, so that the pattern of reoperation must be defined with some care. An initial suture, for example, can hardly be said to have failed if at some later point in time a neurolysis or a cuff removal was performed; the only operation which would provide compelling evidence of failure would be a second suture, or a graft.

The organization of the discussion depends upon the character of the first operation of definitive intent, i. e., whether it was a complete suture, a lysis, a partial suture, or a graft. There were so few cases in the last two groups that no attempt was made to relate the chance of reoperation to any characteristic of injury or operation; attention was confined to estimation of the probability of reoperation following each of these procedures as a first operation. Extensive analysis seemed warranted only for cases in which a complete suture or a lysis was the first operation. The lysis sample, of course, is biased for estimating the probability of reoperation itself because of the nature of the sampling plan.

1. First Operation Suture

Some 13 characteristics of injury and the definitive operation, all of which have been described earlier, were selected for this phase of study. Reoperation was defined as a second suture (rarely a graft); cases in which a subsequent exploration, lysis, cuff removal or other procedure was done were not regarded as having been reoperated upon. The criterion of failure, therefore, is a conservative one, and reoperation is defined as resuture. In addition, studies were made on the reason for any subsequent operation and the reason for any later known failure.

The entire analysis of first sutures may be brought together in the following summary on the probability of reoperation following initial suture. Appropriate tables are included to illustrate findings of particular interest.

a. The gross level of the injury has no apparent effect in lesions of the median and ulnar nerves. In the lower extremity, on the other hand, peroneal nerve lesions were reoperated upon twice as often as sciatic-peroneal, whereas tibial nerve injuries showed a low percentage of reoperation. Table 37 gives the data for these comparisons.

b. Type of lesion is quite strongly associated with the chance of reoperation, completely severed nerves being resutured about twice as often as incompletely divided nerves (table 38). The nerves themselves also differ quite significantly as to the chance of reoperation.

c. Chronic infection delaying repair has no surely significant influence on the chance of reoperation; there is some suggestion that such cases were less often resutured. The same suggestion is present in the material on associated bone and joint injury. Associated arterial injury and major plastic repair at the site of nerve injury have no influence upon the possibility of resuture.

d. The interval from injury to operation is strongly associated with the chance of reoperation, earlier suture being followed by resuture much more frequently than later. This trend was quite noticeable in upper extremity injuries (fig. 7).

Table 37.—*Chance of Resuture and Gross Site, Lesions With First Operation Complete Suture, by Nerve*

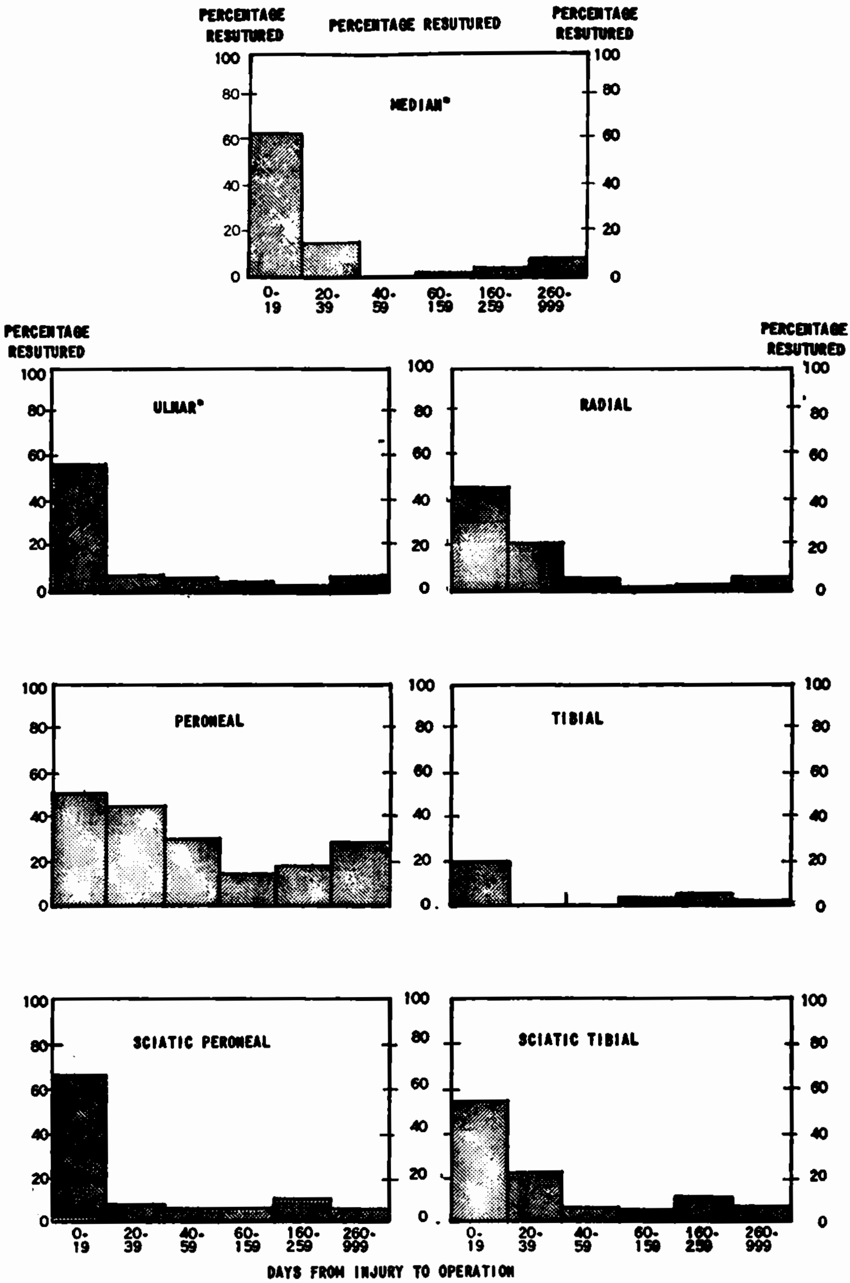
Nerve	High lesions		Low lesions	
	Number cases	Percentage resutured	Number cases	Percentage resutured
Median	213	5.6	230	9.1
Ulnar	382	9.1	349	8.3
Sciatic-peroneal	306	9.8	....	....
Peroneal	....	....	232	21.1
Sciatic-tibial	238	10.1	....	....
Tibial	....	....	154	3.9

Table 38.—*Chance of Resuture and Type of Injury, Lesions With First Operation Complete Suture, by Nerve*

Nerve	Type of injury			
	Severance		Incomplete	
	Number cases	Percentage resutured	Number cases	Percentage resutured
Median	303	9.9	109	1.8
Ulnar	520	9.8	175	5.7
Radial	271	5.9	88	4.5
Peroneal	151	23.8	81	16.0
Tibial	103	1.9	51	7.8
Sciatic-peroneal	205	10.2	101	8.9
Sciatic-tibial	156	12.2	82	6.1

It was also found that initial sutures performed overseas were reoperated upon about five times as often as those done in the Zone of Interior (table 39). This finding reflects the high incidence of failure following nerve suture overseas and merits full consideration here. In 1946, a preliminary study was conducted of regeneration in 419 cases of "early" nerve suture, where a definitive nerve suture had been performed in an overseas installation at an average time period of 39 days after the initial injury (89). This group of cases was compared, in terms of regeneration, with 89 cases in which nerve suture had been performed on the day of injury and/or the day of initial wound debridement. The study utilized follow-ups at 12 months after injury and, since only the first phases of normal neural regeneration could be assessed at this time, the analysis was devoted in large part to obvious failures occurring in each group. Table XII of that early report is reproduced in part here

Figure 7. *Percentage of Cases Resutured by Days From Injury to Operation*



*Completely divided by injury

as table 40 and exhibits a much higher incidence of failure in sutures performed in advanced installations than in those done in general hospitals overseas. Neuropathological studies in 16 of the 20 failures in the emergency suture group suggested: (1) semantic confusion in the use of the terms "definitive suture," "coaptation" or "approximation suture," and "bulb suture;" (2) destruction of fascicles by badly placed sutures; (3) failure to recognize the longitudinal extent of injury; (4) frequent infection; (5) disruption of suture lines; and (6) badly scarred nerve suture beds. These and other studies (46) showed clearly, however, that a good coaptation suture, i. e., simple approximation by a single suture of severed nerve ends visualized at debridement, reduced the extent of resection of pathologic tissue necessary at secondary nerve repair.

Table 39.—*Chance of Resuture and Echelon of First Suture, Lesions With First Operation Complete Suture, by Nerve*

Nerve	Overseas		Zone of Interior	
	Number cases	Percentage resutured	Number cases	Percentage resutured
Median	66	25.8	379	4.2
Ulnar	148	27.0	582	4.0
Radial	77	18.2	282	2.1
Peroneal	50	32.0	182	18.1
Sciatic-peroneal	57	22.8	249	6.8
Sciatic-tibial	44	25.0	194	6.7

Table 40.—*Likelihood of Failure in Relation to Hospital Installation, Early Nerve Suture Overseas*

Overseas installation of suture	Total cases	Failures	
		Number	Percent
General hospital	419	21	5.0
Forward installation	89	20	22.4

In the present study, 149 cases of emergency, or immediate or primary nerve suture were available for study. Again, the simplest criterion for failure was the fact of a second suture. When the percentage of cases requiring resuture is calculated for successive intervals from injury to operation, separately for each nerve (fig. 7), an average resuture rate of 51 percent is found for the interval 0–19 days from injury to suture; obtained directly the figure is 54 percent, representing 81 resutures among 149 cases. Under the exigencies of military neurosurgery, this interval would include all emergency sutures and a scattering of sutures done at the time of secondary wound closure. In abstracting the clinical records an effort was made to ascertain the purpose and expectation of the surgeon prior to undertaking any subsequent operation, as well as the evidence on which his opinion was based. His purpose was categorized as follows:

Reason for surgery	*Cases*
Exploration merely to see what had been done	1
Exploration, believing failure may have occurred	59
Repair obvious failure	17
Reason unknown	4
Total	81

The evidence for his opinion was grouped as follows:

Evidence of opinion	*Cases*
X-ray	2
Clinical evidence, no recovery	43
Clinical evidence, poor recovery	27
Palpation of neuroma	5
Unstated	4
Total	81

Further, on the basis of what the surgeon found at reoperation, an effort was made in the abstracting to indicate the probable reason, usually expressed by the surgeon, for any failure which was believed to have occurred. The 81 failures may be described in terms of this classification as follows:

Reason for obvious failure	*Cases*
Tension, with separation of suture-line	24
Scar tissue or neuroma formed at site of suture-line	53
Separation of suture-line and neuroma	2
Unknown	2
Total	81

In view of the often-repeated assertion that many Z/I surgeons preferred to explore every peripheral nerve lesion, whether or not sutured overseas, and the possible implication that the overseas sutures were more often resutured in the Z/I merely because of excessive zeal on the part of Z/I surgeons, the senior author (BW) reviewed the original records on median and high ulnar lesions with this possibility in mind. The records of 54 cases were reviewed among the 59 meeting these specifications, 5 being in use by investigators concerned with other parts of this report and temporarily unavailable. The choice of resuture, often verified by neuropathological studies, or simple exploration, appeared well-chosen in this series of hand-analyzed cases. Representative cases have not been described in detail but are available, as are all case folders, for the interested student.

e. Tension noted during the operation and recorded in the operation report appears to have had a significant influence since the chance of reoperation was about four times as high in the cases with at least moderate tension as in those with no tension.

f. Special operative features are reliably associated with the chance of resuture for the median and ulnar but not for other nerves, the effect being that resuture is rare among those with special operative features generally. The study of particular features was confined to bulb suture and transposition. Among all the nerves there were 142 cases of bulb suture followed by definitive suture, with only 12 resutures or 8.5 percent. For a set of cases matched as to nerve, but having no special operative features of any kind, the percentage reoperated upon was 13.6, which does not differ significantly from 8.5 percent. In complete lesions of the ulnar nerve there were 314 cases with transposition but no other special operative feature, and in only 12 or 3.8 percent was resuture attempted, in contrast to 26.3 found in cases with no special operative features. The latter difference is large and quite significant statistically. These differences represent a reluctance on the part of the operator to attack again surgical problems that have already had the benefit of extreme efforts to overcome nerve gap.

g. Suture material appeared to be a factor in the chance of reoperation, cases with tantalum suture being less often resutured.

h. On the average, cases with stay suture were resutured with 1.9 times the frequency observed for cases in which stay suture was not used.

i. No effect was found associated with the length of surgical defect.

j. Sutures performed by essentially untrained surgeons were repeated about five times as often as those done by trained neurosurgeons and general surgeons with neurosurgical training. This may represent an influence of echelon of repair.

k. The operator's evaluation of nerve ends correlates somewhat with the chance of reoperation, and in the expected direction.

If a resuture were necessary, surgical intervention usually started either as an exploration of a possible failure or a frank effort to repair an obvious failure but there were large differences among the nerves in the relative importance of the two purposes (table 41). Failure was more often obvious in the leg nerves generally, and rarely obvious in the ulnar and median.

Table 41.—*Reason for Resuture, Lesions With First Operation Complete Suture, by Nerve*

Nerve	Exploration in belief of possible failure	Repair of obvious failure	Total cases
Median	28	4	32
Ulnar	53	7	60
Radial	14	4	18
Peroneal	36	13	49
Sciatic-peroneal	18	12	30
Tibial	3	3	6
Sciatic-tibial	14	8	22
Total known	166	51	212

Table 42.—*Evidence for Decision To Resuture, Lesions With First Operation Complete Suture, by Nerve*

Nerve	X-ray	Clinical evidence of no recovery	Clinical evidence of poor recovery	Palpation of neuroma	Total cases
Median	1	13	14	4	32
Ulnar	1	26	28	6	61
Radial	2	9	7	0	18
Peroneal	12	21	15	1	49
Sciatic-peroneal	13	14	2	0	29
Tibial	2	2	2	0	6
Sciatic-tibial	7	10	4	0	21
Total known	38	95	72	11	216

Table 43.—*Reason for Obvious Failure of First Suture, Lesions With First Operation Complete Suture, by Nerve*

Nerve	Tension causing separation of suture line	Scar tissue or neuroma	Other	Total cases
Median	8	22	3	33
Ulnar	13	47	3	63
Radial	7	12	1	20
Peroneal	34	11	4	49
Sciatic-peroneal	24	5	1	30
Tibial	2	2	2	6
Sciatic-tibial	19	5	0	24
Total known	107	104	14	225

Evidence for the decision to reoperate was also made the subject of a comparison of nerves; highly significant differences were found (table 42). The variation exhibited in table 42 parallels that seen in connection with the reason for surgery. In the lower extremity there was frequently X-ray or clinical evidence of no recovery. In the upper extremity X-ray evidence was rare; resuture was more often undertaken because recovery seemed poor.

The reason for obvious failure of the first suture was also studied for variation among nerves, and quite significant differences were found (table 43). The chief reasons were tension, with separation of the suture-line, and scar tissue or neuroma formed at the suture-line. In the lower extremity failure is more often (72 percent) attributed to tension with separation of the suture-line and, in the upper extremity, to the formation of scar tissue or neuroma at the suture-line (70 percent).

2. First Operation Lysis

A much more limited study was done on lesions first treated by lysis, using only the following characteristics:

a. Interval from injury to operation.
b. Type of lysis.
c. Training of surgeon.

These studies show, for the sample of initial lyses used here, that a subsequent suture was done in 6.2 percent and a subsequent lysis, exploration, or cuff removal in 11.8 percent. The sampling plan for the present study, with its major emphasis upon definitive suture, and secondary emphasis upon definitive lysis, is a poor basis for estimating the chance that an initial lysis might suffice and be followed by additional surgery of one kind or another. However, the sample is not obviously biased in regard to the effect which various characteristics of injury and treatment might have upon the rate of reoperation, whatever the true average level may be. Differences among nerves are of little importance except that subsequent suture was rare in the tibial. In the upper extremity, gross height of lesion is of some importance; in median and ulnar injuries the chance of subsequent suture is 2.1 percent in high and 15.6 percent in low lesions first treated by lysis. Interval from injury to operation has considerable influence upon the chance of reoperation, early lyses being repeated or replaced by sutures more often than late. Training of surgeon bears no evident relation to the chance of reoperation. The type of lysis originally performed also has no relation to the chance of reoperation.

3. First Operation Partial Suture

No detailed analysis was made of the probability of reoperation following partial suture. Among the 216 partial sutures done at first operation 44 cases were reoperated upon as follows:

Complete suture	12
Partial suture	4
Lysis, cuff removal, etc	28
Total	44

The differences among nerves are not statistically significant.

4. First Operation Graft

Reoperation following an initial graft was studied in the 42 cases available in the entire series. Of these, 12 were never reoperated upon, in 10 any reoperation was confined to exploration, cuff removal, or lysis, and in 20 an end-to-end anastomosis was eventually done.

D. CUFF REMOVAL

This brief analysis has to do with the matter of cuff removal in relation to selected characteristics of the nerve injury and its definitive treatment. The placing of some form of protective cuff about a peripheral nerve anastomosis has engaged the interest of surgeons since the beginning of nerve surgery. In World War II, and thus in the sample under study, the suture-line cuffs were formed from tantalum, either held in a cylindrical form by absorbable sutures or annealed in the desired circular form. In the present investigation first operations with sutures were chosen for all 7 major nerves and those with cuffs were subdivided as follows:

1. Cuff placed and not removed—755 cases, or 76.7 percent.
2. Significant cuff removal—94 cases, or 9.6 percent. A significant cuff removal was defined as an operative procedure designed to remove an assumed barrier to the normal course of nerve regeneration.
3. Routine cuff removal—135 cases, or 13.7 percent. Here the cuff was removed simply in the course of operative study of the suture line or because the therapeutic role of the cuff was regarded as temporary.

The proportions falling into these three groups were then studied in relation to the following characteristics of the nerve injury without finding any significant variation:

a. Site of injury.
b. Type of lesion.
c. Associated bone and joint injury.
d. Medical echelon and tension.
e. Special operative techniques.

The significant cuff removals were done on the basis of factors outside the scope of the present analysis, namely, those having to do with the course of regeneration following suture.

E. DISPOSITION FROM MILITARY HOSPITALS

In abstracting the details of the injury and its management note was made of disposition in the expectation that useful information might be obtained on variation in the percentage of men returned to duty. However, when the material on disposition was tabulated for the representative sample of sutures it was found that the percentage of men returned to duty was so small as to render fruitless any extended study of variation. For all 1,890 sutures in the representative sample (Registry cases within the sampling area) the percentage returned to duty is only 2.3, and the variation among the seven major nerves is confined within the range of 0.6 to 4.2 percent, as follows:

Median	2.9
Ulnar	1.7
Radial	3.3
Peroneal	4.2
Tibial	3.2

Sciatic-peroneal	0.9
Sciatic-tibial	0.6
Total	2.3

F. TIME IN MILITARY HOSPITALS

Duration of hospitalization provides a rough measure of the medical cost of an illness or injury, and since there are rather good comparative military data on such broad categories as disease generally, nonbattle injury, and wounded-in-action plus battle injury, the opportunity was taken, in abstracting data from the service medical records, to note the total time from injury to final discharge from military hospital, usually at the same time as separation from service on a certificate of disability. Analysis of the resulting observations has been directed chiefly at establishing any important differentials among the major nerves and assessing the relative influence of associated injuries of various kinds upon the time spent in hospital.

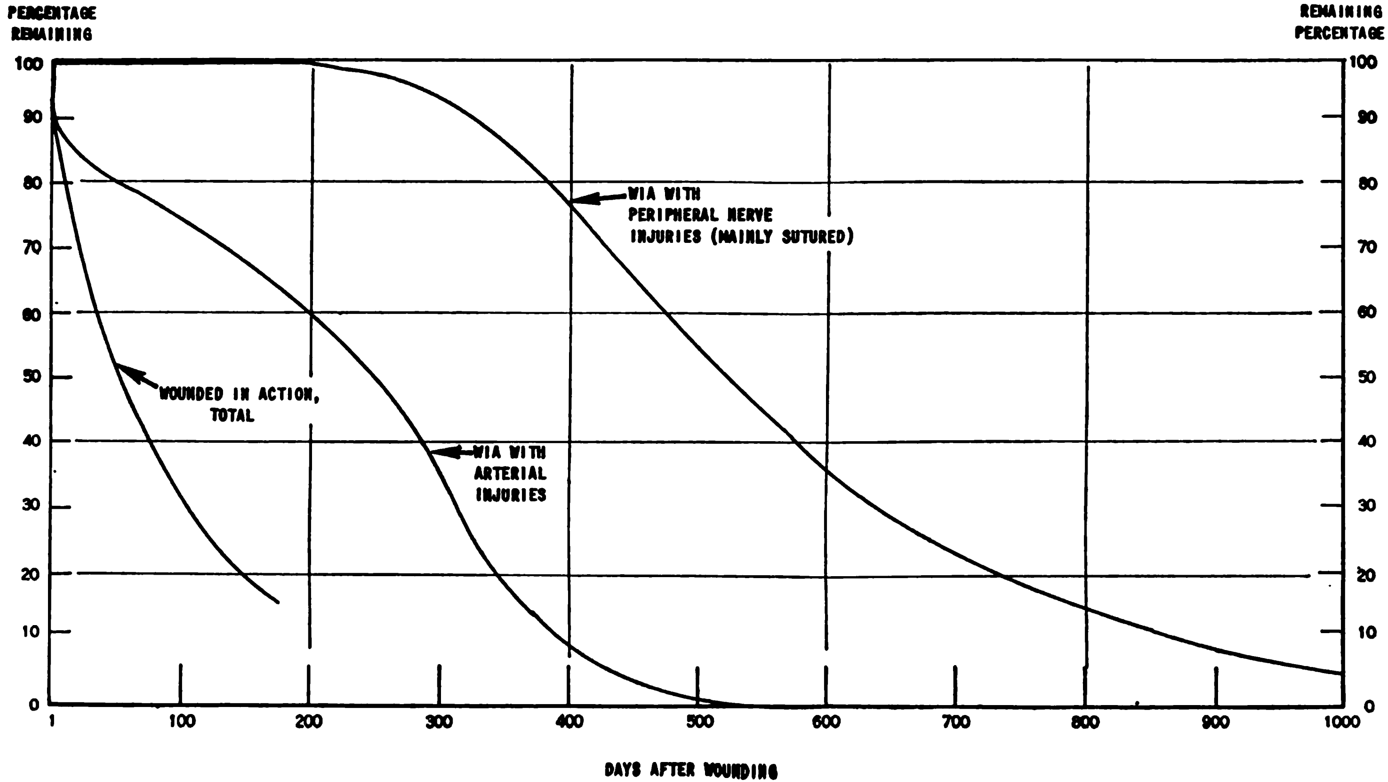
On the average the men in this series, largely one of sutured nerve lesions, spent 523 days in service hospitals in contrast to about 54 days for Army wounded generally in World War II (4). The complete distribution appears in figure 8 in comparison with the estimate for the Army wounded of World War II; the data are plotted in the form of the number remaining in hospital on successive days after admission. It will be seen that the number discharged from hospital prior to day 200 is negligible, and that the great bulk of the men were in hospital between 1 and 2 years.

The actual duration of hospitalization was in many cases far less than that indicated, since many patients spent much of their time on furlough or leave from hospital. In general, men were hospitalized near their homes and, when specialized physical therapy was not important, they spent a great deal of time with their families.

Men whose lesions fall into the representative sample of complete sutures do not vary greatly by nerve injured, although, of course, duration is longer for men with sciatic lesions. In table 44 the major nerves are compared as to median duration of hospitalization.

The effects of associated lesions were sought by nerve, the nerves of the upper extremity being studied in the greatest detail. Table 45 exhibits some of the variation attributable to associated bone, arterial, and soft-tissue defects or chronic infection in pure lesions managed by complete suture. The variation seen in the median is quite significant statistically. Uncomplicated bone and arterial injuries do not appear to prolong hospitalization, but other complications or combinations of these associated injuries do greatly delay hospitalization; about 50 percent of the latter group remained in hospital beyond day 600, and only 15 percent were discharged before day 400. In the ulnar lesions, on the other hand, the variation seen in table 45 lies well within chance limits. In the radial,

Figure 8. *Percentage of Patients Remaining in Hospital on Successive Days After Admission, U. S. Army Wounded in World War II, by Type of Injury*



men with uncomplicated bone injuries were retained in hospital longer than men with none of the complications considered here, and men with two or more complications, infection, or plastic repair were delayed even further. In men with pure peroneal or tibial nerve lesions the various complications were considerably less frequent and exerted less effect upon duration.

Table 44.—*Median Days in Military Hospital, Men With Complete Sutures in the Representative Sample, by Nerve*

Nerve	Median days	Nerve	Median days
Median	541	Tibial	471
Ulnar	504	Sciatic-peroneal	620
Radial	498	Sciatic-tibial	615
Peroneal	558		
		All nerves	533

Associated nerve injuries were also studied for their possible effect upon duration of stay in hospital, but only in the median was significant evidence seen. In table 46 these data are presented for complete sutures on the median nerve with no complications involving bone, artery, or soft-tissue. In the ulnar and peroneal lesions associated nerve injury appeared to have no significant effect upon duration of stay. In the smaller tibial sample a suggestive difference was found between men with and men without associated nerve lesions, and of the type seen in table 46 for the median.

In view of the variable influence of associated nerve and other lesions upon the duration of hospitalization for men with a given nerve lesion, the major nerves were compared on the basis of pure lesions devoid of all the complications which have been enumerated. No roster restrictions were placed upon the selection of cases, however. Table 47 provides these data for the three major nerves of the upper extremity, from which the advantage of uncomplicated radial injuries is immediately apparent. In addition, men with ulnar lesions evidently were required to stay longer than men with median injuries. Tibial and peroneal lesions were similarly compared and found to differ significantly; 38 percent of the men with peroneal lesions were in hospital on day 600, in contrast to 17 percent of the men with tibial lesions.

Finally, for all median sutures in the representative sample a rough division was made into those with poor, fair, and good motor recovery on the basis of the modified British scale [9] and length of stay tabulated sepa-

[9] This scale is presented on p. 75 and discussed on pp. 113–117. The three recovery groups were selected as 0–2, 3–4, and 5–6 on the scale appearing on p. 75.

rately for each group. Figure 9 presents the results of this comparison, which shows remaining on day 600 about 22 percent of the good results, 36 percent of the fair, and 58 percent of the poor.

Table 45.—*Duration of Hospitalization and Associated Injuries, Pure Nerve Lesions of the Upper Extremity Treated by Complete Suture*

Type of associated injury	Percentage distribution by days in hospital				Number of cases
	Less than 400	400–599	600 or more	Total	
Median					
None	47.6	37.8	14.6	100.0	82
Bone only, with normal healing	36.5	44.4	19.0	99.9	63
Arterial only	41.7	54.2	4.2	100.1	24
Other [1]	15.3	32.2	52.5	100.0	59
Total	35.5	39.9	24.6	100.0	228
Ulnar					
None	27.7	50.5	21.7	99.9	184
Bone only, with normal healing	30.3	48.7	21.1	100.1	152
Arterial only	53.1	37.5	9.4	100.0	32
Other [1]	26.5	49.0	24.5	100.0	102
Total	30.0	48.7	21.3	100.0	470
Radial					
None	42.5	40.2	17.2	99.9	87
Bone only, with normal healing	23.9	54.9	21.2	100.0	113
Arterial only	100.0	0	0	100.0	2
Other [1]	12.9	45.9	41.2	100.0	85
Total	26.8	47.4	25.8	100.0	287

[1] Bone with abnormal healing, or chronic infection, or plastic repair at site of nerve injury, or combinations of any of these with bone injuries healing normally or with arterial injury.

Table 46.—*Days in Hospital and Presence of Associated Nerve Injury, Complete Sutures on the Median Nerve, in Men With No Other Associated Injury*

Days in hospital	Associated nerve injury [1]	
	None	Any
	Percent	*Percent*
Less than 400	47.6	19.4
400–499	12.2	22.6
500–599	25.6	21.0
600–799	8.5	19.4
800 or more	6.1	17.7
Total	100.0	100.1
Number of cases	82	62

[1] Involving ulnar, radial, axillary, or musculocutaneous.

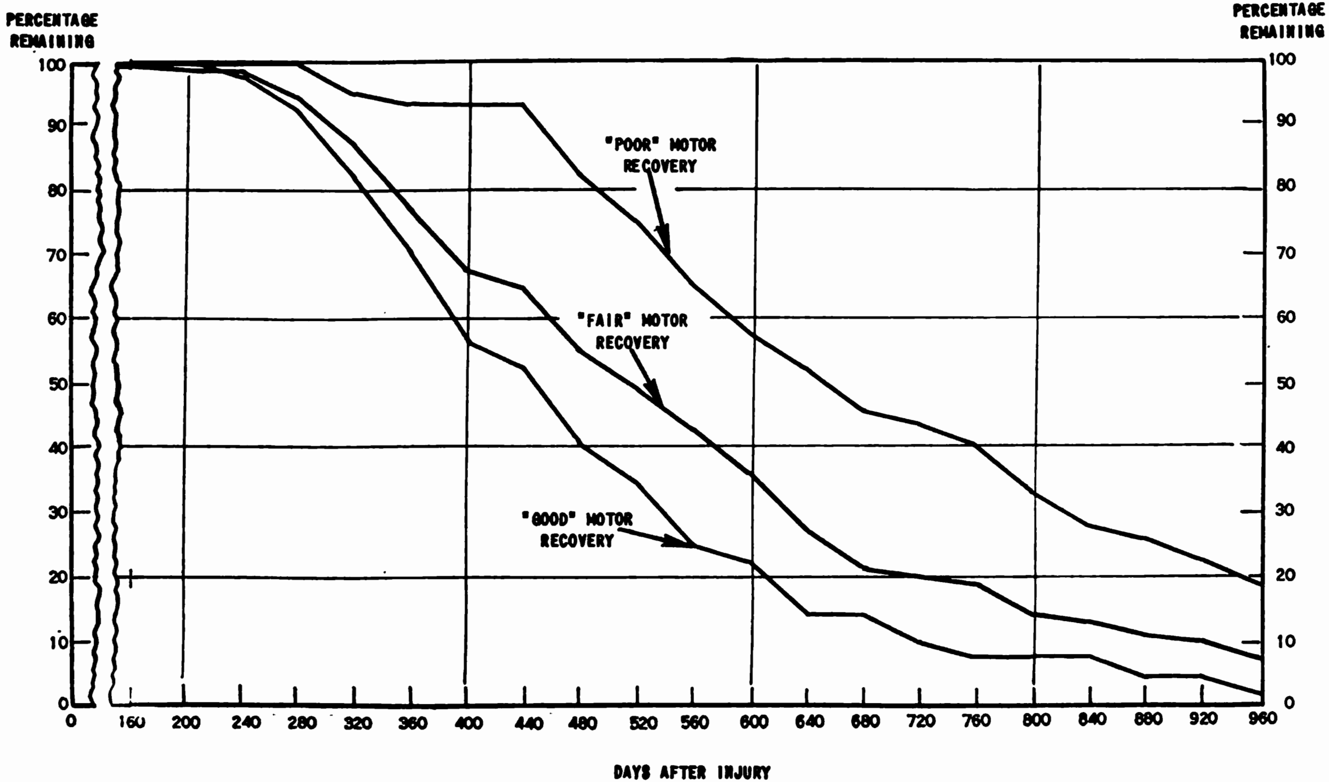
Table 47.—*Days in Hospital for Men With Uncomplicated Nerve Lesions* [1] *Treated by Complete Suture, Nerves of the Upper Extremity*

Days in hospital	Median	Ulnar	Radial	Total
	Percent	*Percent*	*Percent*	*Percent*
Less than 300	6.9	4.6	12.5	6.8
300–399	28.5	19.2	28.1	23.6
400–499	16.7	30.3	32.3	26.7
500–599	23.6	21.1	9.4	19.6
600–699	9.7	9.6	7.3	9.2
700 or more	14.6	15.3	10.4	14.2
Total	100.0	100.1	100.0	100.1
Number of lesions	144	261	96	501

[1] No associated injuries of any kind.

Length of hospitalization is a major factor in the medical logistics of peripheral nerve injuries. It is seriously questioned whether military hospitals should be asked to assume the entire burden of such care, and also whether such duration of hospitalization as is exhibited here should not now be regarded as excessive. This problem was attacked in World War II through the close association of convalescent hospitals with general hospitals to which men returned for reevaluation at regular intervals.

Figure 9. *Percentage of Patients Remaining in Hospital on Successive Days After Admission, Men From Representative Sample of Army Registry With Complete Median Sutures, by Motor Recovery at Follow-up*



G. SUMMARY

No attempt will be made here to summarize the considerable detail of background material presented here on the acute injury, its surgical management, and the other points of special interest. The definitions and relationships presented here are, however, fundamental to an understanding of the subsequent chapters on regeneration, in which they figure prominently in the search for the determinants of end results. One might wish that additional information had been available, in reliable form, on the injury and its management, for peripheral nerve regeneration is an extraordinarily complicated matter, and even the array of factors presented in this chapter will not suffice to refine the surgeon's prognosis to the accuracy he might like. It remains unfortunately true that some factors with important influences upon regeneration are not subject to measurement, or even observation, in a clinical series.

Chapter III

RECOVERY OF MOTOR FUNCTION

Melvin D. Yahr and *Gilbert W. Beebe*

A. INTRODUCTION

Of all the functions subserved by the peripheral nerves, that of movement is perhaps the most strategic to adequate performance by the affected limb, and is certainly the most susceptible of reliable assessment. Although practical function involves a great deal more than the strength of discrete movements, the latter provide an excellent approach to the investigation of the basic sources of variation in the regeneration of peripheral nerves. Only from such knowledge can the surgeon hope to plan effectively for the care of the individual patient with an injury to a peripheral nerve, whether it be an injury of war or the result of an ordinary accident. The surgeon needs to know what results to expect from his efforts at repair, and from his decisions not to resect and suture, and to know this not only in terms of the probability that a particular result will fall at one point or another on some scale of relative excellence but also in terms of those characteristics of injury and alternatives in management which tend to determine end result. Strength of movement constitutes a valuable statistical device for describing variation and for ferreting out factors which play a significant part in it, and it is appropriate, therefore, that the motor chapter contain a systematic study of the factors associated with variation in regeneration. There are, of course, other interests in regeneration but in the main these require more specialized study than seems feasible on the basis of the clinical records of military hospitals and the follow-up studies provided by a large cooperative investigation. The theoretical basis for understanding peripheral nerve regeneration is naturally of great concern to the surgeon, but it is too much to expect that his clinical observations on regeneration will contribute more than indirectly to the advancement of such theoretical knowledge.

In the plan of the chapter there is first a methodological part in which are described the various methods used in the assessment of motor regeneration. There follows an essentially descriptive treatment of the statistical data on motor recovery in representative samples of peripheral nerve injuries treated by suture or by lysis. The two remaining parts of the chapter are rather more analytical in nature, being directed at some of the factors which have been thought to influence regeneration, factors which are of such nature as to be identifiable in clinical material, e. g., length of surgical gap, and type of suture material.

Since adequate reinnervation is but one determinant of satisfactory muscular movement, complete absence of movement is compatible with alternative explanations of very different implications for regeneration. Parallel electrical studies are of value in determining when absence of movement probably connotes failure of regeneration and when other factors are involved. Electrical data constitute the subject of a subsequent chapter which includes an analysis of the relation between voluntary movement and that induced by electrical stimulation.

B. METHODS OF EVALUATING MOTOR FUNCTION

Most of the skilled acts which are affected by peripheral nerve injury depend upon the coordinated movement of sets of muscles innervated by more than one peripheral nerve. In order to assess the regeneration of a particular peripheral nerve it is imperative that the examiner isolate the movements of those muscles which were affected by the injury. The basic motor examination, in turn, consists of evaluating the movements of such individual muscles as act alone, or of groups of cooperating muscles innervated by a single nerve. In the analysis of such motor function one may pass in review the ratings on each muscle or seek some method of combining the information about the entire set of affected muscles. Although both methods have been followed in the present study, chief attention has been accorded to the individual muscle; methods of describing the set of affected muscles, e. g., by averaging, have seemed essentially arbitrary in principle and without any real advantage except the convenience of a smaller bulk of data.

Examiners differ as to their willingness to infer the power of a specific muscle from the strength of a certain movement, and the choice of muscles for routine testing in the present study represents some compromise among the responsible investigators. An initial list of movements was agreed upon at the Hot Springs meeting discussed earlier, but as the examination forms and coding sheets were developed a number of changes seemed necessary and the final list appears in table 48. The abductor pollicis brevis was not originally accepted as a standard muscle for purposes of testing, but in two centers this muscle was routinely examined and it appears in the final analysis of individual muscles. The muscles marked for intensive study represent a further selection on the basis of representativeness, ease of examination, and accuracy of assessment.

At the time of the Hot Springs meeting it was proposed that the observations on each muscle extend to a tracing of the motion as a curve in space as well as to the measurement of its strength. Each aspect of the motion would then be expressed quantitatively, as a fraction of the normal, and the product of these two fractions would be taken as the final measure of performance for the individual muscle. In the end, however, agreement was reached on a much simpler plan in which attention was confined to

Table 48.—*Standard Muscles Chosen for Routine Follow-up Study, by Nerve and by Proximal or Distal Location*

Nerve	Muscle	
	Proximal	Distal
Median	Flexor Carpi Radialis. Flexor Pollicis Longus.[1] Flexor Digitorum Profundus 2.[1]	Opponens Pollicis. Abductor Pollicis Brevis.[1]
Ulnar	Flexor Carpi Ulnaris. Flexor Digitorum Profundus 4 and 5.[1]	Abductor Digiti Quinti.[1] Adductor Pollicis. 1st Dorsal Interosseus.[1]
Radial	Triceps. Brachioradialis. Extensor Carpi Radialis.[1] Extensor Digitorum Communis.[1] Extensor Carpi Ulnaris.	Abductor Pollicis Longus. Extensor Pollicis Longus.[1] Extensor Pollicis Brevis.
Tibial and Sciatic-tibial.	Gastrocnemius-Soleus.[1] Tibialis Posticus. Flexor Digitorum Longus.[1] Flexor Hallucis Longus.[1]	Interossei (any intrinsic muscle).
Peroneal and Sciatic-peroneal.	Tibialis Anticus.[1] Extensor Digitorum Longus.[1] Extensor Hallucis Longus.[1] Peroneus Longus.[1]	

[1] Muscles chosen for most intensive analysis; the abductor pollicis brevis did not appear in the original standard list and does not figure in either the count of affected muscles now contracting or in the average power of distal muscles.

strength of movement. For each affected muscle the examiner was required first to observe voluntary movement visually, and second, if movement against resistance was possible, to estimate its strength in quantitative terms, using the spring-scale technique of Lewey (41) or the Newman Myometer (57). The visual observations were classified in accordance with the following scheme:

1. No voluntary contraction is perceptible.
2. Perceptible contraction only.
3. Movement, but not against gravity.
4. Movement against gravity, but not against resistance.
5. Movement against resistance.

This classification, it may be noted, is essentially that used by the British Medical Research Council (70) except that in the latter classification movement against resistance is subdivided into "some" and "powerful" resistance. In the present study the power of muscles capable of movement against resistance was scaled in a roughly quantitative fashion, as already indicated, the normal homologous muscle serving as the control. It was thus possible to express strength of movement as a percentage of normal; the muscle unable to move against resistance is rated 0 on this quantitative scale, even if it be capable of movement against gravity. Although a 100-point scale was employed by examiners in making the quantitative ratings, when the resulting data were first tabulated it was found that the ratings centered on multiples of 5 and the scale was accordingly reduced to 20-odd intervals: 00, 01 to 02, 03 to 07, etc.

There are certain inherent limitations in the method of examination adopted for the present study. The examiner must be quite expert if he is to guard against substitution and trick movements and he must be well aware of the problem of anomalous innervation. The patient must be a cooperative individual who, through muscle retraining, is capable of voluntarily activating the muscle. Every examiner has seen patients with good muscle mass and evidence of nerve regeneration, but who have not relearned use of the muscle. This is especially true in the hand where long flexors and extensors are substituted for the small intrinsic muscles of the hand. Not infrequently is the extensor digitorum substituted for the abductor digiti quinti as an abductor of the fifth digit when evidence of regeneration is cited for this muscle. The patient without retraining in the use of the latter muscle continues to substitute the movement acquired during the phase of denervation. In addition, many patients are unable to initiate an isolated movement of a muscle, such as abduction of the fifth digit utilizing the abductor digiti quinti as a prime mover, but will utilize this muscle with good power in association with other muscles when making a fist. During examination, an interval of instruction may enable a patient to contract a muscle against resistance which earlier he was unable to move at all.

There are three main factors to be considered in motor recovery following peripheral nerve injury: (1) growth of nerve fibers in both length and diameter; (2) preservation of muscle mass; and (3) retraining in the use of previously denervated muscles. The longer the period of denervation the greater will be the attendant atrophy in affected muscles, and the poorer the level of physical therapy directed at muscle reeducation the more often will voluntary activation fail even in the presence of adequate reinnervation and minimal muscular atrophy. In the upper extremity, where dexterity of movement is a major goal of treatment, physical therapy is characteristically intensive. In the lower extremity weight-bearing and gross movement are the objectives and are early accomplished by the use of a brace or other supporting device. The natural consequence is a less intensive program of muscle reeducation on the part of the physical therapist and a lesser expenditure of effort by the patient to relearn the use of reinnervated muscles. Most patients indulge in a passive program of watchful waiting with massage and/or electrical stimulation the only therapeutic effort. It is not unusual to see a patient still resorting to a foot-drop brace in the presence of adequate peroneal regeneration, for example.

In preparing a summary of the history for both clinical and statistical purposes, care was taken to determine precisely which muscles had been paralyzed by injury and remained so prior to such surgical intervention as was undertaken. In addition, to guard against extraneous influences on the movement of muscles the examiner was required to classify each muscle according to the following scheme:

1. Affected by injury or operation, nerve branch sacrificed.
2. Affected, working tendon transplant.
3. Affected, loss of muscle or tendon substance by direct injury.
4. Affected, with none of the above special features.

Only muscles in the fourth category are studied in this chapter.

Several methods have been used to combine the observations on individual muscles into various patterns representing, say, all affected muscles on a limb, or all the distal muscles. These auxiliary measures are as follows:

1. Arithmetic average of relative power of groups of affected muscles, separated into distal and proximal groups.
2. Number of affected muscles in standard list (table 48) which now contract, separated into distal and proximal groups.
3. British assessment of motor recovery, an adaptation of the scale used by the Nerve Injuries Committee of the Medical Research Council of Great Britain.

In the first two indices each affected muscle has equal weight, but a distinction is made between the proximal and the distal muscles. In the British assessment consideration is given to both proximal and distal muscles and to the entire range of movement and power; it is most useful in high lesions affecting both proximal and distal muscles. The categories of the British scale as used in this study differ slightly from those most recently published (70) by the British group and are as follows:

0. No contraction.
1. Return of perceptible contraction in the proximal muscles.
2. Proximal muscles acting against gravity, no return of power in intrinsic muscles.
3. Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles.
4. Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance.
5. Return of function as in category 4, with the addition that some synergic and isolated movements are possible.
6. Complete recovery.

The most recent British scale subdivides category 3, providing for those cases of ulnar injury in which there is recovery in all the ulnar intrinsic muscles as distinguished from those in which there is merely a flicker of action in the hypothenar muscles alone. Also, the British group employs the assessment scale in precisely this form for upper extremity cases only, whereas in this study it has been employed for all nerves without modification. In the grading of peroneal and tibial lesions the British group rarely encountered cases other than those of category 1 above, and so subdivided this category by averaging the ratings of the individual muscles on a scale of 0 to 5, corresponding roughly to those employed here in observing the contraction and movement of individual muscles.

The presentation of a single case will suffice to illustrate the similarities and differences among the several motor indices routinely utilized in the present study.

Case 2080: A radial nerve suture, lower third of the arm, with seven muscles affected, the results of the motor examination at follow-up being as follows:

Brachioradialis: Movement against resistance not tested.

Extensor carpi radialis: Movement against resistance, measured at 50 percent of normal.

Extensor digitorum: Movement against resistance, measured at 65 percent of normal.

Extensor carpi ulnaris: Movement against resistance, measured at 0 percent of normal (perceptible movement was, however, present).

Abductor pollicis longus: Movement against resistance, measured at 25 percent of normal.

Extensor pollicis longus: Movement against resistance, measured at 27 percent of normal.

Extensor pollicis brevis: Movement against resistance, measured at 25 percent of normal.

The average power ratings are as follows:

Proximal muscles: 30–39 percent.

Distal muscles: 20–29 percent.

The numbers of affected muscles in the standard list capable of contraction, similarly, are:

Proximal muscles: 4.

Distal muscles: 3.

The British assessment is grade 4 on the scale employed here.

C. DESCRIPTION OF MOTOR RECOVERY

It will be recalled, from the description of the sampling plan on pages 5–13, that the entire sample of 2,720 men studied here includes many with injuries or other characteristics of special interest, and by that token, of possibly atypical prognosis. In planning the tables for this descriptive part of the chapter, therefore, it was considered desirable to restrict the selection of cases to those in the representative sample. The analysis in chapter II (pp. 31–53), showing the differences among groups of cases drawn from the three major groups of rosters, further documents the need for this distinction which was made as follows:

1. All sutured cases were taken from the Army Peripheral Nerve Registry; and
2. Cases from the Registry were excluded if they fell outside the sampling area for the center to which they had been allocated.

In addition, about 25 percent of the cases had no follow-up and for any particular muscle the number of injuries available for study depends upon the site of lesion.

The descriptive data will be presented in two parts, the first pertaining to the individual muscles and the second to groups of muscles, either proximal, distal, or all combined. All data on individual muscles or groups thereof are confined to cases in which these muscles were affected by the original injury.

1. Individual Muscles

Although some average value may be the most important characteristic of the detailed distribution tabulated for each muscle, such averages provide no information about the often great individual variation seen in particular muscles. Figure 10 provides a graphic summary of the variation observed in the recovery of the abductor pollicis brevis. Relative strength of movement is scaled along the abscissa, and the height of the bars denotes the relative frequency with which muscles were observed to respond with a given strength of movement. The tallest bar, for the interval 0 to 12 percent of normal strength, is divided into three components: 19.5 percent with no contraction at all, 37.5 percent with visible contraction, but not against resistance, and 6.7 percent with movement against resistance rated at 12 percent or less of normal, or 64 percent in all. The remaining 36 percent scatter widely over the range of relative power above 12 percent. The upper line provides a *cumulative* distribution of the relative frequencies denoted by the vertical bars. The device of the cumulative distribution has been adopted in figure 11 to conserve space and to facilitate visual comparison of the distributions obtained for the various muscles studied here; the underlying data appear in table 49 in the same form except that a distinction is made among muscles unable to contract, those with visible contraction but not against resistance, and those contracting only weakly against resistance. Several properties of cumulative distributions generally may be noted as a guide to the interpretation of figure 11: (a) a rectangular, or flat, distribution having the same relative frequency in every region of the strength scale would appear as a straight line from the origin to the upper right corner; (b) if one cumulative distribution lies everywhere above another it is because the former distribution is more concentrated at the lower end of the strength scale; (c) the cumulative curve rises over a region only to the extent that the underlying distribution contains frequencies there, so that a rapid rise in a region denotes some concentration of cases there and a plateau denotes an absence of cases; and (d) a very favorable curve would start near the origin, remain fairly close to the abscissa over much of the range of relative power, and increase rapidly only in the region of normal relative power. As plotted in figure 11, each distribution shows the percentage of affected muscles rated at a specified relative strength or less, the strength being indicated by the horizontal axis.

The proximal muscles, in the main, are more variable in their strength of movement and are less concentrated at the lower end of the strength scale. In none of the distributions of figure 11 is the increase a very sharp one in the range of 90 to 100 percent of normal, and in most instances there is little or no increase at all in this region because very few muscles were observed to have normal power 5 years after suture. For only 5 of the 23 muscles do more than 5 percent of the measurements of strength fall in the region of 90 to 100 percent of normal: flexor pollicis longus, flexor digitorum profundus 2, flexor digitorum profundus 4 and 5, extensor carpi radialis, and gastrocnemius and soleus. These are the most proximal muscles in their respective sets, but not every set is represented because in this series the tibialis anticus, representing peroneal and sciatic-peroneal muscles, does not recover normal power with even this small frequency. At the other end of the scale one finds that the distributions for the most distal muscles in each set usually start with 50 percent or more rated 0 in power, indicating that in 50 percent or more of the cases there is inability to move the muscle against resistance. In the muscles innervated by the peroneal and sciatic-peroneal, however, failure to move against resistance is found in over half the cases for every one of the four muscles charted in figure 11.

Although the interest here is in the individual muscle, some comparison among muscles is helpful in understanding the variation in results which may be expected following suture. In the median set, for example, the flexor pollicis longus and the flexor digitorum profundus 2 have almost identical distributions, while that for the abductor pollicis brevis is much less favorable. The disparity, it may be noted, is not simply confined to the proportion of cases in which movement against resistance was possible, but extends to the measured strength of those cases in which such movement was seen. Thus, it was observed that for muscles with movement against resistance, power was 80 percent or better in about 22 percent of the flexor pollicis longus muscles and in only 2 percent of the abductor pollicis brevis muscles.

Another noteworthy feature of the distributions exhibited in figure 11 for sutured lesions is that they rarely climb steeply, as such curves do when cases are concentrated at a particular point along the horizontal axis, but usually rise gently and somewhat after the fashion of a rectangular distribution, which follows a straight line when plotted in cumulative form. That is, examiners failed to note any real concentration of cases at any point except 0 on the power scale; if movement was made against resistance, its measured power might fall anywhere along the scale with almost equal probability.

The *average power* for all the sutured lesions affecting a given muscle is shown in table 50 in systematic form. All the standard muscles are represented, not merely the 23 chosen for most intensive study. Average power is expressed in two forms: (a) all examined cases are included, a 0 rating being assigned to those in which there was no voluntary movement against resistance; and (b) the average pertains only to those in which there was voluntary movement against resistance. The averages are arithmeticaverages, and for descriptive purposes one might in some instances prefera median average value as somehow more representative, particularly in the face of a concentration of cases at 0. However, the mean or arithmetic average is an easier statistic to work with in many ways and has been used routinely in this study. Approximate medians may be read off figure 11 as the point on the horizontal axis at which the cumulative dis-

Figure 10. *Strength of Movement of the Abductor Pollicis Brevis Following Complete Suture of Median Nerve, Strength of Movement Against Resistance, as Percentage of Normal*

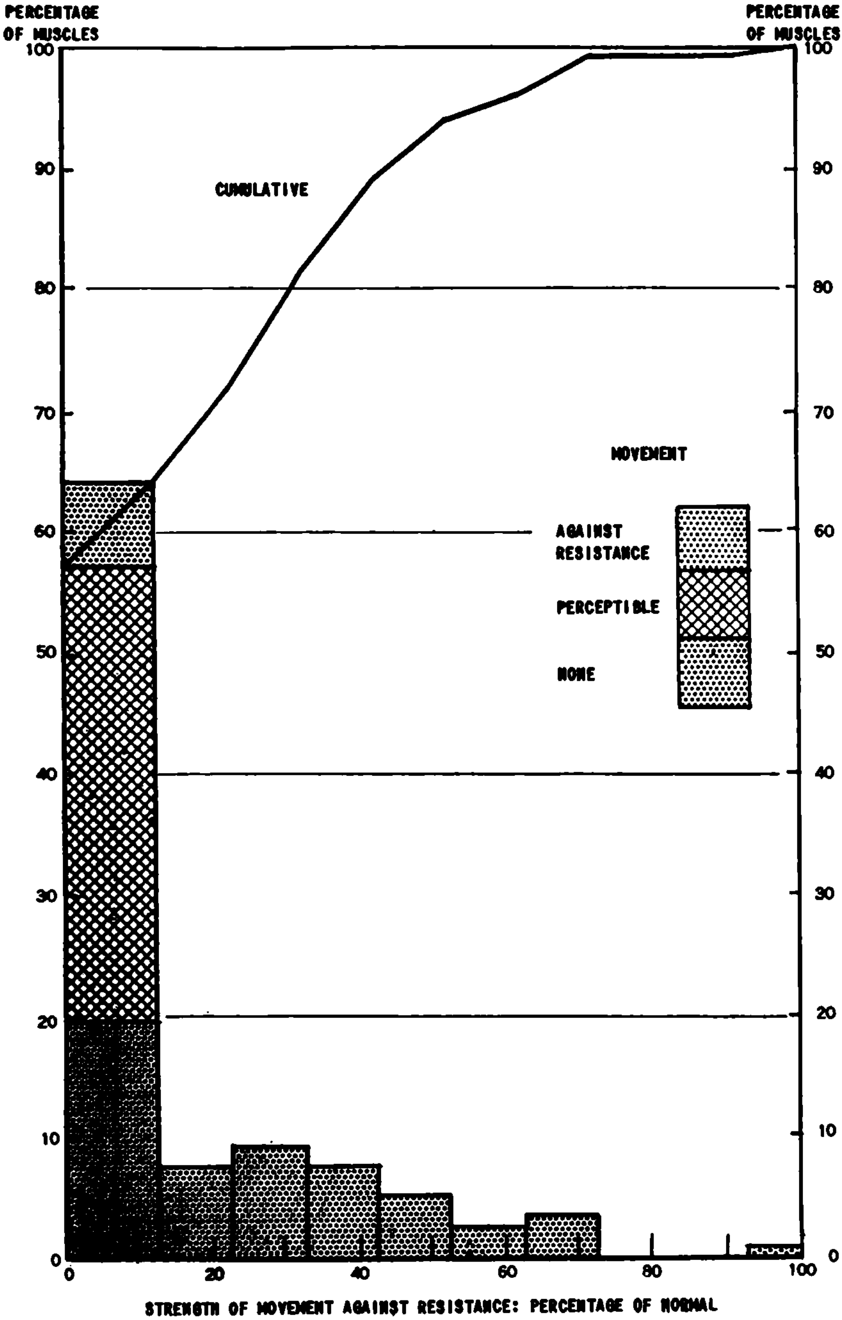


Figure 11 (p. 1). *Cumulative Percentage Distributions of Affected Muscles by Relative Strength of Movement Following Complete Suture—Median*

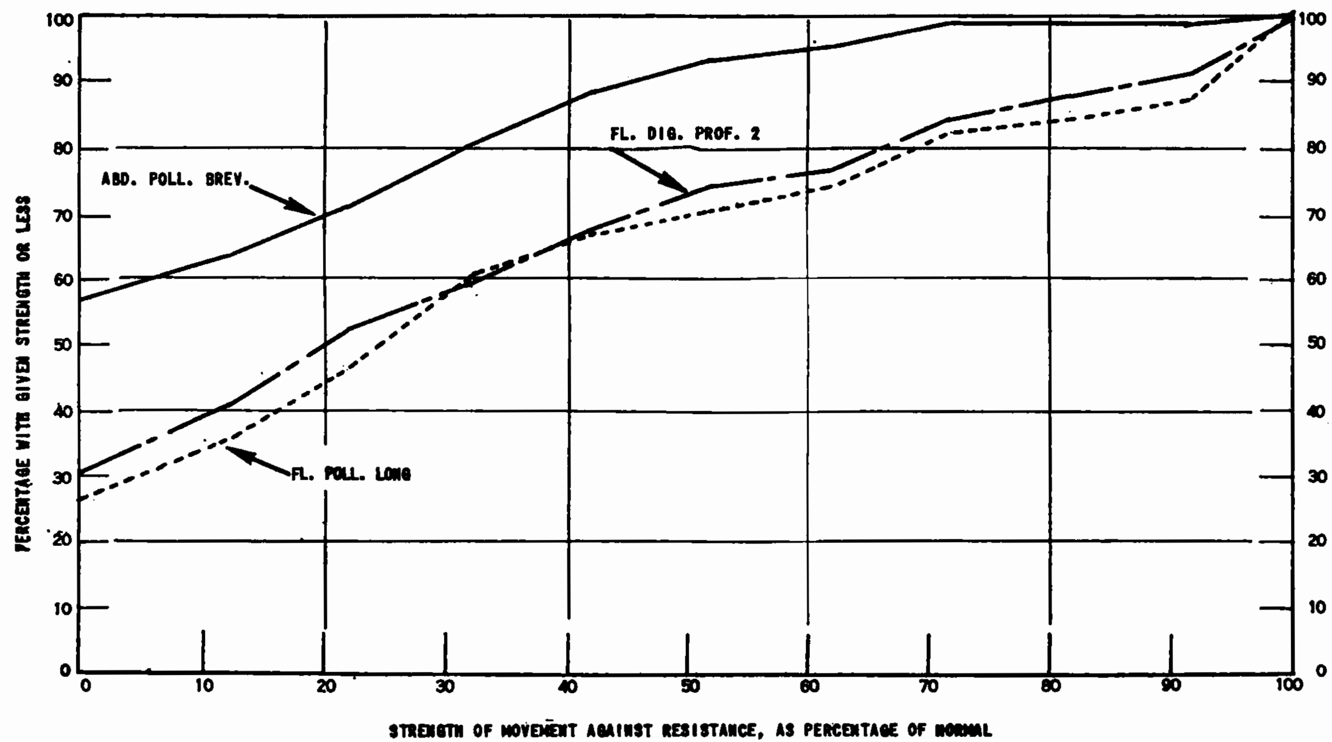


Figure 11 (p. 2). *Cumulative Percentage Distributions of Affected Muscles by Relative Strength of Movement Following Complete Suture—Ulnar*

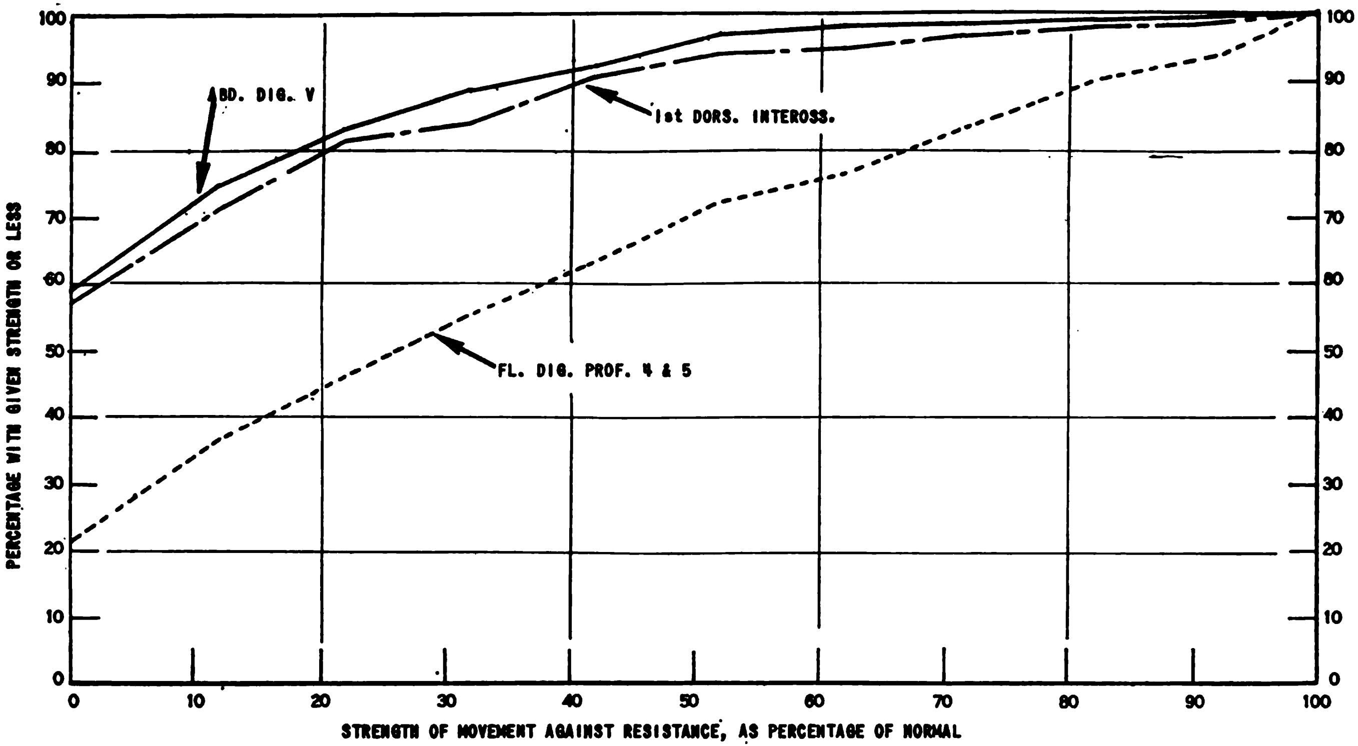


Figure 11 (p. 3). *Cumulative Percentage Distributions of Affected Muscles by Relative Strength of Movement Following Complete Suture—Radial*

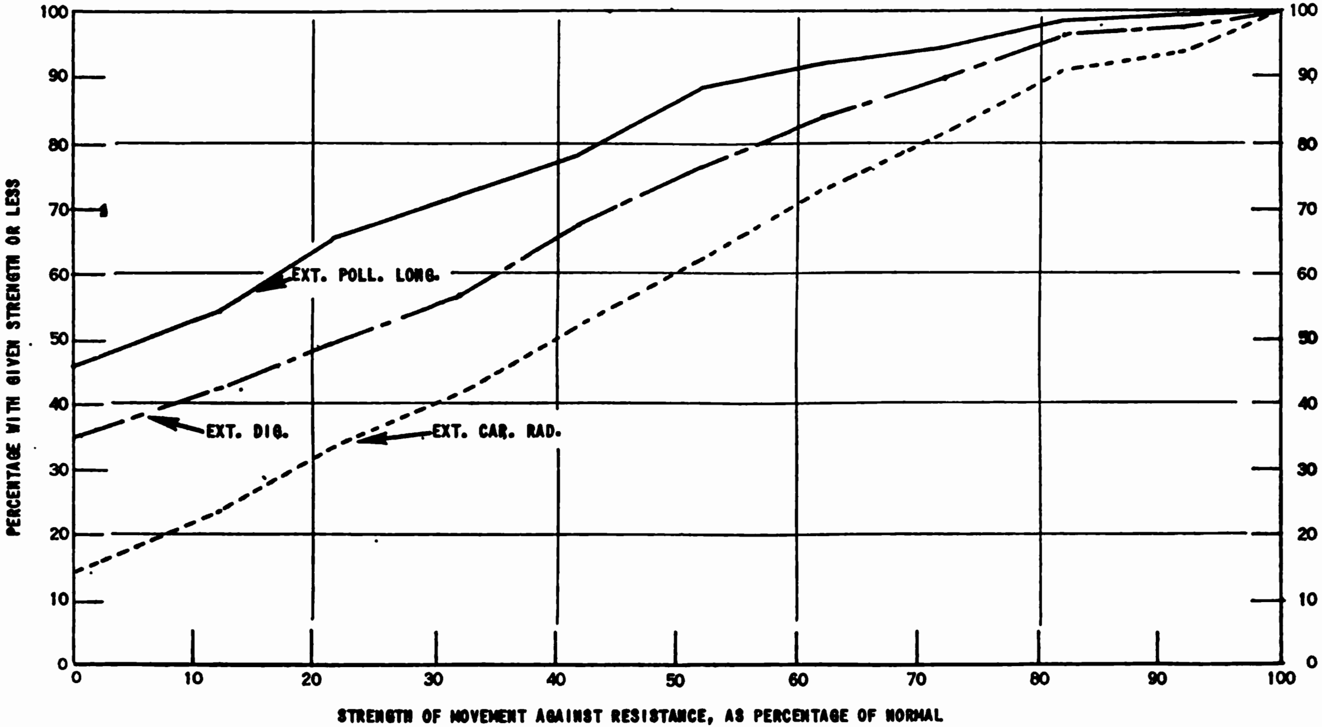


Figure 11 (p. 4). *Cumulative Percentage Distributions of Affected Muscles by Relative Strength of Movement Following Complete Suture—Peroneal*

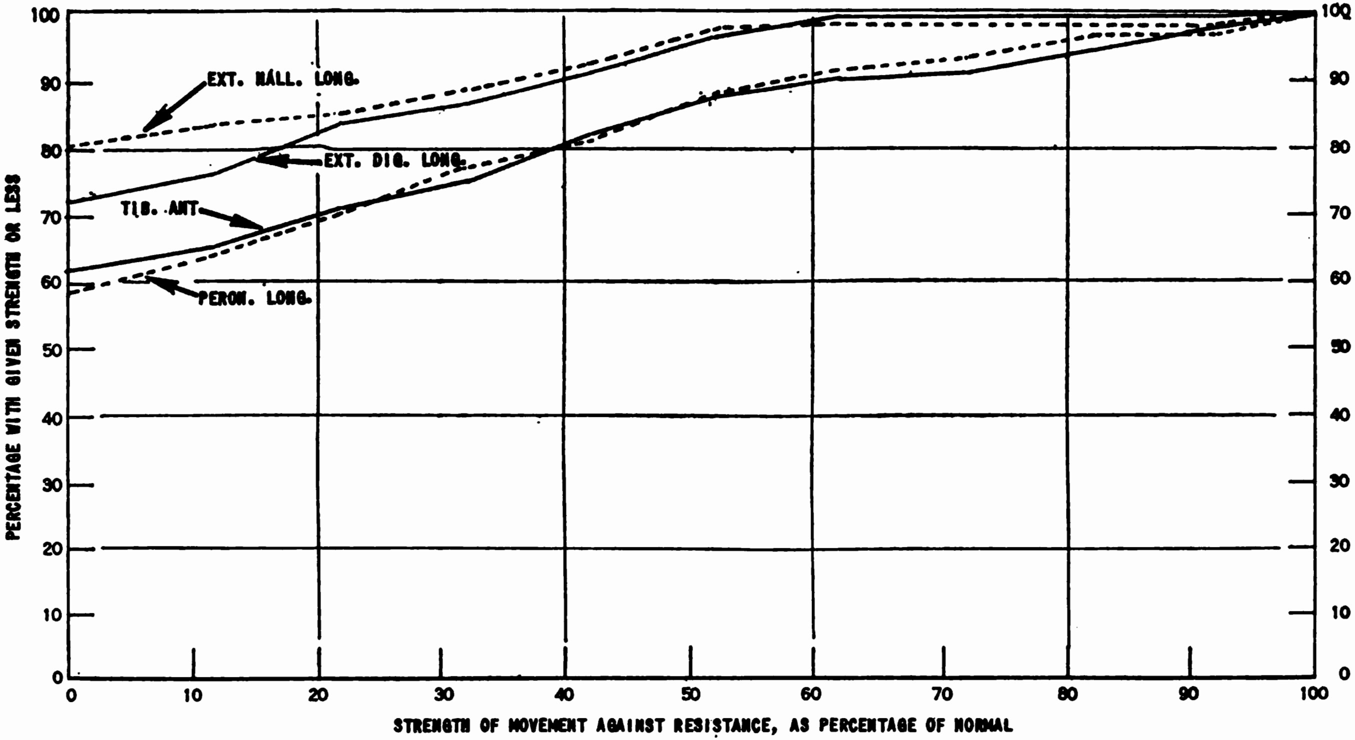


Figure 11 (p. 5). *Cumulative Percentage Distributions of Affected Muscles by Relative Strength of Movement Following Complete Suture—Sciatic-Peroneal*

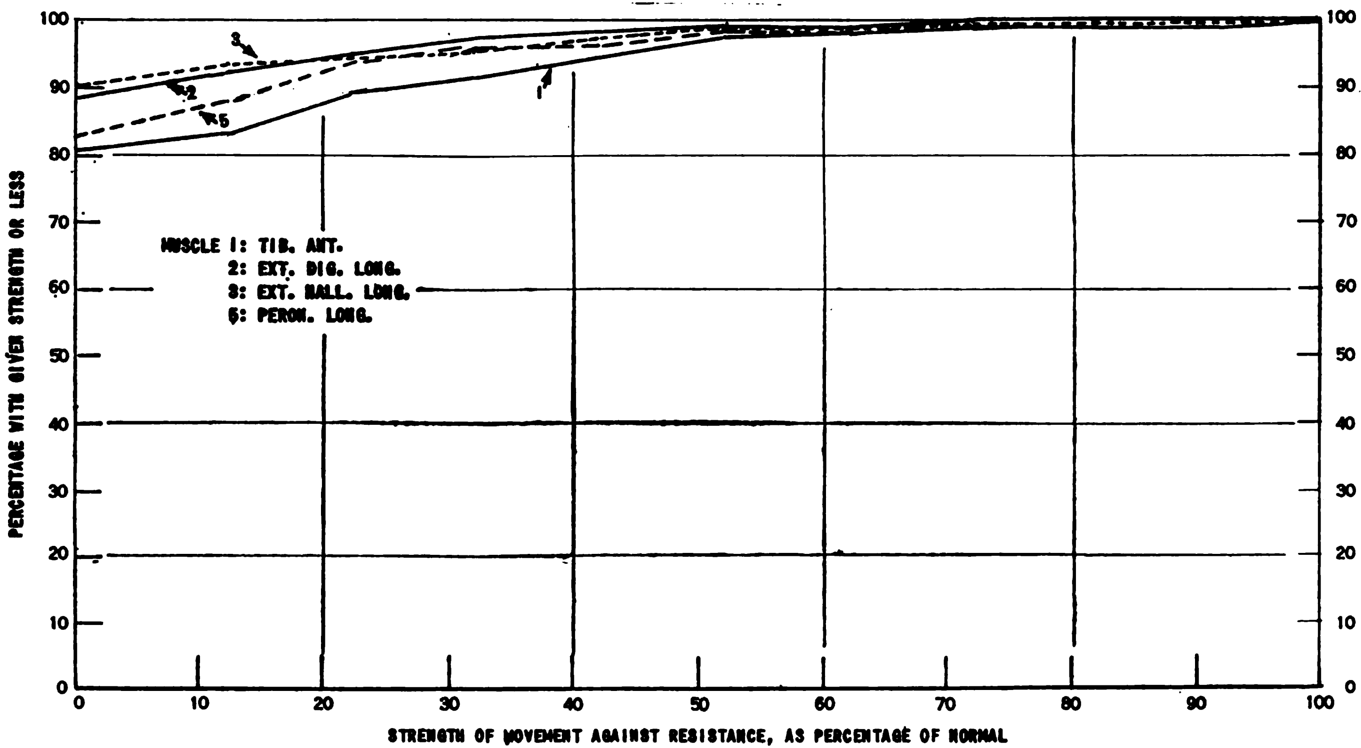


Figure 11 (p. 6). *Cumulative Percentage Distributions of Affected Muscles by Relative Strength of Movement Following Complete Suture—Tibial*

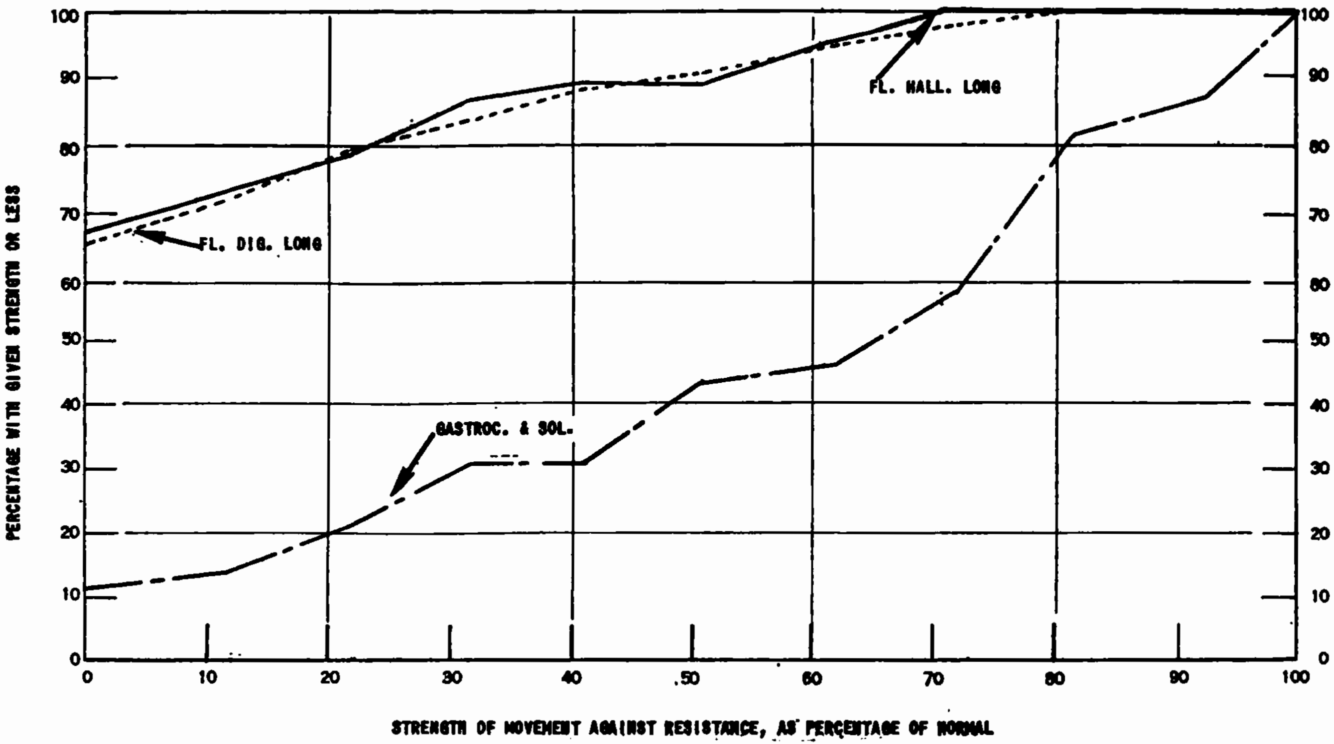
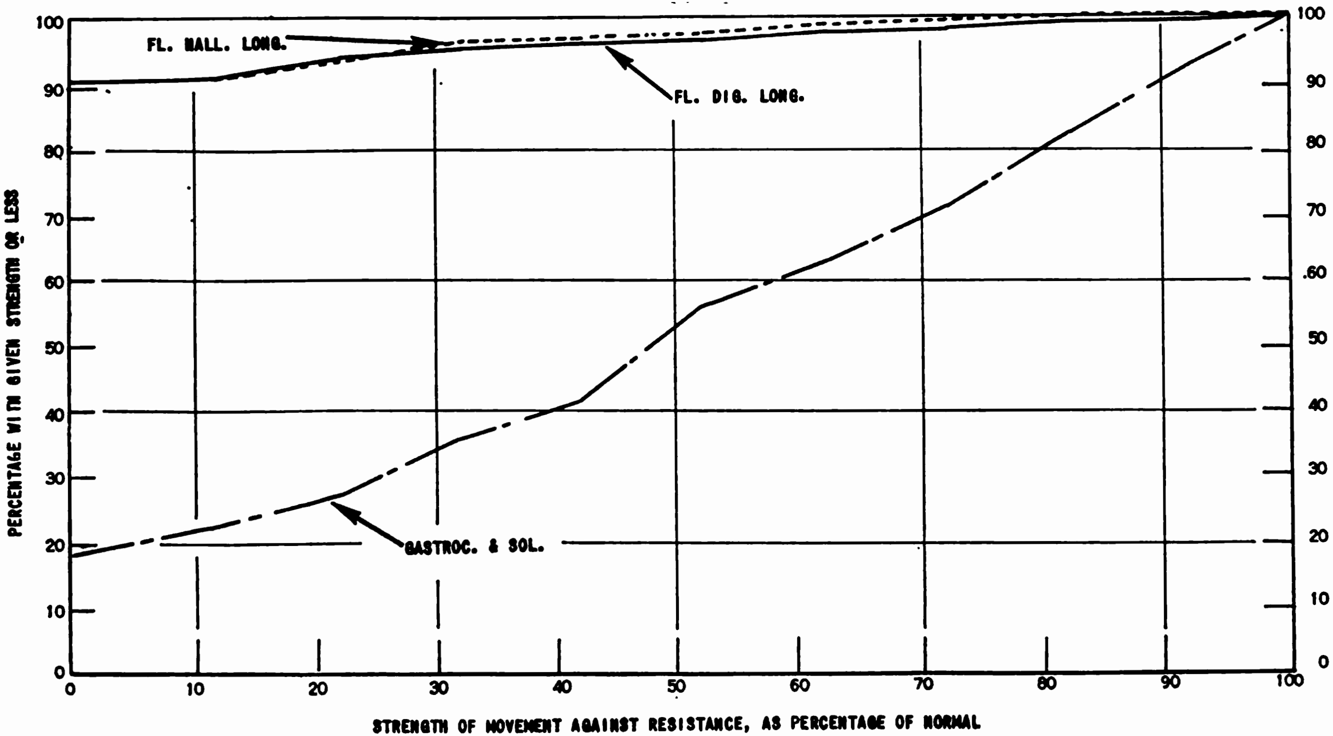


Figure 11 (p. 7). *Cumulative Percentage Distributions of Affected Muscles by Relative Strength of Movement Followin Complete Suture—Sciatic-Tibial*



tribution passes the 50-percent mark on the vertical axis. Thus the median average for the abductor pollicis brevis is at 0, whereas the mean is 14 percent.

In view of the poor showing of lower extremity muscles in figure 11, where the impression is based chiefly upon failure to move against resistance, it is of special interest to note, in table 50, that these muscles do not appear at such a disadvantage when the comparison is confined to muscles capable of contracting against resistance. That is, the factors responsible for poor motor return in the lower extremity determine chiefly whether there will be contraction against resistance; if such contraction is present, actual power is not very different from that for the muscles of the upper extremity.

Table 50 is a reference table, summarizing a great deal of the motor data from the present study. It pertains to all complete sutures in the representative sample, regardless of site of lesion, type of injury to the nerve, and the like.

Site of lesion was classified in accordance with the scheme already presented in chapter II. Although the full detail is of interest, most of the information implicit in knowledge of site is contained in the distinction between high and low sites as defined for this study, i. e., high lesions are those occurring at or above the elbow or, in the lower extremity, involving the sciatic, and low lesions are those below the elbow or below the bifurcation of the sciatic into peroneal and tibial nerves. Accordingly, systematic high-low comparisons are presented first; these appear in table 51 for complete sutures only. No comparison has been made for the radial since virtually all lesions studied here are high. Since only about 85 percent of the muscles whose voluntary movement was observed by examiners were actually measured as to strength, any machine table with information on *both* aspects of motor performance might carry two different numbers differing, on the average, by the indicated amount. Although all computation has of course been based on precisely correct counts of cases, it seemed unnecessary to include both numbers in the tables and accordingly, whenever two counts might have been used, the smaller number (N) was chosen for presentation. There are three aspects to the comparison detailed in table 51.

Table 49.—*Relative Strength of Movement Following Complete Suture, Individual Muscles Affected by Injury*

Nerve and muscle	Number of cases	Cumulative percentage with given strength or less											
		No movement against resistance		Movement against resistance, by percentage of normal power									
		No contraction	Visible contraction	12	22	32	42	52	62	72	82	92	100
Median													
Fl. poll. long	113	10.62	26.55	35.61	46.68	60.76	67.81	70.83	74.86	82.91	84.93	87.95	100.02
Fl. dig. prof. 2	165	10.30	30.30	40.91	52.86	59.50	68.13	74.76	77.41	84.71	88.03	91.35	99.98
Abd. poll. brev	128	19.53	57.03	63.77	71.36	80.64	88.23	93.29	95.81	99.17	99.17	99.17	100.01
Ulnar													
Fl. dig. prof. 4 & 5	323	5.88	21.67	37.06	46.76	55.46	63.50	72.54	76.90	83.92	90.29	93.98	100.01
Abd. dig. V	436	12.61	59.63	75.06	83.13	89.25	92.67	97.32	98.06	98.31	99.29	99.78	100.03
1st dors. inteross	328	17.68	57.31	71.54	81.03	85.41	90.88	94.16	95.25	97.07	98.16	98.52	99.98
Radial													
Ext. car. rad	189	5.82	14.81	23.50	33.35	40.30	50.73	62.90	73.32	81.43	90.70	94.18	99.97
Ext. dig	177	11.30	35.03	43.08	49.27	57.32	67.84	76.50	83.30	89.48	96.28	98.14	100.00
Ext. poll. long	179	16.76	45.25	54.58	65.78	72.00	78.22	88.80	91.91	94.40	98.13	99.37	99.99
Tibial													
Gastroc. & sol	35	5.71	11.42	14.58	20.90	30.39	30.39	43.05	46.21	58.86	81.01	87.33	99.99
Fl. dig. long	58	34.48	65.51	72.41	79.31	83.91	88.51	90.81	95.41	97.71	100.01	100.01	100.01

Fl. hall. long	58	32.76	67.24	73.79	78.17	86.91	89.10	89.10	95.66	100.04	100.04	100.04	100.04
Sciatic-tibial													
Gastroc. & sol	137	5.84	19.71	22.99	28.72	36.09	41.82	57.39	63.94	72.95	83.60	90.15	99.98
Fl. dig. long	134	72.39	90.30	91.92	95.16	95.16	96.78	97.59	98.40	98.40	99.21	99.21	100.02
Fl. hall. long	134	71.64	90.30	91.92	94.35	95.97	97.59	98.40	99.21	99.21	100.02	100.02	100.02
Peroneal													
Tib. ant	129	24.81	62.02	65.98	71.51	75.46	82.58	88.12	90.49	91.28	94.44	96.02	99.98
Ext. dig. long	138	34.06	72.47	76.93	84.37	87.35	91.82	96.29	99.26	99.26	99.26	99.26	100.00
Ext. hall. long	136	45.59	80.15	84.12	85.71	89.68	92.85	97.61	98.40	98.40	98.40	98.40	99.99
Peron. long	138	28.99	58.70	64.81	70.93	77.05	81.64	88.52	91.58	93.11	96.94	96.94	100.00
Sciatic-peroneal													
Tib. ant	168	41.07	80.36	83.53	89.23	91.76	94.92	97.46	98.09	99.35	99.35	99.35	99.98
Ext. dig. long	170	57.06	88.82	92.32	95.12	97.22	98.62	99.32	99.32	100.02	100.02	100.02	100.02
Ext. hall. long	167	64.67	90.42	93.83	94.51	95.19	97.92	99.29	99.29	99.97	99.97	99.97	99.97
Peron. long	170	44.71	82.95	88.64	91.80	95.59	96.85	98.75	98.75	100.01	100.01	100.01	100.01

Table 50.—*Mean Power of Affected Muscles Following Complete Suture*

Nerve and muscle	Number of cases	Mean power as percentage of normal: All cases	Mean power as percentage of normal: Cases with movement against resistance
Median			
Fl. car. rad	141	55.99	(1)
Fl. poll. long	103	33.16	46.78
Fl. dig. prof. 2	155	31.13	45.95
Opponens	187	23.69	(1)
Abd. poll. brev	124	13.67	33.24
Ulnar			
Fl. car. uln	253	59.57	(1)
Fl. dig. prof. 4 & 5	304	33.92	44.07
Abd. dig. V	425	9.63	24.81
Add. poll	393	23.66	(1)
1st dors. inteross	305	10.90	28.42
Radial			
Triceps	39	57.05	(1)
Brachiorad	111	48.56	(1)
Ext. car. rad	175	41.26	49.12
Ext. dig	167	28.08	44.66
Ext. car. uln	177	36.07	(1)
Abd. poll. long	113	14.69	(1)
Ext. poll. long	169	19.14	36.76
Tibial			
Gastroc. & sol	32	55.94	63.93
Tib. post	37	35.68	(1)
Fl. dig. long	53	10.09	35.67
Fl. hall. long	54	9.44	34.00
Inteross	76	3.36	(1)
Sciatic-tibial			
Gastroc. & sol	125	46.08	58.77
Tib post	129	18.72	(1)
Fl. dig. long	133	3.31	36.67
Fl. hall. long	133	2.82	31.25
Inteross	120	.42	(1)
Peroneal			
Tib. ant	128	17.38	46.35
Ext. dig. long	137	8.61	31.89
Ext. hall. long	134	6.68	35.80
Peron. long	135	17.00	42.50
Sciatic-peroneal			
Tib. ant	166	5.91	31.65
Ext. dig. long	167	2.25	23.50
Ext. hall. long	165	2.36	27.79
Peron. long	168	4.26	26.52

[1] Not calculated.

Table 51.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Gross Site of Lesion*

Nerve and muscle	High lesions				Low lesions				Statistical tests [2]
	N [1]	Percentage contracting	Mean power: All cases	Mean power: Cases moving against resistance	N [1]	Percentage contracting	Mean power: All cases	Mean power: Cases moving against resistance	
Median									
Fl. car. rad	103	96.52	51.99	60.17	38	92.31	66.84	74.71	*
Fl. poll. long	70	88.46	27.93	41.60	33	91.43	44.24	56.15	*
Fl. dig. prof. 2	106	87.72	22.26	36.88	49	94.12	50.31	60.12	**
Opponens	96	75.75	18.44	34.04	91	91.75	29.23	45.08	**
Abd. poll. brev	63	78.12	12.38	35.45	61	82.81	15.00	31.55	NS
Ulnar									
Fl. car. uln	178	96.14	56.63	66.32	75	97.44	66.53	72.32	*
Fl. dig. prof. 4 & 5	206	93.69	31.67	41.82	98	95.05	38.65	48.56	NS
Abd. dig. V	232	84.87	7.20	21.14	193	90.40	12.55	28.16	**
Add. poll	217	84.85	18.94	33.69	176	92.51	29.49	40.23	**
1st dors. inteross	164	78.41	8.96	25.77	141	86.84	13.16	30.93	*
Tibial									
Gastroc. & sol	125	94.16	46.08	58.77	32	94.29	55.94	63.93	NS
Tib. post	129	68.66	18.72	53.67	37	85.00	35.68	60.00	**
Fl. dig. long	133	27.61	3.31	36.67	53	65.52	10.09	35.67	*
Fl. hall. long	133	28.36	2.82	31.25	54	67.24	9.44	34.00	*
Inteross	120	14.05	.42	50.00	76	51.81	3.36	31.92	*

Table 51.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Gross Site of Lesion*—Con.

Nerve and muscle	High lesions				Low lesions				Statistical tests[2]
	N[1]	Percentage contracting	Mean power: All cases	Mean power: Cases moving against resistance	N[1]	Percentage contracting	Mean power: All cases	Mean power: Cases moving against resistance	
Peroneal									
Tib. ant	166	58. 93	5. 91	31. 65	128	75. 19	17. 38	46. 35	**
Ext. dig. long	167	42. 94	2. 25	23. 50	137	65. 94	8. 61	31. 89	**
Ext. hall. long	165	35. 33	2. 36	27. 79	134	54. 41	6. 68	35. 80	*
Peron. long	168	55. 29	4. 26	26. 52	135	71. 01	17. 00	42. 50	**

[1] Number of muscles studied; see text.

[2] Probability that observed difference between means for all muscles, or a larger difference, might arise by chance. Results of statistical tests are abbreviated as follows:

NS = Not significant

* = Significant at .05 level

** = Significant at .01 level

a. The percentage with at least a perceptible contraction, given for the 23 muscles most intensively studied;

b. The mean power, expressed as a percentage of normal power, of all cases tested, rating as 0 all those in which there was no movement against resistance; and

c. The mean power of only those in which there was movement against resistance.

Systematic tests of significance have been made only on the basis of the second of these, the results of which appear in the last column of the table and are uniformily in favor of the low lesions, although not significantly so in all instances. The percentage contracting, on the other hand, does not differ so characteristically between high and low lesions, impressive differences being found only in the lower extremity. The mean power for cases in which there was movement against resistance does not distinguish high and low lesions quite as sharply as the mean for all examined cases, but the general picture is the same except for the tibial, where the proportion of muscles moving against resistance is so small for the flexor digitorum longus and the flexor hallucis longus that the corresponding mean values are subject to quite large sampling errors. If one plots the two mean values for each muscle and site of lesion in a correlation diagram, a rather smooth curve will be found to fit the data for the muscles of the upper extremity, suggesting that high-low differences are equally well described in terms of either index. This is not true of the lower extremity for which, in addition, any fitted curve would follow a different path, since it is primarily the mean relative power for all cases which is depressed in the lower extremity. On the whole the data for complete sutures suggest the following general conclusions:

a. Motor recovery is better after low lesions than after high, but in the upper extremity the advantage is greatest in the most proximal muscles and doubtful in the most distal.

b. In the upper extremity the advantage of the lower lesions is less a matter of the ability of muscles to contract than of actual strength of movement.

c. The advantage of the tibial over the sciatic-tibial lesions is chiefly a matter of ability to contract rather than strength of movement, but the peroneal exceed the sciatic-peroneal cases not only in regard to the proportion contracting but also strength of movement for those able to contract.

Although the amount of information on lysed cases is not nearly so large as that for the sutured cases it seems important to present it here. Table 52 presents a summary of the data on the representative sample of lysed cases. There was too little information on the median to justify its presentation, the great majority of lysed median lesions having been high in their location, and not all the ulnar muscles are represented by enough cases to merit separate presentation. The only suggestion of a site effect in table 52 derives from the tibial which is not represented by very many low lesions, and statistical tests do not give this suggestion much weight. It would appear, therefore, that the effect of gross site of lesion is particularly large only for the sutured lesions, not for the lysed.

Table 52.—*Mean Power of Affected Muscles Following Neurolysis, by Gross Site of Lesion*

Nerve and muscle	High lesions		Low lesions		Statistical tests [1]
	Number of cases	Mean power, all cases	Number of cases	Mean power, all cases	
Ulnar					
Abd. dig. V	57	33.42	27	36.67	NSI
Add. poll	52	45.00	27	56.85	NSI
1st dors. inteross	45	33.78	23	33.91	NSI
Peroneal					
Tib. ant	35	37.71	25	40.20	NSI
Ext. dig. long	32	30.63	23	33.70	NSI
Ext. hall. long	33	24.24	24	19.58	NSI
Peron. long	35	36.29	22	38.64	NSI
Tibial					
Gastroc. & sol	44	64.55	15	64.67	NSI
Tib. post	44	39.32	14	49.64	NS
Fl. dig. long	48	23.23	16	32.50	NSI
Fl. hall. long	47	21.49	18	32.50	NS
Inteross	38	8.42	14	16.43	NSI

[1] Results of statistical tests are abbreviated as follows:
NSI = Not significant, by inspection only.
NS = Not significant, by formal test.

Further detail on the effect of site of lesion is presented in table 53 for sutured cases only. As in table 51, three different indices of motor recovery are employed, although statistical tests were confined to the average power of all tested muscles, whether or not able to contract against resistance. In the median there is no evidence of any uniform gradient associated with site; in the proximal muscles the lowest lesions do best, and in the distal muscle site seems relatively unimportant. There is a suggestion, however, that recovery of the abductor pollicis brevis may be notably poor in the quite high lesions of shoulder and upper third of arm. In the proximal median muscles both the probability of any visible contraction and the power of any contraction against resistance appear to depend on site of lesion. In the ulnar the situation is only roughly similar. For the flexor digitorum profundus there is no real evidence that site has a strong influence on any of the several motor indices. In the abductor digiti quinti, on the other hand, all three indices are sensitive to site, and there is some suggestion of a gradient, with the poorest results found in the highest lesions. Although the statistical tests on the first dorsal interosseus are less conclusive than those on the abductor digiti quinti, the data are roughly similar.

A word is required here on the nature and limitations of the statistical tests employed. It is a cardinal principle in the theory of testing hypotheses that the hypothesis be framed independently of the data upon which it is tested. In the present application, the hypothesis chosen for testing, in advance of the calculation of the motor indices, was merely that recovery is independent of site. The probability results obtained in these tests, then, apply only to this hypothesis and not to others which might reasonably have been proposed.

In only one of the radial muscles, the extensor digitorum communis, do the data of table 53 suggest any important variation with site of lesion. Both the proportion contracting and the power of muscles moving against resistance increase as the lesion advances distally, but only for power is the observed variation statistically significant by the criterion employed here.

The peroneal and sciatic-peroneal nerves are studied separately, with the sites as shown in table 53. Statistically significant variation was noted only for the tibialis anticus in sciatic-peroneal lesions and for the extensor digitorum longus in peroneal lesions. Apart from the high-low difference already discussed the only evidence of any general effect of site is seen in the proportion of sciatic-peroneal muscles able to contract at least minimally; power seems surely involved only in the tibialis anticus. The variation seen in the peroneal is unimpressive, for the statistical conclusion of heterogeneity in the extensor digitorum longus rests upon rather slender grounds.

In the tibial and sciatic-tibial nerves, as may be seen from table 53, site of lesion seems to be clearly a factor in the probability of contraction for the flexor digitorum longus and the flexor hallucis longus, but not in the relative strength of the muscles able to move against resistance.

Type of lesion was classified in accordance with the scheme presented in chapter II, but in this clinical series the type of lesion cannot be divorced from surgical handling. The surgeon who appraises an injured nerve will generally confine his intervention to a neurolysis only if the nerve remains in continuity and appears relatively undamaged, and will perform a complete suture on a lesion in continuity only if he believes considerable damage to have been done. Accordingly, the comparisons permitted by the clinical material are as follows:

a. Within the set of complete sutures, and on the basis of the operator's observation of the gross external appearance of the lesion and the appearance of the cross section, a distinction may be made between apparently complete and apparently incomplete lesions.

b. Complete sutures, partial sutures, and lyses may be compared with the understanding that it is primarily the type of lesion which distinguishes these three operation groups.

c. Within the set of lysis cases, a distinction may be made between nerves judged essentially normal and those thought by the operator to exhibit some scarring or neuroma formation.

Table 53.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Specific Site of Lesion*

Specific site	Median muscles											
	Fl. poll. long.				Fl. dig. prof. 2				Abd. poll. brev.			
	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$
Shoulder plus upper ⅓ arm	35	77.8	21.43	37.50	48	78.4	18.02	36.04	30	65.6	5.67	34.02
Middle ⅓ arm	32	83.8	35.94	50.00	48	90.2	22.29	34.51	30	78.1	10.67	32.01
Lower ⅓ arm plus elbow	31	91.7	27.74	40.95	50	87.5	22.60	35.31	36	84.2	16.81	33.62
Upper ⅓ forearm	17	75.0	22.94	39.00	25	85.7	32.20	47.35	21	78.3	14.05	26.82
Middle ⅓ forearm and below	26	100.0	52.31	68.00	34	100.0	62.50	68.55	79	81.3	14.75	36.41
Statistical tests [1]			**				**				NS	

Specific site	Ulnar muscles											
	Fl. dig. prof. 4 & 5				Abd. dig. V				1st dors. inteross.			
	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$
Shoulder, 1st & 2d ⅓ arm	129	92.6	30.04	41.23	145	81.4	6.69	20.64	99	69.4	6.41	26.44
Lower ⅓ arm	71	94.9	31.41	42.88	84	88.5	5.12	17.92	69	84.5	7.32	22.95

Elbow	59	90.5	29.83	42.92	65	88.4	10.38	24.99	50	86.8	12.20	26.52
Upper ⅓ forearm	48	98.1	37.64	47.55	67	92.9	9.93	20.79	53	89.3	12.64	30.45
Middle ⅓ forearm, Lower ⅓ forearm	60	93.5	40.67	53.05								
Middle ⅓ forearm					88	89.9	14.66	28.67	59	84.6	10.51	25.84
Lower ⅓ forearm					65	90.9	12.46	28.93	49	82.4	13.78	33.76
Wrist, hand	......	......	......	....	40	87.8	10.63	38.66	34	88.2	13.09	44.51
Statistical tests [1]	......	......	NS	....	......	*	**	....	......	*	NS	....

Specific site	Radial muscles											
	Ext. car. rad.				Ext. dig.				Ext. poll. long.			
	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$
Upper ⅓ arm	55	89.7	32.64	41.75	50	84.6	15.60	33.91	50	75.9	11.30	33.24
Middle ⅓ arm	94	96.1	39.47	48.82	90	86.3	24.72	40.45	91	80.0	18.63	34.60
Lower ⅓ arm	65	96.0	41.62	50.10	63	90.4	29.44	52.99	62	87.2	16.69	34.49
Statistical tests [1]	......	NS	NS	....	......	NS	*	....	......	NS	NS	....

See footnotes at end of table.

Table 53.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Specific Site of Lesion*—Continued

Specific site	Peroneal and sciatic-peroneal muscles															
	Tib. ant.				Ext. dig. long.				Ext. hall. long.				Peron. long.			
	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$
Sciatic-peroneal cases																
Upper ⅓ thigh......	129	54.3	2.61	24.05	130	36.9	1.65	21.45	128	28.9	1.64	26.24	130	49.2	2.96	21.38
Middle ⅓ thigh......	66	60.3	5.53	24.33	67	42.9	1.49	19.97	67	34.8	2.99	28.62	67	57.1	4.55	25.40
Lower ⅓ thigh......	32	71.9	13.75	36.67	31	59.4	4.52	28.02	31	48.4	1.45	14.98+	30	67.7	7.00	35.00
Statistical tests [1].....	.....	**	**	....	.....	NS	NS	....	.....	NS	NS	....	.....	NS	NS	......
Peroneal cases																
Lower ⅓ thigh......	23	69.6	15.00	57.50	24	62.5	0.63	15.12+	24	37.5	2.50	30.00+	23	70.8	8.91	25.62
Knee..............	111	75.0	17.88	48.41	119	66.4	10.25	34.85	115	56.3	7.04	36.80	116	71.3	20.30	51.19
Upper ⅓ leg........	27	75.9	15.00	36.82	31	67.7	11.77	30.41	30	60.0	14.00	38.18	29	70.0	13.79	36.36
Statistical tests [1].....	.....	NS	NS	....	.....	*	*	....	.....	NS	NS	....	.....	NS	NS	......

Specific site	Tibial and sciatic-tibial muscles											
	Gastroc. & sol.				Fl. dig. long.				Fl. hall. long.			
	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$

Sciatic-tibial cases												
Upper ⅓ thigh	95	94.1	42.47	56.04	101	16.8	2.52	36.36	100	18.0	2.15	30.71
Middle ⅓ thigh	49	94.5	44.18	52.80	54	37.0	2.31	20.79	54	33.3	2.50	27.00
Lower ⅓ thigh	26	92.9	52.88	62.49	26	40.7	3.85	100.00+	26	41.4	2.12	55.12+
Statistical tests [1]	......	NS	NS	....	......	**	NS	....	......	*	NS	....
Tibial cases												
Lower ⅓ thigh, knee, and upper ⅓ leg	......	......	......	....	46	52.1	5.33	27.24	45	58.7	6.89	31.01
Middle ⅓ leg and below	......	......	......	....	23	80.8	13.91	39.99	24	74.1	9.58	32.85
Statistical tests [1]	......	......	......	....	......	*	NS	....	......	......	NS	....

[1] Results of statistical tests are abbreviated as follows:
NS = Not significant.
* = Significant at .05 level.
** = Significant at .01 level.
Tests summarized in the % column were done on three sets of proportions—those with no perceptible contraction, those with some contraction but not against resistance, and those with contraction against resistance.

NOTE: The symbols used in the headings may be defined as follows:
N = number of cases for specified site.
% = percentage with at least perceptible contraction.
$\overline{X}_1$ = mean relative power of all cases tested.
$\overline{X}_2$ = mean relative power of muscles capable of movement against resistance.
+ = means based on less than 5 cases.

These different comparisons will be discussed in turn.

Lesions treated by complete suture were classified as either complete divisions, partial divisions, or neuromas in continuity, but in tabulations on type of injury these three groups were reduced to a dichotomy between complete and incomplete lesions. Neuromas in continuity dominate the incomplete lesions; in the entire set of 2,556 sutures among all 3,656 lesions studied here, 68 percent were classified as complete divisions, 6.5 percent partial divisions, 25 percent neuromas in continuity, and 0.5 percent other or unspecified types of lesion. Table 54 provides a complete summary of the information available on type of lesion, and provides no evidence of any effect of type of lesion, provided a complete suture was done. Only in 3 out of 36 tests was a significant discrepancy noted, and the differences between pairs of means do not seem especially one-sided in their distribution.

Table 54.—*Mean Power of Affected Muscles Following Complete Suture, by Type of Lesion*

Nerve and muscle	Complete lesions		Incomplete lesions [1]		Statistical tests [2]
	Number of cases	Mean power all cases	Number of cases	Mean power all cases	
Median					
Fl. car. rad	98	56. 28	30	54. 67	NS
Fl. poll. long	73	31. 99	22	36. 59	NS
Fl. dig. prof. 2	107	31. 78	35	26. 43	NS
Opponens	131	20. 69	41	31. 59	*
Abd. poll. brev	85	12. 47	27	14. 44	NS
Ulnar					
Fl. car. uln	180	58. 97	55	61. 45	NS
Fl. dig. prof. 4 & 5	217	35. 03	66	30. 33	NS
Abd. dig. V	308	8. 62	91	12. 82	NS
Add. poll	278	22. 82	91	25. 88	NS
1st dors. inteross	230	10. 76	60	12. 08	NS
Radial					
Triceps	27	50. 37	12	72. 08	*
Brachiorad	83	43. 67	28	63. 04	*
Ext. car. rad	132	39. 51	43	46. 63	NS
Ext. dig	126	27. 30	41	30. 49	NS
Ext. car. uln	135	33. 78	42	43. 45	NS
Abd. poll. long	85	14. 94	28	13. 93	NS
Ext. poll. long	126	18. 06	43	22. 33	NS
Ext. poll. brev	77	15. 00	19	15. 26	NS

See footnotes at end of table.

Table 54.—*Mean Power of Affected Muscles Following Complete Suture, by Type of Lesion*—Continued

Nerve and muscle	Complete lesions		Incomplete lesions [1]		Statistical tests [2]
	Number of cases	Mean power all cases	Number of cases	Mean power all cases	
Peroneal					
Tib. ant	78	14.81	50	21.40	NS
Ext. dig. long	83	7.47	54	10.37	NS
Ext. hall. long	81	6.11	53	7.55	NS
Peron. long	84	13.57	51	22.65	*
Tibial					
Gastroc. & sol	18	62.50	14	47.50	NS
Tib. post	21	40.24	16	29.69	NS
Fl. dig. long	34	12.21	19	6.32	NS
Fl. hall. long	35	9.57	19	9.21	NS
Inteross	52	3.46	24	3.13	NS
Sciatic-peroneal					
Tib. ant	116	5.39	50	7.13	NS
Ext. dig. long	116	2.28	51	2.16	NS
Ext. hall. long	113	1.77	52	3.65	NS
Peron. long	115	3.78	53	5.28	NS
Sciatic-tibial					
Gastroc. & sol	87	46.67	38	44.74	NS
Tib. post	91	16.65	38	23.68	NS
Fl. dig. long	93	2.04	40	6.25	NS
Fl. hall. long	93	2.15	40	4.38	NS
Inteross	86	0.58	34	0.00	NS

[1] For the median and ulnar, incomplete lesions are confined to neuromas in continuity; for other nerves they include partial divisions.

[2] Results of statistical tests are abbreviated as follows:
NS=Not significant
*=Significant at .05 level.

Lysed and completely sutured cases are compared in table 55; separate comparisons are made in table 55 for high lesions and for low lesions in the case of muscles in which there are important high-low differences, since sutured and lysed cases are not always homogeneous as to the proportions classified as high and low. Although the only probabilities shown in table 55 are based on tests of means for all cases, including as 0 those not contracting against resistance, parallel tests were also done on

Table 55.—*Percentage of Affected Muscles Contracting and Mean Power Following Definitive Operation, for Complete Sutures and Neurolyses*

Nerve, muscle, and gross site	Complete suture[1]				Neurolysis[1]				Statistical tests[2]
	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	
Median									
Fl. car. rad	141	95.45	55.99	64.18	53	98.44	73.40	79.39	**
Fl. poll. long	103	89.38	33.16	46.79	47	92.31	64.47	73.90	**
Fl. dig. prof. 2 (high)	106	87.72	22.26	36.87	54	98.36	57.59	63.47	**
Opponens (high)	96	75.76	18.44	34.04	49	85.45	35.20	46.62	**
Opponens (low)	91	91.75	29.23	45.11	13	100.00	41.92	60.55	NS
Abd. poll. brev	124	80.47	13.67	33.24	43	85.42	23.14	43.26	*
Ulnar									
Fl. car. uln	253	96.49	59.57	68.20	56	98.57	62.14	69.60	NS
Fl. dig. prof. 4 & 5 (high)	206	93.69	31.67	41.82	54	100.00	59.72	68.61	**
Fl. dig. prof. 4 & 5 (low)	98	95.05	38.65	48.56	10	80.00	38.50	48.13	NS
Abd. dig. V (high)	232	84.87	7.20	21.14	57	97.06	33.42	51.48	**
Abd. dig. V (low)	193	90.40	12.55	28.16	27	100.00	36.67	47.15	**
Add. poll. (high)	217	84.85	18.94	33.69	52	93.75	45.00	55.71	**
Add. poll. (low)	176	92.51	29.49	40.23	27	96.55	56.85	63.96	**
1st dors. inteross	305	82.32	10.90	28.41	68	91.36	33.82	46.00	**

Radial									
Triceps	39	100.00	57.05	61.80	11	100.00	76.82	76.82	*
Brachiorad	111	92.14	48.56	68.23	14	100.00	66.07	71.15	NS
Ext. car. rad	175	94.18	41.26	49.12	23	95.83	58.70	61.37	*
Ext. dig	167	88.70	28.08	44.66	29	96.55	51.90	62.71	**
Ext. car. uln	177	92.67	36.07	49.88	26	96.30	53.85	63.64	**
Abd. poll. long	113	77.69	14.69	36.89	18	85.71	35.56	49.24	**
Ext. poll. long	169	83.24	19.14	36.76	28	85.71	32.68	45.75	*
Ext. poll. brev	96	79.09	15.05	36.12	16	83.33	34.38	45.84	**
Peroneal									
Tib. ant	128	75.19	17.38	46.35	25	84.00	40.20	59.12	**
Ext. dig. long	137	65.94	8.61	31.88	23	86.96	33.70	51.67	**
Ext. hall. long	134	54.41	6.68	35.80	24	66.67	19.58	42.72	NS
Peron. long	135	71.01	17.00	42.50	22	86.96	38.64	53.13	*
Sciatic-peroneal									
Tib. ant	166	58.93	5.91	31.65	35	91.67	37.71	54.99	**
Ext. dig. long	167	42.94	2.25	23.48	32	85.71	30.63	54.45	**
Ext. hall. long	165	35.33	2.36	27.81	33	86.11	24.24	53.33	**
Peron. long	168	55.29	4.26	26.51	35	89.19	36.29	55.22	**
Sciatic-tibial									
Gastroc. & sol	125	94.16	46.08	58.78	44	100.00	64.55	71.01	**
Tib. post	129	68.66	18.72	53.67	44	89.80	39.32	64.08	**
Fl. dig. long	133	27.61	3.31	36.69	48	67.31	23.23	61.95	**
Fl. hall. long	133	28.36	2.82	31.26	47	66.67	21.49	63.13	**
Inteross	120	14.05	0.42	50.40	38	53.49	8.42	79.99	*

See footnotes at end of table.

Table 55.—*Percentage of Affected Muscles Contracting and Mean Power Following Definitive Operation, for Complete Sutures and Neurolyses*—Continued

Nerve, muscle, and gross site	Complete suture [1]				Neurolysis [1]				Statistical tests [2]
	N	%	$\bar{X}_1$	$\bar{X}_2$	N	%	$\bar{X}_1$	$\bar{X}_2$	
Tibial									
Gastroc. & sol.	32	94.29	55.94	63.93	15	100.00	64.67	69.29	
Tib. post.	37	85.00	35.68	60.01	14	100.00	49.64	53.46	
Fl. dig. long.	53	65.52	10.09	35.65	16	94.12	32.50	47.27	
Fl. hall. long.	54	67.24	9.44	33.98	18	94.74	32.50	45.00	
Inteross.	76	51.81	3.36	31.92	14	85.00	16.43	57.51	

[1] The symbols used in the headings may be defined as follows:
N=number of cases for specified site.
%=percentage with at least perceptible contraction.
$\bar{X}_1$=mean relative power of all cases tested.
$\bar{X}_2$=mean relative power of muscles capable of movement against resistance.

[2] Results of statistical tests are abbreviated as follows:
NS=Not significant.
*=Significant at .05 level.
**=Significant at .01 level.

the proportions contracting and with about the same results. It is readily apparent from table 55 that the advantage of the lysed cases is twofold—the probability of contraction is higher and the muscles which do contract against resistance have more power. It is also of interest to note that the advantage is not limited to proximal muscles, but extends with equal force to distal muscles. The comparisons in terms of mean power obscure the fact that the sutured and lysed cases both extend over the entire range of power from 0 to 100 percent, differing only in their relative concentration at different regions of the scale. The lysed cases studied here, it may be noted, are those in which the clinical record contained definite evidence of denervation immediately prior to operation.

By way of interpretation it may be noted that neurolysis in any particular form is done whenever the surgeon believes that the total situation promises a higher degree of recovery if he virtually leaves the nerve alone than if he subjects it to resection and suture. The details of this complex evaluation are discussed in chapter XII. The statistics presented here simply reflect the soundness of the surgical judgment and must not be considered a comparison of competing forms of surgical therapy. In a study of late results there is no way to evaluate the possible role of neurolysis in the relief of acute nerve-segment compression, as by a band of scar tissue. The cases with neurolyses may even appear in a slightly more favorable light in such a survey than they should, since instances of mistaken judgment will often lead to resection and suture after a long delay, a delay which would tend to lower the average results of suture. In the representative sample only 1 percent of the first complete sutures had been preceded by lyses. The excellent recovery of the neurolysed cases does demonstrate that some lesions causing total dysfunction can, in due time, permit far better regeneration than can be effected by suture. This recognition by the surgeon at nerve operation is the critical point at issue, and the criteria governing his decision are discussed in chapter XII.

The magnitude of the discrepancy between lysed and sutured lesions is by no means uniform for all nerves and muscles and for the several indices of recovery. For sutured lesions of the upper extremity the average percentage with at least minimal contraction is, on the average, about 94 percent of that observed for parallel lysed cases, but for the lower extremity no simple average will describe the relationship, and no curve fits the data well. The average power of muscles capable of movement against resistance following suture is about 74 percent of parallel values for lysed lesions, but the scatter is too great for any single average, or any fitted curve, to have much meaning.

Partial sutures were, of course, done only rarely and on lesions which operators regarded as surely partial in extent. Table 56 provides comparative data for complete sutures, partial sutures, and lyses, for those nerves for which there were at least 10 cases with partial suture. Although no formal tests were done on these data, there is a clear suggestion that a ial sutures occupy a position intermediate between complete sutures and lyses. For the 20 muscles included in table 56 the average ranks of the three treatment groups [10] are

Complete suture	1.2
Partial suture	1.9
Lysis	2.9

where 3 represents the greatest average power.

Most lysed cases were described by surgeons as "normal nerve compressed by scar," but a significant number were called neuromas in continuity and a few partial divisions, and it is of interest to explore the prognostic significance of these descriptions by the operator. In the statistical tests, which are summarized in table 57, it was assumed that cases classified as "normal nerve compressed by scar" must be at least as good as those called neuromas or partial lesions; that is, one-tailed tests [11] were done. Even on the more powerful one-tailed basis, however, only 3 of the 17 differences were found to be significant, and although the mean is usually higher for the nerves operators regarded as normal in appearance, one can hardly call the evidence in their favor conclusive. Of equal interest is the fact that relative power is usually less than 50 percent even in muscles affected by lesions in normal-appearing nerves; the highest mean is 75 percent. Plainly the operator was unable to detect the damage done to the grossly intact nerve.

Age at injury is sharply restricted, not merely by the fact of military service but even more particularly by the fact that the men were predominantly battle casualties. The possible effect of age was sought only for ulnar lesions and by correlating age and relative power. None of the resulting correlation coefficients was impressive, and although several of them seemed significantly different from 0 in the narrow sense of a statistical test, their overall average is only +0.12, too low to be of any real interest and contrary to expectation in sign.

2. Groups of Muscles

The previous section is concerned entirely with the individual muscle. Two methods of grouping have been attempted, chiefly for descriptive purposes: (a) that in which the affected muscles on the limb of a particular individual are characterized as a group; and (b) that in which representative muscles innervated by a given nerve are averaged on the basis of average values for each muscle.

[10] Each set of 3 means was ranked 1, 2, and 3, where 1 represents the *lowest* and 3 the highest, mean power, and the 20 such ranks for each operation-group were then averaged to the figures shown.

[11] Most statistical tests on two sample means, percentages, etc. done in testing hypotheses for this study are two-tailed, i. e., the null hypothesis will be rejected whenever the difference is sufficiently large, regardless of its direction, but one-tailed tests have been performed in certain instances when one was willing to reject the null hypothesis only if the difference lay in a predetermined direction.

Table 56.—*Mean Power of Affected Muscles Following Definitive Operation, by Type of Operation*

Nerve and muscle	Type of operation					
	Complete suture		Partial suture		Neurolysis	
	Number of cases	Mean power, all cases	Number of cases	Mean power, all cases	Number of cases	Mean power, all cases
Median						
Fl. car. rad.	141	55.99	10	60.50	53	73.40
Fl. poll. long.	103	33.16	9	16.67	47	64.47
Fl. dig. prof. 2.	155	31.13	12	18.33	59	57.03
Opponens	187	23.69	17	32.06	62	36.61
Abd. poll. brev.	124	13.67	10	21.50	43	23.14
Radial						
Ext. car. rad.	175	41.26	10	46.00	23	58.70
Ext. dig.	167	28.08	12	43.75	29	51.90
Ext. car. uln.	177	36.07	11	47.27	26	53.85
Abd. poll. long.	113	14.69	10	20.00	18	35.56
Ext. poll. long.	169	19.14	12	16.25	28	32.68
Ext. poll. brev.	96	15.05	7	14.29	16	34.38
Peroneal						
Tib. ant.	128	17.38	16	44.69	25	40.20
Ext. dig. long.	137	8.61	19	18.16	23	33.70
Ext. hall. long.	134	6.68	20	14.50	24	19.58
Peron. long.	135	17.00	11	41.82	22	38.64
Sciatic-tibial						
Gastroc. & sol.	125	46.08	11	55.91	44	64.55
Tib. post.	129	18.72	12	33.75	44	39.32
Fl. dig. long.	133	3.31	12	13.75	48	23.23
Fl. hall. long.	133	2.82	12	11.25	47	21.49
Inteross.	120	.0048	10	2.00	38	8.42

Table 57.—*Mean Power of Affected Muscles Following Definitive Neurolysis, by Type of Lesion*

Nerve and muscle	Normal nerve compressed by scar		Neuroma and partial division		Statistical tests[1]
	Number of cases	Mean power, all cases	Number of cases	Mean power, all cases	
Median					
Fl. car. rad	35	75.14	23	71.30	NS
Fl. poll. long	29	63.45	23	68.70	NS
Fl. dig. prof. 2	37	60.95	27	54.07	NS
Opponens	39	40.64	29	35.52	NS
Abd. poll. brev	22	22.95	26	31.92	NS
Ulnar					
Fl. car. uln	29	65.86	26	57.69	NS
Fl. dig. prof. 4 & 5	35	61.43	28	49.64	NS
Abd. dig. V	47	37.02	37	33.65	NS
Add. poll	44	52.73	33	47.12	NS
1st dors. inteross	39	35.38	28	35.71	NS
Sciatic-peroneal					
Tib. ant	23	57.17	14	18.21	**
Ext. dig. long	20	40.75	14	18.57	NS
Peron. long	24	43.75	13	24.62	*
Sciatic-tibial					
Gastroc. & sol	32	72.50	14	53.21	*
Fl. dig. long	34	25.74	15	12.00	NS
Fl. hall. long	34	22.94	15	10.67	NS
Inteross	23	10.87	15	5.00	*

[1] Tests were one-tailed, attributing to chance any apparent advantage of neuromas and partial lesions except that tests on median muscles were done on three means corresponding to normal nerve, neuroma, and partial division, and without regard to the pattern of variation among them. Results are abbreviated as follows:

NS = Not significant
* = Significant at .05 level
** = Significant at .01 level.

The simplest pattern of recovery for the individual patient is the count of affected muscles which at follow-up were found to contract. The muscles considered are those listed in table 48, except that the abductor pollicis brevis was not used, and separate counts were made for the proximal and distal muscles as well as for both proximal and distal combined. In complete lesions, the number of affected muscles is determined, of course, by level of injury and by the particular selection of representative muscles for this study. For complete sutures, table 58 summarizes the tabulated data in distribution form, for those numbers of affected muscles which are represented by sufficient cases to warrant study. In the median, ulnar, and radial it is most usual for *all* affected proximal muscles to contract, the percentages ranging from about 75 to 90. In the peroneal and tibial lesions all affected proximal muscles were found to contract in about 50 percent of the cases, and in the sciatic about 25 to 30 percent. Only in the peroneal and sciatic-peroneal is there an appreciable percentage in which *none* of the affected proximal muscles contracts. The distal muscles are often single muscles, and the concept of pattern applies here only to the ulnar and radial, with three distal muscles each. The distributions seem only somewhat less favorable than those for the proximal muscles. Table 58 also contains the distributions for proximal plus distal muscles. It must be borne in mind that the number affected is, of necessity, the most distal set of that number in the standard list. Thus a complete median lesion with a single standard muscle affected is a low lesion, and the muscle necessarily the opponens.

Two features of table 58 are worthy of some discussion. One is the fact that the percentage of ulnar and radial lesions in which *all* affected proximal muscles contract does not vary much by the number of proximal muscles affected, while for proximal plus distal muscles such is not the case. Two factors play a role in this discrepancy. First, all proximal muscles tend to contract to such an extent that it makes little difference how many are combined into a set; all are high lesions and site is not critical. Second, when proximal and distal muscles are combined, sets of cases with different numbers of affected muscles now vary considerably by site of lesion, which of course has a large effect upon the probability that distal muscles, at least, will contract. In the ulnar, for example, the only cases with all five standard muscles affected are those with site at or above the upper third of the forearm.

Another feature of interest in table 58 is the evidence it provides that the recovery patterns of affected sets of muscles are not chance patterns, but that the affected muscles are correlated with one another in their likelihood of recovery. This is shown roughly in table 59 by the comparison of the proportions observed with no and with all affected muscles contracting and the proportions expected if the likelihood of recovery were independent from muscle to muscle. The expected values are crude in that site of lesion was not taken into account in their calculation, but the effect of this

Table 58.—*Percentage Distribution of Injured Nerves by Number of Muscles*[1] *Contracting at Follow-up, by Number Affected, Complete Sutures Only*

Nerve	Number of affected muscles	Number of lesions studied	Percentage distribution of lesions by number of contracting muscles									
			0	1	2	3	4	5	6	7	8	Total
Proximal muscles only												
Median	3	106	4.7	9.4	10.4	75.5	......	......	......	......	......	100.0
Ulnar	1	28	14.3	85.7	......	......	......	......	......	......	......	100.0
	2	317	2.8	8.2	88.9	......	......	......	......	......	......	99.9
Radial	3	22	4.5	4.5	9.1	81.8	......	......	......	......	......	99.9
	4	105	2.9	......	3.8	12.4	80.9	......	......	......	......	100.0
	5	49	......	4.1	6.1	......	10.2	79.6	......	......	......	100.0
Tibial	4	34	2.9	8.8	20.6	14.7	52.9	......	......	......	......	99.9
Sciatic-tibial	4	132	6.1	22.7	43.2	4.5	23.5	......	......	......	......	100.0
Peroneal	4	137	21.2	8.0	8.0	15.3	47.4	......	......	......	......	99.9
Sciatic-peroneal	4	170	35.9	10.0	13.5	8.8	31.8	......	......	......	......	100.0
Distal muscles only												
Median	1	221	17.6	82.3	......	......	......	......	......	......	......	99.9
Ulnar	3	321	8.1	4.7	9.0	78.2	......	......	......	......	......	100.0
Radial	3	115	18.2	2.6	5.2	73.9	......	......	......	......	......	99.9
Tibial	1	83	48.2	51.8	......	......	......	......	......	......	......	100.0
Sciatic-tibial	1	121	85.9	14.0	......	......	......	......	......	......	......	99.9

Proximal and distal muscles combined

Median	1	48	6.2	93.8	......	......	......	......	......	......	......	100.0
	4	94	4.3	6.4	6.4	15.9	67.0	......	......	......	......	100.0
Ulnar	3	59	8.5	3.4	5.1	83.0	......	......	......	......	......	100.0
	4	24	......	4.2	4.2	4.2	87.5	......	......	......	......	100.1
	5	222	1.4	2.7	5.0	6.8	14.4	69.8	......	......	......	100.1
Radial	6	16	6.2	6.2	6.2	......	6.2	......	75.0	......	......	99.8
	7	62	4.8	......	4.8	1.6	4.8	4.8	8.1	71.0	......	99.9
	8	24	......	8.3	8.3	......	4.2	8.3	4.2	4.2	62.5	100.0
Peroneal	4	137	21.2	8.0	8.0	15.3	47.4	......	......	......	......	99.9
Tibial	1	23	39.1	60.9	......	......	......	......	......	......	......	100.0
	3	14	28.6	7.1	21.4	42.9	......	......	......	......	......	100.0
	5	25	4.0	12.0	20.0	16.0	20.0	28.0	......	......	......	100.0
Sciatic-peroneal	4	170	35.9	10.0	13.5	8.8	31.8	......	......	......	......	100.0
Sciatic-tibial	5	119	5.9	25.2	42.0	2.5	13.4	10.9	......	......	......	99.9

[1] In standard set listed in table 48, abductor pollicis brevis excepted.

Table 59.—*Observed and Expected Percentages of Complete Lesions With All and With No Affected Muscles Contracting at Follow-up*

Nerve	Number of affected muscles	Number of lesions	Percentages of lesions: Observed		Expected	
			No muscle contracting	All muscles contracting	No muscle contracting	All muscles contracting
Median	4	94	4.3	67.0	0.0	64.0
Ulnar	3	59	8.5	83.0	0.3	63.5
	4	24	0.0	87.5	0.0	59.8
	5	222	1.4	69.8	0.0	57.7
Radial	6	16	6.2	75.0	0.0	39.6
	7	62	4.8	70.9	0.0	36.5
	8	24	0.0	62.5	0.0	36.5
Peroneal	4	137	21.2	47.4	1.1	19.2
Sciatic-peroneal	4	170	35.9	31.8	6.8	4.9

refinement would not be great, and would increase some discrepancies while decreasing others.

The proportion of affected muscles found to contract is not a powerful tool for exploring the effects of various characteristics of the lesion, but in view of the interest which attaches to the comparison of lysed and sutured lesions table 60 has been prepared to make this comparison on the basis of proximal muscles. The lysed cases have some advantage in every set of cases and although the difference is not always statistically significant there can be no doubt of a general discrepancy of important magnitude, most marked in the lower extremity.

Groups of muscles have also been characterized, for a single individual, by the mean power of all affected proximal muscles and of all affected distal muscles. As indicated by table 58, the latter index is of particular interest in ulnar and radial lesions, since each of these is represented by three distal muscles. Table 61 contains a summary of all the data on the proximal muscles affected by complete sutures, and shows the average power of the affected proximal muscles on a given limb to be a highly variable quantity. There is little difference among the three major nerves in the upper extremity, but of course their distributions are much more favorable than those for nerves of the lower extremity. The two tibial components are definitely superior to their peroneal counterparts, and the common peroneal has a definite advantage over the sciatic-tibial.

Gross site of lesion was also studied, in sutured lesions, on the basis of the average power of proximal muscles, with a result consistent with that obtained with the individual muscles. Type of lesion was ob-

Table 60.—*Comparison of Lysed and Completely Sutured Lesions as to Percentage With All Affected Proximal Muscles Contracting at Follow-up*

Nerve	Number of affected muscles	Completely sutured		Lysed	
		Number of lesions	Percentage with all muscles contracting	Number of lesions	Percentage with all muscles contracting
Median	3	106	75.5	49	89.8
Ulnar	2	317	89.0	72	97.2
Radial	4	105	81.0	8	100.0
	5	49	79.6	10	100.0
Tibial	4	34	52.9	16	93.8
Sciatic-tibial	4	132	23.5	48	64.6
Peroneal	4	137	47.4	21.	71.4
Sciatic-peroneal	4	170	31.8	35	80.0

Table 61.—*Percentage Distribution of Completely Sutured Lesions by Mean Relative Power of Affected Proximal Muscles*

Mean power	Nerve						
	M	U	R	P	T	SP	ST
0– 9	11.2	12.5	18.0	51.2	21.6	80.1	31.5
10–19	13.0	8.6	7.9	16.3	27.5	9.3	23.8
20–29	9.9	9.6	9.0	11.4	11.8	4.6	18.5
30–39	8.7	8.3	9.0	5.7	5.9	1.3	7.7
40–49	16.1	10.2	12.4	7.3	13.7	2.6	6.2
50–59	7.5	12.2	12.4	4.9	5.9	2.0	6.2
60–69	15.5	10.9	14.6	1.6	3.9	0	2.3
70–79	3.7	9.9	7.9	1.6	5.9	0	1.5
80–89	4.3	7.9	5.1	0	2.0	0	.8
90 or more	9.9	9.9	3.9	0	2.0	0	1.5
Total	99.8	100.0	100.2	100.0	100.2	99.9	100.0
Number of cases	161	303	178	123	51	151	130

served to have no effect on the mean values for complete lesions. Lysed and sutured cases, however, were observed to differ quite significantly and table 62 presents some comparative data in support of this conclusion. Statistical tests of homogeneity were usually made on the basis of a more detailed classification of relative power than is provided by table 62.

The third evaluation of the pattern of motor recovery for the individual case was made on the basis of the modified British classification of motor recovery already discussed. Great importance must be attached to this assessment as being the most summary motor statement on the regeneration of the nerve as a whole. It may, however, be debated whether the classification, in the sense of a scale, has precisely the same meaning for every major nerve to allow meaningful comparisons among nerves. Table 63 provides information on the British classification for all complete sutures and separately for high and low sutures on the median and ulnar nerves. The importance of at least gross site of lesion is reflected in the distributions of table 63. Lower lesions always do somewhat better, although in the ulnar the difference between high and low lesions is the least of all. To the extent that the ulnar, median, and radial may be compared on the basis of this scale, the radial makes by far the best showing if the comparison is confined to high lesions. Ulnar lesions are similar to median if they are high, but below the elbow they do not do nearly so well. The tibial lesions appear to recover better than the peroneal, in these comparisons, and the sciatic-tibial better than the sciatic-peroneal.

Table 62.—*Comparison of Lysed and Completely Sutured Lesions as to Percentage With Stated Average Power of All Affected Proximal Muscles*

Nerve	Range of relative power compared	Lysed		Sutured	
		Number of lesions	Percentage with stated average power	Number of lesions	Percentage with stated average power
Median	50 or more	60	71.7	161	41.0
Ulnar	50 or more	64	64.1	303	50.8
Radial	50 or more	31	67.7	178	43.8
Peroneal	10 or more	25	72.0	123	48.8
Tibial	20 or more	19	78.9	51	50.9
Sciatic-peroneal	10 or more	33	75.8	151	19.9
Sciatic-tibial	20 or more	44	75.0	130	44.6

The distributions of table 63 bear little relation to the 5 year results recently published by the British group, and although such discrepancies can hardly be explained they can at least be exhibited and center variation in the United States material explored. In addition, there are a few small differences between the 1954 British version of the classification and the United States modification adopted for this study in 1949, and clarity will be served by presenting the two classifications in parallel, as follows:

U. S. Modification	*British, 1954*
0. No contraction.	0. No contraction.
1. Return of perceptible contraction, proximal muscles only.	1. Return of perceptible contraction, proximal muscles only.
2. Proximal muscles acting against gravity, no return of power in intrinsic muscles.	1+. (Median) Proximal muscles able to contract against gravity, but paralysis of the thenar muscles. 1+. (Ulnar) Proximal muscles able to contract against gravity, but paralysis of the intrinsic muscles of the hand.
3. Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles.	2. Return of perceptible contraction in both proximal and distal. 2+. (Ulnar) Recovery in all ulnar intrinsics, more than mere flicker in hypothenar muscles.
4. Return of function in both proximal and distal muscles of such extent that all important muscles are of sufficient power to act against resistance.	3. Return of function in both proximal and distal muscles of such extent that all important muscles are of sufficient power to act against resistance.
5. Return of function as above, with the addition that some synergic and isolated movements are possible.	4. Same as category 3, with addition that all synergic and isolated movements are possible.
6. Complete recovery.	5. Complete recovery.

Detailed comparisons of the United States and British results are made in tables 64, 65, and 66 for the median, ulnar, and radial nerves. The only consistent difference involving all three nerves pertains to the complete failures—although there are not many in the United States series there are none in the British. The United States ratings are considerably more favorable for the median and ulnar, the British for the radial. The difference between the two series of ulnar lesions may be influenced in part by the failure of the United States modification to contain a counterpart of the British rubric 2+.

The fact of considerable variation between the two series lends additional interest to the extent of the variation noted among the five United States centers. The general subject of center variation in the United States series was discussed in chapter I (pp. 21–22). The comparison of centers in this respect was made on the basis of all lesions treated by complete suture in an effort to make it as powerful as possible, but at the cost of some loss of homogeneity in the underlying clinical material. Table 67 provides the data resulting from this study. Subdivision of the United States sample in this way naturally subjects the distributions to much greater sampling error, but it seems clear that the differences between the United States and British series are of the same order of magnitude as those seen among

Table 63.—*Modified British Classification of Motor Recovery Following Complete Suture, by Nerve*

Nerve and gross site	Percentage distribution on British classification [1]							Total cases
	0	1	2	3	4	5, 6	Total	
Median: High	1.6	13.7	16.9	25.0	29.8	12.9	99.9	124
Low	5.5	......	11.0	22.9	29.4	31.2	100.0	109
Total	3.4	7.3	14.2	24.0	29.6	21.5	100.0	233
Ulnar: High	2.5	8.3	9.2	37.9	31.7	10.4	100.0	240
Low	4.7	1.6	5.2	34.2	38.3	16.1	100.1	193
Total	3.5	5.3	7.4	36.3	34.6	12.9	100.0	433
Radial	4.6	8.1	14.2	27.4	24.4	21.3	100.0	197
Peroneal	20.3	28.3	13.0	13.0	18.1	7.2	100.0	138
Tibial	15.4	15.4	22.0	23.1	16.5	7.7	100.1	91
Sciatic-peroneal	37.6	32.9	14.1	7.6	5.9	1.8	99.9	170
Sciatic-tibial	6.6	18.4	53.7	13.2	5.9	2.2	100.0	136

[1] The rubrics of classification are as follows:

0 No contraction at all

1 Return of perceptible contraction, proximal muscles only

2 Proximal muscles acting against gravity, no return of power in intrinsic muscles

3 Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles

4 Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance

5 Return of function as in 4, with the addition that some synergic and isolated movements are possible

6 Complete recovery.

Table 64.—*Comparison of United States and British Ratings of Motor Recovery, Complete Sutures on Median Nerve*

Code symbols		Percentage distributions	
United States modification	British, 1954	United States cross section	British, 5-year results
0	0	3.4	0
1	1	7.3	3.8
2	1+	14.2	32.8
3	2	24.0	30.7
4	3	29.6	14.1
5+6	4+5	21.5	18.6
Total		100.0	100.0
Number of lesions		233	290

the five United States centers. It will be noted, however, that each of the United States centers classified at least a few cases as absolute failures. In general the variability seen among centers in the classification of motor recovery in this fashion greatly exceeds that observed in determinations on the relative power of individual muscles.

Table 65.—*Comparison of United States and British Ratings of Motor Recovery, Complete Sutures on Ulnar Nerve*

Code symbols		Percentage distributions	
United States modification	British, 1954	United States cross section	British, 5-year results
0	0	3.5	0
1	1	5.3	0
2	1+	7.4	5.3
3	2, 2+	36.3	75.5
4	3	34.6	14.3
5+6	4+5	12.9	4.9
Total.............		100.0	100.0
Number of lesions....		433	384

Table 66.—*Comparison of United States and British Ratings of Motor Recovery, Complete Sutures on Radial Nerve*

Code symbols		Percentage distributions	
United States modification	British, 1954	United States cross section	British, 5-year results
0	0	4.6	0
1	1	8.1	10.5
2	1+	14.2	0
3	2	27.4	28.0
4	3	24.4	24.6
5+6	4+5	21.3	36.9
Total.............		100.0	100.0
Number of lesions....		197	114

Table 67.—*British Classification of Motor Recovery Following Complete Suture, by Center*

Center	Percentage distribution as to motor recovery [1]								Total number of lesions
	0	1	2	3	4	5	6	Total	
1. Median									
Boston	0	13.0	21.7	34.8	17.4	13.0	0	99.9	46
Chicago	3.8	11.5	19.2	23.1	19.2	19.2	3.8	99.8	26
New York	6.7	6.7	10.6	39.4	30.8	4.8	1.0	100.0	104
Philadelphia	9.3	5.1	14.4	25.4	22.9	22.0	.8	99.9	118
San Francisco	0	2.2	8.7	2.2	52.2	32.6	2.2	100.1	46
Total	5.6	6.8	13.8	27.6	28.2	16.8	1.2	100.0	340
2. Ulnar									
Boston	5.9	8.8	16.2	27.9	33.8	7.4	0	100.0	68
Chicago	5.4	5.4	3.6	19.6	62.5	1.8	1.8	100.1	56
New York	4.1	2.7	5.4	57.4	29.1	1.4	0	100.1	148
Philadelphia	2.9	3.4	7.3	37.6	28.8	19.0	1.0	100.0	205
San Francisco	1.2	4.9	1.2	33.3	42.0	16.0	1.2	99.8	81
Total	3.6	4.3	6.6	39.2	34.8	10.8	.7	100.0	558
3. Radial									
Boston	9.3	5.6	25.0	19.4	27.8	13.9	0	100.0	36
Chicago	6.7	6.7	16.7	16.7	23.3	20.0	10.0	100.1	30
New York	4.3	10.6	8.5	40.4	31.9	4.3	0	100.0	94
Philadelphia	3.0	7.5	17.9	20.9	19.4	31.3	0	100.0	67
San Francisco	0	11.4	8.6	25.7	28.6	22.9	2.9	100.1	35
Total	4.2	8.8	14.1	27.9	26.7	16.8	1.5	100.0	262

[1] See table 63 for the rubrics of classification.

The influence of type of lesion was also explored by means of the modified British classification, with the same conclusion as that already reached on the basis of individual muscles, namely, that severed nerves and lesions in continuity, both sutured, are indistinguishable at follow-up. Incomplete lesions treated by lysis, however, were found to differ quite significantly from those treated by complete suture. Table 68 presents the data on lyses which may be compared with the information of table 63 on complete sutures. It was noted on page 105 that comparisons of sutured and lysed lesions in terms of mean relative power at follow-up tended to obscure the important fact that the distributions do not lie in different regions of the power scale but are merely concentrated differently. The full distributions of tables 63 and 68 will permit further analysis of sutures and lyses along these lines, e. g., to show how often lysis was followed by recovery which seems poorer than that usually expected from suture.

Further information on the influence of site is contained in table 69 for complete sutures on the median, ulnar, and radial. In the median it would appear that the influence of site does not follow a simple gradient, but is specific in the region of the forearm, wrist, and hand, lesions in the lower one-third of the forearm making the best recovery.

There were in the entire sample 42 so-called multiple lesions, or injuries to more than one site on a single nerve, of which 26 involved severance plus another injury and 32 were completely sutured. Among the latter there were 28 with follow-up adequate to permit coding of the modified British motor classification, with the result shown in table 70. Although all but one nerve is represented and the cases are very few, it is plain that the multiple lesions did much less well than other sutures. If the expected distribution of these 28 cases is calculated from the data of table 63, one finds the overall discrepancy exhibited in table 71.

Table 68.—*Modified British Classification of Motor Recovery Following Neurolysis, by Nerve*

Nerve and gross site	Percentage distribution on British classification [1]							Total cases
	0	1	2	3	4	5, 6	Total	
Median:								
High	0	4.7	12.5	14.1	29.7	39.1	100.1	64
Low	6.7	0	6.7	20.0	0	66.7	100.1	15
Total	1.3	3.8	11.4	15.2	24.1	44.3	100.1	79
Ulnar:								
High	1.4	1.4	2.8	19.7	31.0	43.7	100.0	71
Low	0	0	6.1	24.2	27.3	42.4	100.0	33
Total	1.0	1.0	3.8	21.2	29.8	43.3	100.1	104
Radial	6.1	6.1	6.1	18.2	33.3	30.3	100.1	33
Peroneal	8.0	8.0	12.0	20.0	36.0	16.0	100.0	25
Tibial	0	8.3	16.7	16.7	29.2	29.2	100.1	24
Sciatic-peroneal	7.9	10.5	15.8	15.8	31.6	18.4	100.0	38
Sciatic-tibial	0	14.0	24.0	34.0	16.0	12.0	100.0	50

[1] See table 63 for the rubrics of classification.

Table 69.—*Modified British Classification of Motor Recovery Following Complete Suture,*[1] *by Specific Site of Lesion, for Median, Ulnar, and Radial Nerves*

Specific site	Percentage distribution on British classification[2]							Total cases
				Median				
	0	1	2	3	4	5, 6	Total	
Shoulder, upper ⅓ arm	3.7	16.7	22.2	29.6	16.7	11.2	100.1	54
Middle ⅓ arm	5.4	12.5	17.9	23.2	35.7	5.4	100.1	56
Lower ⅓ arm	0.0	5.0	10.0	32.5	32.5	20.0	100.0	40
Elbow, upper ⅓ forearm	7.3	7.3	18.2	25.5	27.3	14.5	100.1	55
Middle ⅓ forearm	5.8	0.0	7.7	23.1	32.7	30.8	100.1	52
Lower ⅓ forearm, wrist, hand	9.2	2.3	9.2	29.9	27.6	21.8	100.0	87
Total	5.8	7.0	14.0	27.3	28.5	17.4	100.0	344
				Ulnar				
	0+1	2	3	4–6			Total	
Upper ⅓ arm	24.14	10.34	39.66	25.86	......	......	100.00	58
Middle ⅓ arm	11.48	11.48	36.07	40.98	......	......	100.01	61
Lower ⅓ arm	4.29	5.71	45.71	44.29	......	......	100.00	70
Elbow	4.00	10.00	28.00	58.00	......	......	100.00	50
Upper ⅓ forearm	6.90	0	32.76	60.34	......	......	100.00	58
Middle ⅓ forearm and below	5.93	7.41	3.48	51.85	......	......	100.00	135
Total	8.80	7.41	36.34	47.45	......	......	100.00	432
				Radial				
	0	1	2	3	4	5+6	Total	
Shoulder, upper ⅓ arm	5.2	10.3	20.7	31.0	22.4	10.3	99.9	58
Middle ⅓ arm	3.9	8.7	13.6	21.4	35.0	17.5	100.1	103
Lower ⅓ arm and below	3.8	8.5	10.4	32.1	21.7	23.6	100.1	106
Total	4.1	9.0	13.9	27.7	27.0	18.4	100.1	267

[1] Material on the ulnar nerve is restricted to Army Registry cases within the sampling area, but for the median and radial nerves this restriction was not made here.
[2] See table 63 for rubrics of classification.

For describing the average recovery of lesions upon the major nerves use has also been made of the arithmetic averages of several performance characteristics of the individual muscles chosen as most representative for each nerve. Each nerve is represented by 3 or 4 such muscles as described

Table 70.—*Modified British Classification of Motor Recovery Following Complete Suture, Multiple Lesions Only, by Nerve*

British motor classification	No. of injured nerves, by nerve					
	M	U	R	P	T	SP
No contraction	4	1	....	....	....	1
Perceptible contraction, proximal only	2	2	1	1	1	1
Proximal against gravity, no power in intrinsics	1	1	....	....	1	....
Proximal against gravity, perceptible contraction in intrinsics	....	3	1	....	....	....
Proximal and distal against resistance	....	4	1	....	....	....
As above, plus some synergic and isolated movements	1	1	....	....	....	....
Total	8	12	3	1	2	2

Table 71.—*Effect of Multiple Lesions Per Nerve on Motor Recovery, Lesions With at Least One Complete Suture, All Major Nerves Combined*

British motor classification	Number of injured nerves	
	Observed	Expected
At best perceptible contraction in proximal muscles	14	4.80
Proximal against gravity, no more than perceptible contraction in distal	7	11.15
Both proximal and distal against resistance	7	12.04
Total	28	27.99

in the footnote to table 72. Distal muscles are represented only for the upper extremity, the ulnar having 2, the median and radial 1 each, and on that account alone the averages of table 72 will seem an arbitrary basis for comparing the several nerves. However, such comparisions are of dubious meaning at best; one is primarily interested in the overall picture for a particular nerve, and for this purpose the device has whatever merit inheres in the selection of the muscles upon which it is based.

In the first column of table 72 appears the average percentage of muscles exhibiting at least a perceptible contraction. It was obtained by averaging the separate three or four values for the particular muscles selected as representative, giving each such muscle equal weight. Other columns were obtained in a similar fashion. As in the tables on individual muscles two averages are given for relative power, one for all muscles regardless of their ability to contract and the other for only those muscles found capable of contracting against resistance.

Table 72.—*Summary of Motor Recovery Based on Average Performance of Selected Muscles,*[1] *by Nerve and Type of Operation*

Nerve and gross site	Average percentage of muscles contracting		Mean relative power	
	Total	Against resistance	All muscles	Muscles contracting against resistance
Complete sutures				
Median, High	85.00	57.00	20.00	37.98
Low	89.50	71.50	36.50	49.27
Total	86.50	61.70	25.98	41.99
Ulnar, High	85.66	50.80	15.98	29.58
Low	90.76	57.62	21.48	53.83
Total	88.00	54.00	18.15	32.43
Radial	88.71	68.31	29.46	43.51
Peroneal	66.66	31.69	16.56	52.18
Tibial	75.69	51.95	25.15	44.53
Sciatic-peroneal	48.23	14.47	3.69	36.49
Sciatic-tibial	50.05	33.24	17.40	42.23
Neurolyses				
Median, High	91.47	80.71	48.87	59.76
Low	96.67	65.57	44.64	69.03
Total	92.10	79.30	51.54	60.22
Ulnar, High	96.55	79.76	42.31	54.93
Low	89.63	78.02	36.36	48.01
Total	96.60	80.80	41.23	53.85
Radial	92.70	83.34	47.76	56.61
Peroneal	81.15	63.25	33.03	51.66
Tibial	96.29	79.47	43.22	53.85
Sciatic-peroneal	88.16	61.75	32.22	54.50
Sciatic-tibial	78.00	57.91	36.42	65.36

[1] The muscles averaged are those described in the footnote to table 48, including the abductor pollicis brevis.

3. Summary

All the motor indices employed here in describing motor recovery yield consistent results, but the observations made on individual muscles affected by representative lesions treated by suture or neurolysis have been most extensively studied. There is certainly a great deal of inherent variability in the material. Study of the individual muscles shows some concentration at 0 power, varying by muscle and by nerve, but otherwise a fairly uniform distribution of values over much of the range of relative power. Essentially normal power, say 90 percent or more of that of the control limb, is relatively rare. There is considerable similarity in adjacent muscles innervated by the same nerve, but on the whole the proximal muscles make much the better return within any set specific to a single nerve, and there is great variation from one set to another and especially between those of the upper and those of the lower extremity. In addition, site of lesion is observed to exert a profound influence upon motor recovery following complete suture, distal lesions doing far better than proximal, especially from the standpoint of the more proximal muscles. Gross site of lesion has no apparent influence on motor recovery following neurolysis, however. Among upper extremity sutures the advantage of the more distal lesions is less a matter of the ability of muscles to contract than of actual strength of movement. Among sutures on lesions of the lower extremity the pattern is more complex: tibial lesions are favored over sciatic-tibial only as to the likelihood of contraction, not as to actual strength of any movement, while peroneal lesions recover better than sciatic-peroneal in both aspects.

Recovery following complete suture is not reliably associated with the apparent character of the lesion. The same conclusion applies to neurolysis. Lysed, partially sutured, and completely sutured lesions recover in that order, the advantage of lysed lesions being quite large.

The factor of age, in young men wounded in combat, would not be expected to exert any effect upon motor recovery and none was observed.

D. INFLUENCE OF ASSOCIATED INJURIES, INFECTIONS, AND THERAPEUTIC PROCEDURES

To explore the possible influence of associated injuries and complications, all roster and sampling restrictions were removed in favor of full utilization of all available case material. In most instances the exploration was confined to a study of the data on individual muscles, especially the smaller set described in table 48. The specific conditions which were explored for their effect on motor recovery are the following:

- Associated nerve injury.
- Bone and joint injury, and type of healing.
- Infection of sufficient degree to delay repair.
- Associated arterial injury.
- Plastic repair at site of nerve suture.

It should be emphasized that it is the movement of individual muscles which is studied here, not motor function in the synergistic sense. For the most part these conditions were investigated only for complete sutures. Two of them, at least, namely, infection and bone injury, are confounded with time, in that presence of the condition tends to delay repair in any case, and some consideration must be given to untangling any effects which may be confounded in this way.

1. Associated Nerve Injury

Because of the specificity of the tests of motor recovery, it was not anticipated that associated nerve injuries would have any appreciable effect upon motor recovery and comparatively little study has been made of the problem. High median lesions, treated by complete suture, were subdivided into those with and those without a complete suture on the ulnar, and although no consistent pattern of superiority was noted for the pure median lesions when all 5 muscles were studied, the advantage of the 2 distal muscles (opponens and abductor pollicis brevis) seems clear enough (table 73).

Table 73.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture of High Median Lesions, by Presence of Associated Ulnar Lesion Also Completely Sutured*

Median muscle	Complete ulnar suture						Statistical tests[1]	
	Present			Absent				
	Number of cases	Percentage contracting against resistance	Mean power, all cases	Number of cases	Percentage contracting against resistance	Mean power, all cases	A	B
Fl. car. rad	49	89	57.4	40	90	60.4	NS	NS
Fl. poll. long	34	84	41.0	28	64	25.9	NS	NS
Fl. prof. ind	49	65	25.4	39	63	16.9	NS	NS
Opponens	41	45	11.1	35	63	23.6	NS	**
Abd. poll. brev	33	26	8.0	26	67	21.0	**	*

[1] Two series of tests (one-tailed) were done, one on the percentage contracting against resistance (col. A), the other on mean power (col. B). Results of statistical tests are abbreviated as follows:

NS=Not significant
*=Significant at .05 level
**=Significant at .01 level.

A somewhat similar study was made of sciatic lesions, those with complete sutures on both sciatic components being contrasted with those in which only one component was completely sutured (table 74). In the sciatic-peroneal comparisons there is no suggestion that the complete sciatic lesions did not do as well as those requiring suture of the sciatic-peroneal component only. However, in the sciatic-tibial comparisons there is adequate evidence that, in the flexor digitorum longus and the flexor hallucis longus, complete sciatic lesions actually do less well than those requiring suture of the sciatic-tibial component only. The advantage of the incomplete lesions is not shown by the comparison of mean values for these muscles, but these tests are rather insensitive in this particular instance, and more reliance may be placed on the comparison of percentages contracting against resistance.

Table 74.—*Percentage of Affected Muscles Contracting Against Resistance and Mean Power Following Complete Suture, Complete and Incomplete Sciatic Lesions Compared*

Muscle	Complete			Incomplete			Statistical tests [1]	
	Number of cases	Percentage contracting against resistance	Mean power, all cases	Number of cases	Percentage contracting against resistance	Mean power, all cases	A	B
Peroneal								
Tib. ant.	144	18.6	5.80	73	16.2	2.97	NS	NS
Ext. dig. long.	142	10.3	1.76	75	9.2	1.73	NS	NS
Ext. hall. long.	143	7.6	1.50	72	9.6	2.50	NS	NS
Peron. long.	142	18.1	4.08	74	14.5	2.84	NS	NS
Tibial								
Gastroc. & sol.	134	81.0	42.35	30	81.2	53.17	NS	NS
Fl. dig. long.	144	6.2	2.40	32	18.8	4.22	*	NS
Fl. hall. long.	143	4.9	1.61	32	21.9	5.47	**	NS

[1] Two series of tests (one-tailed) were done, one on the percentage contracting against resistance (col. A), the other on mean power (col. B). Results of statistical tests are abbreviated as follows:

NS = Not significant
* = Significant at .05 level
** = Significant at .01 level.

2. Associated Bone and Joint Injury

Peripheral nerve injuries are commonly accompanied by injuries to bones and joints, and their management complicated thereby. As explained in chapter II, attention was paid not only to the presence of such associated injuries but also to their outcome, and both aspects are examined here. The investigation was done on the basis of individual muscles, both power and ability to contract being examined in detail. Neither aspect of motor recovery appears to have been influenced, in any general way, by the presence of such injuries or by the character of their healing. Table 75 summarizes the available data on presence of bone injury. In a few of the

Table 75.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Presence of Associated Bone and Joint Injury*

Nerve	Muscle	Bone injury [1]						Statistical tests [2]	
		Absent			Present				
		N	%	$\bar{X}$	N	%	$\bar{X}$	A	B
Median, high...	Fl. poll. long......	80	70.8	30.88	18	60.0	16.11	NS	NS
	Fl. dig. prof. 2....	116	63.1	21.72	30	57.6	18.17	NS	NS
	Abd. poll. brev....	75	41.3	12.73	21	27.3	6.67	NS	NS
Median, low....	Fl. poll. long......	16	76.5	49.06	27	69.0	35.74	NS	NS
	Fl. dig. prof. 2....	22	79.2	53.86	37	85.7	47.16	NS	NS
	Abd. poll. brev....	41	55.1	18.29	59	46.2	12.03	NS	NS
Ulnar, high.....	Fl. dig. prof. 4 & 5.	160	.....	29.16	97	.....	31.29	....	NS
	Abd. dig. V......	184	32.4	5.57	108	37.8	8.94	NS	NS
	1st dors. inteross...	134	.....	7.50	82	.....	8.35	....	NS
Ulnar, low.....	Fl. dig. prof. 4 & 5.	46	.....	39.13	64	.....	38.56	....	NS
	Abd. dig. V......	115	44.4	11.00	144	46.6	13.20	NS	NS
	1st dors. inteross...	87	.....	10.52	107	.....	13.88	....	NS
Radial.........	Ext. car. rad......	80	87.0	43.94	152	81.2	35.66	NS	*
	Ext. dig..........	78	70.8	31.99	146	54.6	20.48	*	**
	Ext. poll. long.....	78	58.0	18.91	148	46.8	15.37	NS	NS
Peroneal.......	Tib. ant.........	108	.....	17.45	54	.....	15.74	....	NS
	Ext. dig. long.....	114	.....	8.77	61	.....	9.84	....	NS
	Ext. hall. long....	112	.....	7.01	58	.....	8.71	....	NS
	Peron. long.......	111	42.2	17.39	58	41.0	18.19	NS	NS
Tibial.........	Gastroc. & sol....	30	.....	50.67	15	.....	67.67	....	NS
	Fl. dig. long......	45	.....	6.00	24	.....	12.29	....	NS
	Fl. hall. long......	47	21.3	6.28	22	42.3	11.14	NS	NS
Sciatic-peroneal.	Tib. ant.........	162	.....	5.23	65	.....	4.54	....	NS
	Ext. dig. long.....	162	.....	2.38	66	.....	1.06	....	NS
	Ext. hall. long....	159	.....	1.98	67	.....	2.09	....	NS
	Peron. long.......	162	20.7	4.66	65	9.0	2.25	*	NS
Sciatic-tibial....	Gastroc. & sol....	124	.....	45.52	46	.....	42.72	....	NS
	Fl. dig. long......	131	.....	3.02	51	.....	1.67	....	NS
	Fl. hall. long......	130	8.4	2.62	51	5.9	1.27	NS	NS

[1] Symbols used in headings are defined as follows:
N = Number of injured nerves
% = Percentage contracting against resistance
$\bar{X}$ = Mean relative power, all cases.

[2] Results of statistical tests are abbreviated as follows:
NS = Not significant
* = Significant at .05 level
** = Significant at .01 level.

Probabilities were obtained as follows: A represents test of proportions with no contraction, with contraction but not against resistance, and with contraction against resistance; B represents two-tailed test on means.

tests on the effect of the mere presence of such associated injuries, including those on two radial muscles, individually significant differences are noted, but too few to support the notion of any general effect. One could neither affirm nor deny an effect confined to the radial without paying more attention to specific site of injury, with which bone injury is confounded.

Abnormal healing was so rare as to permit of investigation at only a few points, and these are given in detail in table 76. The data there provide no reason for believing that the character of healing exerted a real effect on motor recovery.

3. Chronic Infection Delaying Repair

Although infection was not a frequent problem, it complicated the management of lesions on every nerve with sufficient frequency to permit a systematic study of the effect associated with it. Table 77 shows this effect to be a real one, especially in the upper extremity. Since in the ulnar the effect is seen only in the proportion making some contraction, however weak, the detail of the table extends to both the percentage making any movement and the percentage moving against resistance, and to both the mean power for all muscles and that for only those able to contract against resistance. As a rough measure of the magnitude of the effect one may take the difference between (or alternatively the ratio of) the two percentages contracting against resistance for any muscle. If these be averaged one finds that in lesions complicated by infection muscles contract against resistance only about two-thirds as often as muscles not so complicated.

Table 76.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Type of Healing of Associated Bone and Joint Injury*

Nerve	Muscle	Healing: Normal [1]			Other [1]			Statistical tests [1]	
		N	%	$\bar{X}$	N	%	$\bar{X}$	A	B
Median	Fl. poll. long	32	75.0	......	17	47.1	......	NS	....
	Fl. dig. prof. 2	49	73.6	36.63	18	72.7	27.50	NS	NS
	Abd. poll. brev	56	48.2	......	31	29.0	......	NS	....
Ulnar (high)	Fl. dig. prof. 4 & 5	63	.....	30.32	34	.....	33.09	....	NS
	Abd. dig. V	67	.....	9.93	41	.....	7.32	....	NS
	1st dors. inteross	47	18.2	9.57	35	10.3	6.71	*	NS
Radial	Ext. car. rad	98	85.0	36.53	54	74.1	34.07	NS	NS
	Ext. dig	94	52.0	19.95	52	59.3	21.44	NS	NS
	Ext. poll. long	96	49.0	16.30	52	42.6	13.65	NS	NS

[1] The abbreviations used here are the same as those of table 75, and probabilities were obtained in the same way.

Table 77.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Presence of Chronic Infection Delaying Suture*

Nerve and muscle	Chronic infection [1]										Statistical tests [2]	
	Absent					Present						
	N	$\%_1$	$\%_2$	$\bar{X}_1$	$\bar{X}_2$	N	$\%_1$	$\%_2$	$\bar{X}_1$	$\bar{X}_2$	A	B
Median												
Fl. poll. long	10	40.0	30.0	....	....	147	89.1	72.8	....	....	**	....
Fl. dig. prof. 2	12	66.6	33.3	....	....	211	89.1	70.6	....	....	NS	....
Abd. poll. brev	19	70.0	10.0	2.63	49.97	179	79.8	48.5	14.27	33.17	**	*
Ulnar												
Fl. dig. prof. 4 & 5	28	83.8	80.6	31.61	40.23	341	94.5	75.2	32.99	44.82	*	NS
Abd. dig. V	43	80.0	37.8	7.67	21.99	512	88.4	40.2	9.64	24.80	NS	NS
1st dors. inteross	35	66.7	41.7	10.00	25.00	378	83.1	38.6	10.08	29.09	*	NS
Radial												
Ext. car. rad	20	90.9	54.5	18.75	37.50	212	94.9	86.0	40.38	47.82	**	**
Ext. dig	19	66.7	38.1	6.84	21.66	205	89.5	62.7	26.12	43.53	*	**
Ext. poll. long	20	57.1	9.5	1.75	35.00	206	83.3	54.8	18.08	35.14	**	**

Peroneal												
Tib. ant.	16	68.8	43.8	17.81	40.71	146	75.1	36.2	17.88	51.19	....	NS
Ext. dig. long	17	64.7	23.5	4.71	20.02	158	66.5	29.2	9.62	34.54	....	NS
Ext. hall. long	16	43.8	12.5	2.19	17.52	154	55.0	23.4	8.15	38.03	....	NS
Peron. long	16	64.7	29.4	7.81	31.24	153	71.9	43.1	18.66	46.05	....	NS
Tibial												
Gastroc. & sol.	2	100.0	50.0	....	....	46	95.6	91.3	....	....	....	....
Fl. dig. long	6	50.0	33.3	....	....	68	63.2	29.4	....	....	....	....
Fl. hall. long	5	80.0	60.0	....	....	68	63.3	26.5	....	....	....	....
Sciatic-peroneal												
Tib. ant.	21	47.6	23.8	6.43	27.01	206	59.6	18.3	4.89	27.98	....	NS
Ext. dig. long	21	19.1	4.8	0.95	19.95	207	44.1	11.4	2.10	21.74	....	NS
Ext. hall. long	21	19.1	4.8	0.00	0.00	205	34.8	9.2	2.22	26.77	....	NS
Peron. long	21	38.1	14.3	3.57	24.99	206	55.7	17.6	4.00	24.97	....	NS
Sciatic-tibial												
Gastroc. & sol.	17	94.1	76.5	....	....	169	94.1	81.7	....	....	....	....
Fl. dig. long	17	0	0	0.00	0.00	165	28.9	9.0	2.91	34.30	....	NS
Fl. hall. long	17	0	0	0.00	0.00	164	27.9	8.5	2.47	31.16	....	NS

[1] Symbols used in headings are defined as follows:

N = number of cases tested

$\%_1$ = percentage with at least perceptible contraction

$\%_2$ = percentage contracting against resistance

$\bar{X}_1$ = mean power, all cases

$\bar{X}_2$ = mean power, cases contracting against resistance.

[2] The abbreviations used here are the same as those of table 75, and probabilities were obtained in the same way.

Since the criterion of infection involves a delay in repair, and differences of considerable magnitude are observed in association with both infection and, as shown below, time itself, an effort was made to ascertain whether the apparent effect of infection could be explained on the basis of a delay in repair. The investigation was confined to three radial muscles and is summarized in table 78. Plainly most if not all of the discrepancy associated with infection can be explained on the basis of delay in repair, and to the extent that the radial may be taken as representative it would appear that effect of infection is probably confined to the delay in repair it generally produces. In the radial this delay was appreciable; the average interval from injury to definitive suture is 151 days for lesions without infection and 386 for those with infection. The calculated values of table 78 are based on linear regression lines for power and day of operation, which for the radial seem technically satisfactory, and provide estimates of power for sutures done at day 386, which is the average for lesions with infection.

Table 78.—*Observed Average Power of Representative Radial Muscles Following Complete Suture, by Presence of Infection at Site of Lesion, and Calculated Power for Sutures Delayed to Same Extent as Lesions With Infection*

Radial muscle	Observed mean power, by presence of infection		Calculated mean power, suture done at 386 days
	Absent	Present	
Ext. car. rad.	40.38	18.75	20.5
Ext. dig.	26.12	6.84	10.2
Ext. poll. long.	18.08	1.75	7.2
Mean day of repair	151	386	386

4. Associated Arterial Injury

Among lesions in the upper extremity, and especially in high median injuries, associated arterial injury was common, but varying greatly by specific site of injury. For this reason alone peripheral nerve lesions will seem to be adversely affected by associated arterial injuries unless differences in site are taken into account. When site is controlled in some detail, as in table 79, the weight of the evidence seems to favor the view that an associated arterial lesion affects motor recovery adversely. Since there are only six independent sets of cases for specific sites, and recovery in one muscle is not independent of that in another in the same man, the aggregate amount of independent information is not large, but the observed discrepancies at the higher sites have a probability of less than .01. One might wish to discount evidence based solely upon differentials in relative power, on the ground that arterial injuries would often, and independently of any

Table 79.—*Percentage of Affected Muscles Contracting and Mean Power Following Suture, by Presence of Associated Arterial Injury and Specific Site*

Muscle and site	Arterial injury: Absent				Arterial injury: Present			
	Number of cases	Percent contracting: Total	Percent contracting: Against resistance	Mean power, all cases	Number of cases	Percent contracting: Total	Percent contracting: Against resistance	Mean power, all cases
Median								
Fl. poll. long.								
Arm, upper $2/3$	34	88.9	69.4	29.26	32	71.4	62.9	26.28
Arm, lower $1/3$	10	72.7	63.6	22.20	11	100.0	75.0	35.18
All other sites	39	97.6	73.8	39.87	13	73.3	66.7	27.00
Total	83	91.0	70.8	33.40	56	77.4	66.1	28.20
Fl. dig. prof. 2								
Arm, upper $2/3$	47	88.0	62.0	21.28	47	80.0	58.0	18.47
Arm, lower $1/3$	18	89.5	68.4	25.22	18	88.9	61.1	19.28
All other sites	52	94.7	82.5	48.08	19	82.6	73.9	37.32
Total	117	91.3	72.2	33.79	84	82.4	62.6	22.90
Abd. poll. brev.								
Arm, upper $2/3$	30	72.7	36.4	8.00	29	69.0	20.7	8.45
Arm, lower $1/3$	15	66.7	46.7	20.33	11	100.0	66.7	18.09
All other sites	86	82.1	48.4	14.08	23	79.3	51.7	13.04
Total	131	78.3	45.5	13.40	63	78.6	41.4	11.81

Table 79.—*Percentage of Affected Muscles Contracting and Mean Power Following Suture, by Presence of Associated Arterial Injury and Specific Site*—Continued

Muscle and site	Arterial injury							
	Absent				Present			
	Number of cases	Percent contracting		Mean power, all cases	Number of cases	Percent contracting		Mean power, all cases
		Total	Against resistance			Total	Against resistance	
Ulnar								
Fl. dig. prof. 4 & 5								
Arm, upper ⅔	72	94.7	74.7	31.07	52	89.3	71.4	28.02
All other sites	206	95.5	79.5	35.73	33	84.8	54.5	23.73
Total	278	95.3	78.3	34.53	85	87.6	65.2	26.35
Abd. dig. V								
Arm, upper ⅓	35	80.0	20.0	3.77	38	71.1	34.2	4.32
Arm, middle and lower ⅓	118	89.3	37.2	7.92	33	81.8	24.2	5.00
Forearm, lower ⅔	111	91.2	53.1	15.29	40	87.5	32.5	8.58
All other sites	145	91.5	47.7	11.52	25	80.0	12.0	1.24
Total	409	89.8	43.8	10.84	136	80.1	27.2	5.17

1st dors. inteross.								
Arm, upper ⅓	23	58.3	8.3	.43	30	50.0	20.0	5.30
Arm, middle and lower ⅓	87	88.5	45.8	9.99	24	68.0	12.0	2.75
Forearm, lower ⅔	73	86.3	48.8	11.67	33	76.5	32.4	12.21
All other sites	117	88.4	45.5	13.52	18	85.0	25.0	5.06
Total	300	85.7	43.6	11.04	105	68.8	22.9	6.85
Radial								
Ext. car. rad.								
Arm, upper ⅓	36	97.4	92.1	41.53	18	78.9	57.9	17.61
All other sites	167	96.3	85.0	40.52	7	100.0	88.9	54.71
Total	203	96.4	86.2	40.70	25	85.7	67.9	28.00
Ext. dig.								
Arm, upper ⅓	33	94.1	58.8	22.30	16	70.6	29.4	6.31
All other sites	164	87.6	63.5	27.90	8	100.0	77.8	32.38
Total	197	88.7	62.7	26.96	24	80.8	46.2	15.00
Ext. poll. long.								
Arm, upper ⅓	33	80.0	48.6	17.12	16	72.2	22.2	3.19
All other sites	166	82.5	55.4	19.37	8	88.9	44.4	10.00
Total	199	82.1	55.2	19.00	24	77.8	29.6	5.46

nerve injury, result in some loss of muscle power. However, the evidence in favor of an effect is not confined to relative power, but extends to both minimal contraction and contraction against resistance. Although one would perhaps not expect the effect of a delay in repair to be confounded with that of arterial injury, it is nevertheless of interest to note that time plays no part in producing these differentials. The mean day of definitive suture is as shown in table 80 for each nerve, in relation to arterial injury. There is even some suggestion that definitive sutures were done a little earlier on lesions with associated arterial injury. If the percentages contracting against resistance are employed in developing an estimate of the average magnitude of the effect of arterial injury, one finds that muscles affected by such injuries contract against resistance with only 82 percent of the frequency observed for muscles not so affected and of comparable site.

Table 80.—*Associated Arterial Injury and Average Days From Injury to Definitive Suture, by Nerve and Gross Site*

Nerve and gross site	Mean day of repair	
	Arterial injury absent	Arterial injury present
Median, high	154	150
Ulnar, low	184	170
Radial, all	175	139

Since the evidence is clear that arterial injury plays a role in motor recovery, and that arterial injury is confounded with site, the effect of site upon motor recovery merits review on the basis of cases with no associated arterial lesion. This may also be done from table 79, which parallels table 53 presented earlier in the discussion of the effect of specific site upon motor recovery. Very little change is introduced by this refinement; muscles for which motor recovery varies by site in table 53 look about the same in table 79, largely because of the superior performance of low lesions.

5. Plastic Repair at Site of Nerve Suture

Such repairs were abstracted from the clinical records, it may be recalled, whenever a definitive major plastic procedure had been done at the site of the nerve injury, regardless of indications, provided it was performed before regeneration of the nerve following definitive suture. Such repairs were not done often enough to permit any very powerful exploration of their effect, even in this large series. Only in median, ulnar, and peroneal lesions may they be studied fruitfully. In the peroneal their deleterious effect seems plain enough; in the median and ulnar the evidence is less compelling, but somewhat in support of the conclusion that the effect is a general one. Table 81 contains the data studied in connection with this problem. The data are so few, and so variable by nerve and by muscle, that little purpose is served by an estimate of the average magnitude of the effect, and somewhat different results are obtained by different methods of estimation. However, it may be said that muscles affected by plastic repair contract against resistance about 80 percent as often as those not so affected.

For low median and all peroneal lesions some exploration was made on the possible confounding of plastic repair with delay in nerve suture, but none was found. The differences in date of definitive suture are statistically insignificant and too small to produce large effects.

6. Summary

In reviewing the records of the original injury and its management, the opportunity was taken to record those associated injuries and procedures which might influence nerve regeneration and muscle strength, and these have now been intensively studied for evidence of variation in capacity of muscles to contract and in their relative power. It should be emphasized that the study of associated injuries is here confined to their influence upon the strength of certain representative movements, and that a movement which is not possible because of defects in a joint, or destruction of muscle or tendon, is excluded from consideration.

Associated nerve injuries have not been subjected to the intensive study accorded other associated conditions, but evidence from both upper and lower extremity lesions suggests that the recovery of one nerve is probably prejudiced by injury to another. Following high median suture recovery of distal muscles (opponens and abductor pollicis brevis) was definitely poorer in men who also had ulnar sutures on the same limb. No effect of associated sciatic-tibial sutures could be demonstrated for limbs with sciatic-peroneal sutures, but the recovery of tibial muscles was much poorer following suture of both sciatic branches than following suture of the sciatic-tibial alone.

Associated bone and joint injuries were systematically investigated both as to presence and as to character of healing, but without developing statistically significant evidence of any influence upon motor recovery.

Chronic infection was noted only if sufficiently prolonged to delay repair, and although statistically significant differences were found, suggesting an average loss of one-third in the expected percentage of muscles capable of contracting against resistance, an investigation on three radial muscles strongly suggests that most or all of this large effect may be explained solely on the basis of the delay in repair. Evidence is lacking, therefore, of any specific deleterious effect attributable to infection.

Table 81.—*Percentage of Affected Muscles Contracting and Mean Power Following Suture, by Presence of Plastic Repair at Site of Nerve Suture*

Nerve, site, and muscle	Plastic repair: Not done: Number of cases	Not done: Percentage contracting: Total	Not done: Percentage contracting: Against resistance	Not done: Mean power, all cases	Done: Number of cases	Done: Percentage contracting: Total	Done: Percentage contracting: Against resistance	Done: Mean power, all cases	Statistical tests on means [1]
High median									
Fl. poll. long	102	84.3	67.6	....	7	85.7	85.7	....	....
Fl. dig. prof. 2	143	84.6	61.5	....	12	91.7	66.7	....	....
Abd. poll. brev	96	77.1	39.6	....	6	66.7	16.7	....	....
Low median									
Fl. poll. long	39	89.7	71.8	....	7	85.7	71.4	....	....
Fl. dig. prof. 2	56	94.6	83.9	....	10	90.0	80.0	....	....
Abd. poll. brev	84	85.6	55.7	17.20	16	52.9	17.6	0.93	**
High ulnar									
Fl. dig. prof. 4 & 5	236	92.9	74.6	30.95	23	92.3	69.2	24.35	NS
Abd. dig. V	264	84.8	33.7	6.91	30	87.1	45.2	8.33	NS
1st dors. inteross	197	76.7	36.7	8.45	21	90.9	27.3	4.05	NS

Low ulnar										
Fl. dig. prof. 4 & 5	94	97.0	83.0	42.36	16	87.5	56.3	17.91	**
Abd. dig. V	221	92.1	48.0	12.95	39	82.1	33.3	8.46	NS
1st dors. inteross	165	88.4	41.6	12.94	30	72.7	45.5	9.17	NS
Peroneal										
Tib. ant	136	76.1	40.6	22.50	26	66.7	18.5	5.96	**
Ext. dig. long	145	67.6	31.8	10.28	30	60.0	13.3	3.67	NS
Ext. hall. long	140	55.6	25.7	9.00	30	46.7	6.7	1.00	*
Peron. long	139	71.9	45.2	19.75	30	67.7	25.8	8.00	*

[1] Results of statistical tests (two-tailed) are abbreviated as follows:
NS=Not significant
*=Significant at .05 level
**=Significant at .01 level.

408980—57——11

Comcomitant arterial injuries appear to be associated with an average loss of about one-seventh in the expected percentage of muscles contracting against resistance, and no evidence was obtained that delay in definitive nerve suture plays any role in this relationship.

In the peroneal, and to some extent also in the median and ulnar, a plastic procedure performed at the site of nerve injury prior to nerve regeneration was found to be associated with an average loss of about one-fifth in the expected percentage of muscles contracting against resistance. Any delay in definitive nerve suture associated with such plastic repair is of too little moment to play any role in this relationship.

E. INFLUENCE OF TECHNICAL ASPECTS OF MANAGEMENT

Although the greatest immediate interest in a follow-up study on peripheral nerve injuries attaches to any conclusions which may be drawn in the area of management, it is precisely in this area that it is most difficult to draw clear and simple conclusions. The reason, of course, is that management is not experimental but therapeutic in intent, so that the choice of procedures immediately becomes entangled with prognosis. Nevertheless, because of the great practical importance of information about the management of peripheral nerve injuries, because the difficulty is not peculiar to this series but extends to any not frankly experimental in nature, and because the present series is large enough to allow the use of statistical devices for coping with confounding where such seems indicated, the major characteristics of treatment have been studied systematically in the expectation that useful, if not always unequivocal, conclusions might be forthcoming. For the most part, the elements of treatment have been studied individually, more than one being introduced only in connection with efforts to cope with serious confounding. A much more complex, multivariate analysis might have been attempted, but its possible usefulness was suggested only late in the study when the funds for statistical work had been very largely expended, and the statistician believed that the additional information it would provide might well prove to be small.

In the analysis of treatment factors the entire series was used, regardless of roster and sampling area.

1. Number of Operations

Particular importance attaches to the definition of an "operation" employed in this study, and the reader is referred to page 40 for a discussion of the principles involved in the coding of operations. Not more than half of the definitive sutures with more than one operation had more than one *suture;* for each nerve usually half or more had a lysis before or after suture, or a so-called significant cuff removal. Since one would expect lesions with more than one operation to have a poorer prognosis than those with a single, the data of table 82 offer no surprise, unless it be that the advantage enjoyed by lesions operated on but once is not larger. Without any estimate of how badly the cases reoperated upon would have fared had the second procedure not been done, there is lacking any statistical basis for assessing its benefit.

There were 10 lesions with 4 operations each, and table 83 provides a summary of the sequence of operations in each instance and of such follow-up information as became available. Although few in number, these cases constitute strong evidence, if any were needed, that repeated suture need not be self-defeating; most of these had 3 complete sutures and some recovery was noted in 8 of the 9 with follow-up data.

2. Days from Injury to Definitive Repair

Time intervening between injury and repair was studied more intensively than any other single characteristic, not only because of the importance accorded it in the surgical literature but also because it was found to be confounded with so many other factors in the study. In the previous section it was seen that associated injuries often greatly delay definitive repair, and it is to be expected that various aspects of management will change as time progresses without definitive repair. A circumstance which *a priori* would be expected to exert a great influence upon the relation between recovery and time to definitive repair is the fact that the lesion which was observed not to be doing well would often be resutured. Since resuture would necessarily take place at a later date, a connection would seem established between cases of poor prognosis and long interval, but the evidence of the present series is that any such connection may do no more than exaggerate slightly the intrinsic relation between time and motor recovery.

The basic evidence of relationship between motor recovery and interval from injury to definitive operation appears in figure 12. The average relative strength of any muscle varies somewhat with timing of definitive repair in relation to date of injury. However, the association is not a very strong one and criteria of statistical significance are not always met by the data. Although Pearsonian (product-moment) correlation coefficients were not routinely calculated, for 2 radial muscles they are shown in table 84, by site, for complete radial sutures. It is in the radial muscles that the correlation is most obvious, however, as may be seen from the correlation ratios [13] presented in table 85. Although the relationship is a quite definite one, therefore, it is variable from nerve to nerve and even within the set of muscles innervated by a particular nerve, and none too strong at best.

[13] If the regression relationship between two variables is precisely linear, the correlation ratio and the Pearsonian (product-moment) correlation coefficient are the same.

Table 82.—*Mean Power of Affected Muscles After Complete Suture, by Number of Operations Performed*

Nerve, site, and muscle	Number of operations: One — Number of cases	One — Mean power	Two or more — Number of cases	Two or more — Mean power	Statistical tests [1]
High median					
Fl. poll. long	81	27.96	17	29.12	NS
Fl. dig. prof. 2	123	22.11	23	15.00	NS
Abd. poll. brev	76	10.46	20	15.00	NS
Low median					
Abd. poll. brev	84	13.27	16	21.56	NS
High ulnar					
Fl. dig. prof. 4 & 5	207	32.27	52	22.79	*
Abd. dig. V	233	7.92	61	3.77	*
1st dors. inteross	174	8.76	44	5.11	NS
Low ulnar					
Fl. dig. prof. 4 & 5	92	39.82	18	33.61	NS
Abd. dig. V	203	13.14	57	9.21	NS
1st dors. inteross	154	12.82	41	10.61	NS
Radial					
Ext. car. rad	192	38.70	40	37.63	NS
Ext. dig	189	26.19	35	15.29	NS
Ext. poll. long	192	17.08	34	14.12	*
Peroneal					
Tib. ant	115	20.91	47	7.02	**
Ext. dig. long	120	10.75	55	5.64	*
Ext. hall. long	117	8.80	53	4.91	NS
Peron. long	114	22.94	55	6.73	**
Sciatic-peroneal					
Tib. ant	177	5.74	50	2.50	NS
Ext. dig. long	177	2.57	51	0	*
Ext. hall. long	176	2.56	50	.10	*
Peron. long	176	4.86	51	.88	*
Sciatic-tibial					
Gastroc. & sol	135	47.37	35	34.71	*
Fl. dig. long	143	2.69	39	2.44	NS
Fl. hall. long	142	2.50	39	1.28	NS

[1] Results of statistical tests are abbreviated as follows:
NS=Not significant.
*=Significant at .05 level.
**=Significant at .01 level.
All tests here are one-tailed.

Table 83.—*Summary of Motor Recovery in 10 Cases With 4 Operations*

Case No.	Nerve	Character of surgery at each operation in sequence				Motor performance				
						Number of muscles				British motor summary [1]
						Affected		Contracting		
		First	Second	Third	Fourth	Prox.	Dist.	Prox.	Dist.	
1175	Ulnar	Suture	Suture	Lysis	Suture	2	3	2	V	2
3206	.....do	.....do	Lysis	Suture	Lysis	0	3	0	V	4
3924	Median	Lysis	Suture	.....do	.....do	0	1	0	1	4
5187	Ulnar	Partial suture	Transplantation	.....do	Suture	2	3	2	V	3
5377	Peroneal	Suture	Suture	.....do	.....do	4	0	3	0	1
5377	Tibial	.....do	.....do	.....do	.....do	4	1	2	0	2
3626	Ulnar	Graft	Graft	Exploration	.....do	......	No follow-up		......	....
3828	Median	.....do	.....do	.....do	.....do	3	1	V	0	1
4153	Sciatic-peroneal	Partial suture	Suture	Suture	Cuff removed	4	0	1	0	1
4153	Sciatic-tibial	.....do	.....do	.....do	....do	4	1	0	0	0

[1] The modified British motor scale is as follows:

0 No contraction.
1 Return of perceptible contraction in the proximal muscles.
2 Proximal muscles acting against gravity, no return of power in intrinsic muscles.
3 Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles.
4 Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance.
5 Return of function as in position 4, with the addition that some synergic and isolated movements are possible.
6 Complete recovery.

Figure 12 (p. 1). *Mean Relative Power in Relation to Interval From Injury to Definitive Suture, by Nerve and Muscle—High Median, Low Median*

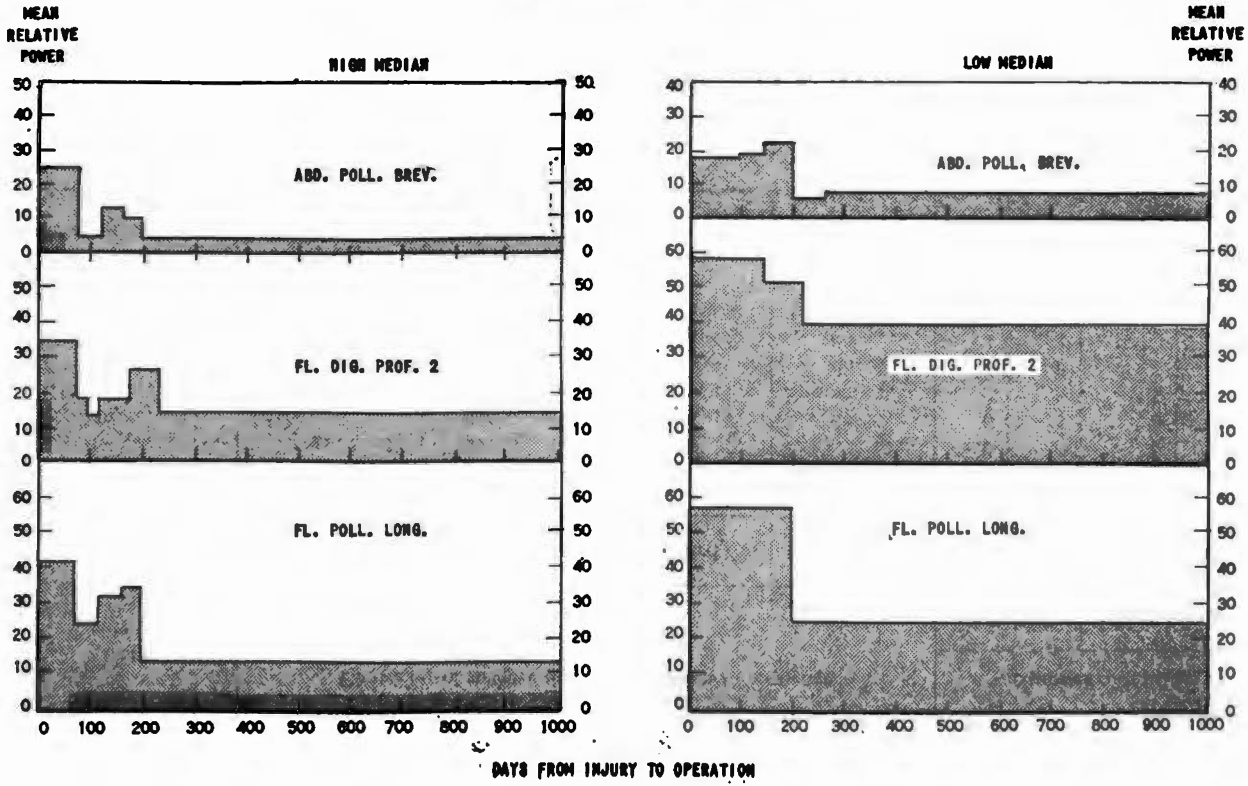


Figure 12 (p. 2). *Mean Relative Power in Relation to Interval From Injury to Definitive Suture, by Nerve and Muscle—High Ulnar, Low Ulnar*

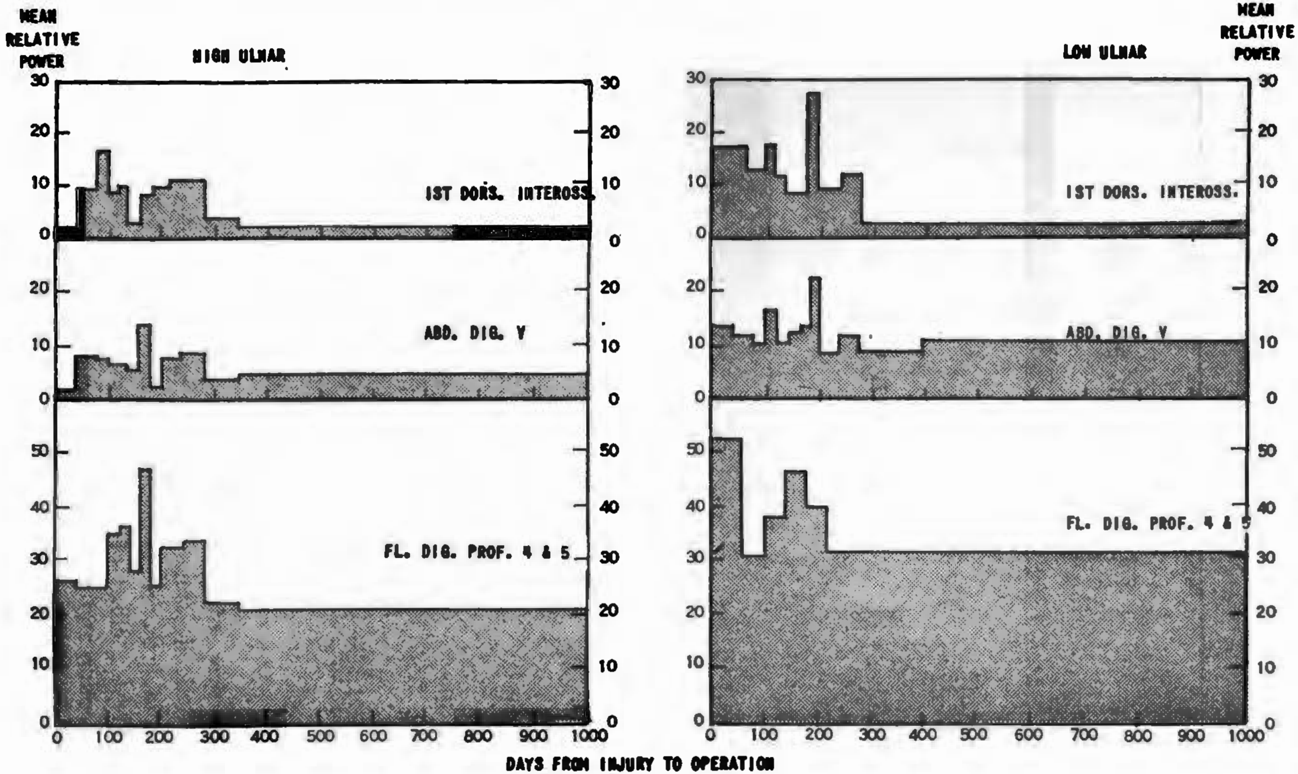
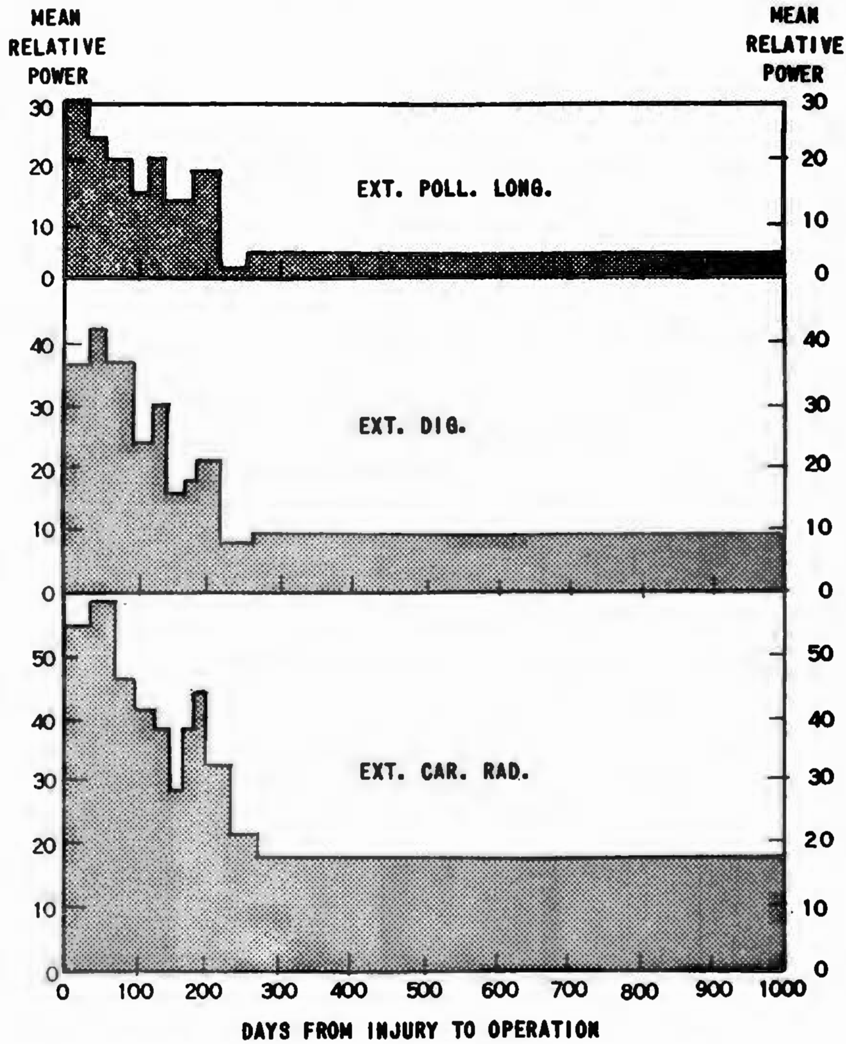


Figure 12 (p. 3). *Mean Relative Power in Relation to Interval From Injury to Definitive Suture, by Nerve and Muscle—Radial*



The proportion of muscles capable of contraction was not studied as systematically as mean power, but table 86 contains the information which is available on certain median and ulnar muscles following definitive suture. Plainly the effect of time extends to both the likelihood of perceptible contraction and the likelihood of movement against resistance, but again, as in the observations on relative power, the effect is not seen either in all nerves or in all muscles, and tends to be especially marked in muscles innervated by the radial and the peroneal. Also, the effect often seems greatest in the most distal muscles.

Figure 12 (p. 4). *Mean Relative Power in Relation to Interval From Injury to Definitive Suture, by Nerve and Muscle—Peroneal, Sciatic-Peroneal*

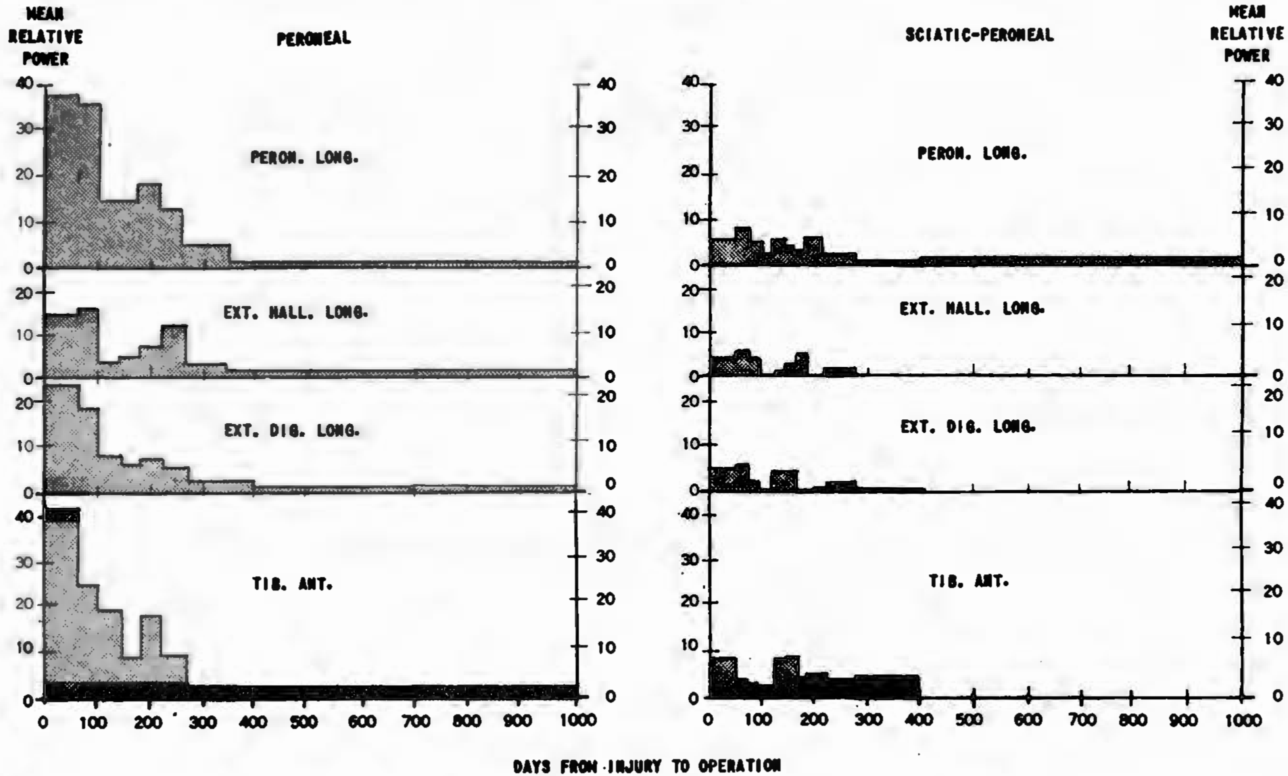


Figure 12 (p. 5). *Mean Relative Power in Relation to Interval From Injury to Definitive Suture, by Nerve and Muscle—Tibial, Sciatic-Tibial*

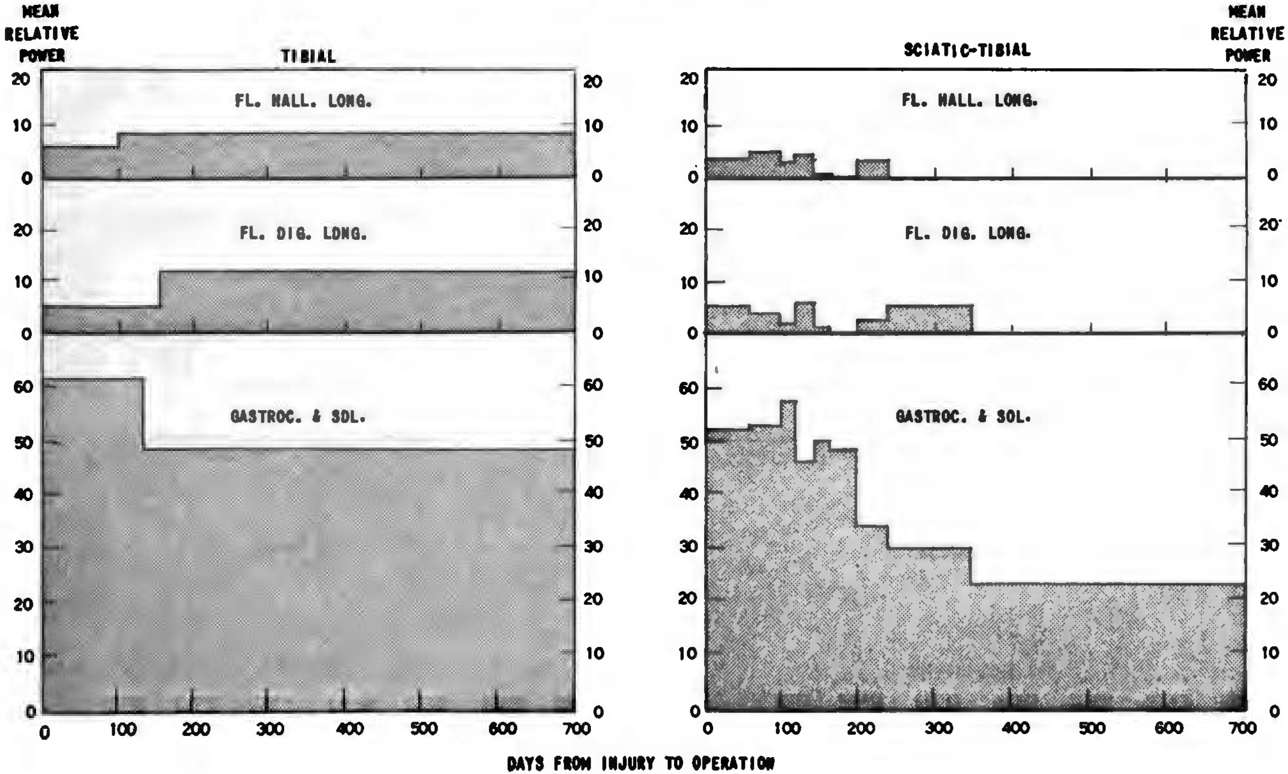


Table 84.—*Correlation Coefficients Between Relative Power of Muscle Movement and Time From Injury to Definitive Suture, by Site, Two Radial Muscles*

Site of lesion in arm	Correlation between relative power and time from injury to definitive suture	
	Ext. car. rad.	Ext. dig.
Upper third	−.20	[1]−.30
Middle third	[2]−.41	[2]−.38
Lower third	[2]−.36	[1]−.28

[1] Significant at .05 level.
[2] Significant at .01 level.

Table 85.—*Correlation Ratios Between Relative Power and Days From Injury to Definitive Suture, by Nerve and by Muscle*

Nerve, site, and muscle	Correlation ratio [1]	Nerve, site, and muscle	Correlation ratio [1]
Median, high		Radial, all—Continued	
Fl. dig. prof. 2	.304	Ext. dig	.404
Abd. poll. brev	.385	Ext. poll. long	.335
Median, low		Peroneal, all	
Fl. poll. long	.401	Tib. ant	.408
		Ext. dig. long	.407
Ulnar, low		Ext. hall. long	.300
		Peron. long	.468
1st. dors. inteross	.294		
		Sciatic-tibial	
Radial, all			
		Gastroc. & sol	.322
Ext. car. rad	.422		

[1] Shown only for those muscles in which the ratio differs significantly ($P<.05$) from 0.

The confounding of time and associated injuries has already been mentioned. For 1 representative muscle innervated by each of 4 nerves a special study was made on the correlation of time and muscle power for cases with and without each of several associated conditions. In general, as may be seen from table 87, the (Pearsonian) correlation coefficient is the same, whether calculated for cases with or without each of the associated conditions.

Table 86.—*Relation Between Interval From Injury to Definitive Suture and Capacity to Contract Affected Muscles, by Nerve and Muscle*

Nerve, gross site, and muscle	Number of cases [1]	Percentage contracting, by days from injury to final suture			Percentage contracting against resistance, by days from injury to final suture		
		1–99	100–179	180 or more	1–99	100–179	180 or more
Median, low							
Opponens	160	93.7	88.9	83.1	65.6	66.7	55.4
Abd. poll. brev	114	87.5	83.9	76.3	62.5	51.6	44.1
Ulnar, high							
Fl. dig. prof. 4 & 5	278	95.4	97.0	85.6	75.9	79.2	66.7
Abd. dig. V	301	87.5	87.2	80.8	31.8	40.4	31.7
1st dors. inteross	232	82.1	76.4	76.3	37.3	32.6	38.2
Ulnar, low							
Abd. dig. V	265	92.2	91.8	88.3	46.9	50.0	41.7
1st dors. inteross	205	91.7	89.3	79.3	43.8	44.0	40.2

[1] The total number of tested muscles, and thus the sum of the bases for the several percentages for each muscle and not for any single percentage.

On the premise that complete and incomplete lesions might differ considerably as to the extent of distal regeneration expected from lengthening the interval from injury to suture, several muscles were chosen for a special study of the role of type of lesion:

Median: abductor pollicis brevis, for which a gross relationship with time seemed clear, especially in high lesions.

Ulnar: abductor digiti V, for which no evidence of relationship had previously been found.

Radial: extensor carpi radialis, extensor digitorum, and extensor pollicis longus, for each of which a quite marked correlation with time had been found.

The investigation provided no reason for believing that type of lesion played any role in the relation between time and ultimate muscle power. Table 88 presents parallel mean values for complete and incomplete lesions, both completely sutured.

Several aspects of the management of the lesion were considered from the standpoint of their possible effect on the relation between recovery and time to repair. The echelon of repair was one of these, since all overseas sutures were of necessity done early. Three representative muscles were studied in this connection: extensor carpi radialis, abductor pollicis brevis, and peroneus longus (for peroneal lesions only, i. e., those below

Table 87.—*Correlation Coefficients Between Relative Muscle Power and Time From Injury to Definitive Suture, for Completely Sutured Nerve Lesions With and Without Associated Injuries, by Muscle*

Nerve, muscle, and gross site	Associated condition							
	Bone and joint		Infection		Arterial injury		Plastic repair	
	Absent	Present	Absent	Present	Absent	Present	Absent	Present
Median (fl. poll. long.)								
High	....	....	....	....	−.12	−.29	....	....
Low	....	....	....	....	....	....	....	....
All	....	....	−.19	−.29	....	....	....	....
Ulnar (abd. dig. V)								
Low	....	....	....	....	−.10	+.19	....	....
Radial (ext. car. rad.)								
All	−.33	−.39	−.35	−.34	−.41	−.46	....	....
Peroneal (ext. hall. long.)								
All	....	....	....	....	....	....	−.19	−.23

Table 88.—*Comparison of Mean Relative Muscle Power of Complete and Incomplete Lesions, Both Completely Sutured, by Interval From Injury to Definitive Suture, by Nerve and Muscle*

A. Radial Muscles

Days from injury to definitive repair	Ext. car. rad.		Ext. dig.		Ext. poll. long.	
	Complete lesions	Incomplete lesions	Complete lesions	Incomplete lesions	Complete lesions	Incomplete lesions
0–99	52.4	56.4	36.9	43.2	21.7	32.8
100–139	38.1	42.2	28.0	25.6	20.1	13.9
140 or more	26.9	37.0	13.8	15.3	9.3	16.1

B. Ulnar, abd. dig. V

Days from injury to definitive repair	Complete lesions	Incomplete lesions
0–59	9.5	7.3
60–119	8.4	12.8
120–179	8.5	14.2
180–239	9.1	12.0
240 or more	7.4	10.0

C. Median, abd. poll. brev.

Days from injury to definitive repair	Complete lesions	Incomplete lesions
0–99	19.5	19.2
100–159	10.3	18.2
160–219	13.3	14.7
220 or more	5.6	12.0

the branching of the sciatic). When overseas sutures were removed from the series the association between time and muscle recovery remained unchanged. Table 89 contains the data underlying this conclusion.

Another aspect of treatment thought to introduce some bias into the data has already been mentioned, namely the fact that the date of definitive repair was necessarily advanced for cases requiring reoperation. Accordingly, a study was made on the basis of time to first suture, but again the relationship to time appears in full force. In part this is because so many resutures were actually done fairly early in the Z/I following suture overseas. Table 90 presents the relation between motor recovery and time to first suture, in terms of capacity to contract against resistance as well as mean power of all muscles, whether contracting against resistance or not.

Since, as will be shown later, both the interval from injury to suture and the surgical gap are quite reliably associated with ultimate muscle power, both factors were explored simultaneously on the basis of the extensor carpi radialis and the extensor digitorum, with attention to the site of injury. For time and gap themselves the Pearsonian correlation coefficients are all significant at the .01 level:

Table 89.—*Percentage of Affected Muscles Contracting Against Resistance, Following Complete Suture in Z/I, by Time From Injury to Definitive Suture*

Nerve and muscle		Percentage contracting, by days from injury to suture				
		0–99	100–139	140–179	180–259	260 or more
Median	Abd. poll. brev	47.1	39.1	36.4	23.5	18.2
Radial	Ext. car. rad	92.3	86.2	82.4	80.9	56.8
Peroneal	Peron. long	66.7	53.6	35.3	36.1	13.0

Table 90.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Time From Injury to First Complete Suture*

Nerve	Site	Muscle	Days from injury to suture	Number of cases	Percentage contracting against resistance	Mean relative power, all cases
Median	High	Fl. poll. long	1–99	34	82.4	38.4
			100–179	49	67.3	26.6
			180–279	17	47.1	20.6
			280 or more	9	66.7	16.2
		Fl. dig. prof. 2	1–99	50	76.0	26.77
			100–179	68	52.9	16.77
			180–279	22	54.5	23.81
			≥280	15	66.7	15.83
		Abd. poll. brev	1–99	35	51.4	17.80
			100–179	42	38.1	8.68
			180–279	16	25.0	8.13
			≥280	9	11.1	5.00
	Low	Fl. poll. long	1–99	9	77.8	43.13
			100–179	11	90.9	59.50
			180–279	16	68.8	37.33
			≥280	9	44.4	21.67
		Fl. dig. prof. 2	1–99	13	92.3	50.00
			100–179	17	88.2	53.13
			180–279	24	79.2	46.82
			≥280	11	72.7	44.44
		Abd. poll. brev	1–99	28	64.3	18.25
			100–179	29	51.7	17.86
			180–279	30	40.0	15.56
			≥280	26	42.3	6.04
Ulnar	High	Fl. dig. prof. 4 & 5.	1–99	104	73.1	23.57
			100–179	95	80.0	37.96
			180–279	52	69.2	31.90
			≥280	27	66.7	23.80

Table 90.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Time From Injury to First Complete Suture*—Continued

Nerve	Site	Muscle	Days from injury to suture	Number of cases	Percentage contracting against resistance	Mean relative power, all cases
Ulnar	High	Abd. dig. V	1–99	106	28.3	5.73
			100–179	102	42.2	8.93
			180–279	60	33.3	7.17
			≥280	33	36.4	5.45
		1st dors. inteross.	1–99	80	36.3	8.66
			100–179	83	31.3	7.93
			180–279	44	43.2	9.76
			≥280	25	36.0	3.54
Ulnar	Low	Fl. dig. prof. 4 & 5.	1–99	35	77.1	38.86
			100–179	42	78.6	41.10
			180–279	27	85.2	37.09
			≥280	11	81.8	37.00
		Abd. dig. V	1–99	73	45.2	11.16
			100–179	98	49.0	13.21
			180–279	67	47.8	13.02
			≥280	27	33.3	10.58
		1st dors. inteross.	1–99	55	41.8	13.49
			100–179	75	42.7	11.99
			180–279	56	51.8	15.00
			≥280	19	15.8	3.68
Radial	All	Ext. car. rad	1–99	83	95.2	52.46
			100–179	93	83.9	36.80
			180–279	51	78.4	30.22
			≥280	28	53.6	18.33
		Ext. dig	1–99	79	77.2	37.28
			100–179	90	63.3	23.71
			180–279	45	40.0	13.56
			≥280	24	29.2	9.13
		Ext. poll. long	1–99	78	64.1	23.77
			100–179	90	60.0	16.76
			180–279	46	30.4	9.67
			≥280	25	20.0	6.25
Peroneal	All	Tib. ant	1–99	59	49.2	25.95
			100–179	50	34.0	13.40
			180–279	42	28.6	12.50
			≥280	15	20.0	2.69
		Ext. dig. long	1–99	60	45.0	17.89
			100–179	56	25.0	5.71
			180–279	46	19.6	5.22
			≥280	17	5.9	1.18
		Ext. hall. long	1–99	59	35.6	13.21
			100–179	54	16.7	3.11
			180–279	45	17.8	7.78
			≥280	17	5.9	2.06
		Peron. long	1–99	61	57.4	30.34

Table 90.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Time From Injury to First Complete Suture*—Continued

Nerve	Site	Muscle	Days from injury to suture	Number of cases	Percentage contracting against resistance	Mean relative power, all cases
Peroneal	All	Peron. long	100–179	54	37.0	11.04
			180–279	45	33.3	13.26
			≥280	17	23.5	4.67
Tibial	All	Gastroc. & sol.	1–99	18	88.9	59.44
			100–179	16	93.8	55.33
			180–279	10	80.0	47.22
			≥280	4	100.0	70.00
		Fl. dig. long	1–99	21	19.0	5.24
			100–179	25	32.0	6.88
			180–279	17	23.5	12.94
			≥280	11	54.5	10.00
		Fl. hall. long	1–99	20	20.0	5.75
			100–179	26	38.5	10.21
			180–279	17	23.5	9.69
			≥280	10	30.0	2.78
Sciatic-peroneal.	All	Tib. ant.	1–99	71	19.7	5.23
			100–179	92	19.6	5.61
			180–279	40	15.0	5.13
			≥280	26	19.2	2.31
		Ext. dig. long	1–99	71	14.1	3.24
			100–179	94	12.8	2.06
			180–279	40	5.0	.88
			≥280	27	3.7	.19
		Ext. hall. long	1–99	68	13.2	3.60
			100–179	93	9.7	1.87
			180–279	40	5.0	1.00
			≥280	27	0	0
		Peron. long	1–99	72	22.2	5.21
			100–179	92	16.3	3.65
			180–279	40	17.5	4.50
			≥280	27	7.4	.93
Sciatic-tibial	All	Gastroc. & sol.	1–99	58	82.8	48.06
			100–179	80	85.0	51.07
			180–279	33	72.7	33.17
			≥280	17	70.6	26.00
		Fl. dig. long	1–99	58	12.1	3.53
			100–179	78	6.4	1.88
			180–279	32	6.3	2.97
			≥280	17	5.9	2.06
		Fl. hall. long	1–99	57	10.5	3.51
			100–179	78	9.0	2.01
			180–279	32	3.1	1.56
			≥280	17	0	0

Site of radial lesion	*Correlation between time and gap*
Upper third, arm	+.70
Middle third, arm	+.27
Lower third, arm	+.54

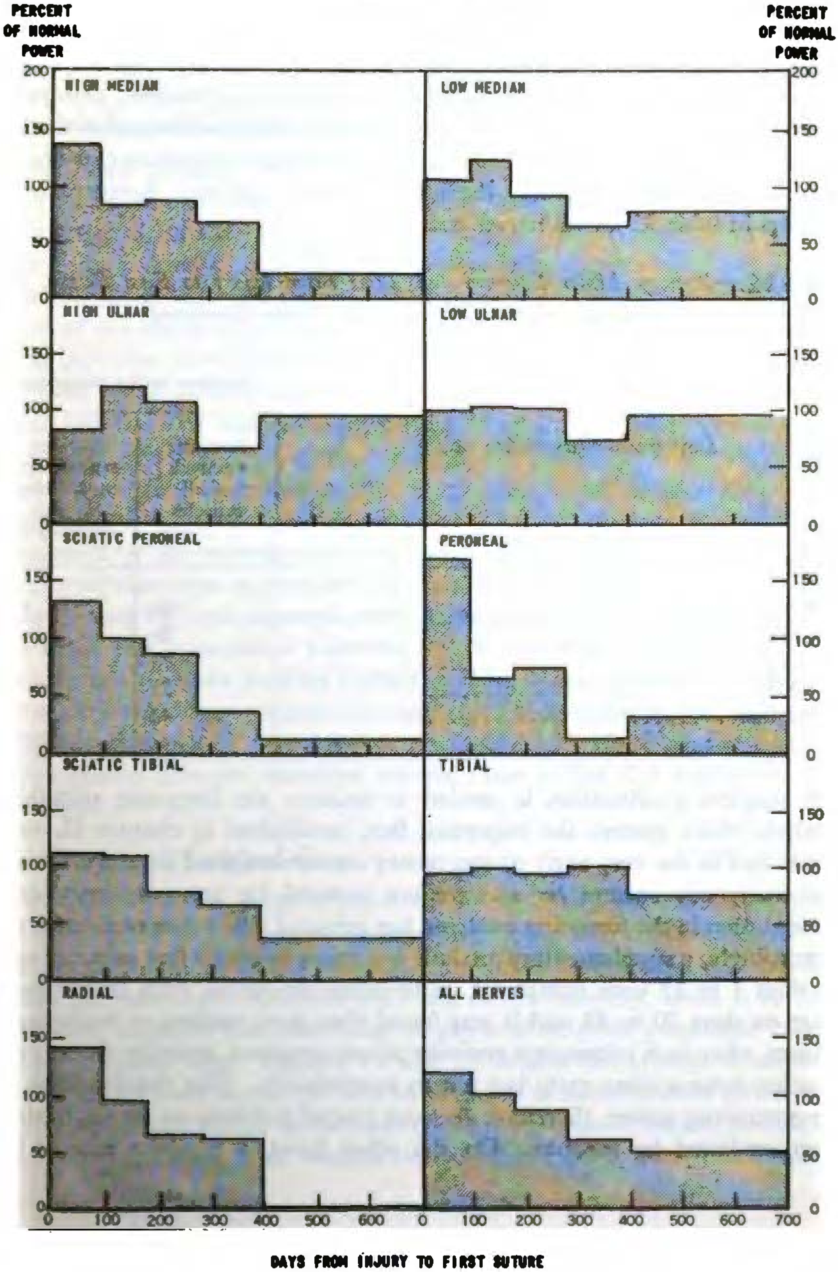
If the influence of gap is removed by the method of partial correlation no great change is observed in the correlation between time and power, as may be seen in the parallelism between the two sets of coefficients in table 91. The correlations between time and gap and between gap and power are not high enough to exert any great influence upon the relationship between time and power which remains the most important relationship of the three.

Table 91.—*Correlation Between Relative Power and Time From Injury to Definitive Suture, Directly and With Influence of Gap Removed, Two Radial Muscles, by Site*

Radial muscle and site of lesion	Correlation coefficients for time and relative power	
	Directly	Influence of gap removed
Ext. car. rad.		
Upper third, arm	−.20	−.10
Middle third, arm	−.41	−.36
Lower third, arm	−.36	−.38
Ext. digitorum		
Upper third, arm	−.30	−.15
Middle third, arm	−.38	−.35
Lower third, arm	−.28	−.30

Estimation of the average magnitude of the effect of delayed repair will depend in part upon whether one believes the effect to be the same for all nerves and which index of motor recovery is employed. To portray an average line of relationship for each nerve, and for all nerves combined, figure 13 has been prepared, for lesions sutured only once, by expressing the average strength of any set of cases located on the time scale as a percentage of the average for all cases, regardless of date of repair of the particular lesion. *It seems plain that the relationship is linear and that the best time to repair in general is the earliest time feasible.* Figure 13 suggests, for example, that muscles innervated by nerves sutured in the interval from 280–399 days after injury will have about half the power observed for muscles innervated by nerves sutured within the first 100 days. If optimum power is taken as 100 percent for immediate sutures, then on the average there is a loss of 1 percent about every 6 days. Alternatively, one may take the linear regression equations fitted to the data on several radial muscles, which yield about the same results. These equations are, where Y denotes relative power and X number of days from injury to suture:

Figure 13. *Average Relative Muscle Power in Relation to Time From Injury to First Suture, by Nerve*



Ext. car. rad	$Y=51.40-.0800X$
Ext. dig	$Y=34.62-.0632X$
Ext. poll. long	$Y=23.07-.0412X$

Since the optimum power is indicated by the intercept value in each case, the relative losses at the end of 100 days are 16, 18, and 18 percent for the 3 muscles in turn, which is very close to the value of about 17 percent obtained by rough graphic interpolation from figure 13, panel for all nerves combined. It must be emphasized, however, that any such average conceals the variation among muscles, and particularly the fact that the effect tends to be strong in those innervated by the radial and peroneal, and weak or even absent in the ulnar and tibial muscles. Alternatively, if one considers as the index of motor recovery the percentage of muscles capable of movement against resistance, the effect is fairly similar. A comparison appears in table 92 for all nerves combined.

Table 92.—*Average Motor Recovery and Time From Injury to First Suture, for Two Indices of Motor Recovery, All Nerves Combined*

Days from injury to first suture	Relative motor recovery	
	Average strength of all muscles	Average percentage contracting against resistance
1–99	100	100
100–179	84	94
180–279	74	76
280–399	51	73
400 or more	43	34

A surgical qualification is needed to balance the foregoing statistical analysis which ignores the important fact, established in chapter II, that about half of the very early or emergency sutures required resuture. Also, the emergency sutures *per se* were not isolated for separate study and presentation in the foregoing analyses, but grouped with other early sutures. Accordingly, a supplementary analysis was made in which first sutures done on days 1 to 19 were compared, as to follow-up status, with first sutures done on days 20 to 49 and it was found that these earliest or emergency sutures, after such subsequent resuture as was required, actually did as well as other sutures done early but not so immediately. The disadvantage of the emergency suture, therefore, does not extend to follow-up status, having been mediated by resuture. On the other hand, a resuture rate of 50 percent is intolerably high. Also, it appears from the analysis of the emergency sutures that, in these instances at least, the value of resuture has been clearly established.

3. Calendar Date of Definitive Suture

To mobilize surgeons in time of war is a tremendous task and the expectation is that satisfactory administrative and technical arrangements may not exist at the outset. It is of some interest, therefore, to observe in the material on motor recovery no evidence that definitive sutures done at one calendar time were any more or less successful than those done at another.

4. Echelon of Definitive Repair

Although the great bulk of the sutures were done in Z/I general hospitals, a special effort was made to include early, overseas sutures for comparative purposes. As table 93 clearly shows, the definitive sutures done overseas are accompanied by much better results at follow-up, on the average, than was obtained with Z/I sutures. There are two artifacts which rob these data of any meaning for surgical policy: (a) the overseas sutures were early; and (b) those overseas sutures which remain as the definitive sutures were in men whose clinical progress was satisfactory and considered not to warrant resuture. It was noted in chapter II that the resuture rate was considerably higher for first sutures done overseas than for those first done in the Z/I. When the follow-up data were compared on the basis of definitive first sutures only, to counteract the second source of bias, the advantage possessed by the overseas cases was found to be only slightly lessened. The factor of time was approached by matching Z/I and overseas cases as to day of surgery, and although early Z/I sutures were not common enough to make this approach a powerful one, it did yield remarkably identical results for the three muscles studied. Table 94 summarizes the data thus obtained, which are confined to contraction against resistance. The great difference in time of repair seems responsible, therefore, for the apparent discrepancy between definitive sutures done in the Z/I and those done overseas.

5. Length of Surgical Gap

As already noted, surgical gap is only weakly correlated with strength of muscle power at follow-up, although moderately correlated with time from injury to definitive repair. That is, although on the average the very long gaps are associated with markedly less motor recovery, there is so much inherent variation that knowledge of gap is of no great prognostic value in the individual case. Figures 14 and 15 depict the average relationship observed for each nerve, the first on the basis of mean relative power of all muscles and the second on the basis of the percentage of muscles contracting against resistance. The construction of figure 14 is exactly like that of

Table 93.—*Mean Relative Power of Affected Muscles Following Definitive Suture Overseas and in the Z/I*

Nerve, gross site, and muscle			Overseas sutures		Z/I sutures		Statistical tests [1]
			Number of cases	Mean power	Number of cases	Mean power	
Median	All	Fl. poll. long	17	40.88	126	31.47	NS
	High	Fl. dig. prof. 2	19	31.84	127	19.37	*
	All	Abd. poll. brev	18	26.67	180	11.81	**
Ulnar	High	Fl. dig. prof. 4 & 5	42	27.38	217	30.94	NS
	High	Abd. dig. V	46	6.74	248	7.12	NS
	High	1st dors. inteross	34	8.24	184	7.99	NS
	Low	Fl. dig. prof. 4 & 5	18	38.33	92	38.89	NS
	Low	Abd. dig. V	37	12.70	223	12.20	NS
	Low	1st dors. inteross	26	18.08	169	11.48	NS
Radial	All	Ext. car. rad	38	58.16	194	34.66	**
	All	Ext. dig	37	36.89	187	22.03	**
	All	Ext. poll. long	40	25.00	186	14.84	*
Peroneal	All	Tib. ant	29	33.97	133	13.23	**
	All	Ext. dig. long	29	20.17	146	6.95	**
	All	Ext. hall. long	29	12.24	141	6.63	NS
	All	Peron. long	29	38.10	140	13.43	**
Sciatic-peroneal.	All	Tib. ant	35	6.86	192	4.75	NS
	All	Ext. dig. long	35	4.29	193	1.58	NS
	All	Ext. hall. long	34	6.62	192	1.20	**
	All	Peron. long	36	6.67	191	3.46	NS
Sciatic-tibial.	All	Gastroc. & sol	30	49.33	140	43.86	NS
	All	Fl. dig. long	32	4.06	150	2.33	NS
	All	Fl. hall. long	32	3.91	149	1.88	NS

[1] Results of statistical tests are abbreviated as follows:
NS=Not significant
*=Significant at .05 level
**=Significant at .01 level.

Table 94.—*Comparison of Overseas and Z/I Definitive Sutures Matched as to Time From Injury to Repair, as to Number of Affected Muscles Moving Against Resistance*

Nerve and muscle	Overseas sutures		Z/I sutures	
	Number of cases	Number moving against resistance	Number of cases	Number moving against resistance
Median: Abd. poll. brev	14	8	18	8
Radial: Ext. car. rad	19	19	19	18
Peroneal: Peron. long	29	20	33	23
Total	62	47	70	49

figure 13, explained on page 154. Figure 15 is only roughly parallel, each plotting point for a particular nerve having been obtained by averaging directly the several percentages contracting against resistance observed for the individual muscles involved. The average for all nerves was then obtained from the averages for each nerve by weighting the latter by the number of lesions studied. Both figures tell about the same story for all nerves combined: In terms of both mean power and percentage contracting against resistance there is a loss of about 6 percent per cm., where 100 percent is the value (either mean strength or percentage contracting against resistance) for gaps under 1 cm. It must be emphasized, however, that in these data the apparent sensitivity of power to differences in length of gap varies by nerve, and that it may well be that no average picture fairly represents them all. Finally, it must be borne in mind that the data are clinical, not experimental, in nature. The surgeon sought to resect enough tissue to obtain good nerve ends, and yet not so much as to interfere with approximation or to incur an undue risk of disruption. The longer gaps, in general, are associated with more extensive wounds involving other tissue; shorter gaps may arise in part from excessive caution on the part of the surgeon. For these reasons the clinical observations do not lead so surely to definite conclusions as would experimental observations, in which length of gap could be randomly assigned.

6. Transposition or Extensive Mobilization as Special Operative Features

The possible influence of transposition and extensive mobilization was systematically explored along the lines of table 95, without finding evidence of any general effect common to all nerves. Any suggestion of an effect is confined to the peroneal and sciatic-peroneal. The study was repeated with a limitation to lesions sutured only once, in order to guard against the possibility that the deleterious effects of transposition and extensive mobilization were lost sight of through the fact that their definitive sutures were second sutures, but no statistical evidence of heterogeneity was observed even with this refinement. It does seem well established, then, that these two special operative features have no demonstrably adverse influence upon motor recovery.

Figure 14. *Average Relative Muscle Power in Relation to Length of Surgical Gap at Definitive Suture, by Nerve*

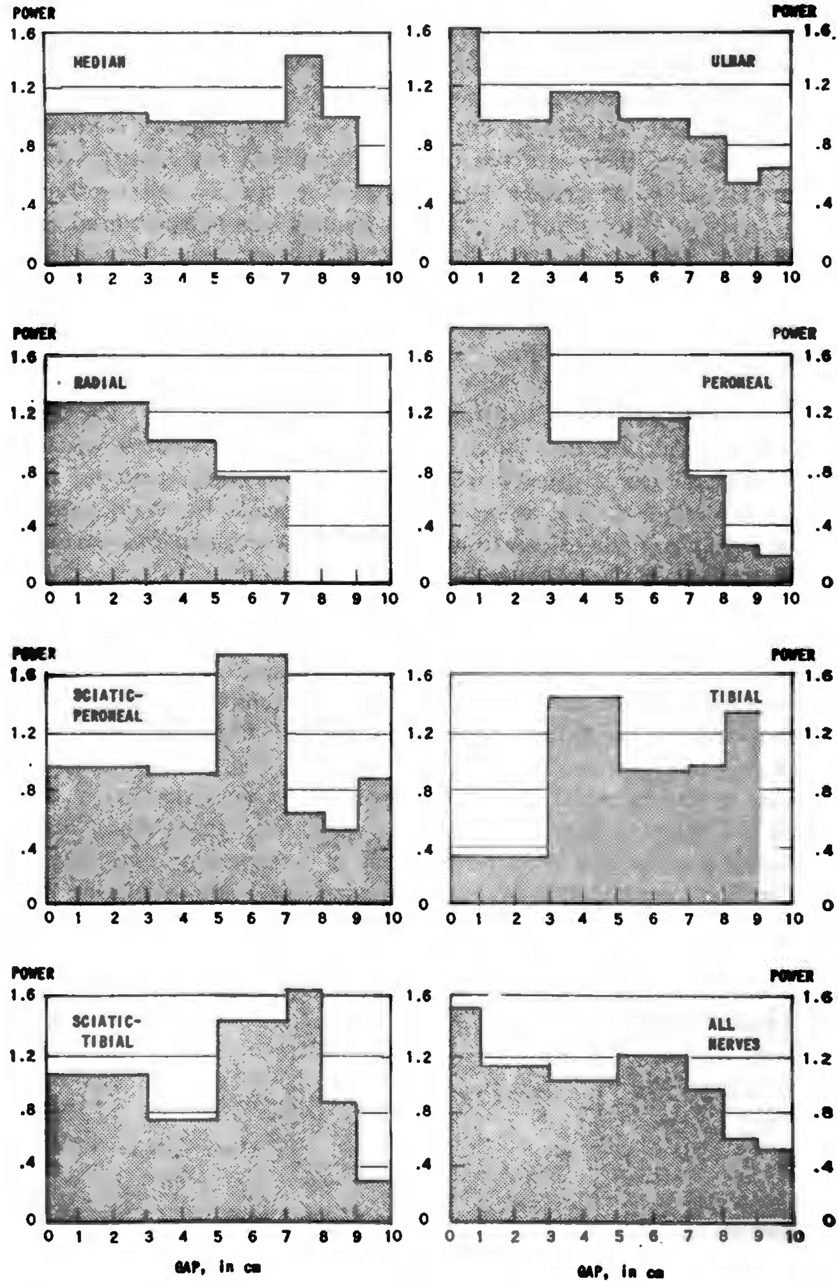


Figure 15. *Average Percentage of Muscles Contracting Against Resistance in Relation to Length of Surgical Gap at Definitive Suture, by Nerve*

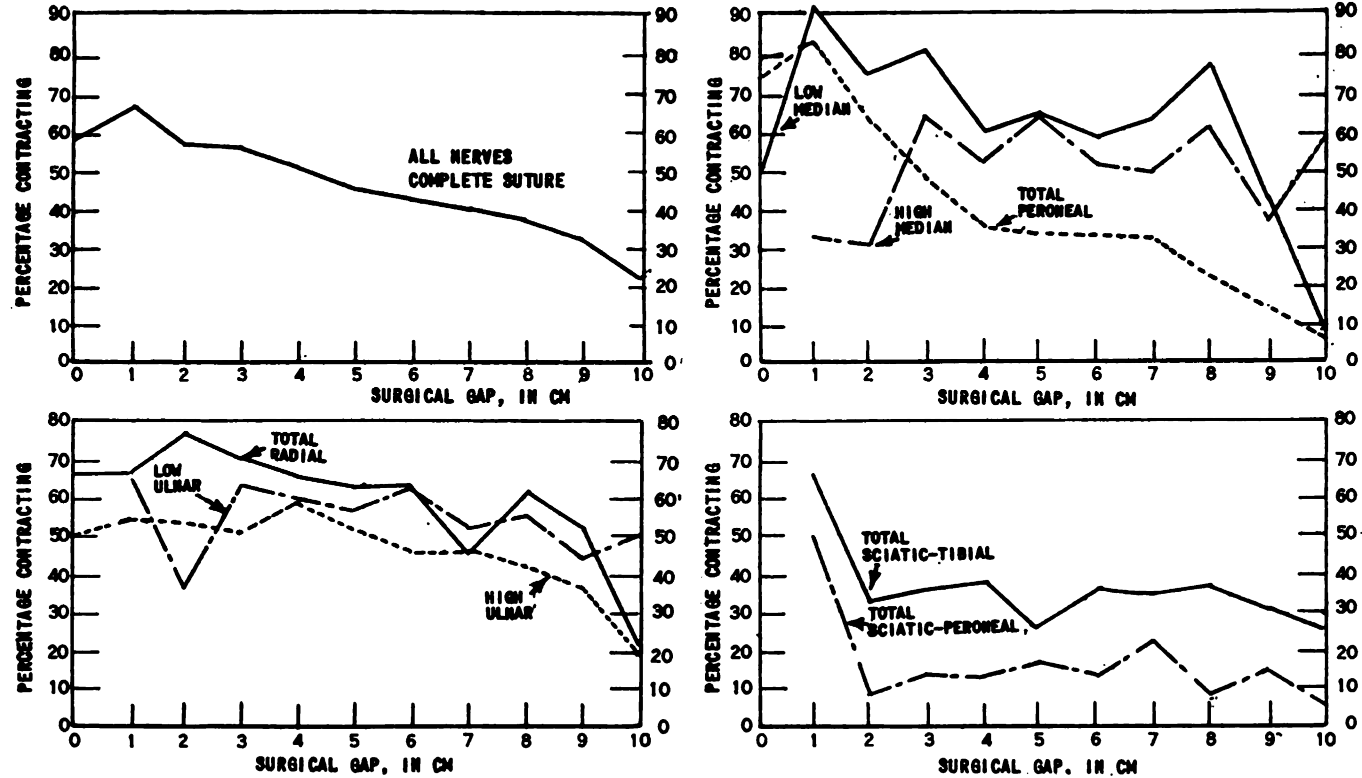


Table 95.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Presence of Transposition or Extensive Mobilization at Definitive Suture*

Nerve, gross site, and muscle	Special operative features: None				Special operative features: Transposition or extensive mobilization				Statistical tests on means [1]
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
High median									
Fl. poll. long	54	87.1	69.4	28.89	31	81.8	69.7	29.03	NS
Fl. dig. prof. 2	78	82.9	63.4	22.44	53	85.5	58.2	19.15	NS
Abd. poll. brev	54	73.7	40.4	12.78	34	80.6	38.9	10.59	NS
Low median									
Fl. poll. long	24	96.1	76.9	42.92	18	78.9	63.2	39.44	NS
Fl. dig. prof. 2	32	97.3	91.9	55.47	24	88.5	69.2	42.29	NS
Abd. poll. brev	57	79.2	49.3	11.84	39	83.7	53.5	19.23	NS
High ulnar									
Fl. dig. prof. 4 & 5	53	89.4	59.6	23.58	187	94.5	79.0	32.81	NS
Abd. dig. V	59	85.2	26.2	3.81	210	84.7	37.7	8.19	*
1st dors. inteross	46	70.2	21.3	4.02	153	81.2	41.2	9.48	NS
Low ulnar									
Fl. dig. prof. 4 & 5	20	90.4	71.4	36.00	84	96.6	83.0	39.14	NS
Abd. dig. V	76	92.3	47.4	13.88	167	90.0	45.9	11.21	NS
1st dors. inteross	56	91.4	46.6	16.25	125	85.0	42.1	11.16	NS

Radial									
Ext. car. rad	130	95.2	88.4	41.23	48	98.1	84.6	37.40	NS
Ext. dig	129	89.5	62.7	24.53	45	89.4	57.4	27.78	NS
Ext. poll. long	129	84.4	53.2	16.90	47	77.6	49.0	15.74	NS
Peroneal									
Tib. ant	110	81.3	43.8	20.23	40	68.3	24.4	10.25	NS
Ext. dig. long	114	75.9	36.2	11.71	47	52.1	16.7	5.53	NS
Ext. hall. long	111	64.0	27.2	8.47	45	37.0	15.2	7.56	NS
Peron. long	109	79.1	47.8	21.28	46	62.5	37.5	13.80	NS
Tibial									
Gastroc. & sol.[3]	35	97.2	88.6	....	11	90.9	90.9	....	....
Fl. dig. long	42	58.2	25.6	6.43	22	60.0	36.0	10.68	NS
Fl. hall. long	42	65.1	27.9	8.21	22	58.3	33.3	8.86	NS
Sciatic-peroneal									
Tib. ant	128	61.2	21.7	5.64	84	55.3	15.3	4.17	NS
Ext. dig. long	129	42.7	13.7	3.18	84	41.9	7.0	.48	**
Ext. hall. long	128	33.3	12.4	3.01	83	34.5	4.8	.84	NS
Peron. long	130	56.5	20.6	5.15	82	52.9	14.1	2.20	NS
Sciatic-tibial									
Gastroc. & sol	95	96.1	82.4	48.21	63	93.0	81.7	41.03	NS
Fl. dig. long	100	28.7	9.9	3.25	69	23.2	7.2	2.25	NS
Fl. hall. long	100	28.7	9.9	2.95	68	22.1	5.9	1.62	NS

[1] Results of statistical tests are abbreviated as follows:

NS = Not significant. ** = Significant at .01 level.

* = Significant at .05 level. [3] Mean power not calculated.

Table 96.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Presence of Antecedent Bulb Suture*

Nerve, gross site, and muscle	Bulb suture: Not done [1]				Bulb suture: Done				Statistical tests on means [2]
	Number of cases	Percentage contracting: Total	Percentage contracting: Against resistance	Mean relative power, all cases	Number of cases	Percentage contracting: Total	Percentage contracting: Against resistance	Mean relative power, all cases	
High median									
Fl. poll. long	62	87.1	69.4	([3])	11	81.8	72.7	([3])	([3])
Fl. dig. prof. 2	82	82.9	63.4	([3])	14	92.8	71.4	([3])	([3])
All median									
Fl. dig. prof. 2	112	([3])	([3])	32.54	15	([3])	([3])	28.67	NS
High ulnar									
Fl. dig. prof. 4 & 5	57	89.4	59.6	([3])	11	72.8	45.5	([3])	([3])
Abd. dig. V	61	85.2	26.2	([3])	15	86.7	40.0	([3])	([3])
1st dors. inteross	47	70.2	21.3	([3])	12	66.7	25.0	([3])	([3])

All ulnar									
Abd. dig. V	135	[3]	[3]	9.48	25	[3]	[3]	6.00	NS
1st dors. inteross	102	[3]	[3]	10.74	20	[3]	[3]	5.25	NS
Radial									
Ext. car. rad	130	95.2	88.4	41.23	24	88.0	60.0	23.13	**
Ext. dig	129	89.5	62.7	24.53	21	72.7	40.9	15.95	NS
Ext. poll. long	141	84.4	53.2	[3]	21	61.9	38.1	[3]	[3]
Peroneal									
Ext. dig. long	116	75.9	36.2	[3]	10	20.0	0	[3]	....
Ext. hall. long	114	64.0	27.2	[3]	10	10.0	0	[3]	....
Peron. long	115	79.1	47.8	[3]	10	30.0	0	[3]	....
Sciatic-peroneal									
Tib. ant	129	61.2	21.7	[3]	13	53.9	15.4	[3]	....
Ext. dig. long	131	42.7	13.7	[3]	13	30.8	7.7	[3]	....
Ext. hall. long	129	33.3	12.4	[3]	13	30.8	0	[3]	....
Peron. long	131	56.5	20.6	[3]	13	38.5	7.7	[3]	....
Sciatic-tibial									
Gastroc. & sol	102	96.1	82.4	[3]	12	83.4	66.7	[3]	....
Fl. dig. long	101	28.7	9.9	[3]	12	25.0	0	[3]	....
Fl. hall. long	101	28.7	9.9	[3]	12	16.7	0	[3]	....

[1] Cases with no special operative features of any kind.
[2] Results of statistical tests are abbreviated as follows:
NS=Not significant.
**=Significant at .01 level.
[3] Not calculated.

7. Bone Resection

It is not often that the surgeon finds it necessary to resect normal bone in the interests of achieving a more satisfactory anastomosis; in this series such resection was undertaken on 9 limbs involving 13 complete sutures as follows: median (4), ulnar (3), radial (6). The surgical gaps were not always long, ranging from 3 to 14 cm. and averaging 6.4 cm. Follow-up examinations were performed on 5 of the men and for 7 sutured nerve lesions motor recovery was classified according to the modified British code as follows:

	Modified British classification	*Number of lesions*
0	No contraction at all	None
1	Return of perceptible contraction, proximal muscles only	None
2	Proximal muscles acting against gravity, no return of power in intrinsics.	None
3	Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles.	Median (1) Ulnar (2) Radial (2)
4	Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance.	Radial (2)
5	Return of function as in category 4, with the addition that some synergic and isolated movements are possible.	None
6	Complete recovery	None

Although the sample is pitifully small, it suggests that peripheral nerve regeneration in such cases is no different from recovery generally following nerve suture.

8. Bulb Suture

The analysis of bulb sutures was made on the basis of both the definitive suture and the first suture, but there is very little difference between them since first sutures following bulb suture were rarely reoperated upon. There is not a great deal of information on bulb sutures, but such material as the series provides indicates that these cases did much less well than those not handled in this way. A summary of these data appears in table 96 for definitive sutures. It must be observed, however, that bulb suture is a staged procedure ordinarily reserved for long gaps, and that the evidence of this series is that gap *per se* is a factor to be reckoned with. Accordingly, the bulb sutures have also been compared with other sutures on gaps of similar length [13] and found not to differ appreciably, as may be seen from table 97. In short, preliminary bulb suture cannot be shown to have exercised any deleterious effect upon ultimate muscle recovery in this series.

[13] An indirect procedure underlies this comparison. The estimates for cases in which bulb suture was not done were obtained as follows: Trend-lines were fitted by inspection to the individual panels of figure 14, for gaps of 0 to 8 cm., and extended to 10 cm., at which point the value of the trend-line was taken as the estimate of power for cases without bulb suture.

9. Character of Nerve Ends at Definitive Suture

Operation reports did not always describe the gross appearance of the nerve ends which, after freshening, were ultimately approximated in the definitive suture; about a third of the sutures could not be satisfactorily coded in this respect. Although proximal and distal ends were assessed separately, it was rare for a surgeon to describe the ends as other than good or excellent, so that the only feasible analysis consists of pitting cases with both ends described as good against those with one or both ends described as only fair or even poor. Table 98 presents the data thus obtained, and makes it tolerably clear that the surgeon's description of nerve ends is of only limited prognostic value. Lesions in which the anastomosed ends were described as good or excellent appear to advantage in by no means every comparison, but do predominate with sufficient frequency to leave little doubt about their general superiority. On the average in cases with one nerve end described as only fair or even poor the tested muscles failed to contract perceptibly with 1.37 times the frequency observed for those in which both ends were described as good. They contracted against resistance about .85 times as often, and their average power (whether contracting against resistance or not) was about .79 times as much.

Table 97.—*Definitive Sutures With and Without Prior Bulb Suture, and Average Percentage of Affected Muscles Contracting Against Resistance, by Nerve*

Nerve sutured	Average percentage of affected muscles contracting against resistance: Bulb suture	No bulb suture
High median	59	40
High ulnar	37	35
Radial	46	45
Peroneal	0	15
Sciatic-peroneal	8	5
Sciatic-tibial	22	25

Table 98.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Operator's Description of Nerve Ends at Definitive Suture*

Nerve, gross site, and muscle	Character of nerve ends							
	Both good or excellent				One or more fair or poor			
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases
		Total	Against resistance			Total	Against resistance	
High median								
Fl. poll. long	44	85.5	66.7	23.64	21	72.0	56.0	17.85
Fl. dig. prof. 2	66	88.2	60.3	19.47	32	75.7	51.4	13.75
Abd. poll. brev	45	85.7	40.8	7.78	19	47.6	33.3	9.47
Low median								
Fl. poll. long	25	92.0	68.0	[1]	7	85.7	71.4	[1]
Fl. dig. prof. 2	33	94.0	78.8	[1]	9	88.9	88.9	[1]
Abd. poll. brev	45	79.3	45.3	9.67	22	87.5	50.0	15.45
High ulnar								
Fl. dig. prof. 4 & 5	123	92.3	71.5	27.15	44	91.0	70.5	34.20
Abd. dig. V	136	81.7	35.0	7.76	52	83.0	30.2	6.92
1st dors. inteross	94	74.6	37.3	7.55	45	80.9	36.2	5.78

Low ulnar								
Fl. dig. prof. 4 & 5	59	96. 9	84. 6	41. 64	16	87. 6	68. 8	33. 22
Abd. dig. V	134	93. 5	51. 8	15. 11	43	81. 4	34. 9	6. 55
1st dors. inteross	99	87. 8	45. 3	12. 22	34	80. 0	25. 7	6. 03
Radial								
Ext. car. rad	100	97. 2	85. 3	38. 50	52	87. 7	73. 7	35. 00
Ext. dig	93	89. 9	60. 6	26. 83	50	77. 7	48. 1	17. 70
Ext. poll. long	95	82. 0	58. 0	19. 26	46	76. 0	38. 0	9. 24
Peroneal								
Tib. ant	84	75. 0	32. 1	15. 06	34	65. 8	22. 9	7. 65
Ext. dig. long	93	66. 7	26. 9	9. 10	37	51. 3	16. 2	5. 14
Ext. hall. long	91	58. 3	22. 0	7. 75	35	25. 7	11. 4	6. 00
Peron. long	91	74. 2	40. 9	16. 81	36	59. 4	35. 1	12. 36
Tibial								
Gastroc. & sol	27	96. 3	85. 2	(1)	10	100. 0	100. 0	(1)
Fl. dig. long	38	64. 3	28. 6	6. 84	15	62. 5	25. 0	10. 00
Fl. hall. long	42	69. 1	26. 2	(1)	15	53. 3	13. 3	(1)
Sciatic-peroneal								
Tib. ant	108	61. 8	22. 7	5. 06	50	54. 0	10. 0	2. 30
Ext. dig. long	110	43. 4	11. 5	1. 77	50	42. 0	6. 0	. 70
Ext. hall. long	110	38. 4	10. 7	2. 09	49	26. 5	2. 0	(1)
Peron. long	107	59. 4	20. 7	4. 63	50	48. 0	6. 0	. 70
Sciatic-tibial								
Gastroc. & sol	87	98. 0	82. 5	46. 26	36	85. 0	75. 0	33. 06
Fl. dig. long	103	21. 1	3. 2	1. 31	39	15. 4	2. 6	. 90
Fl. hall. long	94	21. 3	4. 3	1. 65	39	10. 3	0	(1)

[1] Not calculated.

It is of interest to note here that there is some correlation between the surgeon's gross evaluation of nerve ends and that based on later histopathological study of the same cases by Dr. William R. Lyons. (See ch. XI.) For the 152 cases with both ratings, regardless of nerve involved, the relationship is shown in table 99.

Table 99.—*Relation Between Surgeon's Description of Nerve Ends Sutured at Definitive Operation and Neuropathologist's Average Rating as to Expected Recovery* [1]

Surgeon's description of nerve ends	Number of cases	Neuropathologist's average rating
Both good or excellent	84	54
Both fair	49	43
Both poor	11	26
Mixed	8	48
Total	152	48

[1] On a scale of 0 to 100; see pp. 512–513 for complete description.

10. Tension Upon Suture Line

The operator reported his impression of the tension on the suture line even less often than he described the nerve ends; 46 percent of the definitive sutures could not be coded adequately for this characteristic. In all but 21 percent of the sutures which were adequately described the operator observed tension to be essentially absent or slight, and in such instances the code rubric "no tension" was employed. However, the failure of the operator to note significant tension with any real frequency does create difficulties in studying the significance of his characterization of degrees of tension, and the main analysis here, as reported in table 100, consists of comparisons of sutures described as having at least moderate tension v. those with less than moderate tension. Although the data are not without some evidence that sutures under at least moderate tension did less well, especially those on radial lesions, if one insists that any effect be general, applying to all nerves, then the evidence is seen to be insufficient. For the numbers of lesions involved the differences are too small, and their direction too often contrary to expectation, to permit the conclusion that the operator's report of tension is of real value in prognosis. The comparatively few lesions described by surgeons as characterized by severe tension were also studied separately but without adding appreciably to the evidence of association with follow-up status. It would appear, then, from these data and those of chapter II that the prognostic value of the surgeon's report of tension on the suture line is limited to the likelihood of resuture.

Table 100.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Operator's Evaluation of Tension on Definitive Suture Line*

Nerve, gross site, and muscle	Tension on suture line								Statistical tests on the proportions [1]
	Absent				At least moderate				
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
High median									
Fl. poll. long	47	87. 2	72. 3	([2])	14	64. 3	42. 9	([2])	....
Fl. dig. prof. 2	63	85. 9	60. 9	20. 56	18	66. 6	44. 4	13. 33	....
Abd. poll. brev	40	82. 5	45. 0	([2])	15	40. 0	26. 7	([2])	....
Low median									
Fl. poll. long	17	82. 3	64. 7	([2])	7	100. 0	71. 4	([2])	....
Fl. dig. prof. 2	28	92. 9	75. 0	([2])	5	100. 0	100. 0	([2])	....
Abd. poll. brev	36	86. 7	55. 6	17. 64	16	88. 9	27. 8	3. 44	....
High ulnar									
Fl. dig. prof. 4 & 5	120	94. 5	75. 6	31. 54	26	88. 4	53. 8	22. 88	....
Abd. dig. V	138	86. 5	39. 7	7. 10	23	76. 0	36. 0	3. 48	NS
1st dors. inteross	99	84. 6	39. 4	7. 93	21	76. 2	23. 8	9. 76	....

See footnotes at end of table.

Table 100.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Operator's Evaluation of Tension on Definitive Suture Line*—Continued

Nerve, gross site, and muscle	Tension on suture line								Statistical tests on the proportions [1]
	Absent				At least moderate				
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
Low ulnar									
Fl. dig. prof. 4 & 5	56	96.4	75.0	....	13	92.3	92.3	....	....
Abd. dig. V	127	91.7	42.1	11.50	24	91.7	50.0	9.85	NS
1st dors. inteross	101	82.1	34.9	9.60	18	88.9	55.6	18.61	....
Radial									
Ext. car. rad	84	94.8	82.3	37.86	39	95.6	80.0	31.15	....
Ext. dig	81	86.2	62.1	27.90	35	82.9	51.2	12.57	....
Ext. poll. long	80	80.5	55.2	18.13	39	71.4	35.7	7.82	NS
Peroneal									
Tib. ant	79	70.9	30.4	([2])	9	66.6	22.2	([2])	....
Ext. dig. long	86	67.4	27.9	([2])	12	50.0	8.3	([2])	....
Ext. hall. long	83	54.2	21.7	([2])	12	25.0	8.3	([2])	....
Peron. long	86	73.2	45.3	([2])	12	41.6	8.3	([2])	NS

Tibial									
Gastroc. & sol..................	29	100.0	93.1	([3])	3	66.7	66.7	([3])	....
Fl. dig. long....................	43	58.1	27.9	([3])	5	60.0	40.0	([3])	....
Fl. hall. long..................	44	54.5	22.7	([3])	5	60.0	40.0	([3])	NS
Sciatic-peroneal									
Tib. ant........................	95	60.4	20.8	5.89	36	47.2	13.9	4.31	....
Ext. dig. long..................	96	41.8	12.2	1.41	36	36.2	5.6	2.50	....
Ext. hall. long..................	96	33.0	10.3	2.50	35	28.6	5.7	2.57	....
Peron. long....................	97	54.6	17.5	([3])	35	45.7	8.6	([3])	NS
Sciatic-tibial									
Gastroc. & sol..................	70	94.9	82.1	45.50	34	94.5	77.8	39.56	....
Fl. dig. long....................	76	19.7	3.9	1.32	36	27.8	5.6	.83	....
Fl. hall. long..................	75	20.0	5.3	1.67	36	27.8	5.6	.56	NS

[1] Tests were done on the proportions with no perceptible contraction, with perceptible contraction but not against resistance, and with contraction against resistance. Results of tests abbreviated as follows: NS—Not significant.

[3] Not calculated.

11. Suture Material

Although the great majority of World War II sutures were accomplished with tantalum wire, perhaps a fourth were performed with silk and in the sampling plan for this study a special effort was made to include cases from Dr. Thomas I. Hoen's plasma glue series. There are two comparisons of intrinsic interest, then—tantalum v. silk and tantalum v. plasma glue. Since the choice of suture material was made by the individual surgeon, there is no reason to expect that tantalum and silk sutures would differ in any important particular associated with prognosis, e. g., length of gap, etc., but no study has actually been made on this point, and to that extent their comparability is merely assumed here. The only factor which seemed worthy of scrutiny was echelon of definitive suture, but since 73 percent of overseas sutures and 70 percent of Z/I sutures were accomplished with tantalum, it was concluded that there was no confounding of suture material and echelon.

Tantalum and silk sutures were compared directly, muscle by muscle, but only small and statistically insignificant differences were found. Table 101 presents these comparisons in detail.

Special attention was, however, paid to the plasma glue series since it did not constitute an organic part of the Army Peripheral Nerve Registry but represented the work of a single surgeon at a particular Navy hospital (St. Albans) in the Z/I, and despite the fact, already described, that it represented consecutive, unselected cases seen at that hospital. The comparison of tantalum and plasma glue sutures was made on the basis of the following characteristics, separately by nerve and, for median and ulnar lesions, by gross site:

Associated nerve injury.
Handedness.
Type of injury to nerve.
Specific site.
Associated bone and joint injury.
Chronic infection delaying repair.
Associated vascular injury.
Plastic repair at site of nerve suture.
Number of operations.
Days from injury to definitive repair.
Length of surgical defect.
Condition of nerve ends.
Special operative features, e. g., bulb suture, transposition, and mobilization.
Reason for any resuture.
Reason for any obvious failure of suture.

On all of these characteristics except three the tantalum and plasma glue cases are indistinguishable—specific site of lesion, number of operations, and days from injury to definitive repair. For sutures on the median and ulnar, but not for those on the other nerves, the lesions sutured by plasma glue were more distal than those sutured by tantalum. Low median and low ulnar sutures done by plasma glue were usually in the lower third of

Table 101.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Type of Suture Material Used in Definitive Suture*

Nerve, gross site, and muscle	Suture material								Statistical tests [1]	
	Tantalum				Silk				A	B
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases		
		Total	Against resistance			Total	Against resistance			
High median										
Fl. poll. long	71	87.2	73.1	30.07	22	76.0	60.0	23.86	....	NS
Fl. dig. prof. 2	107	83.9	64.3	21.59	32	88.6	62.9	23.28	....	NS
Abd. poll. brev	73	79.4	39.7	([2])	21	71.4	38.1	([2])	....	....
Low median										
Fl. poll. long	28	93.3	83.3	47.14	10	70.0	60.0	35.00	....	NS
Fl. dig. prof. 2	40	95.4	88.4	53.25	15	87.5	75.0	43.33	....	NS
Abd. poll. brev	70	85.7	54.3	([2])	15	66.7	46.7	([2])	....	....

See footnotes at end of table.

Table 101.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Type of Suture Material Used in Definitive Suture*—Continued

Nerve, gross site, and muscle	Suture material								Statistical tests[1]	
	Tantalum				Silk					
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	A	B
		Total	Against resistance			Total	Against resistance			
High ulnar										
Fl. dig. prof. 4 & 5	185	93.5	76.9	31.38	60	93.6	73.0	31.00	....	NS
Abd. dig. V	215	84.1	35.9	6.33	64	89.2	33.8	9.53	NS	NS
1st dors. inteross	172	77.4	35.5	(2)	47	85.1	40.4	(2)	....	....
Low ulnar										
Fl. dig. prof. 4 & 5	181	94.1	78.8	40.94	19	100.0	84.2	31.39	....	NS
Abd. dig. V	173	92.7	48.6	11.80	53	84.9	39.6	11.32	NS	NS
1st dors. inteross	143	86.8	42.7	(2)	39	87.2	51.3	(2)	....	....
Radial										
Ext. car. rad	155	95.9	88.8	41.03	57	90.0	76.7	37.98	....	NS
Ext. dig	149	91.0	62.8	26.31	55	84.3	63.2	25.55	....	NS
Ext. poll. long	148	84.7	52.9	17.09	55	77.2	57.9	20.55	NS	NS

Peroneal										
Tib. ant.	109	71.1	36.9	18.07	42	83.4	42.9	17.86	....	NS
Ext. dig. long	117	62.4	27.4	9.66	48	73.5	32.7	9.17	....	NS
Ext. hall. long	113	53.6	21.1	8.36	48	59.2	26.5	6.67	....	NS
Peron. long	113	70.1	45.3	19.60	46	72.9	35.4	14.57	NS	NS
Tibial										
Gastroc. & sol.	31	96.9	93.9	61.77	11	91.6	83.3	45.91	....	NS
Fl. dig. long	42	61.7	34.0	8.69	23	65.2	26.1	8.48	....	NS
Fl. hall. long	44	69.6	33.3	8.30	21	71.4	23.8	8.33	NS	NS
Sciatic-peroneal										
Tib. ant.	163	61.2	21.2	5.71	47	53.2	17.0	4.50	....	NS
Ext. dig. long	163	44.3	13.2	1.93	48	35.5	6.3	2.92	....	NS
Ext. hall. long	162	36.0	11.6	2.47	47	25.5	2.1	1.06	....	NS
Peron. long	163	55.4	17.5	3.96	46	53.2	17.0	4.67	NS	NS
Sciatic-tibial										
Gastroc. & sol.	122	93.9	83.2	46.43	34	94.9	82.1	42.79	....	NS
Fl. dig. long	127	29.0	10.2	2.72	39	20.5	5.1	3.46	....	NS
Fl. hall. long	126	28.3	9.4	2.38	39	20.5	5.1	2.69	NS	NS

[1] Probabilities were obtained as follows: A is based on tests of the proportions without perceptible contraction, with perceptible contraction but not against resistance, and with contraction against resistance; B is based on two-tailed tests of means. Results of tests abbreviated as follows: NS—Not significant.

[2] Not calculated.

the forearm or in the wrist, while those done by tantalum were more often in the upper and middle thirds of the forearm. Insofar as this confounding of site and suture material would be expected to bias the suture comparisons, the bias would favor the plasma glue cases, since the more distal lesions do as well as or better than those proximal to them in the median and ulnar, but the magnitude of any bias could hardly be appreciable. The heterogeneity as to number of operations is somewhat more serious. The observations appear in table 102. Since not all operations were sutures, the discrepancy was explored further to ascertain if the plasma glue sutures more often required resuture, but such is not the case: they had more often been operated upon previously. Finally, the mean interval from injury to operation was found to be much greater for plasma glue cases (table 103).

Table 102.—*Percentage of Definitive Sutures With More Than One Operation, by Type of Suture Material, and by Nerve and Gross Site*

Nerve and gross site	Percentage with more than one operation	
	Tantalum	Plasma glue
Low median	16	45
Low ulnar	20	29
Radial	17	19
Sciatic	19	38

Table 103.—*Mean Days From Injury to Definitive Suture, by Type of Suture Material, and by Nerve and Site*

Nerve and gross site	Mean interval, in days	
	Tantalum	Plasma glue
Low median	216	270
Low ulnar	179	218
Radial, all	148	390
Sciatic, all	174	286

Tantalum and plasma glue sutures were first compared directly and, as would be expected from the differences already noted in number of operations and interval from injury to operation, large and statistically quite significant differences were found. However, the results of these biased comparisons are not shown, but in their stead table 104 presents the best unbiased comparisons which could be developed from the present series. The latter selection was based on suture material at the first suture, to obviate the bias associated with the fact that so many of the St. Albans cases had previously been operated upon before the plasma glue sutures were performed, and the series were roughly matched for interval from injury to first suture because lesions in the St. Alban's series were operated upon somewhat later than those in the silk and tantalum series. These restrictions reduced the available plasma glue series to about 50 cases, 20 low median, 20 low ulnar, and 12 radial sutures. In table 104 these are contrasted with comparable silk and tantalum sutures on the basis of the voluntary contraction of representative muscles; any doubt as to their homogeneity is dissipated by these data. If suitable care is taken to insure comparability of material, therefore, there is no reason to believe that motor regeneration following plasma glue suture differs in any way from that following suture with silk or tantalum.

Table 104.—*Voluntary Contraction of Representative Affected Muscles Following Complete Suture, by Nerve and Type of Suture Material*

Voluntary contraction	Silk and tantalum		Plasma glue	
	Number	Percent	Number	Percent
Low median				
None	15	*18.8*	3	*15.0*
Perceptible or against gravity, but not against resistance	24	*30.0*	7	*35.0*
Against resistance	41	*51.2*	10	*50.0*
Total	80	*100.0*	20	*100.0*
Low ulnar				
None	19	*8.8*	4	*20.0*
Perceptible or against gravity, but not against resistance	98	*45.1*	9	*45.0*
Against resistance	100	*46.0*	7	*35.0*
Total	217	*99.9*	20	*100.0*
Radial				
None	9	*6.3*	1	*8.3*
Perceptible or against gravity, but not against resistance	15	*10.5*	1	*8.3*
Against resistance	119	*83.2*	10	*83.3*
Total	143	*100.0*	12	*99.9*

12. Use of Cuff

About one-third of the definitive sutures were accomplished with the aid of a cuff, almost always one of tantalum foil. Also, about 1 out of 4 cuffs was removed some time after it had been placed. The observations permit, then, the exploration of two problems: (a) differences associated with the original decision to employ a cuff; and (b) differences associated with the subsequent decision to remove one already placed. These problems were first studied grossly on the material as a whole, without regard for the possibility that cuffs might be used more on one type of case than another. Table 105 contains all the pertinent data for the first problem, and very strongly suggests that cases with tantalum foil generally had a somewhat better recovery than lesions not so treated. On the average, both mean relative power and percentage of muscles contracting against resistance were about 20 to 25 percent higher when tantalum cuff had been used.

Surgical experience in the Z/I suggested that the decision not to employ a cuff might often be based on considerations which were unfavorable to regeneration. Examples are: (a) the presence of a large discrepancy in the size of a still partially scarred proximal end and an atrophied distal end in a late repair; (b) rerouting of the nerve might force location of the suture-line directly beneath the skin where the use of a cuff would be inadvisable; and (c) in a badly scarred area it might be thought that a foreign body might not be well tolerated. For these reasons a better controlled comparison of lesions with and without cuff was made on the basis of only those sutures which met the following specifications:

Army Registry cases only.
Absence of chronic infection delaying repair and of associated injuries involving bone, joint, or artery, or requiring plastic repair.
Surgical gap of 6 cm. or less.
Suture in the interval 40 to 199 days after injury.

Among lesions meeting these specifications those in which a cuff was placed at definitive suture had no real advantage, as may be seen in table 106. The selection of cases to receive tantalum cuffs was also investigated in relation to the presence or absence of the associated injuries listed above, whether gap was more or less than 6 cm., and whether suture was done in the interval 40–199 days or later. It was found that the likelihood that a cuff would be placed at definitive suture varied quite markedly among the eight groups representing all the combinations of these factors, the influence of time being paramount. In figure 16 a comparison is made between the group of cases having the least favorable combination of these factors (one or more associated injuries, long gap, delayed suture) and the group having the most favorable (no associated injuries, short gap, and relatively early suture). The discrepancy between them as to percentage with cuff is marked for every nerve. It does appear, therefore, that lesions with cuffs in this series generally have a more favorable initial prognosis.

Table 105.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Use of Tantalum Foil Wrapping at Definitive Suture*

Nerve, gross site, and muscle	No cuff used				Tantalum cuff				Statistical tests on means [1]
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
High median									
Fl. poll. long	47	75. 9	61. 1	26. 81	41	90. 7	72. 1	23. 78	NS
Fl. dig. prof. 2	72	84. 8	58. 2	22. 29	59	83. 3	63. 3	16. 69	NS
Abd. poll. brev	50	75. 0	32. 7	10. 10	36	79. 5	46. 2	14. 03	NS
Low median									
Fl. poll. long	27	86. 2	65. 5	34. 26	15	93. 4	86. 7	55. 00	NS
Fl. dig. prof. 2	30	91. 9	78. 4	43. 17	25	96. 0	92. 0	55. 80	NS
Abd. poll. brev	68	82. 7	49. 4	12. 21	25	80. 8	65. 4	25. 20	**
High ulnar									
Fl. dig. prof. 4 & 5	145	91. 8	68. 4	28. 28	86	93. 5	78. 3	29. 83	NS
Abd. dig. V	167	84. 8	31. 6	6. 32	97	83. 8	34. 3	6. 55	NS
1st dors. inteross	125	76. 5	33. 3	7. 52	71	75. 0	36. 8	8. 24	NS

See footnotes at end of table.

Table 105.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture, by Use of Tantalum Foil Wrapping at Definitive Suture*—Continued

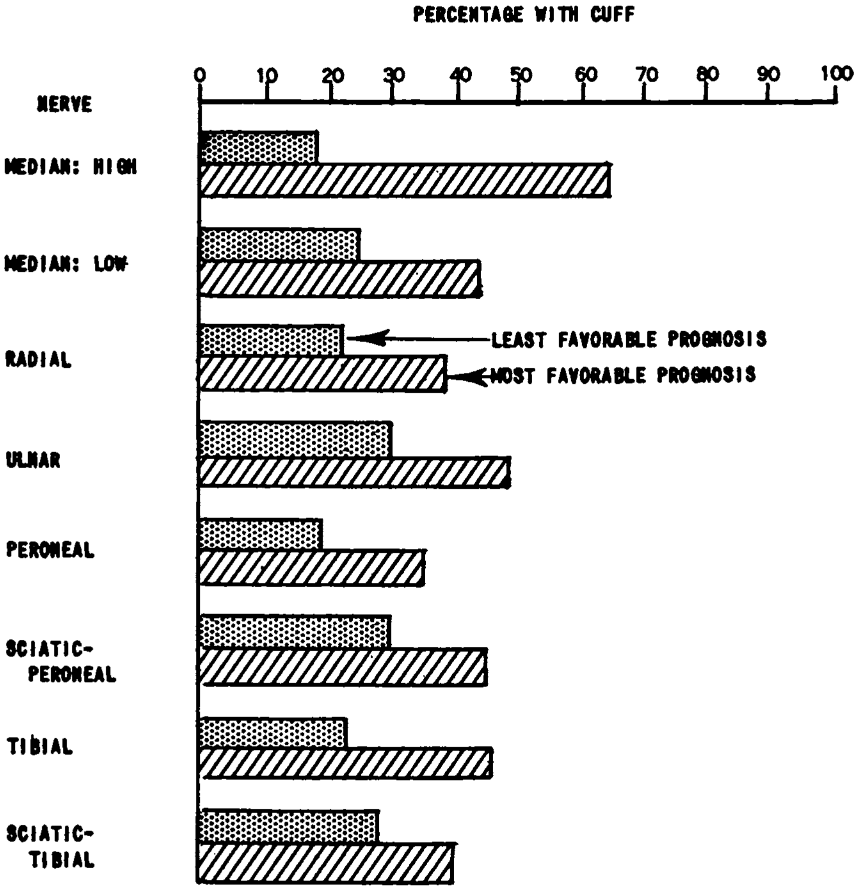
Nerve, gross site, and muscle	No cuff used				Tantalum cuff				Statistical tests on means [1]
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
Low ulnar									
Fl. dig. prof. 4 & 5	56	96. 6	78. 3	39. 34	40	92. 9	78. 6	39. 75	NS
Abd. dig. V	148	92. 7	43. 4	11. 70	84	89. 5	47. 1	12. 80	NS
1st dors. inteross	117	88. 6	40. 2	12. 39	59	82. 8	45. 3	12. 29	NS
Radial									
Ext. car. rad	123	93. 5	78. 4	34. 72	89	94. 9	88. 8	42. 25	NS
Ext. dig	120	86. 3	62. 1	23. 58	86	90. 1	58. 2	25. 23	NS
Ext. poll. long	121	78. 2	52. 6	16. 03	85	86. 5	49. 4	16. 71	NS
Peroneal									
Tib. ant	108	70. 2	31. 5	13. 19	34	85. 3	52. 9	26. 18	*
Ext. dig. long	120	62. 6	26. 8	7. 79	35	77. 2	34. 3	14. 43	NS
Ext. hall. long	118	49. 6	19. 8	6. 86	33	61. 8	32. 4	11. 21	NS
Peron. long	115	67. 2	37. 7	15. 17	34	80. 0	57. 1	24. 41	NS

Tibial									
Gastroc. & sol.	30	96.7	86.7	([2])	12	100.0	100.0	([2])	....
Fl. dig. long	41	57.8	26.7	7.07	20	76.2	38.1	10.00	NS
Fl. hall. long	41	59.5	19.0	5.61	20	78.2	47.8	11.25	NS
Sciatic-peroneal									
Tib. ant.	119	50.8	15.8	4.34	91	72.8	21.7	5.93	NS
Ext. dig. long	121	39.0	8.9	2.07	90	48.9	13.0	2.11	NS
Ext. hall. long	120	29.8	5.8	1.21	89	41.1	14.4	3.48	NS
Peron. long	121	49.6	15.5	3.31	89	64.9	20.9	4.83	NS
Sciatic-tibial									
Gastroc. & sol.	91	94.0	78.0	41.59	65	94.4	86.1	50.69	NS
Fl. dig. long	98	20.2	6.1	2.04	71	33.8	11.3	3.10	NS
Fl. hall. long	98	20.2	6.1	1.53	70	34.3	11.4	3.64	NS

[1] Results of tests (two-tailed) are abbreviated as follows:
NS=Not significant.
*=Significant at .05 level.
**=Significant at .01 level.

[2] Not calculated.

Figure 16. *Percentage of Definitive Sutures Completed With Aid of Tantalum Cuff, Two Prognostic Groups From Army Registry*



The fact of selection, coupled with the failure of cases with cuffs to appear at an advantage when the comparison is restricted to a fairly homogeneous set of cases (table 106), robs the present data of any value in support of the therapeutic usefulness of the tantalum cuff. Conversely, however, the data by no means disprove the value of the cuff as a therapeutic device; the data simply do not fulfill the requirements of an unbiased treatment comparison.

Cuff removal was studied in all cases wrapped in tantalum foil at the definitive suture, but no real evidence was developed to suggest that the practice, which became a very nearly routine procedure in some neurosurgical centers, exerted any effect upon motor recovery. Table 107 provides the data upon which this conclusion rests.

13. Use of Stay Suture

In about 11 percent of all definitive nerve sutures and grafts the operation reports failed to specify whether stay sutures had been placed; they were definitely employed in about 25 percent of the remainder. In chapter II it was noted that resort to the stay suture was considerably more frequent among the sutures of some rosters than among others, but in the initial exploration of the material for any possible effect associated with the use of stay sutures this fact was ignored and all rosters were combined. It was also thought that sutured lesions in which the heavy stay sutures had been placed might be characterized by appreciably longer gaps than those in which stay sutures were not used, but analysis showed this not to be the case.

Table 106.—*Mean Power Following Complete Suture and Percentage of Affected Muscles Contracting Against Resistance, by Use of Tantalum Foil Wrapping at Definitive Suture, Lesions of Comparable Prognosis*

Nerve and muscle	No cuff used			Tantalum cuff		
	Number of cases	Mean relative power, all cases	Percentage contracting against resistance	Number of cases	Mean relative power, all cases	Percentage contracting against resistance
High median						
Fl. car. rad.	6	57.3	83	14	41.4	86
Fl. poll. long.	5	30.4	60	10	13.4	60
Opponens	5	0	0	14	20.6	64
Low median						
Fl. car. rad.	1	64.0	100	1	99.0	100
Fl. poll. long.	2	55.0	100	1	99.0	100
Opponens	6	11.7	50	5	63.4	100
High ulnar						
Fl. car. uln.	21	53.1	90	15	64.4	100
Fl. dig. prof. 4 & 5	21	31.2	76	16	26.3	75
Abd. dig. V	21	12.8	52	16	7.1	25
1st dors. inteross.	16	13.1	44	13	14.3	46
Low ulnar						
Fl. car. uln.	2	65.0	100	5	55.8	80
Fl. dig. prof. 4 & 5	4	52.8	100	9	38.6	67
Abd. dig. V	10	13.2	70	16	16.3	56
1st dors. inteross.	8	21.4	63	11	19.8	64

Table 106.—*Mean Power Following Complete Suture and Percentage of Affected Muscles Contracting Against Resistance, by Use of Tantalum Foil Wrapping at Definitive Suture, Lesions of Comparable Prognosis*—Continued

Nerve and muscle	No cuff used			Tantalum cuff		
	Number of cases	Mean relative power, all cases	Percentage contracting against resistance	Number of cases	Mean relative power, all cases	Percentage contracting against resistance
Radial						
Triceps	7	25.6	86	1	97.0	100
Brachiorad	14	49.0	93	15	57.7	87
Ext. car. rad	21	44.4	95	18	45.4	94
Ext. car. uln	22	41.9	91	19	40.2	79
Peroneal						
Tib. ant	17	23.2	59	10	37.8	70
Ext. dig. long	17	12.8	59	10	9.5	30
Ext. hall. long	17	7.2	47	10	10.0	30
Peron. long	16	24.3	69	10	25.6	70
Tibial						
Gastroc. & sol	7	54.3	100	2	73.5	100
Tib. post	7	17.9	43	2	45.0	50
Fl. dig. long	8	9.1	38	4	2.5	25
Sciatic-peroneal						
Tib. ant	24	8.0	25	19	1.7	16
Ext. dig. long	25	4.0	16	19	2.3	16
Ext. hall. long	24	2.2	8	19	2.3	16
Peron. long	25	7.8	28	19	1.2	16
Sciatic-tibial						
Gastroc. & sol	26	53.5	92	17	32.6	76
Tib. post	26	25.7	50	17	13.5	41
Fl. dig. long	26	3.8	8	17	1.5	12

Comparisons of sutured lesions with and without stay sutures were made on the basis of mean relative power of affected muscles and are summarized in table 108. In two of the individual muscles the differences between means are significant in the statistical sense, but the direction of these two differences is not the same, and the overall pattern of variation among all the nerves is hardly more than suggestive of an effect favoring lesions without stay sutures. No more refined study of the possible role of the stay suture seemed worth while.

Table 107.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture and Wrapping in Tantalum Foil at Definitive Suture, by Status as to Subsequent Cuff Removal*

Nerve, gross site, and muscle	Cuff removal								Statistical tests on means [1]
	Done				Not done				
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
High median									
Fl. poll. long	10	100.0	100.0	31.00	31	87.5	62.5	21.45	([2])
Fl. dig. prof. 2	15	86.7	66.7	13.00	44	82.2	62.2	17.95	NS
Abd. poll. brev	10	83.3	33.3	8.00	26	77.8	51.9	16.35	([2])
Low median									
Fl. poll. long	4	100.0	100.0	73.75	11	90.9	81.8	48.18	([2])
Fl. dig. prof. 2	4	100.0	100.0	67.50	21	95.3	90.5	53.57	([2])
Abd. poll. brev	6	57.1	57.1	20.83	19	89.5	68.4	26.58	([2])

See footnotes at end of table.

Table 107.—*Percentage of Affected Muscles Contracting and Mean Power Following Complete Suture and Wrapping in Tantalum Foil at Definitive Suture, by Status as to Subsequent Cuff Removal*—Continued

Nerve, gross site, and muscle	Cuff removal								Statistical tests on means [1]
	Done				Not done				
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
High ulnar									
Fl. dig. prof. 4 & 5	24	88.0	76.0	23.96	62	95.5	79.1	32.10	NS
Abd. dig. V	27	82.2	39.3	5.56	70	84.5	32.4	6.93	NS
1st dors. inteross	22	82.6	39.1	7.73	49	71.6	35.8	8.47	NS
Low ulnar									
Fl. dig. prof. 4 & 5	8	87.5	87.5	49.38	32	94.1	76.5	37.34	([3])
Abd. dig. V	25	80.0	36.0	7.80	59	93.4	51.7	14.92	NS
1st dors. inteross	19	79.0	47.4	16.84	40	84.4	44.4	10.13	NS
Radial									
Ext. car. rad	18	100.0	90.9	35.00	71	93.5	88.2	44.08	NS
Ext. dig	18	85.0	55.0	16.39	68	91.6	59.2	27.57	NS
Ext. poll. long	16	89.5	63.2	18.75	69	85.7	45.7	16.23	NS

Peroneal										
Tib. ant.	6	83.3	33.3	20.00	28	85.7	57.1	27.50	([2])
Ext. dig. long.	6	66.6	33.3	17.50	29	79.3	34.5	13.79	([2])
Ext. hall. long.	6	50.0	33.3	15.83	27	64.2	32.1	10.19	([2])
Peron. long.	6	50.0	33.3	19.17	28	86.2	62.1	25.54	([2])
Tibial										
Gastroc. & sol.	2	100.0	100.0	60.00	9	100.0	100.0	74.44	([2])
Fl. dig. long.	4	75.0	25.0	1.25	16	76.5	41.2	12.19	([2])
Fl. hall. long.	5	40.0	20.0	1.00	15	88.9	55.6	14.67	([2])
Sciatic-peroneal										
Tib. ant.	27	64.3	21.4	5.00	64	76.6	21.9	6.33	NS
Ext. dig. long.	26	39.3	10.7	.77	64	53.2	14.1	2.66	NS
Ext. hall. long.	26	33.3	11.1	1.54	63	44.5	15.9	4.29	NS
Peron. long.	26	67.8	21.4	2.50	63	63.5	20.6	5.79	NS
Sciatic-tibial										
Gastroc. & sol.	17	94.5	77.8	47.94	48	94.5	88.9	51.64	NS
Fl. dig. long.	18	16.7	5.6	.28	53	39.6	13.2	4.06	NS
Fl. hall. long.	17	17.7	5.9	1.76	53	39.6	13.2	4.25	NS

[1] Results of tests (two-tailed) abbreviated as follows: NS=Not significant.

[2] Not calculated.

Table 108.—*Mean Relative Power of Affected Muscles Following Definitive Suture With and Without Stay Suture*

Nerve	Gross site	Muscle	None used		Used		Statistical tests [1]
			Number of cases	Mean power	Number of cases	Mean power	
Median.....	High...	Fl. dig. prof. 2....	96	22.14	33	12.88	NS
	Total..	Abd. poll. brev....	127	13.86	49	11.02	NS
Ulnar.......	High...	Fl. dig. prof. 4 & 5.	176	31.14	45	20.56	*
		Abd. dig. V.......	200	7.18	52	5.00	NS
		1st. dors. inteross..	148	8.11	35	6.86	NS
	Low...	Fl. dig. prof. 4 & 5.	70	39.74	24	30.27	NS
		Abd. dig. V.......	171	10.70	59	15.19	NS
		1st. dors. inteross..	138	12.93	36	8.19	NS
Radial......	Total..	Ext. car. rad......	153	38.69	56	35.63	NS
		Ext. dig..........	146	26.78	55	18.45	NS
		Ext. poll. long.....	144	18.37	58	12.33	NS
Peroneal....	Total..	Tib. ant..........	107	15.47	32	14.38	NS
		Ext. dig. long.....	116	8.84	36	7.50	NS
		Ext. hall. long.....	111	7.25	35	8.43	NS
		Peron. long.......	110	15.50	35	17.29	NS
Sciatic-peroneal.	Total..	Tib. ant..........	133	4.82	67	5.90	NS
		Ext. dig. long.....	133	2.22	68	1.84	NS
		Ext. hall. long.....	133	1.20	66	4.24	*
		Peron. long.......	132	4.02	68	4.04	NS
Sciatic-tibial.	Total..	Gastroc. & sol.....	95	46.74	57	43.77	NS
		Fl. dig. long......	102	3.58	61	1.07	NS
		Fl. hall. long......	101	3.22	61	.82	NS

[1] Results of tests are abbreviated as follows:
NS = Not significant.
* = Significant at .05 level.

14. Technique of the Definitive Lysis

About 30 percent of the definitive lyses were internal, i. e., involved saline injection (25 percent) or fascicular dissection (5 percent), and the opportunity was taken to compare internal with external lyses to the extent permitted by this material, on the frank assumption that the two groups were comparable to begin with. The comparisons are made in table 109 on the basis of mean relative power. Although large and significant differences are observed for the gastrocnemius and soleus in sciatic-tibial lesions, and for the extensor hallucis longus in peroneal, for the median, ulnar, and radial muscles the differences are so small that one cannot conclude that there is adequate evidence of any *general* effect common to all nerves. If, in a larger sample, there were a clear difference between external and internal lyses on nerves of the lower extremity, one would be inclined to believe that it reflected a selection of cases with more intraneural damage rather than that the procedure *per se* had an untoward effect.

15. Training of Surgeon

As reported in chapter II, the limited exploration which was made of level of training in association with other variables contained no real suggestion that the lesions operated upon by the better-trained differed in prognosis from those operated upon by surgeons with no special training. Training was first studied on the basis of the definitive suture, and when no general association with motor recovery was found, it was repeated on the basis of the first suture. The details of the latter comparison appear in table 110. However, the latter analysis, covering both mean power and the percentage contracting against resistance, led to the same conclusion. Since any confounding of training and initial prognosis may be rather more complex than would be revealed by such exploration as it has been possible to do on these data, it cannot be argued that level of training actually exerted no general effect upon motor recovery during World War II. However, it is plain that no case for such an effect can be built upon these data. It will be noted in table 110 that the roughly 30 tibial lesions sutured by trained neurosurgeons did considerably better than the approximately 40 sutured by men with less training. This was noted in all 3 tibial muscles, although only 1 is shown here.

16. Summary

Despite the obvious difficulties inherent in the search for treatment effects in a clinical series, from the foregoing study of some of the practical details of surgical management a number of clear-cut conclusions emerge together with suggestive evidence of effects. One of the most definite and most important of these concerns elapsed time: For all nerves generally it seems rather well established by these data that the final level of motor recovery is maximal for early sutures, and that subsequent delay in suture involves a variable loss which averages about 1 percent of maximal performance for every 6 days of delay. The very earliest, or emergency, sutures done within 19 days of injury do as well at follow-up as other early sutures, but only after half of them had been resutured. Although the effect of time seems clearly a general one, its magnitude varies not only by nerve but also by muscle within the set innervated by a particular nerve. The effect seems especially large in distal muscles, and in those innervated by the radial and the peroneal. Whether sutures were done overseas or in the Z/I is of no prognostic importance if one takes time into account; the real advantage of overseas sutures seems adequately explained by the difference in time from injury to repair. The effect of time also confounds that of gap, there being a definite correlation between the two. Information about gap is of less prognostic value than information about time, but if time be ignored the effect of gap is a significant one; there is an average loss of about 6 percent per cm. from the optimal motor recovery following sutures on the shortest gaps, until the critical limit is reached when suture becomes impossible.

Table 109.—*Percentage of Affected Muscles Contracting and Mean Power Following Neurolysis, by Type of Neurolysis*

Nerve and muscle	Type of neurolysis								Statistical tests on means [2]
	External				Internal [1]				
	Number of cases	Percentage contracting		Mean relative power, all cases	Number of cases	Percentage contracting		Mean relative power, all cases	
		Total	Against resistance			Total	Against resistance		
Median									
Fl. poll. long	35	92.1	89.5	65.14	19	95.3	90.5	67.37	NS
Fl. dig. prof. 2	45	98.0	90.2	60.56	21	100.0	91.3	53.81	NS
Abd. poll. brev	32	83.8	64.9	28.59	18	88.9	55.6	24.72	NS
Ulnar									
Fl. dig. prof. 4 & 5	47	96.3	87.0	57.45	19	100.0	91.7	54.47	NS
Abd. dig. V	62	98.6	73.6	35.48	26	96.8	77.4	35.38	NS
1st dors. inteross	48	91.2	78.9	34.17	23	92.3	76.9	40.65	NS
Radial									
Ext. car. rad	19	95.0	95.0	56.05	6	100.0	100.0	72.50	NS
Ext. dig	24	100.0	83.3	56.04	7	85.7	85.7	43.57	NS
Ext. poll. long	23	86.9	73.9	34.35	6	83.3	66.7	21.67	NS

Peroneal									
Tib. ant.	15	93.3	73.3	41.00	11	72.7	54.5	36.36	NS
Ext. dig. long	15	86.6	73.3	43.33	9	88.9	55.6	16.67	NS
Ext. hall. long	14	85.7	71.4	30.71	10	40.0	10.0	2.50	NS
Peron. long	13	92.3	76.9	44.23	9	80.0	70.0	31.11	*
Sciatic-peroneal									
Tib. ant.	24	100.0	80.8	47.08	15	80.0	60.0	35.00	NS
Ext. dig. long	22	92.0	68.0	34.09	14	80.0	60.0	27.50	NS
Ext. hall. long	22	92.3	57.7	26.59	14	80.0	46.7	22.86	NS
Peron. long	25	96.3	74.1	36.40	14	80.0	66.7	42.86	NS
Sciatic-tibial									
Gastroc. & sol.	33	100.0	97.4	74.70	15	100.0	81.3	49.00	*
Fl. dig. long	35	72.5	47.5	27.14	16	50.1	31.3	11.25	NS
Fl. hall. long	35	69.2	41.0	23.43	16	50.0	25.0	11.88	NS

[1] The internal neurolyses include the 17 percent with intrafascicular dissection in the column for the percentage contracting, but the number of cases and mean relative power include only those with saline injection.

[2] Results of tests (two-tailed) are abbreviated as follows:

NS=Not significant.

*=Significant at .05 level.

Table 110.—*Percentage of Affected Muscles Contracting and Mean Power Following First Complete Suture, by Level of Neurosurgical Training of Operator*

Nerve, gross site, and muscle	Level of surgical training									Statistical tests on means [1]
	Trained neurosurgeon			General surgeon with supplementary training			No special training in neurosurgery			
	Number of cases	Percentage contracting against resistance	Mean relative power, all cases	Number of cases	Percentage contracting against resistance	Mean relative power, all cases	Number of cases	Percentage contracting against resistance	Mean relative power, all cases	
High median										
Fl. poll. long	42	73.3	34.29	39	62.8	18.59	17	71.4	35.00	NS
Fl. dig. prof. 2	60	62.5	19.75	59	61.9	21.44	27	60.7	22.78	NS
Abd. poll. brev	39	32.5	8.21	37	43.9	11.22	20	38.1	18.00	NS
Low median										
Fl. poll. long	23	70.8	42.39	8	87.5	47.50	11	61.5	30.91	NS
Fl. dig. prof. 2	30	75.0	44.50	11	100.0	59.09	17	85.7	49.71	NS
Abd. poll. brev	48	50.0	17.08	27	48.3	14.63	24	50.0	8.96	NS
High ulnar										
Fl. dig. prof. 4 & 5	116	82.1	33.92	80	66.7	26.88	63	69.0	28.25	NS
Abd. dig. V	131	36.8	7.90	89	33.0	5.45	74	33.8	7.50	NS
1st dors. inteross	98	39.8	10.61	68	32.4	5.96	52	32.8	5.87	NS

Low ulnar										
Fl. dig. prof. 4 & 5	35	79.5	36.47	42	83.7	38.61	33	73.5	41.52	NS
Abd. dig. V	84	44.2	9.24	95	40.8	10.58	81	53.7	17.41	*
1st dors. inteross	74	41.3	13.11	73	44.4	10.62	48	40.0	13.85	NS
Radial										
Ext. car. rad	108	85.7	38.52	74	81.3	38.99	48	80.4	36.04	NS
Ext. dig	102	63.6	25.25	75	58.4	27.53	44	54.9	16.59	NS
Ext. poll. long	106	55.0	14.25	71	50.0	18.38	46	46.3	18.15	NS
Peroneal										
Tib. ant	66	35.8	18.79	61	32.3	14.18	36	45.9	17.50	NS
Ext. dig. long	75	24.0	9.53	64	23.1	6.25	37	46.2	13.11	NS
Ext. hall. long	74	23.0	8.51	62	12.7	5.81	35	36.8	8.57	NS
Peron. long	74	33.8	15.61	60	43.8	18.08	35	53.8	21.29	NS
Tibial										
Gastroc. & sol	20	95.5	73.00	15	87.5	42.33	10	80.0	44.00	**
Fl. dig. long	29	48.4	15.52	26	10.7	1.35	14	26.7	5.71	*
Fl. hall. long	27	42.9	13.70	27	16.7	2.22	15	26.7	7.33	*
Sciatic-peroneal										
Tib. ant	111	20.7	6.05	66	22.1	5.68	50	10.0	1.90	NS
Ext. dig. long	112	12.4	2.50	66	13.0	1.89	50	4.0	1.00	NS
Ext. hall. long	111	8.1	2.30	66	14.7	2.42	49	2.0	.82	NS
Peron. long	112	17.9	5.45	66	21.4	3.03	49	10.2	1.84	NS

See footnotes at end of table.

Table 110.—*Percentage of Affected Muscles Contracting and Mean Power Following First Complete Suture, by Level of Neurosurgical Training of Operator*—Continued

Nerve, gross site, and muscle	Level of surgical training									Statistical tests on means [1]
	Trained neurosurgeon			General surgeon with supplementary training			No special training in neurosurgery			
	Number of cases	Percentage contracting against resistance	Mean relative power, all cases	Number of cases	Percentage contracting against resistance	Mean relative power, all cases	Number of cases	Percentage contracting against resistance	Mean relative power, all cases	
Sciatic-tibial										
Gastroc. & sol.	84	82.2	45.60	48	77.4	45.42	39	82.2	41.03	NS
Fl. dig. long.	89	12.2	3.54	50	6.0	2.30	45	2.2	1.11	NS
Fl. hall. long.	88	11.2	2.44	50	6.0	3.30	45	2.2	.56	NS

[1] Results of tests (two-tailed) are abbreviated as follows:
NS=Not significant.
*=Significant at .05 level.
**=Significant at .01 level.

Such special operative features as transposition and extensive mobilization have no demonstrably adverse influence upon motor recovery. Although lesions first treated by bulb suture recover less well than others, when differences in length of gap are taken into account it is plain that therein lies the source of the disadvantage; otherwise lesions treated by bulb suture do as well or as poorly as others.

The operator's report on the gross appearance of nerve ends prior to anastomosis correlated to some extent with that of the neuropathologist and is weakly associated with eventual motor recovery. The operator's report of tension, in contrast, is of no obvious prognostic value.

World War II saw extensive use of tantalum sutures, but the present series makes it plain that such sutures were followed by the same recovery as those done by silk. A special series of plasma glue sutures was also studied and after suitable allowances for differences in the selection of the cases their motor recovery at followup proved to be indistinguishable from those done by silk or tantalum.

Sutured lesions on which cuffs were used seemed to recover more completely than those on which the foil was not used, but perhaps only because the initial selection of cases favored those on which tantalum foil was used. The use of stay sutures seemed to exert no particular influence upon the eventual level of motor recovery.

Neurolyses were done in several ways, but no evidence was found that internal and external neurolyses differed in their effect on recovery.

No demonstrable effect may be attributed to the training of the operator performing the definitive suture.

In most general terms, the analysis serves to identify those aspects of management which do, and those which do not, appear to exert a significant influence upon motor recovery. Of all the characteristics studied, time from injury to suture exerts the greatest influence, and yet this factor alone does not explain much of the great variation seen in the final level of recovery. Moreover, some of the apparent influence of other treatment factors is associated with that of time, so that any overall measure of the extent to which differences in management explain variation in final recovery would not greatly exceed that observed for time alone and would hardly be impressive in any event. In addition to the treatment variables, however, as already shown in the earlier sections of this chapter there are many characteristics of the nerve injury itself, including associated lesions of various kinds, which also have a marked bearing on motor recovery. The most important of these is the character of the lesion itself, insofar as it is reflected in the surgeon's choice between suture and lysis.

F. COMBINED INFLUENCE OF ADVERSE FACTORS UPON MOTOR RECOVERY FOLLOWING SUTURE

Although chief attention has been given to the influence of individual variables affecting motor recovery, there is considerable interest in combining this information for use in prognosis. How good will recovery be if no unfavorable factors intervene? What is the total impact of several unfavorable factors? Such questions may be approached in a variety of ways; only the simplest has been used here. At the outset a set of factors was chosen on the basis of apparent influence upon recovery when studied individually. Sutured lesions were then classified according to presence or absence of these factors taken in all possible combinations. The recovery of each subgroup, and of patterns of subgroups, could then be studied. Of course, such subdivision dissipates the material into often quite small subgroups, and there is need to combine these in some way. The simplest, but least exact, procedure is to group together lesions with the same number of prejudicial factors, regardless of what they might be. The latter technique has been followed here, except that delay in definitive suture has been scaled as either 1 or 2 units of the score, depending on whether the suture was done in the interval 90–269 days after injury or 270 or more.

Only the median and ulnar nerves have been studied in the fashion outlined above, with a separation into high and low lesions, and with recovery based on the relative power of the following muscles:

Median muscles	*Ulnar muscles*
flexor pollicis longus	flexor digitorum prof. 4 & 5
flexor digitorum profundus 2	abductor digiti quinti
abductor pollicis brevis	first dorsal interosseus

Perhaps the most important conclusion which emerges from such an analysis is that even lesions characterized by none of the prejudicial factors listed above do not have very high recovery ratios if strength is used as the criterion. Table 111 gives both indices of recovery for these cases, which are, of course, unfortunately few in number. In addition, the material on one muscle is not independent of that on another innervated by the same nerve. Nevertheless, it seems clear that absence of the selected prejudicial factors will not characteristically insure a return to anything approaching normal strength of movement. Failure to contract at least perceptibly, of course, is rare in this small, selected series, but the mean power of muscles contracting against resistance seems about average, according to the values of table 51 (p. 91).

Once the median cases are subdivided in the fashion described, there are only a few groups containing as many as 10 lesions, and for none of these is the mean power (of all examined muscles, whether contracting or not) remarkably out of line. However, for both high and low lesions there are small groups which suggest that recovery of the most distal muscles may be especially susceptible to the influence of the several variables selected. For example, the average power of the abductor pollicis brevis was found earlier

Table 111.—*Percentage of Affected Muscles Contracting and Mean Power of Muscles Contracting Against Resistance, Median and Ulnar Lesions Treated by Complete Suture With No Prejudicial Factors, by Gross Site*

Muscle	High				Low			
	Perceptible contraction		Power of muscles contracting against resistance		Perceptible contraction		Power of muscles contracting against resistance	
	N [1]	Percent	N [1]	Mean	N [1]	Percent	N [1]	Mean
Median								
Fl. poll. long.....	5	100	2	52	3	100	2	48
Fl. dig. prof. 2...	8	100	5	33	4	100	3	53
Abd. poll. brev...	7	100	3	47	10	100	4	26
Ulnar								
Fl. dig. prof. 4 & 5	24	100	11	43	12	100	10	58
Abd. dig. V.....	24	88	5	23	20	95	11	23
1st. dors. inteross.	19	95	5	31	16	88	6	17

[1] N represents the number of cases upon which the percentage or the mean is based.

to be 12 percent of normal for high lesions and 15 percent for low lesions. Among the high lesions there is one group of 18 cases with moderate delay in repair plus an associated nerve injury, for which the average power is only 5 percent. There is another group of 20 high lesions with these same prejudicial characteristics plus arterial injuries, for which mean power is 6 percent. Finally, there is a group of 11 low lesions with long delay plus associated bone injury for which mean power is 10, in comparison with the overall average of 15. Since the groups are so small, some grouping is necessary to any analysis, and in table 112 are given summary figures for median lesions grouped according to the score obtained by counting the number of prejudicial factors, except that a long delay adds two units. There may be many different ways of reaching the same score, but inspection of the data does not suggest that combining cases on this basis is unwise. In each of the comparisons of table 112 the group with the highest score appears in an unfavorable light, but only for the abductor pollicis brevis is the relationship an impressive one. Here the lesions with the largest number of prejudicial factors have means of only 15 to 20 percent of those computed for the lesions with the smallest number of such factors.

For the ulnar nerve variation in recovery does not follow the scoring except for the first dorsal interosseus, for which the data are much like those for the abductor pollicis brevis. Table 113 contains the mean values arranged as in table 112.

Table 112.—*Mean Relative Power of Affected Muscles Following Complete Suture, Median Lesions by Site and Score on Presence of Prejudicial Factors*

Score	Muscle					
	Fl. poll. long.		Fl. prof. ind. 2		Abd. poll. brev.	
	N[1]	Mean	N[1]	Mean	N[1]	Mean
High lesions						
1–2	20	26	29	22	19	26
3	36	35	53	25	36	12
4	29	26	44	21	26	4
5–7	12	15	18	8	14	5
Total	97	28	144	21	95	12
Low lesions						
0–1	....	....	12	56	26	19
0–2	22	55	....	....	....	....
2	....	....	20	61	25	22
3–7	20	22	26	37	....	....
3	....	....	....	....	31	10
4–7	....	....	....	....	17	3
Total	42	40	58	50	99	14

[1] N represents the number of cases upon which the mean is based.

Table 113.—*Mean Relative Power of Affected Muscles Following Complete Suture, Ulnar Lesions by Site and Score on Presence of Prejudicial Factors*

Score	Muscle					
	Fl. dig. prof. 4 & 5		Abd. dig. 5		1st dors. inteross.	
	N [1]	Mean	N [1]	Mean	N [1]	Mean
High lesions						
1	18	26	22	5	15	10
2	46	28	51	5	41	12
3	98	37	109	10	77	9
4	63	23	71	5	53	6
5–7	28	26	35	4	27	1
Total	253	30	288	7	213	8
Low lesions						
0	12	48	20	12	16	6
1	24	41	55	14	43	17
2	43	44	98	15	69	15
3	....	....	59	7	42	10
3–6	30	27	....	....	....	....
4–6	....	....	24	11	21	5
Total	109	39	256	13	191	12

[1] N represents the number of cases upon which the mean is based.

Chapter IV

ELECTRICAL EVIDENCE OF REGENERATION

Harry Grundfest, Y. T. Oester, and *Gilbert W. Beebe*

A. INTRODUCTION

Numerous electrodiagnostic tests have proved useful in the study of peripheral nerves, both experimentally and clinically. Their clinical value is especially great preoperatively in evaluating the chance of spontaneous recovery, at operation when the surgeon is confronted with the necessity for deciding whether to lyse and leave alone or resect and suture, and later when there may be doubt concerning the progress of regeneration following suture. Inclusion of electrodiagnostic tests in the standard list of follow-up observations was prompted by no strong expectation that they would prove as useful in the evaluation of late results as they are in making early assessments, but rather by the belief that the opportunity should not be missed for comparing their results with those obtained in the study of voluntary movement. Also, there was some hope that electrical studies might throw additional light upon cases classified as failures in motor recovery on the basis of examination of voluntary movement. In retrospect it would also appear that the addition of the electrodiagnostic battery to the standard workup most probably served to improve the quality of the motor studies. Discrepancies between voluntary movement and electrical responses prompted more careful study of individual muscles, and at times alerted examiners to disparities between anatomical reinnervation and functional recovery which could be turned to patients' advantage.

Since the follow-up studies were made about 5 years after injury, neither early nor interim observations could be procured under the design adopted for the study. However, in chapter XII, where electrodiagnostic tests are reviewed from the standpoint of their contribution to surgical diagnosis, early and longitudinal observations are given on the basis of a subsequent study of casualties from the Korean episode, made by Nulsen at Valley Forge General Hospital.

In accordance with the original plan for the analysis of the follow-up data, a complete, separate study was made of the electrical observations along the lines already described in chapter III for voluntary motor recovery.

The standard muscles specified for routine electrodiagnostic tests are those listed in table 48, plus the following:

Peroneal and sciatic-peroneal
- Extensor digitorum brevis
- Peroneus brevis

Tibial and sciatic-tibial
- Flexor digitorum brevis

The content of the present chapter is of more limited scope, however, and for these reasons: (1) The selection of muscles for certain of the electrodiagnostic tests depends so much upon the results of voluntary stimulation that no fair comparison of any two sets of cases could be made without prior assurance of the comparability of their selection, and in practice this means that the analysis of responses to these tests must rest upon the studies of voluntary movement; (2) to the extent that electrical and voluntary data correlate, a separate presentation of motor recovery seems superfluous; (3) the electrical data are so much less extensive than those on voluntary movement that explorations based on the latter are considerably more powerful; and (4) the electrical data are much more subject to center variation than the observations on voluntary movement. Furthermore, the chief clinical value of the electrodiagnostic tests at the point in time at which the follow-up study was done lies in the contribution they make to an understanding of the factors associated with absence of voluntary movement. Accordingly, the electrodiagnostic data are studied here, not as independent evidence on the presence or absence of nerve regeneration, but as auxiliary information of especial value in illuminating some of the factors which may be responsible for the absence of voluntary movement.

B. METHODOLOGY

Essentially four electrodiagnostic tests comprise the standard battery:

1. Stimulation of the nerve.
2. Chronaxiemetry.
3. Galvanic tetanus ratio.
4. Electromyography.

In the coding of data for the statistical analysis provision had also been made for recording the EMG response to stimulation of the nerve, but this observation was made on only one percent of the individual muscles involved in the study and merits no further consideration. Finally, although not an electrodiagnostic test in the same sense as the four listed above, direct muscle stimulation was performed as a means of assessing muscular atrophy

1. Stimulation of Nerve

Monopolar or bipolar electrodes are applied to the skin overlying a motor nerve or are inserted subcutaneously to lie close to or enter the sheaths of the nerve. Electrical stimuli of controllable, graded intensity are applied through the electrodes, either as brief, single shocks or as a train of repetitive excitation. In the different follow-up centers they were variously derived from the capacity-type chronaxiemeter, single or multiple shock square pulse generators, or from an alternating current source (including faradic stimulation). The type of stimulus employed is relatively unimportant provided the strength can be controlled so that an adequate and safe stimulus is delivered to the nerve.

The test ascertains whether the nerve is in functional continuity with a muscle capable of contraction. The sources of discontinuity may be:

a. Absence of anatomical regeneration in the nerve;
b. Absence of reinnervation of the muscle; or
c. Absence of muscle fibers.

The first two conditions could be detected by observing presence or absence of nerve impulses, but this was not done in the present study. Chronaxiemetry, which was extensively carried out, provides the same information in a technically more convenient manner. In the course of the latter test also direct stimulation of the muscle provides information regarding the presence or absence of muscle as well as the nature of the response of the muscle fibers.

Stimulation of the nerve rapidly delimits the functionally intact from the nonfunctional neuromuscular groups. Together with observations on voluntary movement it also provides a clear-cut differentiation between those neuromuscular groups which are not used by the patient because of anatomical defects and those which are not used because of psychic or learning factors. The latter categories of nonuse should not be minimized. In the course of this study it has been found that even experienced observers sometimes attribute to failure of anatomic regeneration a lack of movement apparently caused only by some psychic factor or by a failure in relearning the use of a muscle or even a digit.

Of particular value in early diagnosis is the stimulation of the nerve at two levels, one above and one below the site of injury. In some instances following gunshot injury, when the nerve is in gross continuity, local propagation-block may cause a temporary paralysis which simulates anatomical loss of continuity. This condition may, however, be temporary, lasting up to 3 to 4 months. When temporary, it does not result in neural degeneration and the muscles involved remain excitable to neural stimulation applied below, but not above, the site of block. When block without degeneration is present some 2 weeks after injury it would appear to be preferable to delay surgical intervention until some opportunity for recovery has been provided, since recovery, if it occurs, then takes place without major disruption in the organization of the neuromuscular or the sensory complex, whereas after neurosurgery this occurs inevitably to some extent (5, 44, 61, 66).

In all, observations were made on 6,264 individual muscles, about 40 percent of all those involved in the present study. There were, in addition, 185 individual muscles in which the observation could not be made because an adequate stimulus could not be tolerated. The extent to which direct

Table 114.—*Percentage of Affected Muscles Examined by Nerve Stimulation, Complete Sutures on All Seven Major Nerves, for Muscles With Studies of Voluntary Movement, by Center*

Center	Voluntary movement								
	None			Any			Total		
	Total	Nerve stimulation done [1]		Total	Nerve stimulation done [1]		Total	Nerve stimulation done [1]	
		Number	Percent		Number	Percent		Number	Percent
Boston	224	92	41.1	629	204	32.4	853	296	34.7
Chicago	259	1	0.4	747	3	0.4	1,006	4	0.4
New York	583	539	92.5	1,733	1,681	97.0	2,316	2,220	95.9
Philadelphia	728	403	55.4	1,897	683	36.0	2,625	1,086	41.4
San Francisco	116	9	5.4	897	25	2.8	1,063	34	3.2
Total	1,960	1,044	53.3	5,903	2,596	44.0	7,863	3,640	46.3

[1] Exclusive of those few in which nerve stimulation was attempted but the current could not be tolerated.

nerve stimulation was performed in each center, and the presence of bias in the selection of cases for such stimulation, are shown in table 114, which is confined to 7,863 muscles supplied by the 7 major nerves, complete nerve sutures, standard muscles affected by injury, cases with movement not affected by tendon transplant, by loss of muscle substance by direct injury, or by sacrifice of a nerve branch, and muscles in which an examination of voluntary movement was made. Only in the New York center was direct nerve stimulation routine and the selection of muscles for testing quite unbiased, and in only three centers was nerve stimulation done on any appreciable number of cases. In the aggregate 46 percent of the muscles included in table 114 were examined by direct nerve stimulation, but somewhat more often (53 percent) in cases with no voluntary movement than in cases with voluntary movement (44 percent).

The muscular activity induced by stimulation of the nerve was scaled as follows, for each muscle:

- No contraction.
- Contraction
    - Barely visible.
    - Similar to voluntary contraction.
    - Stronger than voluntary contraction.

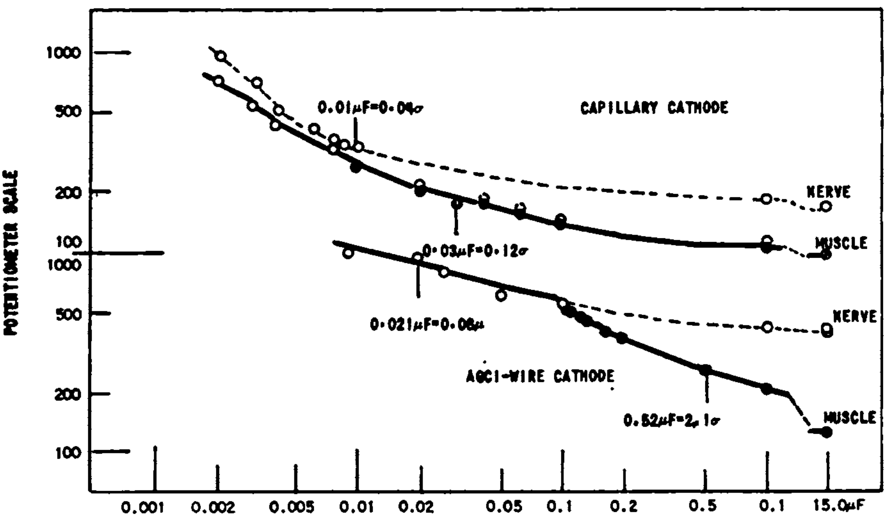
Of the entire set of 6,264 muscles observed following stimulation of the nerve, contractions were observed in 71.4 percent. By type of contraction this total breaks down as follows: 12.9 percent barely visible, 53.4 similar to voluntary contraction, and 5.1 stronger than voluntary contraction. All statistical analysis has been based on the percentages with at least visible contraction and with no contraction.

2. Chronaxiemetry

Principles

The theoretical basis of chronaxiemetry can be simply stated, although many of the details remain unclear. With the exception of certain synaptically activated systems, every excitable tissue (e. g., nerve, muscle, sense organ) can respond to an electrical stimulus of adequate strength. Stimulus thresholds, however, are a function of duration (figure 17). A liminal stimulus of very brief duration will be of higher intensity than one of long duration. However, all excitable tissues possess the property that a stimulus of relatively long ("infinite") duration cannot be effective when reduced

Figure 17. *Change in chronaxie with the size of the stimulating electrode*[1]



[1] The single nerve-muscle fiber preparation of the frog retrolingual membrane; monopolar stimulation of either the nerve or the muscle fiber. The abscissa plots the logarithm of the various capacities used in the stimulating circuit. 1.0 μF is equivalent to 4.0 msec. (or in the older form σ). The ordinates plot (in relative units) the logarithm of the minimal voltage to which a given capacitor was charged to excite the tissue. When the punctate stimulating cathode was a fine saline-filled capillary, the upper strength duration curves were obtained yielding chronaxies of 0.04 msec. for stimulation of the nerve fiber, and 0.12 msec. for one of the muscle fibers innervated by that nerve fiber. The lower curves were obtained when the same pair of units were stimulated with a large chlorided silver wire placed close to the nerve or muscle fiber. The chronaxie of the latter, 2.1 msec. now had increased almost 20-fold, while the chronaxie of the nerve fiber (0.08 msec.), had only doubled. (From Grundfest (28), reprinted by permission from the Journal of Physiology.)

below an intensity which is specific for the type and condition of the tissue and for the nature of the stimulation. The minimal threshold for a stimulus of infinite duration defines the "rheobase" (38). It provides an easily determined quantity, the intensity of the stimulus when the duration of the latter need not be accurately determined, provided it is sufficiently long. Given the rheobase, which furnishes an intensity unit of the stimulus, a single point on the curve of the strength-duration relationship can then be determined which serves as a useful characterization of that curve. That point is the "chronaxie," and it may be defined as the minimal duration of a stimulus with an intensity twice the rheobase. The chronaxie is characteristic of the excitable tissue. Numerous studies have been published (6) on the chronaxie for different neuromuscular groups in normal and diseased conditions. In man the chronaxie of such normal units usually falls in the range below 1 msec. (millisecond) and most frequently below 0.5 msec.

When neuromuscular transmission is eliminated as in nerve degeneration (also in neuromuscular block by curare, etc.) the chronaxies obtained may be in the range of scores of msec. The explanation of this difference has generated considerable dispute. Lapicque (38) believed that the anatomical or pharmacological changes produced an alteration in the strength-duration relation which was reflected in the increase of the chronaxie. Others (28, 65) demonstrated, however, that the normal strength-duration curve of innervated muscle fibers is much more dependent on the conditions of stimulation than is that of the nerve fibers, a major factor being the area of the tissue which is being effectively stimulated. In motor nerve fibers this effective area of stimulation is limited by their myelinated, noded structure, whereas the muscle fiber can be electrically stimulated everywhere on its surface. Therefore, under the conditions of percutaneous stimulation, where the effective electrode is a large surface, the chronaxie of direct electrical stimulation of the muscle is large, while that of the nerve is small. Normally, percutaneous stimulation applied to a motor point excites primarily nerve fibers, yielding a low chronaxie. When the muscle is denervated, however, only direct stimulation of its fibers is possible, and under the conditions of stimulation the chronaxie obtained is high.

As reinnervation proceeds, the chronaxie decreases from the large values of the denervated muscle through various intermediate values, and tends to return toward the normal, low value when reinnervation of the whole muscle has taken place. No entirely satisfactory explanation of this phenomenon is available. At least one factor resides in the nature of the observations. The measurements are carried out by suitable stimulation of a motor point, with the observer striving for a minimal contraction of the muscle under study. In visual observation the response is probably composed of neurally evoked activity of a number of motor units as well as of directly stimulated nonreinnervated muscle fibers. It is, therefore, likely that the magnitude of the chronaxie will depend on the relative proportions of the differently excited elements and will decrease progressively as that proportion shifts more and more in the direction of completely neural activation. However, this may not be the complete explanation. Denervated fibers may have themselves undergone prolongation of chronaxie as their excitable properties were altered. If the return to normal excitability were gradual after reinnervation the observed chronaxie would likewise decrease gradually.

Usefulness

Whatever the theoretical explanations of the effects might be, it is evident from this study as well as from earlier work that chronaxie is closely correlated with regeneration of the neuromuscular complex. The progressive decline of the chronaxie in the course of successive examinations, therefore, gives an early indication of progress in reinnervation, and is accordingly a useful index. Indeed, it is also possible sometimes to detect the approximate degree of reinnervation of a given muscle. For example, the regrowth of only a small bundle in a motor nerve may be detected by the appearance of a localized region of the muscle possessing a lowered chronaxie while the rest of the muscle, which remains denervated, exhibits a high chronaxie. In the hands of an experienced observer the differences in these values, and also in the appearance of rapid twitches of the reinnervated muscle fibers and slower contraction of still denervated muscle fibers, furnish valuable information. At a single examination, such as characterized this study, chronaxiemetry has a more restricted usefulness, since it can then only reflect the current state of reinnervation or its absence. However, it provides in this connection some critically useful information:

a. The character and degree of the response of directly excited muscle fibers provide a rough estimate of the state and amount of activable muscle tissues.

b. The magnitude of the chronaxie gives an estimate of the degree of reinnervation. It is a more quantitative test of the intactness of the neuromuscular organization than is neural stimulation, but is more time-consuming and requires a more highly trained operator.

c. The finding of a low chronaxie in the face of functional paralysis may indicate the nature of this loss of function. As with nerve stimulation, but in a more quantitative manner, it may indicate presence of a propagation block in the nerve, of psychogenic paralysis, of loss of the learned processes of muscle movement (by virtue of disruption of these patterns by long absence of use, or by virtue of anatomical alterations in the pathways), or of malingering.

Methodology

The chronaxiemeters used in this study fall into two classes, which do not differ basically in the data they can furnish. The electrical pulses generated may be rectangular as produced by a variety of electronic means. The amplitude may be controlled to provide a source of variable voltage or, as in the Golseth-Fizzell instrument (26) used by the Boston and Chicago centers, the stimulator provides a source of controllable current which is maintained at the desired level of output despite variation in the resistance offered by the electrode or by the tissues of the patient. In theory it may be preferable to use the latter "constant current" type of stimulation, but under actual conditions the advantage is doubtful. In clinical measurements the stimulus is applied percutaneously, and the pathway for the current includes a variety of tissues, in addition to the nerve and muscle. Each of these tissues is polarizable and probably to a different extent. The instantaneous stimulating current through the excitable tissue will therefore be complexly determined by the polarization of the different components. At any rate, it would appear that measurements with "constant current" and "constant voltage" pulse generators are essentially equivalent.

Short rectangular pulses (i. e., those below 0.5 msec. in duration) are easily distorted by the electrical properties of the stimulating electrodes and by the tissues of the patients. Furthermore, reproducibility of durations to the second decimal place (i. e., 0.01 msec. in the lowest range of durations) is poor with most electronic circuits. Some centers, therefore, have used stimulators which deliver discharges of condensors charged to a controlled voltage. The theory of the capacitative chronaxiemeter is discussed fully by Lapicque (38). His measurements and many others have demonstrated that the magnitude of the capacity is directly convertible into durations for any given stimulating circuit. The capacitor chronaxiemeters used in this study were capable of delivering pulses varying accurately by increments of 0.01 msec.

The techniques of chronaxiemetry are described in various textbooks (6, 38) and will not be dealt with here. It is, however, necessary to stress that the apparently simple procedure hides a number of pitfalls. Observation by some of us of the measurements made during and after World War II by technicians in military hospitals indicates that much more than routine training is required. The measurements depend to some extent on the accurate placing of electrodes, on correct treatment of these, on the rate at which observations are repeated, and on the experience of the operator in observing and evaluating the response. Even in the hands of the usually experienced examiners of the different follow-up centers results varied too greatly to permit the data of all five centers to be pooled directly. Table 115 illustrates this variation on the basis of data on the abductor digiti quinti following complete suture of the ulnar nerve. There were in all 5,581 chronaxie determinations on individual muscles, or about 36 percent of all the muscles involved in the study. If attention is confined to the 7 major nerves, complete sutures, standard muscles affected by injury, muscles with movement not influenced by sacrifice of a nerve branch, by direct loss of substance through injury, or by tendon transplant, and muscles in which studies of voluntary movement were made, it appears that 44 percent were tested by chronaxiemetry. However, as may be seen in table 116, the centers varied widely in their resort to chronaxiemetry, and in every instance their selection of muscles was a biased one. In the aggregate 25 percent of the muscles incapable of voluntary movement were tested by this means in comparison with 51 percent of the muscles capable of voluntary contraction.

Table 115.—*Center Variation in Chronaxie Determinations on Abductor Digiti Quinti Following Ulnar Nerve Suture*

Chronaxie, in msec.	New York and San Francisco	Boston and Chicago	Philadelphia
	Percent	*Percent*	*Percent*
00	60.5	1.0	17.9
01–02	27.2	54.7	39.3
03–07	11.1	22.1	31.0
08–12	1.2	13.7	9.7
13 or more	0	8.4	2.1
Total	100.0	99.9	100.0
Number of muscles	162	95	145

Table 116.—*Percentage of Affected Muscles Studied by Chronaxiemetry, Complete Sutures on All Seven Major Nerves, Muscles Studied for Voluntary Movement, by Center*

Center	Voluntary movement								
	None			Any			Total		
	Total	Chronaxiemetry done		Total	Chronaxiemetry done		Total	Chronaxiemetry done	
		Number	Percent		Number	Percent		Number	Percent
Boston	224	25	11.2	629	218	34.7	853	243	28.5
Chicago	259	47	18.1	747	170	22.8	1,006	217	21.6
New York	583	228	39.1	1,733	1,349	77.8	2,316	1,577	68.1
Philadelphia	728	166	22.8	1,897	733	38.6	2,625	899	34.2
San Francisco	166	26	15.7	897	520	58.0	1,063	546	51.4
Total	1,960	492	25.1	5,903	2,990	50.7	7,863	3,482	44.3

3. Galvanic Tetanus Ratio

The tetanus ratio (TR) is based upon two quantities which may be obtained in the course of stimulating muscles directly by means of galvanic current: (a) the current required to produce a sustained contraction, or tetanus; and (b) the rheobase or current required to produce a minimal contraction. In human skeletal muscles with normal innervation the tetanus ratio is usually about 3.5 to 4.0, and the normal range is generally taken as 3.0 to 5.0. During a period of complete denervation the ratio approaches and may actually reach unity. During a period of reinnervation the ratio rises sharply, generally markedly above normal values, and as reinnervation progresses it slowly falls to within the normal range.

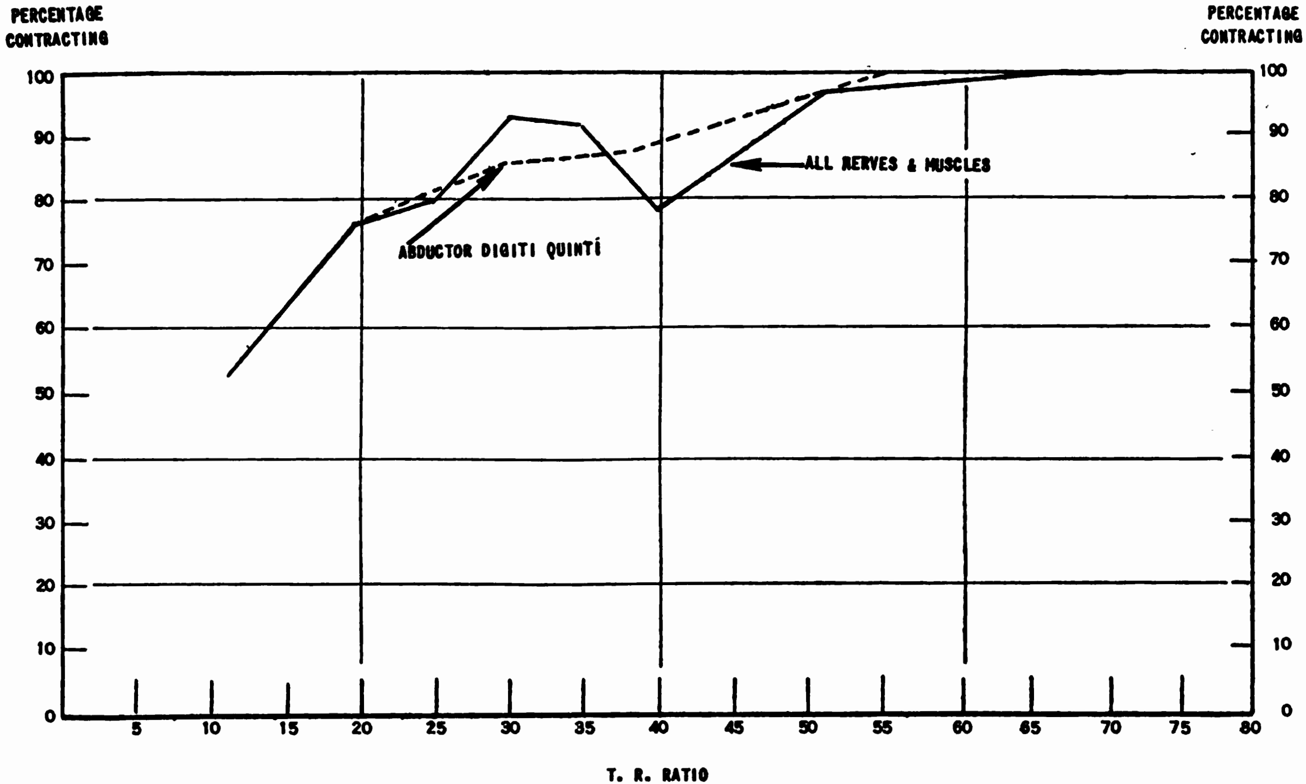
Determinations are made by applying conventional electrodes to the skin overlying the muscle to be tested. A constant-current generator, with an output in the range of milliamperes, and capable of maintaining a fixed output in the face of changes in the resistance of local tissues, is used to stimulate a minimal twitch. The current is then increased until the muscle responds with a sustained contraction (tetanus) during the entire time the current is applied, usually 4 seconds. The current required to produce tetanus is then divided by the current required to produce the least muscle twitch, and the resulting ratio is the tetanus ratio.

Although the tetanus ratio was included in the standard battery of tests agreed to by all investigators, determinations were not often made and for a variety of reasons. In all, determinations were made on 1,138 muscles, regardless of type of injury, extent of surgery, or sampling area. On muscles affected by complete suture, for lesions in the representative sample, 11 muscles were tested often enough to permit some exploration of bias associated with the selection of muscles for testing. Contraction on voluntary stimulation was employed in this investigation, which showed that the TR was more often sought in the presence of voluntary contraction than in the presence of none, so that the set of muscles with TR values is not itself an unbiased set. For example, 18.3 percent of upper extremity muscles observed to contract voluntarily have TR readings in contrast to 12.6 percent of those with no voluntary contraction; this discrepancy has a probability of .03 in the statistical test employed here. For the lower extremity the discrepancy is smaller and by itself well within the range of chance, but both discrepancies, considered jointly, have a probability of about .025. Whereas in the particular representative sample of upper extremity muscles used here 11 percent failed to contract voluntarily, in the set with TR readings the figure is 7.7 percent. The bias is not, therefore, large enough to be very troublesome.

Of greater interest is the relation between voluntary contraction and TR. Although the present series is not large enough to exhibit this relationship in any detail by nerve, it does include an adequate number of readings on the abductor digiti V and, moreover, as may be seen from figure 18, the same average relationship appears to characterize this muscle and all others taken together. An adjustment has been made for the selection of muscles for TR determinations, so that the curves of figure 18 are free from this defect. In the region of TR readings below 3.0 the percentage with voluntary contraction rises rapidly from about 50 to 90 percent, and continues to rise thereafter but more slowly. In the region of TR about 6.0 or more voluntary contraction is very nearly complete.

Although the TR readings were studied in relation to a number of characteristics of injury and treatment, for the reasons already mentioned the

Figure 18. *Percentage of Affected Muscles Contracting Voluntarily After Complete Suture, by Mean Tetanus Ratio, Muscles From the Representative Sample of Lesions*



results will not be given here. However, it may be useful to provide some of the TR data in descriptive form. Table 117 provides average values for muscles with reasonable numbers of readings, and table 118 provides a frequency distribution for the abductor digiti V which was the most extensively studied muscle.

Table 117.—*Mean Tetanus Ratio Readings Following Complete Suture, for Selected Muscles, Lesions in Representative Sample*

Nerve	Muscle	Number tested	Mean tetanus ratio
Median	Opponens	45	3.8
Ulnar	Fl. car. uln	43	4.0
	Fl. dig. prof. 4 & 5	30	4.0
	Abd. dig. V	137	3.7
	Add. poll	34	3.5
	1st dors. inteross	69	3.5
Radial	Ext. car. rad	22	3.4
	Ext. dig	29	3.1
Peroneal	Tib. ant	23	3.3
Tibial	Inteross	24	3.2
Sciatic-peroneal	Tib. ant	26	2.8

Table 118.—*Distribution of TR Readings on Abductor Digiti V Following Complete Suture*

TR	Number	Percent	TR	Number	Percent
.8–1.2	4	2.9	5.8–6.2	2	1.5
1.3–1.7	5	3.6	6.3–6.7	1	0.7
1.8–2.2	8	5.8	6.8–7.2	....	....
2.3–2.7	11	8.0	7.3–7.7	2	1.5
2.8–3.2	34	24.8	7.8–8.2	2	1.5
3.3–3.7	16	11.7	8.3–8.7	1	0.7
3.8–4.2	27	19.7	8.8–9.2	1	0.7
4.3–4.7	10	7.3			
4.8–5.2	9	6.6	Total	137	99.9
5.3–5.7	4	2.9			

4. Electromyography

Principles

As part of their activity the excitable tissues generate electrical responses. These are characteristic of the different type of tissue, but in nerve and muscle the general property is a transient, brief change of potential which at the source (in the excitable membrane) has an amplitude of approximately 100 mv. (millivolts), lasting from about 0.5 msec. (in some nerve fibers) to several msec. (in some muscle fibers) and up to fractions of a second (as in heart muscle). The full value of this potential is measurable only under special conditions (e. g., with a microelectrode inserted into the cell and a suitable recording system). However, a fraction of the potential can be obtained by recording from electrodes closely applied to the responding units. This fraction may vary from some microvolts (single nerve or muscle fiber active *in situ*) up to nearly the full value of the impulse (isolated giant axons in oil).

The ready availability of electronic amplifiers has made it possible to study these impulses, and electromyography is now widely practiced. In many cases the amplified potentials are recorded by direct writers which are commonly used for electroencephalography. These recording devices, however, respond very poorly to the brief impulses of muscle fibers. As a gross index of presence or absence of massed, prolonged activity the records obtained with the direct writers are very useful, but they cannot provide information regarding fine detail or occasional isolated responses. All the electromyographic studies of the various follow-up centers were, therefore, recorded on more suitable equipment employing the cathode ray oscillograph and photography of its traces. The equipment of the different centers varied, some having units commercially available, others being individually designed and constructed according to various specifications. The multiplicity of these designs makes it impossible to describe them here. (For such descriptions see Grundfest (29), Dickinson (19), Whitfield (86).) The electromyographs used by the various centers meet research requirements as to sensitivity and faithfulness of recording.

Methodology

During voluntary activity or on electrical stimulation of a normal innervated muscle, the neural impulses arriving at the muscle set up end-plate activity and a propagated electrical response in the activated muscle fibers. A single motor nerve fiber, by virtue of its terminal branching, innervates a number of muscle fibers which generally respond together as the motor unit. However, both the length of the neural path in the motor unit and the calibers of the different terminal branches may differ to some extent. Therefore, an impulse coursing in a nerve fiber exerts its terminal effect, the activation of the different muscle fiber components of the motor unit, with some asynchrony. A recording electrode in the vicinity of the motor unit, therefore, is subjected to a composite of potential changes which collectively lasts longer than would the electrical response of a single muscle fiber.

In the case of a single electrical stimulation of the nerve the motor unit usually responds only once. However, in voluntary activity the spinal integrative activity usually causes repetitive discharge of the motoneuron, and similar repetitive responses in the motor unit. The rate of the discharge will depend upon the amplitude of the voluntary effort and its duration upon the persistence of the effort. When a single motor unit is in the recording field, as may be achieved by proper choice of recording conditions, by anatomical isolation (as after destruction of most motor units), or by functional isolation (as with extremely weak voluntary effort or electrical stimulation), the response recorded from the motor unit has a rather constant amplitude and form, the deviation being ascribable to baseline instability in the recording equipment, or to shifts of the electrode (both classified as artifacts), or to variation in the number of muscle fibers of the motor unit responding to the neural impulse, and in their relative asynchrony.

The potential recorded by the electrodes is a reflection of the current flowing in the medium surrounding the generators of the excitable tissues. The intrinsic response of the muscle fiber is a relatively simple pulse (external negativity) moving away from the site of initiation (at the end-plate following neural excitation) at a velocity characteristic of the muscle fiber. The generators of the impulse (the muscle fibers) in this case constitute a shifting site in a mass of tissue (the rest of the muscle, fluid, etc.). An impulse generated and propagated in this type of volume conductor is therefore recorded by the electrodes not as a unidirectional pulse but as a complex depending upon the relative change in current flow at the electrodes. The recording situation in a volume conduction is described briefly by Brazier (8) in Fulton's Textbook of Physiology (25), and in much greater detail by Lorente de Nó (45). In general when only one electrode is close to the site of activity a single traveling unidirectional pulse is then altered into a triphasic response indicative of the approach, arrival, and departure of the impulse. However, the electrical responses of muscle and of nerve are not so simple (30) but are composed of the spike and of after-potentials which may be both negative and positive in sign. These complications will affect the form of the response recorded from the volume (8, 25, 45). Furthermore, when several motor units are active, but not synchronously, the algebraic summation of the different phases of their responses will complicate the record still more. In addition, when the muscle fibers do not all lie in parallel within the volume (as is true of many muscles) the impulses coursing in them will travel in divergent paths. The relative contributions of one motor unit and another will therefore vary. For these and other reasons the amplitude of the recorded response may have no strict relation to the number of active motor units, and the form of the response may become complicated because of factors which have no relation to the function of the motor units.

Another class of complications is introduced by the electrical requirement that a potential can be recorded only between two electrodes and not by a single electrode. Thus, when both electrodes are close to the source of the activity, the recorded potential must be the momentary difference of potential between them. In a volume conductor having a moving generator the difference potential can become very complicated indeed, and the potential (being the difference) may be very small, requiring high amplification and consequent instability of base line due to amplifier "noise."

Some of the difficulties of recording with bipolar electrodes can be avoided by using monopolar recording. In this procedure only one electrode (the "active" one) is inserted into the region of activity. The second ("reference") is fixed at some relatively inactive region (skin, tendon, etc.). The potential so recorded is usually larger, and may sometimes appear to have a simple form. However, with monopolar recording it is essential that the reference electrode be in a truly "silent" region. This is not always possible to obtain. Furthermore, activity of elements anywhere in the volume between the active and reference electrode will contribute to the total potential. Therefore, it is frequently more difficult with monopolar leads to record activity confined to single units and sometimes monopolar recording may include activity of elements entirely unrelated to those under study.

Another type of recording employs coaxial electrodes, taking advantage of the availability of small and sharp hypodermic needles. An insulated wire is inserted into the lumen of this and is fixed there. The outside of the needle shaft is carefully insulated, leaving only the tip as a conductor. The internal wire and the concentric needle form the two electrodes leading from the interior of the muscle to the recording amplifier. Since both electrodes are very close together the difference in potential produced by activity in their vicinity becomes rather small. The amplifiers employed with such electrodes must be operated at relatively high gain and designed for low intrinsic noise. The advantage of coaxial electrodes, however, is that the difference in potential between the pair of electrodes is large only when they are very close to an active site. Therefore, the restriction of recording to the activity of one or a few motor units becomes easier, and to that extent also the form of the recorded potential becomes more significant.

Localization of the recording of activity, and avoidance of pickup of extraneous potentials, whether these be generated in the body of the patient or externally (as a. c. pickup, etc.) can be furthered by the use of differential amplifiers (29). In these neither of the two electrodes (active and reference) is grounded, and an additional ground electrode is provided. The advantages of differential recording are discussed in various textbooks of electronics and by Grundfest (29) and Dickinson (19). In the New York center, the amplifier of the electromyograph was highly differential (1:30,000 or better).

The description of the recorded electromyograms given above refers primarily to the response of one or more motor units. In the denervated muscle, the responses obtained can only be due to spontaneous or induced activity of individual muscle fibers. As described above, the response of an individual fiber in a volume conductor will be very small, and may also be briefer than that of the motor unit. For reasons not known, during certain stages of their life-cycle denervated muscle fibers may exhibit spontaneous activity, or fibrillation, which is therefore seen in the records as spontaneous, random potentials of low amplitude and rather short duration. Fibrillation may also be initiated by the act of insertion of the electrodes; or by various mechanical or chemical stimuli. Fibrillation ceases after reinnervation and its occurrence is therefore indicative of denervation, but its absence is no index of reinnervation. The indication of reinnervation must rather be sought in the presence of the larger, longer responses of the motor unit, elicited either by effort of the patient or on stimulation of the nerve.

During the process of reinnervation the response of a motor unit may undergo complex changes but these are beyond the scope of the present analysis. An important finding of this study has been that reinnervated muscles usually show extremely large electrical responses from a few motor units (90). Similar though not as large responses are obtainable from muscles affected by various diseases (poliomyelitis, etc.), but are not found in normal muscles.

In the recording volume of the muscle are also present the impulses of afferent and efferent nerve fibers and the potentials produced at the end-plates. Usually these are small compared with the responses of the muscle fibers, but might play a role in complicating the form of the recorded potentials.

Clinical usefulness of the electromyogram

The present state of knowledge of the electrophysiology of muscle limits to some extent the clinical usefulness of the electromyogram. Thus, as a clinical index the significance of fibrillation is confined to positive identification of the existence of denervated muscle fibers. However, as stated earlier, absence of fibrillation does not indicate the absence of denervated fibers. A second limitation derives from the nature of the response. In a volume conductor this is a complex summation of the activity of many elements. When the experimental conditions are such as to present one or a few easily identifiable units, the result is informative only with respect to these few units—a sampling. Reconstruction of the events in the total population would require a large number of samples, preferably made simultaneously with many separate recording channels. In practice, however, recording is feasible with only a few channels. On the other hand when the recording conditions are such as to obtain the summated electrical activity of the entire muscle, the process of algebraic summation may complicate the data or even lead to erroneous conclusions, and the complexity of the records may defy analysis. Nevertheless, electromyography as a clinical test does have a sphere of usefulness.

In the first place, absence of electromyographic response after neural stimulation, or on effort by the patient, particularly when sampling is adequate, is clear indication of persistent denervation. Secondly, presence of a few active motor units is indicated electromyographically with greater accuracy than with other methods. Although such reinnervation may be of little utility to the patient it nevertheless can serve to indicate that conditions for neural regeneration have been favorable, and perhaps offer a clue to reasons for the absence of further recovery. Thus, some patients possess only slight motor unit activity when asked to perform with a reinnervated member. In some of these chronaxiemetry and nerve stimulation indicate good anatomic regeneration. The lack of voluntary activity frequently may be ascribed to loss of the organized pattern of activity in the central nervous system. Occasionally brief periods of voluntary activity during which the patient is permitted to observe for himself the appearance of the electrical responses on the oscillograph screen are sufficient to encourage in him the relearning process which is needed to develop functional activity. Examiners at the New York center are of the opinion that nonactivity because of learning loss may be frequent and that the use of the electromyogram as a reeducational tool might be useful. Unfortunately, systematic efforts in this direction were not possible.

Electromyographic tests were done on 2,712 individual muscles, or about 17 percent of those studied here. The classification of responses is exhibited in table 119. Two centers (Boston and San Francisco) devoted considerably more effort to electromyographic tests than did the others. Even more important is the very great variation in the classification of responses by the individual centers. To some extent the variation may reflect differences in recording technique, for the electrodes used were bipolar in Boston, monopolar in Chicago, surface and coaxial in Philadelphia, and coaxial in New York and San Francisco. Factors other than the mere choice of electrodes are undoubtedly involved in these disparities, however, some in the area of instrumentation and others in the interpretation of recordings by individual investigators. Efforts in the direction of standardization of equipment and interpretation were entirely too feeble to compete with the difficult problems in this field (11, 18).

Because the number of observations was relatively small, and the center variation extreme, systematic statistical analysis on the electromyographic material has not been considered useful.

5. General Remarks on the Evaluation of the Results and Usefulness of Electrodiagnostic Tests

Electrodiagnostic tests provide information concerning principally the anatomical or lowest level of the complex neuromuscular system,[14] whereas sensory and voluntary motor testing provides information on the recovery of the complex processes. The studies of World War II veterans reported here were made usually 4 to 6 years after definitive suture, so that ample time had elapsed for anatomical regeneration in most cases. Under such circumstances the usefulness of electrodiagnostic tests is rather limited

[14] As noted immediately above, however, electromyography is able to provide some information regarding the more complex events.

Table 119.—*Classification of Electromyographic Recordings at Each Follow-up Center*

Classification of muscles examined electromyographically	Center					
	Boston	Chicago	New York	Philadelphia	San Francisco	Total[1]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Electrical silence	6. 1	11. 7	7. 1	1. 8	1. 7	4. 8
Fibrillation potentials, spontaneous	4. 5	7. 6	2. 7	. 4	3. 7	4. 0
Fibrillation potentials, with insertion of needle	. 2	1. 0	2. 1	......	. 1	. 6
Fibrillation potentials, induced	. 8	. 3	. 2	......	......	. 3
Motor units at rest	2. 7	1. 4	. 2	. 4	......	. 8
Few motor unit potentials with voluntary effort	18. 5	20. 0	6. 5	31. 1	1. 1	10. 7
Many motor unit potentials with voluntary effort	55. 3	37. 9	5. 6	54. 2	9. 6	26. 2
Complex or other potentials	1. 3	2. 1	67. 3	11. 6	1. 6	14. 2
Spontaneous fibrillation potentials with motor unit potentials	4. 8	12. 4	7. 5	. 4	45. 6	21. 8
Spontaneous fibrillation potentials, motor unit potentials, and complex or other potentials	1. 3	1. 7	. 6	......	13. 0	5. 8
Fibrillation potentials with insertion of needle or induced plus motor unit potentials	4. 5	3. 8	. 2	......	23. 6	10. 8
Total	100. 0	99. 9	100. 0	99. 9	100. 0	100. 0
Number of muscles	622	290	480	225	1, 066	2, 712

[1] Includes readings on 29 "multiple lesions" not tabulated by center.

whereas in the early stages of injury and therapy these tests have much greater value. Some demonstration of this may be found in the discussion of the Valley Forge material consisting of peripheral nerve injuries sustained in the Koreanfighting (pp. 576–588). The value of electrodiagnostic data in this series is also limited by the considerable center variation usually characteristic of these observations.

C. ANALYSIS OF ELECTRODIAGNOSTIC DATA

1. Orientation and methodology

Interest in electrodiagnostic tests done by the follow-up centers many years after injury lies in the expectation that they may provide information on some of the factors responsible for absence of voluntary movement. As already indicated, any one of the following factors is sufficient to prevent a voluntary movement:

a. Psychological factors, as seen in malingering and in hysterical paralysis.
b. Failure to relearn use of a muscle following injury.
c. Failure of regeneration in the nerve itself.
d. Lack of innervation of muscle.
e. Absence of muscle fibers.

If, in the absence of voluntary movement, direct nerve stimulation produces a contraction, it may be assumed that one of the first two factors has blocked voluntary movement. In some instances, of course, this assumption would be wrong, either because the voluntary movement is possible but was improperly elicited or observed, or because of corresponding error in reporting movement following nerve stimulation. The design of this study provides no estimates of the frequency with which such errors are made, but the existence of examining error is demonstrated by the fact that 6.3 percent of the muscles with observations on both voluntary movement and direct nerve stimulation were reported as moving voluntarily but not on direct nerve stimulation. However, apart from errors of observation, it may be assumed that movement following electrical stimulation of the nerve, but not voluntarily, points to the operation of one of the first two factors.

If voluntary movement is not possible, and direct nerve stimulation also fails to elicit movement, then some one or more of the last three factors will be considered at fault. Again the possibility of errors must be borne in mind, but precise estimates of their frequency are not obtainable from this study. In such instances the chronaxie determination will be helpful, for a low chronaxie, reflecting activity in the nerve, is indicative of regeneration in the nerve, and a high chronaxes is suggestive of failure.

For the reasons discussed in the preceding section on methodology, the tetanus ratio and the electromyographic response are considered only briefly, and the main analysis is confined to direct nerve stimulation and chronaxie in relation to voluntary movement. Table 120 provides a summary of the New York data on all muscles examined for both voluntary movement and response to direct nerve stimulation. Although the data pertain to no single muscle, they may usefully serve as an introduction to the observations and to the discussion of various ways of handling them. It may be noted, first of all, that the electrical test and voluntary movement correlate rather closely, as they should, but that more muscles (1,789) responded to electrical stimulation than to the voluntary effort at contraction (1,681). The 147 with movement on electrical but not on voluntary stimulation might be considered a measure of the extent to which voluntary contraction is impeded by poor motivation and relearning, but some or all may be a reflection of errors in the neurological examination. Moreover, the 39 responding voluntarily but not electrically are obviously defects in one test or both as noted earlier, but one hardly knows which. The measure of uncertainty is not large, for only 186 muscles or 8.4 percent of the total lie in these two cells of the table, but since the chief interest lies not in the relation of the 186 to the total but rather to the 392 with no contraction in either test, some further refinement would be helpful. In this situation the chronaxie values are especially useful, and table 121 provides these data as an extension of table 120. Unfortunately, the selection of muscles for chronaxie determinations is quite a biased one. Eighty percent of the muscles observed to move voluntarily were studied as to chronaxie in contrast to 41 percent of the muscles not moving voluntarily. Therefore, it has been necessary to adjust the observations for this fact and to present the adjusted data in table 122 as the basis for all calculations. The adjustment consists in inflating the samples with chronaxie determinations in columns 1, 2, 4, and 5 of table 121 to correspond to the totals shown on line 1 of that table. In other words, the assumption is made that muscles on which chronaxie determinations were not made would be distributed exactly like those on which the determinations were made, provided that the response to both voluntary and direct nerve stimulation is fixed as in the column designations of the table.

Table 120.—*Voluntary Movement and Response to Direct Nerve Stimulation for All Affected Muscles Following Complete Sutures on All Seven Major Nerves, New York Center* [1]

Voluntary movement	Response to electrical stimulation of nerve		
	None	Any	Total
None	392	147	539
Any	39	1,642	1,681
Total	431	1,789	2,220

[1] Only muscles with observations on both voluntary movement and response to direct nerve stimulation are included.

The distribution of chronaxies in the 1,642 muscles whose reinnervation is demonstrated by both nerve stimulation and by voluntary response (col. 5 of table 122) is concentrated at the low end of the chronaxie scale. The distribution of the 392 muscles whose probable lack of reinnervation is demonstrated by these same tests (col. 1 of table 122) is less heavily concentrated, but the low end of the scale is a region of low density. On the other hand, the distribution of chronaxies for the 147 muscles (col. 2 in table 122) with contraction following nerve stimulation but not voluntarily differs markedly from the other two. Very high chronaxies are absent, but otherwise the distribution is fairly uniform with only slight peakedness in the range of 3 to 4 msec. This distribution suggests that many of the 147

Table 121.—*Voluntary Movement, Response to Direct Nerve Stimulation, and Chronaxie Determinations, for All Affected Muscles Following Complete Sutures on All Seven Major Nerves, New York Center* [1]

Chronaxie, msec.	Voluntary movement								
	None			Any			Total		
	Contraction following nerve stimulation			Contraction following nerve stimulation			Contraction following nerve stimulation		
	None (1)	Any (2)	Total (3)	None (4)	Any (5)	Total (6)	None (7)	Any (8)	Total (9)
Total	392	147	539	39	1,642	1,681	431	1,789	2,220
Unknown	268	48	316	18	317	335	286	365	651
Known	124	99	223	21	1,325	1,346	145	1,424	1,569
0	0	10	10	2	599	601	2	609	611
1	1	12	13	1	351	352	2	363	365
2	0	10	10	0	133	133	0	143	143
3	1	15	16	0	90	90	1	105	106
4	7	20	27	1	77	78	8	97	105
5	6	11	17	4	45	49	10	56	66
6	16	9	25	6	16	22	22	25	47
7	12	7	19	4	4	8	16	11	27
8	16	4	20	2	6	8	18	10	28
9	11	1	12	1	1	2	12	2	14
≥10	54	0	54	0	3	3	54	3	57

[1] Only muscles with observations on both voluntary movement and response to direct nerve stimulation are included.

muscles had been reinnervated, and that failure of contraction on voluntary stimulation occurred because either the contraction was too small, or the patients had not developed central command of the muscles. The very small group (39 out of 2,220 in col. 4, table 122) with voluntary contraction but no response to electrical stimulation of the nerve might represent errors in either test. None of the 39 muscles has a chronaxie value above 10 msec., which might be taken to suggest that the neurological examination had not erred as often as the electrical. On the other hand an estimated 6 of these muscles (3 observed) had chronaxie values of 0 to 1 msec., and these may be examples of congenitally anomalous innervation. Loss of normal innervating supply would not have affected the anomalous, thereby perhaps leaving intact the ability to contract voluntarily. The remainder might also be explained similarly on the basis of reinnervation by ingrowth of nerves other than those of normal supply. In figure 19 are plotted, in cumulative percentage form, the four estimated distributions of chronaxie values shown in table 122.

Table 122.—*Voluntary Movement, Response to Direct Nerve Stimulation, and Estimated Distribution of Chronaxie Values, for All Affected Muscles Following Complete Sutures on All Seven Major Nerves, New York Center*[1]

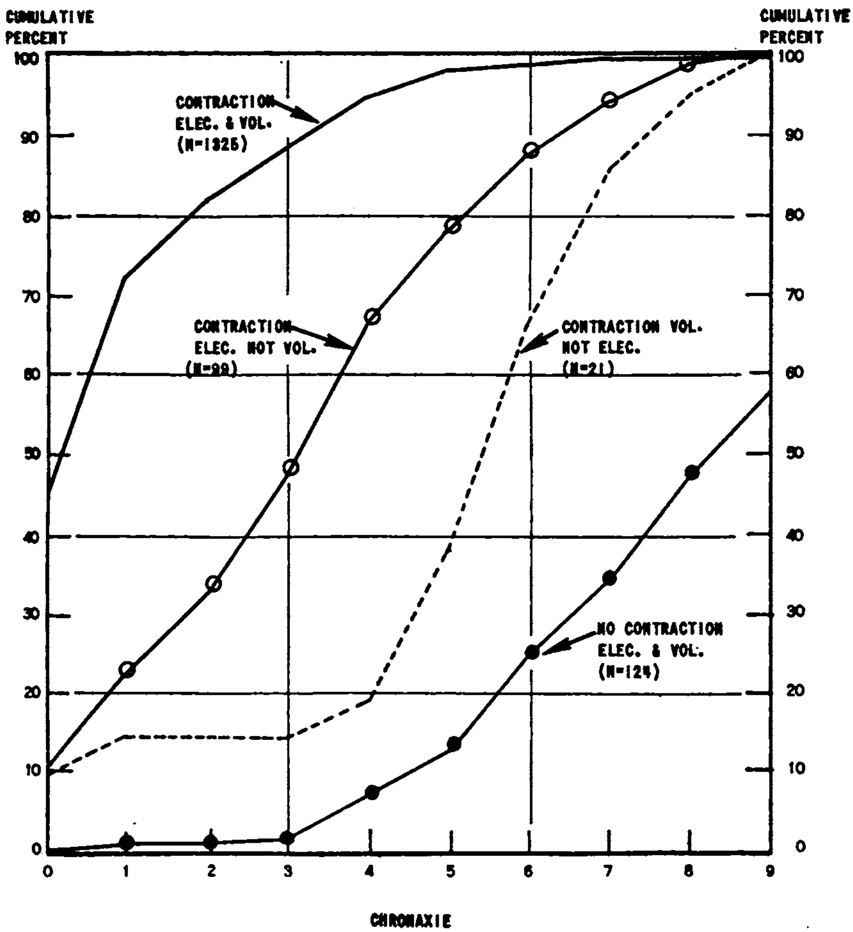
Chronaxie, msec.	Voluntary movement								
	None			Any			Total		
	Contraction following nerve stimulation			Contraction following nerve stimulation			Contraction following nerve stimulation		
	None (1)	Any (2)	Total (3)	None (4)	Any (5)	Total (6)	None (7)	Any (8)	Total (9)
Total	392	147	539	39	1,642	1,681	431	1,789	2,220
0	0	15	15	4	742	746	4	757	761
1	3	18	21	2	435	437	5	453	458
2	0	15	15	0	165	165	0	180	180
3	3	22	25	0	112	112	3	134	137
4	22	30	52	2	95	97	24	125	149
5	19	16	35	7	56	63	26	72	98
6	51	13	64	11	20	31	62	33	95
7	38	11	49	7	5	12	45	16	61
8	50	6	56	4	7	11	54	13	67
9	35	1	36	2	1	3	37	2	39
≥10	171	0	171	0	4	4	171	4	175

[1] Only muscles with observations on both voluntary movement and response to direct nerve stimulation are included. Distributions of chronaxie values shown in table 121 have been inflated to those shown here by multiplying individual frequencies by the ratio of the total on the first line of that table to the number tested, shown on the third line. See text.

Addition of chronaxiemetry to the other tests therefore immediately reveals three important facts: (a) at follow-up the distributions of chronaxie values fail to reveal sharp discontinuities associated with reinnervation and continued denervation; (b) however, the distributions of muscles grouped as to contraction on voluntary stimulation and response to nerve stimulation are concentrated at quite different regions of the scale; and (c) the regions of concentration vary with the pattern of the results of the other two tests: with maximal evidence of regeneration the region of low chronaxie values is densely occupied; with no evidence of regeneration it is the region of high chronaxie values in which concentration occurs; and with mixed evidence of regeneration the distribution is more uniform.

The distributions of table 122 and of figure 19 strongly suggest that chronaxie is not a specific measure or indicator of nerve regeneration but a probability measure of some kind, such that for one chronaxie the probability is high that regeneration has occurred and for another the probability is low. Unfortunately it is not certain, for any particular muscle, whether regeneration has occurred or not; there is merely more or less evidence of regeneration or lack thereof. The particular interest in the chronaxie, therefore, lies in the possibility that it may aid in discriminating between cases with and without regeneration. The suggestion of table 122 is that the chronaxie provides little if any information not already inherent in the results of the other two tests, but one further step was taken on the basis of a cut in the chronaxie scale between high values and low values such as to maximize the agreement between the resulting chronaxie classification and each of the other two tests. When various cuts were tried on the New York data it was found that the regions 0 to 5 and 6 or more produced the best agreement with both voluntary contraction and response

Figure 19. *Cumulative Percentage Distributions of Chronaxie Values by Response to Direct Nerve Stimulation and to Voluntary Stimulation, New York Data on All Muscles.*



to nerve stimulation. That is, if the cut is made in this way there are 163 cases with chronaxie values of 0 to 5 in which voluntary contraction was not observed and 61 cases with chronaxie values of 6 or more in which voluntary contraction was observed, or a total disagreement of 224 cases, 10.1 percent of the entire sample of 2,220 muscles. When response to nerve stimulation is taken as the criterion there are 62 cases with chronaxie values of 0 to 5 in which contraction did not occur and 68 with values of 6 or more in which it did, or a total of 130 disagreements, 5.9 percent of the sample of 2,220 muscles. In each instance this number of disagreements is the smallest of the set obtained by varying the cut. For example, if the cut be made after 3 msec. rather than after 5 the percentage of disagreements rises from 10.1 to 13.4 when voluntary contraction is the criterion and from 5.9 to 12.5 when response to nerve stimulation serves as the criterion. More complex criteria might be evolved than these, as by paying attention not merely to the total number of disagreements but also to their nature, but as may be seen from table 123 it would appear

Table 123.—*Estimated Distribution of Affected Muscles by Voluntary Contraction, Response to Nerve Stimulation and Chronaxie Group, New York Data* [1]

Chronaxie group, msec.	Response to direct nerve stimulation		
	None	Any	Total
A. No voluntary contraction			
0–5	47	116	163
6 or more	345	31	376
Total	392	147	539
B. Voluntary contraction			
0–5	15	1,605	1,620
6 or more	24	37	61
Total	39	1,642	1,681
C. All muscles			
0–5	62	1,721	1,783
6 or more	369	68	437
Total	431	1,789	2,220

[1] Based on table 122.

that no further refinement is likely to be fruitful. If the discrimination between regeneration and lack thereof is predicated solely upon the response to voluntary stimulation, then 539 or 24.3 percent of the muscles will be called denervated. If response to nerve stimulation is the only basis then 431 or 19.4 percent of the muscles will be termed denervated. If both these tests are used in combined fashion, then 392 or 17.7 percent will appear to be definitely denervated and there will be some uncertainty about an additional 186 or 8.4 percent. If, now, the chronaxie information be added on the basis of the cut developed above it would be applied only to the latter group of 186 cases, so that the margin of its contribution is a small one to begin with. The addition of the chronaxie information adds 55 to the count of cases without regeneration and 131 to the count of cases with regeneration, so that the final split is 447 or 20.0 percent without regeneration and 1,773 or 80.0 percent with regeneration. This result differs too little from that obtained with nerve stimulation alone to be of any practical value in estimation, but one must not overlook the considerable contribution made by the chronaxie information to the correct classification of the 147 cases contracting on nerve stimulation but not voluntarily and of the 39 cases contracting voluntarily but not on nerve stimulation.

Although it must remain literally true that no individual muscle can be certified as surely not reinnervated, the amount of information on the probability of such reinnervation is considerable and it is of particular interest to plot, for each point on the chronaxie scale, each of several estimates of the proportion of muscles believed to have been reinnervated. This is done in figure 20 according to the following criteria of reinnervation:

(a) Nerve stimulation only.
(b) Voluntary stimulation only.
(c) Both voluntary and nerve stimulation—both tests agree.
(d) Voluntary and nerve stimulation plus chronaxie to dispose of disagreements between them.

If table 122 is approached more generally, and it is not required that the chronaxie scale be arbitrarily divided into two regions, the following facts stand out:

a. Muscles unable to contract either voluntarily or on nerve stimulation rarely have low chronaxies, and often have high values; almost all values of 10 msec. or more were read on muscles in this group.

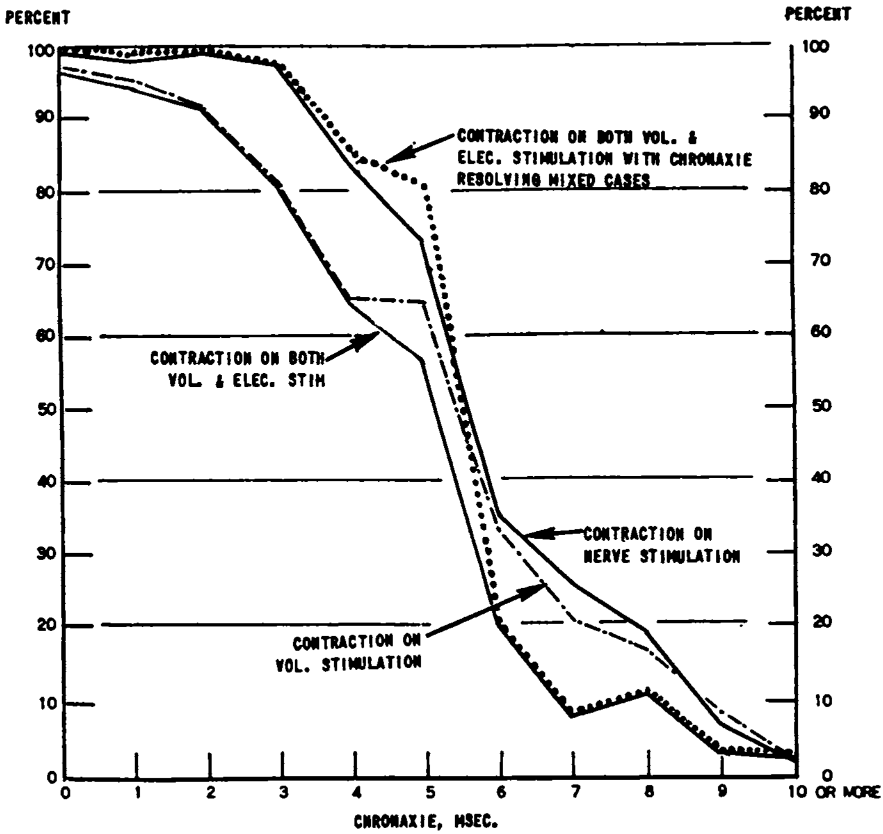
b. Muscles unable to contract voluntarily, but responding to direct nerve stimulation, have no chronaxies in the region of 10 or more msec., but are much less concentrated in the 0 to 3 msec. region than muscles contracting voluntarily.

c. Muscles contracting voluntarily but not on nerve stimulation have scattered chronaxie values, mostly high but none as high as 10 msec.

d. Muscles contracting both voluntarily and on nerve stimulation only rarely (2.3 percent) have chronaxies of 6 msec. or more.

On the basis of these observations one should have little hesitation in concluding that failure to move *both* voluntarily and on nerve stimulation

Figure 20. *Percentage of Muscles With Specific Evidence of Regeneration, by Chronaxie, New York Data on All Muscles*



is almost wholly attributable to failure in regeneration; it cannot often be true that regeneration has occurred but muscle atrophy has been too extensive to support movement. It also seems clear that the great majority of muscles unable to move voluntarily, but responding to nerve stimulation, had been reinnervated; failure to move voluntarily must be attributed to psychological factors in the areas of motivation and learning. The few muscles with voluntary movement and no response to nerve stimulation present no clear-cut picture; certainly they do not look like other muscles able to move voluntarily in that their chronaxies are higher. One would be inclined to prefer the results of the nerve stimulation in most instances here. Finally, it is rare indeed that one would be suspicious of any muscle reported to have contracted both voluntarily and on direct nerve stimulation.

If, now, table 123 is approached from the more general standpoint of the cogency of evidence for regeneration, and with an awareness of the conflicting testimony of the tests, its entries may be organized around two opposite poles representing the counts of muscles for which all three tests agree, namely the 345 with minimal evidence of regeneration and 1,605 with maximal evidence. According to these estimates at least 15.5 percent of the muscles reflect failure of regeneration, and at least 72 percent reflect regeneration. The middle 12 percent can be allocated to one of the other only with some sacrifice of certainty, but on the basis of the observations already cited it would appear that its several parts may be allocated as follows:

Probably not indicative of nerve regeneration

47 muscles for which there is at most weak chronaxie evidence of regeneration

24 muscles for which there is at most evidence of voluntary contraction.

Probably indicative of nerve regeneration

116 muscles with no voluntary contraction, but response to nerve stimulation and low chronaxies

31 muscles with voluntary contraction, and moderately high chronaxies, which responded to nerve stimulation

15 muscles with voluntary contraction and low chronaxie, but failing to respond to nerve stimulation

37 muscles with both voluntary contraction and response to nerve stimulation, but high chronaxie.

In summary, then, these considerations lead to an estimate of 1,804 muscles with, and 416 without, evidence of nerve regeneration, or 81 and 19 percent. These estimates are so close to those of 392 and 1,828 obtainable directly from table 120 that it would hardly seem necessary to present the chronaxie material in detail by muscle.

Since direct muscle stimulation was usually done at the New York center it may be of interest to note that only 1 muscle among 1,552 studied by means of voluntary and direct nerve stimulation failed to contract on direct muscle stimulation; this was 1 of 119 muscles which failed to contract either voluntarily or on direct nerve stimulation. Among 405 muscles examined at Philadelphia there were 5 which failed to contract on direct stimulation, 3 among 51 which did not contract voluntarily or on direct nerve stimulation and 2 among 51 which contracted on direct nerve stimulation but not voluntarily. It seems plain that complete muscle atrophy is rare in this material, and that the failure of muscles to contract voluntarily cannot, therefore, be attributed to this factor.

The Philadelphia observations are presented in table 124 to parallel those of the New York Center in table 121. Without further analysis it is plain that the Philadelphia chronaxie determinations are much less certainly discriminating than those of the New York center. Table 125 presents adjusted data for the Philadelphia center, based on table 124, the adjustment being the same as that performed on the New York data with one exception: account has been taken of the fact that examiners in the Philadelphia center selected muscles for direct nerve stimulation with some regard for their response to voluntary stimulation. The amount of information in table 124 is not large, and inflation to the totals used in table 125 provides only very approximate distributions with sharp discontinuities.

Table 124.—*Voluntary Movement, Response to Direct Nerve Stimulation, and Chronaxie Determinations, for All Affected Muscles Following Complete Sutures on all Seven Major Nerves, Philadelphia Center*[1]

Chronaxie, msec.	Voluntary movement								
	None			Any			Total		
	Contraction following nerve stimulation			Contraction following nerve stimulation			Contraction following nerve stimulation		
	None (1)	Any (2)	Total (3)	None (4)	Any (5)	Total (6)	None (7)	Any (8)	Total (9)
Total	307	96	403	70	613	683	377	709	1,086
Unknown	248	41	289	54	286	340	302	327	629
Known	59	55	114	16	327	343	75	382	457
0	3	3	6	2	55	57	5	58	63
1	2	5	7	1	58	59	3	63	66
2	3	5	8	4	48	52	7	53	60
3	1	5	6	......	15	15	1	20	21
4	7	6	13	2	34	36	9	40	49
5	......	1	1	2	11	13	2	12	14
6	5	8	13	......	18	18	5	26	31
7	......	......	......	......	4	4	......	4	4
8	13	9	22	......	43	43	13	52	65
9	......	......	......	......	1	1	......	1	1
≥10	25	13	38	5	40	45	30	53	83

[1] Only muscles with observations on both voluntary movement and response to direct nerve stimulation are included.

When a division of the chronaxie scale was sought on the basis of minimizing disagreement with the results of direct nerve stimulation, the best division was found to be 0 to 10 v. 11 or more msec., but even on the basis of this division 27 percent of the muscles presented discrepancies between the two tests in comparison with only 6 percent in the New York center.

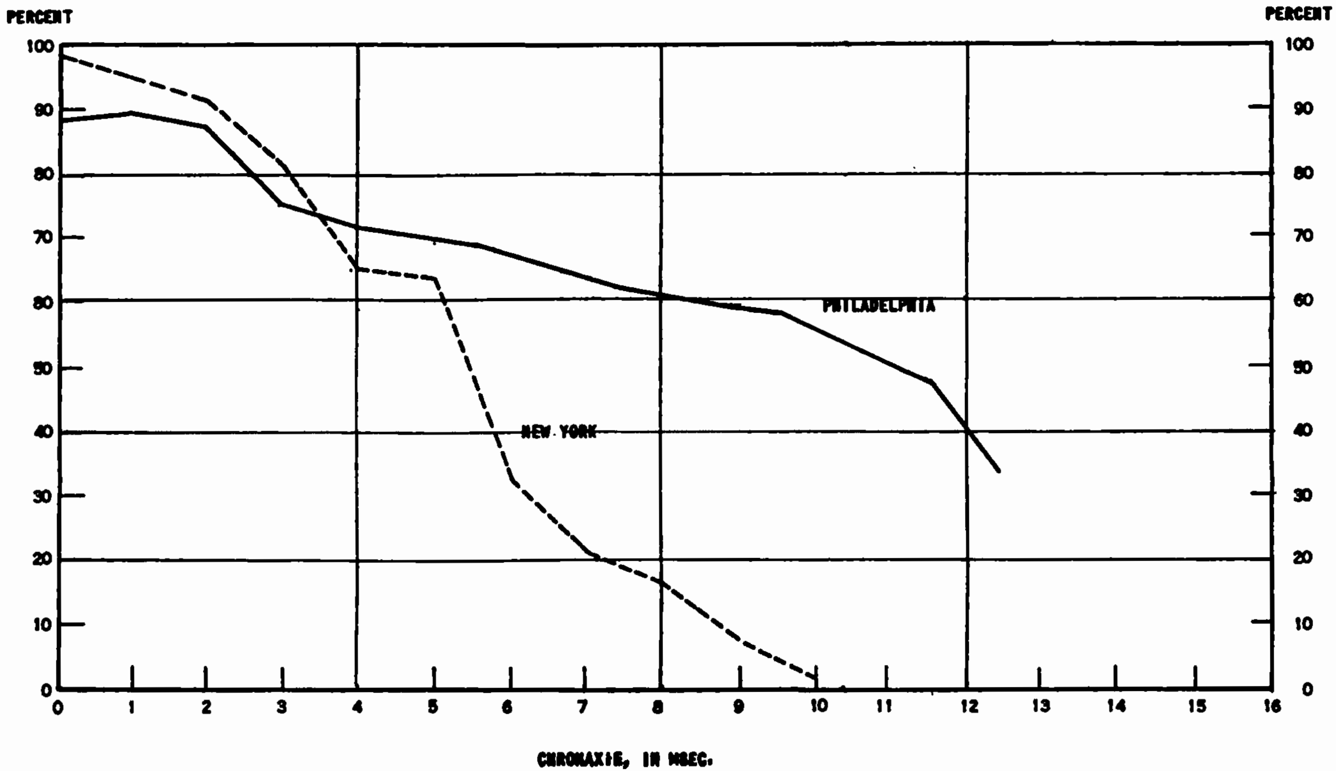
In figure 21 the two centers are compared as to the relation between the several tests. In table 126 are shown the results of dividing the chronaxie scale in the optimum fashion just described. It will be noted that all 3 tests agree in 178 instances with minimal evidence of regeneration, and in 1,552 instances with maximal evidence. The corresponding percentages are 7 and 60, which may be compared with 16 and 72 in the New York data. If the cases in the remaining 6 cells of the table, about which the tests disagree to some extent, are allocated in the fashion described for the New York data the final estimate of the percentage with regeneration is found to be 77, slightly below the value of 81 calculated for the New York data, but well above the values of 72 percent obtained from the data on voluntary contraction alone and 71 percent obtained from the observations on direct nerve stimulation. The numerical discrepancy between the estimates of the two centers is not too important because there are also differences between them in the emphasis they placed upon the examination of specific muscles, and these differences are not taken into account here. The chief lesson of the analysis is the same for both centers, namely that the best estimate which can be made from the data on all three tests is about what may be obtained from the joint observations on voluntary

Table 125.—*Voluntary Movement, Response to Direct Nerve Stimulation, and Estimated Distribution of Chronaxie Values, for All Affected Muscles Following Complete Sutures on All Seven Major Nerves, Philadelphia Data*[1]

Chronaxie, msec.	Voluntary movement								
	None			Any			Total		
	Contraction following nerve stimulation			Contraction following nerve stimulation			Contraction following nerve stimulation		
	None (1)	Any (2)	Total (3)	None (4)	Any (5)	Total (6)	None (7)	Any (8)	Total (9)
Total	555	173	728	193	1,686	1,879	748	1,859	2,607
0	28	9	37	24	284	308	52	293	345
1	19	16	35	12	299	311	31	315	346
2	28	16	44	49	247	296	77	263	340
3	9	16	25	......	77	77	9	93	102
4	66	19	85	24	175	199	90	194	284
5	......	3	3	24	57	81	24	60	84
6	47	25	72	......	93	93	47	118	165
7	......	......	......	......	21	21	......	21	21
8	123	28	151	......	222	222	123	250	373
9	......	......	......	......	5	5	......	5	5
10	57	3	60	12	72	84	69	75	144
11	9	......	9	......	......	......	9	......	9
12	75	9	84	12	77	89	87	86	173
13	......	......	......	......	......	......	......	......	......
14	......	......	......	12	10	22	12	10	22
15	......	......	......	......	......	......	......	......	......
16	47	19	66	12	21	33	59	40	99
17	......	......	......	......	......	......	......	......	......
≥18	47	10	57	12	26	38	59	36	95

[1] In view of selection of muscles for direct nerve stimulation as well as chronaxie, the estimates were developed to reflect the entire sample of muscles with tests for voluntary movement, not merely those tested both for voluntary movement and induction of movement by direct nerve stimulation.

Figure 21. *Percentage of Muscles Contracting Voluntarily, by Chronaxie, Philadelphia and New York Data on All Muscles, Compared*



contraction and response to direct nerve stimulation on the following assumptions:

a. Muscles which move voluntarily are innervated (i. e., errors of positive findings in neurological examination are absent);
b. Muscles which do not move voluntarily but do contract on direct nerve stimulation are innervated (i. e., positive results of the electrical test are valid); and
c. Only those muscles which contract in neither are denervated.

In the New York center about 21 percent of the muscles examined by means of voluntary and direct nerve stimulation were also studied by means of electromyography, and in the Philadelphia center about 19 percent. In both centers there was a marked tendency to avoid electromyographic study of muscles unable to contract voluntarily or on direct nerve stimulation, as may be seen in table 127, which pertains to muscles affected by complete suture and on which both voluntary and direct nerve stimulation was performed.

Although the electromyographic observations are quite sparse, it was thought that they might be useful in distinguishing between muscles which

Table 126.—*Estimated Distribution of Affected Muscles by Voluntary Contraction, Response to Nerve Stimulation and Chronaxie Group, Philadelphia Data*

Chronaxie group, msec.	Response to direct nerve stimulation		
	None	Any	Total
A. No voluntary contraction			
0–10	377	135	512
11 or more	178	38	216
Total	555	173	728
B. Voluntary contraction			
0–10	145	1,552	1,697
11 or more	48	134	182
Total	193	1,686	1,879
C. All muscles			
0–10	522	1,687	2,209
11 or more	226	172	398
Total	748	1,859	2,607

could not be moved voluntarily because of failure in regeneration and those in which absence of voluntary movement might be attributed to other factors. Electromyographic studies on the 33 muscles shown in table 127 as incapable of voluntary movement at the New York center usually showed no more than fibrillation potentials if direct nerve stimulation produced no contraction, and motor unit potentials if direct nerve stimulation resulted in contraction. Table 128 provides the details of this relationship. The very high correlation exhibited there lends considerable support to the validity of the interpretation that failure of voluntary movement is not a direct measure of failure of peripheral nerve regeneration.

Table 127.—*Choice of Muscles for Electromyographic Study in Relation to Voluntary Movement and Results of Direct Nerve Stimulation, by Center*

Results of stimulation		New York			Philadelphia		
Voluntary	Direct nerve	Total muscles	Muscles with electromyographic studies		Total muscles	Muscles with electromyographic studies	
			Number	Percent		Number	Percent
None..........	None.........	120	17	14.2	51	4	7.8
None..........	Contraction....	98	16	16.3	51	3	5.9
Contraction.....	None.........	19	2	10.5	15	2	13.3
Contraction.....	Contraction....	1,319	291	22.1	288	68	23.6
Total...	....	1,556	326	21.0	405	77	19.0

Table 128.—*Electromyographic Interpretations and Response to Direct Nerve Stimulation for Muscles With No Voluntary Movement, New York Data*

Electromyographic interpretation	Response to direct nerve stimulation		
	None	Contraction	Total
At most fibrillation....................	13	1	14
Motor unit potentials..................	4	15	19
Total........................	17	16	33

The analysis of electromyographic data from the New York center was carried one step farther by introducing chronaxie as a fourth variable. It is unfortunate that the data are so few (table 129). They do suffice to show a very intimate association between chronaxie and electromyographic interpretation: $^{13}/_{16}$ cases with at most fibrillation had chronaxies of 6 or more, and $^{294}/_{310}$ cases with motor unit potentials had chronaxies below 6. In the main, also, table 129 reveals all 3 electrical tests to be in moderately good agreement and to point to the necessity for regarding muscles incapable of voluntary contraction as a mixed group, some denervated and some not. The electromyographic data are too few to provide any independent basis for making that distinction, but do at least roughly confirm the distinction based on the results of nerve stimulation and chronaxiemetry. The only discrepancy of note consists of the 4 muscles with motor unit potentials but no movement either voluntarily or on nerve stimulation and chronaxies of 6 or more. One of these 4 was interpreted as "few motor unit potentials with voluntary effort" and 3 as "spontaneous fibrillation potentials plus some motor unit potentials, and no complex or other potentials." Since potentials of the latter variety were noted in only about 8 percent of the 284 with motor potentials and movement on both voluntary and direct nerve stimulation, these 3 cases are not typical of those with motor unit potentials and they will hardly serve to challenge the testimony of the other 2 electrical tests.

Table 129.—*Electromyographic Interpretations in Relation to Voluntary Stimulation, Direct Nerve Stimulation, and Chronaxie, New York Data*

Contraction		Chronaxie 0 to 5 msec.		Chronaxie 6 or more msec.	
Voluntary	Direct nerve stimulation	At most fibrillation	Motor unit potentials	At most fibrillation	Motor unit potentials
None	None	1	0	12	4
None	Some	0	8	1	7
Some	None	0	2	0	0
Some	Some	2	284	0	5
Total		3	294	13	16

2. Estimated Influence of Factors Preventing Voluntary Contraction

The method outlined in the preceding section provides a tool for estimating likelihood of reinnervation and for estimating the frequency with which psychological and neurological processes outside the neuromuscular complex may have impeded the voluntary contraction of reinnervated muscles. Table 130 contains these estimates for muscles of chief interest following complete suture, and is confined to cases in the representative

Table 130.—*Comparative Estimates of Relative Frequency of Reinnervation and of Psychological Blocks to Voluntary Contraction, by Muscle*

Nerve	Muscle	Estimates based on representative sample: Muscles observed for contraction on both voluntary and nerve stimulation: Number tested	Estimates of percentage reinnervated: Voluntary contraction: No.	Voluntary contraction: Pct.	Contraction on direct nerve stimulation: No.	Contraction on direct nerve stimulation: Pct.	Contraction voluntarily *or* on nerve stimulation: No.	Contraction voluntarily *or* on nerve stimulation: Pct.	Voluntary contraction blocked: No.	Voluntary contraction blocked: Pct.+	All muscles observed for contraction on voluntary stimulation: Number tested	Voluntary contraction: No.	Voluntary contraction: Pct.	Estimates based on total sample, muscles observed for contraction on both voluntary and nerve stimulation: Number tested	Contraction voluntarily *or* on nerve stimulation: Total	Voluntary contraction blocked: No.	Voluntary contraction blocked: Pct.
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Median	Fl. poll. long	31	27	87	26	84	28	90	1	3.6	113	101	89	48	42	2	4.8
	Fl. dig. prof. 2	42	37	88	33	79	38	90	1	2.6	165	148	90	63	57	2	3.5
	Abd. poll. brev	72	58	81	59	82	61	85	3	4.9	128	103	80	145	125	12	9.6
Ulnar	Fl. dig. prof. 4 & 5	101	95	94	85	84	96	95	1	1.0	323	304	94	132	124	1	0.8
	Abd. dig. V	217	187	86	184	85	198	91	11	5.6	436	381	87	314	287	15	5.2
	1st dors. inteross	160	126	79	133	83	142	89	16	11.3	328	270	82	237	206	20	9.7

Radial.....	Ext. car. rad......	74	69	93	66	89	70	95	1	1. 4	189	178	94	125	119	1	0. 8
	Ext. dig..........	65	57	88	57	88	59	91	2	3. 4	177	157	89	107	96	4	4. 2
	Ext. poll. long.....	67	55	82	49	73	56	84	1	1. 8	179	149	83	110	92	2	2. 2
Peroneal....	Tib. ant..........	61	43	70	43	70	45	74	2	4. 4	129	97	75	81	60	5	8. 3
	Ext. dig. long.....	62	39	63	38	61	41	66	2	4. 9	138	91	66	82	52	2	3. 8
	Ext. hall. long.....	60	26	43	22	37	31	52	5	16. 1	136	74	54	78	39	8	20. 5
	Peron. long.......	63	41	65	39	62	44	70	3	6. 8	138	98	71	86	61	5	8. 2
Tibial......	Gastroc. & sol.....	8	8	(*)	8	(*)	8	(*)	....	(*)	35	33	94	11	11	(*)	(*)
	Fl. dig. long......	12	7	(*)	8	(*)	8	(*)	1	(*)	58	38	66	17	12	1	(*)
	Fl. hall. long......	13	8	(*)	10	(*)	10	(*)	2	(*)	58	39	67	17	12	3	(*)
Sciatic-per-oneal	Tib. ant..........	93	54	58	65	70	67	72	13	19. 4	168	99	59	142	102	20	19. 6
	Ext. dig. long.....	89	36	40	49	55	50	56	14	28. 0	170	73	43	137	77	21	27. 3
	Ext. hall. long.....	84	24	29	25	30	29	35	5	17. 2	167	59	35	130	44	7	15. 9
	Peron. long.......	90	46	51	53	59	58	64	12	20. 7	170	94	55	139	92	22	23. 9
Sciatic-tib-ial	Gastroc. & sol.....	53	50	94	49	92	52	98	2	3. 8	137	129	94	80	78	2	2. 6
	Fl. dig. long......	48	13	27	16	33	17	35	4	(*)	134	37	28	73	26	8	30. 8
	Fl. hall. long......	48	14	29	17	35	19	40	5	(*)	134	38	28	74	28	10	35. 7
	All upper.......	829	711	86	692	83. 5	748	90. 2	37	4. 9	2, 038	1, 791	88	1, 281	1, 148	59	5. 1
	All lower.......	784	409	52	442	56. 4	479	61. 1	70	14. 6	1, 772	999	56	1, 147	694	114	16. 4
	Grand total.....	1, 613	1, 120	69	1, 134	70. 3	1, 227	76. 1	107	8. 7	3, 810	2, 790	73	2, 428	1, 842	173	9. 4

+The percentages in column 9 are based on the totals of column 6; peroneal muscles 3 and 5 seemed to be most affected by the selection of muscles for nerve stimulation.

*Percentages based on less than 25 cases not shown.

sample. It also contains, for comparative purposes, the following additional estimates:

a. The percentage reinnervated, using as the basis of estimate the percentage contracting voluntarily for all muscles in the representative sample, not merely those in which direct nerve stimulation was done;

b. The percentage reinnervated, using as the basis of estimate the percentage contracting on direct nerve stimulation; and

c. The percentage of cases in which voluntary contraction was blocked by psychological and learning factors, estimated from data on all complete sutures, not merely those in the representative sample.

The estimates based on either voluntary contraction alone or response to nerve stimulation alone do not differ appreciably in the aggregate, but occasionally large discrepancies are noted for individual muscles. When the estimates of columns 3 and 5 of table 130 were correlated, the correlation coefficient was found to be $+.96$,[15] and the equation for the best-fitting straight line is:

$$Y=-7.90+1.11X$$

where Y denotes the percentage contracting voluntarily and X the percentage contracting on direct nerve stimulation. Figure 22 contains a plot of these percentages. The estimates in column 7, reflecting the assumptions stated above and the methodology developed in the preceding section, are considered to be the best estimates for the muscles tabulated, except possibly for the fact that there is some slight bias in the selection of muscles for testing by direct nerve stimulation. However, the bias is considered too small to warrant any further adjustment of the estimates of column 7.

On the average, 23 percent of the muscles unable to contract voluntarily were observed to move on direct nerve stimulation; for the representative sample of sutures the figure is 22 percent. Individual muscles are not represented by enough cases to permit an extensive comparison of muscles, and to compare nerves on the basis of all muscles combined raises problems of the independence of one muscle from another on the same limb. Accordingly, comparisons have been made to only a limited extent and on the basis of individual muscles in a fashion suited to the assumption of independence of all observations combined together. The specific comparisons made, and their results, are as follows:

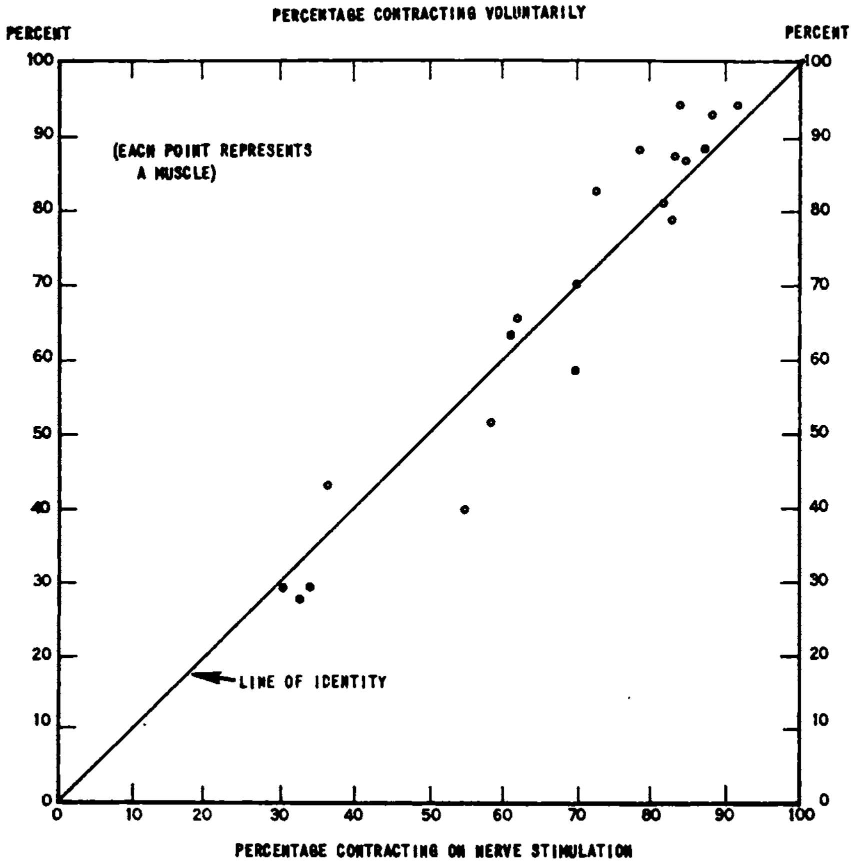
a. The various nerves, with each represented by the muscle with the largest number of cases in which voluntary movement was not possible, provided there be at least 25 such cases, i. e.,

Median—abductor pollicis brevis
Ulnar—1st dorsal interosseus
Peroneal—extensor hallucis longus
Sciatic-peroneal—extensor hallucis longus
Sciatic-tibial—flexor hallucis longus

These muscles are clearly not homogeneous as to the proportion, among all incapable of voluntary movement, which contract on direct nerve stimulation: the median and ulnar muscles more often contract on electrical stimulation.

[15] It should be noted that this coefficient has been obtained on a set of percentages, i. e., averages, which mask a certain amount of individual variation. The corresponding coefficient applicable to individual muscles, as estimated from the four-fold table of voluntary contraction by response to nerve stimulation, is $+.89$.

Figure 22. *Percentage of Affected Muscles Contracting Voluntarily After Complete Suture, and Percentage Contracting on Direct Nerve Stimulation*



b. The abductor pollicis brevis and the 1st dorsal interosseus are obviously quite similar.

c. Peroneal and sciatic-peroneal lesions were compared on the basis of each muscle. For the extensor hallucis longus the peroneal lesions have an advantage, but for the other three peroneal muscles the percentage is higher for sciatic-peroneal. However, for only one muscle (extensor digitorum longus) is the discrepancy a statistically significant one (P about .03), and for the material as a whole it would seem best to take the position that the sciatic-peroneal and the peroneal do not differ.

d. The two sciatic components were compared on the basis of the extensor hallucis longus and the flexor hallucis longus and appeared not to differ by more than chance expectation.

The muscles chosen to represent the upper extremity (abductor pollicis brevis and 1st dorsal interosseus) are, of course, distal muscles while those chosen to represent the lower extremity in the first comparison (a) are proximal muscles, and there may be some confounding on that account. Distal muscles in the lower extremity were not tabulated in this fashion, and proximal muscles in the upper extremity are represented by too few cases to settle the matter; we know only that the five sets of cases studied in the first comparison (a) differ quite significantly.

The foregoing comparison provides a test of the hypothesis that the proportion of muscles able to contract on direct nerve stimulation, among muscles unable to contract voluntarily, is constant from nerve to nerve, muscle to muscle. Perhaps an even more meaningful hypothesis to test is that the proportion of muscles unable to contract voluntarily, among all those innervated, is constant from muscle to muscle and nerve to nerve. The latter proportion is given in columns 9 and 16 of table 130, from which comparisons may be made rather directly. Column 9 is limited to the representative sample of complete sutures, while column 16 applies to all complete sutures for which both voluntary and electrical stimulation was attempted. The evidence of the two columns is the same, and since column 16 rests on many more cases it may be used as the basis for any comparisons. It seems clear, without formal test, that the proportion of reinnervated muscles which do not contract on voluntary stimulation is much higher in the lower extremity than in the upper, and especially for muscles affected by sciatic lesions. However, among the muscles of the lower extremity the gastrocnemius and soleus (following injury to the sciatic-tibial) has an exceptionally low percentage in relation to other muscles of the lower extremity.

In summary, then, table 130 provides the best estimates available in this material of the likelihood of reinnervation and, given reinnervation, of the chance that contraction will not occur on voluntary stimulation. The latter varies by nerve and to some extent by muscle within the set innervated by a given nerve, in that it is much higher in the lower extremity than in the upper, and that among muscles of the lower extremity, the gastrocnemius and soleus are atypical.

Chapter V

RECOVERY OF SENSORY FUNCTION

Y. T. Oester and *Loyal Davis*

A. INTRODUCTION

In keeping with the guiding interests of the study as a whole, the objective of the sensory studies was two-fold: (1) to provide a more adequate and unbiased description of the final level of sensory return following injuries well defined as to extent and anatomic structure; and (2) to utilize differential sensory recovery as an analytic tool for evaluating the effects of characteristics of the nerve injury, of any associated injuries, and of various details in their management. One cannot expect the content of routine clinical records, much less those of war injuries, to be commensurate in their detail and perfection with observations made years after the injury in accordance with a specific research protocol and in comparatively leisurely fashion. The practical objectives and the limitations of the baseline and interim observations, therefore, have guided the selection of sensory tests to be performed at follow-up and have directed interest away from many more basic problems in neurophysiology which might otherwise have been studied. From among specific sensory tests considered to be technically feasible and relatively reliable, a battery has been chosen to provide a representative picture of sensory performance at follow-up. To this description of sensory performance has been added a careful anatomic description of the original injury, with emphasis upon complete sutures. Sensory regeneration is not, therefore, studied here in its longitudinal aspect; rather it is assumed that a maximum return of sensation had occurred in each case prior to the follow-up examination, usually 4 or 5 years after definitive operation. Nor are the quality and extent of the sensory loss, either at injury or at follow-up, mapped in detail, as in earlier studies (24, 59, 60, 76). Finally, and purely as a matter of editorial convenience, the painful sensations of which patients complained either spontaneously or on examination and the limitation of function by sensory deficit are discussed in other chapters.

The organization of the present chapter parallels that of chapter III on motor recovery. There is first a methodological part concerned with the selection of the specific tests of sensory function and with their techniques and instrumentation. The basic, descriptive portrayal of sensory status at follow-up is contained in a separate section which, unlike its counterpart in the motor chapter, is separate from the analysis of the effects of certain characteristics of the nerve lesion itself, a separation enforced by the greater number of individual modalities requiring discussion here. Two final parts follow the organization of the motor chapter in detail, one on the influence of associated injuries, infections, and therapeutic procedures, the other on the apparent effect of certain technical aspects in the surgical management of peripheral nerve injuries.

In preparing the tabulation plan for the sensory chapter, consideration was given to the possibility that the correlation between motor and sensory regeneration might be so high as to render unnecessary any study of the details of surgical management beyond that contemplated in the motor chapter. However, preliminary tabulations suggested that such was not the case and the tables underlying the present chapter follow very closely the pattern described in chapter I, including the detail of the injury-operation groups.

The greater complexity and variety of the sensory determinations, as contrasted with the motor, render difficult the task of writing a single, unified chapter representing the work of all five peripheral nerve centers. In many ways it would have been more adequate, and certainly more satisfying for the workers in each center, to have analyzed and reported upon their own data. However, the original plan of the entire study was predicated upon a common, integrated analysis and it is on that basis that the present chapter proceeds. Conspicuously absent from it are the results of many special sensory studies made in individual centers, especially Chicago, where the sensory examination was most complete. It is hoped that the ancillary data may be presented in subsequent reports from individual centers.

B. METHODS OF EVALUATING SENSORY RECOVERY

At the initial January 1947 conference it was pointed out that there then existed very little information on the specific level of sensory return, by modality, which could be expected following injuries of known extent, and that both practical and scientific interests would be served by the careful assessment of individual modalities. However, since a large-scale, cooperative survey was being planned, and it was agreed that uniform, comparable examinations should be made routinely, it was plain that the standard examination must not be overly elaborate, and that individual follow-up centers should be encouraged to supplement the standard examination with additional determinations of their own choosing in the light of their special interests. Emphasis was, therefore, placed on the more reliable and more objective aspects of sensory response to stimulation, and many tests originally proposed for the standard examination were not chosen. Moreover, when the time came to prepare a code for the statistical analysis, it was realized that the handling of data on areas of sensory loss would present difficulties, and that the most reliable observations were those pertaining to the area of isolated nerve supply (autonomous zone).

Accordingly, the mapping of total areas of diminished or absent sensibility was discontinued except in individual centers, notably Chicago, where there were special interests in the material. The Chicago center also made some observations on the loss of sensory response to temperature and to vibration.

At the January 1947 conference tentative agreement was reached on the content of the sensory examination, as follows:

Mapping of area of loss of touch.
Mapping of area of loss of sensitivity to temperature.
Mapping of area of loss of superficial pain sensation.
Determination of deep pain response at tip of fingers and toes.
Mapping of two-point sensitivity.
Tinel's sign.

At the first planning conference in November 1947 the above list was confirmed, and the standard forms thereafter designed for the project called for specific mapping of areas of sensory loss. The Chicago center printed these forms with provision for an additional distinction between areas of diminished touch (or superficial pain) response and areas of complete loss. At the Chicago conference in January 1949 it was decided to abstract from the sensory examination only the superficial pain and touch thresholds for the autonomous zones, together with the pain and touch responses to deep pressure, and to summarize sensory regeneration on the basis of the scale developed by workers associated with the British Medical Research Council (68). The tests of temperature sensation and two-point discrimination, and the determination of Tinel's sign, were dropped from the list of standard sensory tests. Later, as trial coding proceeded, the group was persuaded to add to the abstract for statistical purposes tests of position sense and localization of stimuli, although these had been omitted from the original protocol.

1. Pain.

Pain was considered in terms of deep pain resulting from pressure, as on the tips of fingers and toes, and of superficial pain resulting from graded pinprick. The superficial pain threshold was determined by means of Lewey's spring algesiometers (42) which were made and calibrated at the same source. The examiner applied the pointed end of this instrument to the appropriate area and exerted steady, gentle force. The end-point was read in grams/mm^2 pressure. The observations on the autonomous zone were scaled as follows for analysis:

a. No sensation of pain.
b. Deep pressure pain only.
c. Superficial pain sensation to 40 gm./mm^2.
d. Superficial pain sensation to 30 gm./mm^2.
e. Superficial pain sensation to 20 gm./mm^2.
f. Superficial pain sensation to 10 gm./mm^2.
g. Superficial pain sensation to 6 gm./mm^2.
h. Superficial pain sensation to $<$6 gm./mm^2.

Although the Chicago charts, and the early charts of the other centers, contain further data of undeniable value on the extent of any deficit in pain sensibility, the data on the autonomous zone are surely the most reproducible, especially since examiners were loath to block adjacent nerves. The five centers were compared, prior to the statistical analysis, on the basis of completely sutured nerves, completely divided at injury, and with no associated nerve injury. The proportions with thresholds of 10 gm or less were compared for sutures of median, ulnar, radial, and peroneal, and with thresholds of 30 gm. or less for the tibial, and appeared to be reasonably homogeneous except that New York ratings were much less favorable on peroneal sutures. Although the specifications for selecting the cases for these comparisons were so rigorous that the number of cases per center was not large, and in consequence the comparisons are not very powerful in the statistical sense, at least gross comparability of examinations seemed assured. Later, when all the ratings of individual centers were compared in more detail, it became plain that the centers did vary considerably in their use of the categories "no pain sensation," "deep pressure pain only," and threshold below 6 gm. Also one center (Chicago) almost never observed thresholds of 30 gm., 20 gm., and 6 gm. and concentrated its readings on the other categories of the classification.

2. Touch

Touch was approached in parallel fashion. Dr. Lewey devised a carefully standardized series of von Frey hairs, also made centrally and calibrated at the Philadelphia center, which all follow-up centers employed. Although the Chicago observations, and those made early in the other centers, extended to mapping the entire area of loss or diminution in touch sensibility, when the material was coded for statistical analysis attention was confined to the autonomous zones. The following scale was used:

0. No sensation, or threshold in excess of 50 gm./mm^2
1. Deep pressure felt with 50 gm./mm^2
2. Deep pressure felt with 35 gm./mm^2
3. Deep pressure felt with 25 gm./mm^2
4. Superficial pressure felt with 16 gm./mm^2
5. Superficial pressure felt with 5 gm./mm^2
6. Superficial pressure felt with 3 gm./mm^2
7. Superficial pressure felt with $<$3 gm./mm^2

The study of center variation in rating touch thresholds was made along the lines already described in connection with the pain threshold, and considerable center variation was found for each of the four nerves sampled (median, ulnar, tibial, and peroneal). The only systematic feature of this variation was the greater tendency of one center (San Francisco) to report thresholds of 3 gm. and a lesser tendency to report "no sensation, or threshold in excess of 50 gm." In addition, however, the Chicago center almost never reported thresholds of 50, 35, 16, and 3 gm. Consideration was given to the possibility of analyzing the touch data by center, but since only one center deviated in a gross way, and accounted for only about 13 percent of the data, this was not done.

One member of the study group (Dr. Lyons) has questioned the ability of the examiners to distinguish reliably between pain and touch reinnervation, pointing out that it is very rare in this material (about 1.7 percent) that examiners reported no pain sensation in the presence of some touch sensibility. He also suggested that there may have been many instances in which regenerated superficial or even deep pain fibers were stimulated by the examiner and their reponse interpreted as sensation of touch or deep pressure. No statistical validation procedure seems applicable here, but the relationship between pain and touch assessments on median, ulnar, peroneal, and tibial nerves is shown in table 131. It will be seen there that 104/684 or 15 percent of the cases with a pain response were considered to have no touch response in contrast to the figure of 1.7 percent already given for absent pain sensitivity in the presence of a touch response.

Table 131.—*Correlation Between Pain and Touch Assessments, Median, Ulnar, Peroneal, and Tibial Nerves*

Pain response	Touch response		
	Absent	Present	Total
Absent	83	10	93
Present	104	580	684
Total	187	590	777

3. Position Sense

The test of position sense consisted of asking the subject to locate the postion of the moved part, screened from his view. The following rough scale was used in classifying the observations for statistical analysis:

0. No position sense
1. Position sense present but reduced
2. Position sense normal.

Unfortunately, the test was performed only about half the time, and in one center (Chicago) almost never. The center comparison was confined to ulnar sutures of the set previously defined, and the resulting variation, exhibited in table 132, seemed sufficient to deny the ratings any real value in the subsequent analyses; accordingly the data are not presented here.

4. Localization

Estimation of the patient's ability (without visual help) to localize stimuli applied to the affected autonomous zone was also a late addition to the standard sensory examination. If no significant pain or sensory

Table 132.—*Center Variation in Reporting of Position Sense*

Follow-up center	Number of lesions, by position sense			
	Absent	Reduced	Normal	Total
A. Complete sutures on ulnar [1]				
Boston	8	4	7	19
New York	2	2	17	21
Philadelphia	15	34	28	77
San Francisco	2	28	4	34
Total	27	68	56	151
B. All nerves, all types of lesion, all operations				
Boston	31	21	124	176
New York	37	24	154	215
Philadelphia	157	264	390	811
San Francisco	12	246	58	316
Total	237	555	726	1, 518

[1] Injury produced complete nerve division, and no other nerve was injured on the same limb.

perception existed, there was so obviously no ability to localize that many examiners did not even code this observation. For example, at the Philadelphia center, where localization was actually tested in about half of the cases, table 133 shows the relation between the performance of the test and the results obtained in tests on the pain and touch thresholds. With some pain or touch sensation, a stimulus, either pain or touch, was chosen, which was easily perceived. In other words, the test was one of localization of touch, where possible, and otherwise consisted in pain localization.

When the observations on localization were abstracted for statistical study they were classified as follows:

0. Absent localization.
1. Split sensation.
2. Normal localization.

Localization was tested in less than half the cases, and presence of anesthesia played a large role in the examiner's decision whether to perform the test. Unfortunately, when the observations were coded for statistical analysis all cases not tested were lumped together as unknowns, so that the material as coded cannot be used except in conjunction with the results of tests on pain and touch thresholds. Quite significant center variation was observed; the percentages with normal localization, for example, are 31, 39, 60, and 62 for the 4 centers, on a range of 178 to 468 cases. Although the variation is less extreme than that observed for position sense, it is nevertheless too large to permit pooling of data with impunity. For these reasons the observations on localization possess only very limited usefulness and their presentation in the following section has been limited to the data from a single center, Philadelphia.

Table 133.—*Percentage of Cases Tested for Localization in Relation to Results of Pain and Touch Stimulation, Complete Sutures on Median, Ulnar, Tibial, and Sciatic-Tibial Nerves Examined at Philadelphia Follow-up Center*

Pain threshold	Touch threshold	Number of lesions studied	Localization test performed	
			Number	Percent
None, or deep pressure only......	None, or >50 gm...	91	11	12
	50 gm. or less.......	47	29	62
40 gm. or less..................	None, or >50 gm...	7	3	43
	50 gm. or less.......	168	118	70
Unknown on either pain or touch.	....	9	0	0
Total..................	....	322	161	50

5. Modified British Summary of Sensory Regeneration

The summary of sensory regeneration was adapted from a scale developed by the Nerve Injuries Committee of the Medical Research Council of Great Britain (68, 70), and consists of the following rubrics:

0. Absence of sensibility in the autonomous zone.
1. Recovery of deep cutaneous pain sensibility within the autonomous zone.
2. Recovery of superficial pain sensibility.
3. Recovery of some degree of superficial cutaneous pain and touch sensibility within the autonomous zone.
4. Return of superficial pain and touch sensibility throughout autonomous zone, with overreaction and inability to localize stimulus.
5. Return of superficial cutaneous pain and touch sensibility throughout autonomous zone, with disappearance of any overresponse.
6. Return of sensibility as above with the addition that there is some recovery of two-point discrimination within the autonomous zone.
7. Complete recovery.

A precise comparison with the British classification is made in table 140, below. The modified British summary of sensory regeneration was adopted at the Chicago conference not only for its value as a summarizing device but also as a possible bridge between the results of the two studies. Exploration of center variation prior to tabulation did not extend to this sensory summary, it having been supposed that any derived summary would merely have the characteristics of its components. Subsequent to the tabulation of the sensory data, however, the centers were compared as to their use of the British classification; 1,924 completely sutured nerves with no associated nerve injury were studied. The observed variation was very discouraging and had it been discovered prior to tabulation and analysis the material of each center would have been studied separately. Table 134 includes the comparative data on the median and ulnar; results with the tibial and sciatic-tibial were no better.

Table 134.—*Comparison of Follow-up Centers as to Classification of Sensory Recovery on Basis of British Summary, Completely Sutured Nerves With No Associated Nerve Injuries*

Center	Percentage distribution of cases by British summary				Total number of nerves
	Not more than return of superficial pain (0, 1, 2) [1]	Pain and touch, with overreaction and inability to localize (3, 4) [1]	Pain and touch, with no overresponse (5, 6, 7) [1]	Total	
Median sutures					
Boston	24.0	40.0	36.0	100.0	50
Chicago	57.1	32.1	10.7	99.9	28
New York	24.3	63.6	12.1	100.0	107
Philadelphia	26.9	31.9	41.2	100.0	119
San Francisco	4.0	48.0	48.0	100.0	50
Ulnar sutures					
Boston	27.5	44.9	27.5	99.9	69
Chicago	67.3	28.8	3.8	99.9	52
New York	35.3	49.7	15.0	100.0	153
Philadelphia	34.8	16.7	48.5	100.0	204
San Francisco	7.9	50.6	41.6	100.1	89

[1] These numbers define the grouping more specifically, in terms of the classification on p. 247.

6. Sensory Evidence of Anatomic Regeneration

In each case a judgment was also made as to evidence of any anatomic regeneration of sensory fibers; similar assessments were made on the basis of the voluntary motor and the electrical tests, it will be recalled. Prior to tabulation, statistical tests on the homogeneity of the five centers were confined to the proportion coded as having any evidence of anatomic regeneration, and these suggested that the centers were sufficiently homogeneous. Later, at the time the centers were compared as to their use of the British summary of sensory regeneration, the matter was restudied with specific attention to evidence of anatomic regeneration of sensory fibers and quite significant variation found, as may be seen in table 135. Two centers seem to deviate excessively from the rest, Chicago in the direction of reporting lower sensory return and San Francisco in the opposite direction, if the cases examined by the five centers are in fact homogeneous to begin with.

Table 135.—*Comparison of Follow-up Centers as to Percentage of Completely Sutured Lesions With Any Evidence of Anatomic Regeneration of Sensory Fibers, Nerves With No Associated Nerve Injury on Same Limb*

Center	Percentage with evidence of regeneration, by nerve			
	Median	Ulnar	Tibial	Sciatic-tibial
Boston	87.5	80.6	100.0	81.3
Chicago	71.4	76.4	58.6	50.0
New York	91.7	90.7	96.7	75.4
Philadelphia	85.7	86.3	88.6	74.6
San Francisco	96.2	95.6	100.0	90.0
Total	88.2	87.3	85.6	73.6

The same pattern of deviation is evident in table 134 on the British summary of sensory regeneration, and suggests the need for some consideration of any independent evidence of the homogeneity of the cases themselves, as contrasted with the sensory evaluations, as has been assumed. Study of the modified British summary of *motor* regeneration tends to confirm this assumption of homogeneity; no absolute confirmation is, of course, possible since the cases are different, but in comparison with an average rank of 3.0 which would be expected from 5 centers with homogeneous material the Chicago cases have an average rank of 2.5 and San Francisco 2.8 among all 5 centers, where the averaging is done over nerves.[16]

[16] Each center was ranked 1, 2, 3, 4, or 5 in order of relative excellence of results on each nerve (M, U, R, P, SP, and ST, only T being omitted for paucity of cases), and the 6 ranks thus obtained for each center were averaged; in entirely homogeneous material each center would have an expected average rank of 3.0, the average of ranks 1, 2, 3, 4, and 5.

7. Sources of Error

In view of the essentially subjective nature of sensation, each and every determination requires the active cooperation of the subject under study. His status in respect to fatigue, willingness to cooperate, and immediate response to his environment, all combine to influence clinical observations on sensory performance. But in addition to these sources of variation, the evidence is that in this study the examiners themselves probably varied greatly in their interpretation of the patients' reactions to sensory stimuli. Of all the clinical observations and assessments abstracted for statistical study, only that on pain is surely adequate for direct pooling of data from the various centers. Since the extent of examiner-variation was not fully appreciated until after the main analysis had been completed on the pooled data it was not possible to extend the analysis to the individual centers to the extent desired. One result is that the effect of characteristics of the nerve injury, of associated injuries, and of variables in the management of the nerve injury, may be analyzed best on the basis of the pain threshold, but the observations on touch and the British classification have also been used. To the extent that variation among the study centers cooperating in the present investigation may be representative of variation among the generality of skilled neurological observers, however, the fact that the group of examiners was as large as five provides some assurance that their examinations will yield an average picture of all possible examinations, rather than one unduly influenced by a particular point of view.

Although examiners were asked to extend their sensory examination to all 7 major nerves (M, U, R, P, T, SP, and ST), and observations on all 7 appear in the present chapter, chief reliance must of course be placed upon the median, ulnar, tibial, and sciatic-tibial injuries. For the radial, peroneal, and sciatic-peroneal the anatomic pattern of sensory supply varies so greatly from one individual to the next, both quantitatively and qualitatively, that the lack of earlier assessments of comparable extent and quality robs the follow-up examination of any real precision in the individual case. Indeed trained observers who look for early evidence of sensory regeneration following nerve injury have learned that no conclusions can be drawn from the degree of sensation present in the so-called autonomous zones of these nerves. On the other hand, the fact of great individual variation in the autonomous zones does not necessarily deny these nerves a role in any statistical analysis on the effects of characteristics of injury and of details of treatment, because there can be no reason to assume any correlation between individual aberrations in pattern of nerve supply and the nature of the lesion or the choice of treatment. Individual variation in the autonomous zones may be considered a random variable in such statistical analyses, tending to obscure the significance of any variation which may derive from the characteristics of injury and treatment. Since the statistical analysis is very largely concerned with ascertaining whether particular factors influence individual modalities in some general way common to all nerves, it has seemed unnecessarily restrictive to exclude the radial, peroneal, and sciatic-peroneal entirely and better to use them for whatever independent data they might contain. To the extent that the autonomous zones for radial and peroneal nerves are smaller than average, or even absent, examiners may be expected to exaggerate the frequency with which sensory fibers have regenerated. However, the data may be used to derive estimates of the likelihood of sensory return, it seems probable that such estimates will be unduly high, but to an unknown extent. Comparisons between these nerves and others, therefore, will not be reliable, although high-low comparisons within each of them may be. A true high-low difference might well be obscured by the error of observation arising out of individual variation in autonomous zones.

In view of the interest which attaches to comparisons of lysed and sutured lesions and in view of the presumably incomplete nature of most lesions subjected merely to neurolysis, all cases of this type were reviewed[17] at the end of the project for positive evidence of sensory loss at the time of operation.

C. DESCRIPTION OF SENSORY RECOVERY FOLLOWING COMPLETE NERVE SUTURE

To avoid any bias which might result from the inclusion of possibly atypical cases, the tables for this section were restricted to the representative sample defined in chapter I (p. 9). The scheme of presentation places emphasis upon the modality of sensation, the injured nerve, and the follow-up center (where necessary), in that order.

1. Pain

For all the complete sutures in the representative sample, without regard to site of injury, extent of injury, presence of associated nerve injury, etc., table 136 provides a summary of findings by nerve. Subject to the qualifications already mentioned, these data are presented as a factual summary of the major findings of the study with respect to deep-pressure and superficial pain. They constitute as good an estimate as one might hope to have of the ultimate level of pain sensibility following peripheral nerve suture in young males. Table 136 is comparable to table 49 in the motor chapter (pp. 88–89), which distributes each sample of affected muscles as to ultimate power following suture. As will be shown by the subsequent analysis, the special features of the wounds incurred by the men studied here, and the fact that they were received in battle, appear to have so little influence upon the ultimate extent of sensory regeneration that one cannot doubt the representativeness of the results as a sample of all peripheral nerve injuries in young males, provided they were treated by suture in the modern manner.

[17] New York and Philadelphia cases were reviewed at those centers, Boston, Chicago, and San Francisco cases by personnel of the NRC Follow-up Agency.

Perhaps the chief lessons of table 136 are that the sutured nerve does regenerate in the great majority of instances, but that complete recovery of superficial pain does not often occur. Some pain sensation (deep or superficial) was observed in 88 to 94 percent of the upper extremities and in 77 to 84 percent of the lower. Some degree of pinprick sensation appears to have returned in 70 to 80 percent of the upper extremities and in 40 to 70 percent of the lower. A normal (<6 gm.) pinprick threshold was recorded in 10 to 18 percent of the upper extremities, and in 6 to 16 percent of the lower.

Table 136.—*Deep-Pressure Pain Response and Superficial Pain Threshold for Completely Sutured Lesions, by Nerve, Autonomous Zone Only*

Threshold [1]	Median	Ulnar	Radial	Tibial	Peroneal	Sciatic-peroneal	Sciatic-tibial
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No sensation of pain	8.5	11.9	5.8	19.0	15.5	22.7	23.3
Deep-pressure pain only	13.6	18.1	14.9	23.2	15.5	27.6	35.7
Superficial pain, 40 gm	14.5	16.2	15.9	15.4	17.0	17.0	12.8
Superficial pain, 30 gm	8.0	8.2	6.2	5.6	4.3	4.4	3.4
Superficial pain, 20 gm	11.7	12.1	6.2	6.9	9.4	2.9	4.3
Superficial pain, 10 gm	17.3	17.5	22.1	16.8	11.9	11.8	11.9
Superficial pain, 6 gm	10.8	6.2	10.7	2.7	10.2	3.7	2.5
Superficial pain, <6 gm	15.7	9.8	18.1	10.5	16.2	9.8	6.2
Total	100.1	100.0	99.9	100.1	100.0	99.9	100.1
Number of lesions	236	430	188	95	142	163	129

[1] About 6 percent of all cases were classified as "hypalgesia, unmeasured," and these have been distributed proportionately over the frequencies for thresholds from 40 gm. to 6 gm.

When the nerves were compared on the basis of the data in table 136 it was found that the median and radial do not differ significantly, but that the ulnar is inferior to both. In the ulnar there are more poor results, and fewer good results, than in the median or the radial, but the discrepancies are not large even if statistically quite significant. In the lower extremity there are also quite significant differences, but they appear to depend entirely upon site, in that peroneal does not differ from tibial, or sciatic-peroneal from sciatic-tibial, but each sciatic component differs from its respective lower segment in the knee and leg.

2. Touch

For all the complete sutures in the representative sample, without regard to site of injury, extent of injury, presence of associated nerve injury, etc., table 137 provides a summary of touch thresholds, by nerve. Like table 136 for pain and table 49 for motor recovery, table 137 gives for touch the chief findings of the entire study. In certain major respects the distributions of touch thresholds are like those of pain thresholds, as would be expected from the fact that the two thresholds are highly correlated. In both instances entirely normal thresholds are by no means common; some sensation is reported in most instances, and there is real variation among the individual nerves. In one respect the distributions for pain and touch differ quite sharply. At the low end of the pain scale there is considerable scatter over the categories "no sensation of pain," "deep pressure pain only," and "superficial pain, 40 gm.," but at the low end of the touch scale there is much more concentration in the lowest category "no sensation, or threshold>50 gm." The touch threshold, in fact, seems to be moderately concentrated in either the lowest region of the scale or in the region of 5 or 16 gm. applied as a superficial touch stimulus. At the high end of the touch scale the pain and touch thresholds look moderately similar.

Table 137.—*Deep-Pressure Touch Response and Superficial Touch Response for Completely Sutured Lesions, by Nerve, Autonomous Zone Only*

Threshold [1]	M	U	R	P	T	SP	ST
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No sensation, or threshold >50 gm.	18.3	24.5	11.8	29.4	34.8	47.2	49.7
Deep-pressure felt with 50 gm. / Deep-pressure felt with 35 gm.	4.6	4.9	4.4	3.1	8.0	6.6	6.3
Deep-pressure felt with 25 gm.	5.4	7.9	6.7	15.9	8.1	6.6	4.7
Superficial pressure felt with 16 gm.	23.2	27.7	21.1	14.3	22.8	9.9	21.3
Superficial pressure felt with 5 gm.	21.8	16.6	20.0	13.5	10.7	8.6	9.4
Superficial pressure felt with 3 gm.	11.4	9.6	17.8	11.1	4.0	5.3	5.5
Superficial pressure felt with <3 gm.	15.3	8.8	18.2	12.6	11.6	15.5	3.1
Total	100.0	100.0	100.0	99.9	100.0	99.7	100.0
Number of lesions	241	433	187	143	95	163	129

[1] About 5 percent of all cases were classified as "hypesthesia, unmeasured," and these have been distributed proportionately over the frequencies for thresholds from 50 gm. to 3 gm.

The differences among nerves are rather like those for pain, lesions in the lower extremity exhibiting much less favorable sensory return than those in the upper, and the ulnar appearing at some disadvantage with respect to both the median and the radial. The tibial and peroneal do not differ significantly as tested here, and this is also true of the sciatic-tibial and sciatic-peroneal components. The peroneal and sciatic-peroneal lesions differ significantly, but not so the tibial and sciatic-tibial. However, if one were to take a position on both peroneal and tibial nerves in relation to their respective components above and below the knee, it would surely be that the tactile sense returned better in the lower lesions.

3. Localization

In the preceding section on methodology it was noted that data on localization could not be considered independently of those on pain and touch and that the several centers varied greatly in their reported results. For these reasons only the Philadelphia data are reported, and on the following assumptions:

(a) If the pain threshold is absent or for deep-pressure only, and touch is absent or >50 gm., any case coded as unknown for localization is regarded as having none; and

(b) If either pain or touch is better than in (a), then cases coded as unknown for localization may be regarded as having the same distribution as those actually tested.

Within the representative sample of complete sutures the Philadelphia center reported on 57 median lesions, 89 ulnar, 7 tibial, and 9 sciatic-tibial. Table 138 gives the details as reported on both median and ulnar lesions, and the results of applying the assumptions stated above. According to these adjusted distributions, then, median and ulnar lesions are indistinguishable as to localization. The specific estimates are:

	Percentage of Cases	
Localization	*Median*	*Ulnar*
None	23	29
Split	32	33
Normal	45	38

The best single estimate which could be made would be an average of the 2, or 26 percent absent localization, 32 percent split, and 42 percent normal.

The observations in table 138 were also scrutinized for any association between split sensation and the level of the pain threshold for cases with a touch threshold below 50 gm., but the observed variation was found to be statistically insignificant. For both median and ulnar combined, split localization was reported in 46 percent of the cases with absent or deep pain threshold only (but with touch <50 gm.), and in 42 percent of the cases with a superficial pain response and touch threshold <50 gm.

4. British Summary of Sensory Regeneration

As indicated earlier, the follow-up centers vary greatly in their use of the modified British scale. Here, however, where interest lies in the average picture of sensory regeneration in a representative sample of injuries, no purpose is served by presenting the ratings separately for each center; only the average of all centers seems useful for this purpose.

Table 138.—*Pain and Touch Thresholds and Localization, Complete Sutures on Median and Ulnar Lesions in the Representative Sample, Philadelphia Data Only*

Localization	Pain threshold								Total
	None or deep-pressure only				Superficial pain felt				
	Touch threshold				Touch threshold				
	Absent or >50 gm.		≤50 gm.		Absent or >50 gm.		≤50 gm.		
	Observed	Estimated	Observed	Estimated	Observed	Estimated	Observed	Estimated	
Median									
Unknown	16	0	1	0	0	0	7	0	0
None	1	17	1	1	0	0	0	0	18
Split	2	2	4	4	0	0	17	20	26
Normal	0	0	8	9	1	1	22	26	36
Total	19	19	14	14	1	1	46	46	80
Ulnar									
Unknown	37	0	8	0	2	0	27	0	0
None	2	39	1	2	1	2	3	4	47
Split	1	1	8	13	1	2	27	38	54
Normal	4	4	4	6	0	0	37	52	62
Total	44	44	21	21	4	4	94	94	163

In table 139 the entire representative sample of sutures is distributed according to the modified British rating. It will be noted from the detail of the classification scheme that the underlying observations extend well beyond the tests of individual modalities already summarized. The frequencies of table 139 support the same general conclusions already noted and in addition enable one to see just how rarely complete sensory recovery occurred. Statistical tests on the homogeneity of the individual nerves tell about the same story as before. The radial appears to have recovered better than either median or ulnar, but the advantage of the median over the ulnar is open to question ($P=.09$). Tibial and sciatic-tibial do not differ, but peroneal injuries appear to have recovered more completely than sciatic-peroneal. The two sciatic components are homogeneous, and the peroneal has some advantage over the tibial, according to these ratings. The apparent superiority of the radial and peroneal nerves is somewhat suspect, for the reasons given in the preceding section.

Since the summary classification was adapted from the one originally proposed by Highet for use by the Nerve Injuries Committee of the Medical Research Council of Great Britain, for the avowed purpose of making some comparison of British and American material, information appearing in the recent British report (70) has been abstracted in table 140 together with parallel data from the present study. The discrepancies are quite large, and at this writing remain unexplained. The British report contains no absolute failures among median and ulnar sutures, in contrast to 20 to 30 percent of the United States cases evaluated as having at most a deep pain response. Examiner variation, as judged by the differences among the five United States centers, would hardly produce such divergent results; the suggestion is strong that the series are basically different, either because of sampling considerations or because of differences in management. All five United States centers reported British S0 and S1 cases among both median and ulnar sutures. On the other hand, it would be an unusual selection which increased the sampling ratio at both the good and the bad ends of the scale, and it therefore seems likely that other factors are at work as well.

Table 139.—*British Summary of Sensory Regeneration for Completely Sutured Lesions, by Nerve*

Summary [1]	M	U	R	P	T	SP	ST
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0 Sensibility absent	11.1	12.2	6.6	15.8	17.5	24.6	22.9
1 Deep pain only	11.9	16.3	9.7	17.2	24.8	25.8	32.6
2 Superficial pain	2.5	4.1	4.6	7.6	4.1	6.0	3.8
3 Some superficial pain and touch	14.7	12.0	15.3	15.8	14.5	14.4	14.4
4 Superficial pain and touch, overreaction and poor localization	28.2	24.0	13.3	16.5	26.8	16.2	15.9
5 Superficial pain and touch, no overresponse	13.9	18.9	25.5	14.5	10.3	7.8	5.3
6 Superficial pain and touch, + 2-pt. discrimation	16.8	12.3	22.4	10.3	1.0	4.2	4.5
/ Complete recovery	0.2	.02	2.5	2.1	1.0	1.2	0.8
Total	99.9	100.0	99.9	99.8	100.0	100.2	100.2
Number of lesions	244	441	196	145	97	167	132

[1] See text (p. 247) for more detail on the classification, keyed to code numbers.

Table 140.—*Comparison of U. S. and British Data on Sensory Regeneration, Complete Sutures on Ulnar, Median, and Tibial Nerves*

British code [1]	Median		Ulnar		Tibial	
	U. S.	British	U. S.	British	U. S.	British
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0 Sensibility absent	11.1	0	12.2	0	17.5	19.5
1 Deep pain	11.9	0	16.3	0	24.8	53.4
2 Some superficial pain and touch	17.2	46.7	16.1	54.0	18.6	18.6
2+ Superficial pain and touch, with overreaction	28.2	15.2	24.0	15.2	26.8	1.7
3 Superficial pain and touch, no overresponse	13.9	29.5	18.9	28.2	10.3	6.8
3+, 4 Superficial pain and touch, plus at least some 2-pt. discrimination	17.6	8.6	12.5	2.6	2.0	0
Total	99.9	100.0	100.0	100.0	100.0	100.0
Number of lesions	244	278	441	390	97	118

[1] The precise parallel between the two classifications is as follows:

British	U. S.
0. Absence of sensibility in autonomous zone.	0. Same as British.
1. Recovery of deep cutaneous pain sensibility within the autonomous zone.	1. Same as British.
2. Return of some degree of superficial pain and tactile sensibility within autonomous zone.	2. Recovery of some superficial pain. 3. Return of some superficial cutaneous pain and touch, autonomous zone.
2+. Recovery of pain and touch sensibility throughout autonomous zone, with persistent overreaction.	4. Return of superficial pain and touch throughout autonomous zone, with overreaction and inability to localize.
3. Return of superficial pain and tactile sensibility throughout the autonomous zone with disappearance of overresponse.	5. Same as British 3.
3+. Good localization with some return of two-point discrimination.	6. Return of superficial pain and touch, plus some two-point discrimination in autonomous zone.
4. Return of superficial pain and tactile sensibility with the addition that there is recovery of two-point discrimination within the autonomous zone.	7. Complete recovery.

Table 141.—*Number of Cases in Each Classification of British Summary of Sensory Regeneration in Relation to Results of Specific Tests on Pain and Touch Thresholds, Complete Ulnar Sutures*

Pain threshold	Touch threshold			
	At most deep pressure with 50 gm.	16–35 gm.	5 gm. or less	Total
A. Absence of sensibility (code 0)				
At most deep-pressure pain	62	0	2	64
Superficial pain, 20–40 gm	0	0	0	0
Superficial pain, <20 gm	0	0	0	0
Total	62	0	2	64
B. Deep pain, or some superficial pain (code 1,2)				
At most deep-pressure pain	45	19	8	72
Superficial pain, 20–40 gm	18	9	0	27
Superficial pain, <20 gm	10	6	0	16
Total	73	34	8	115
C. Superficial pain and touch, with overreaction (code 3,4)				
At most deep-pressure pain	1	11	3	15
Superficial pain, 20–40 gm	2	44	29	75
Superficial pain, <20 gm	2	26	42	70
Total	5	81	74	160
D. Superficial pain and touch, no overreaction (code 5,6,7)				
At most deep-pressure pain	0	8	1	9
Superficial pain, 20–40 gm	0	45	29	74
Superficial pain, <20 gm	0	30	67	97
Total	0	83	97	180

Since agreement with British results is so poor, and the summary scale employed here is largely compounded of more specific tests of pain and touch responses, the United States data on the ulnar were subdivided by pain and touch as a further exploration of the basis of the summary classification by the five United States centers. Table 141 provides the detail of this subdivision, which employs somewhat coarser groupings of pain and touch than appear in tables 136 and 137. The cases studied here, it may be noted, are not confined to the representative sample, but extend to all examined cases in which the pain and touch thresholds were actually measured. From table 141 it may be seen that the summary rubric "absence of sensibility" follows very closely, as it must, the results of the specific tests of pain and touch; although the detail of table 141 is not sufficient to show it, 56 cases were explicitly coded as having neither pain nor touch response, 59 no pain response, and 61 no touch response, in the group of 64 cases. In the entire sample of 519 lesions, there are only 2 others with no pain response at all, and these were erroneously classified as "deep pain only." Apart from a very few possible errors of inclusion and exclusion, therefore, the use made of the British rubric "absence of sensibility" is a faithful summary of the tests of pain and touch thresholds, and it is difficult to see how technical errors in testing could explain the differences noted in table 140 between the United States and British results. The other British rubrics cover a mixed situation as to pain and touch thresholds. In the second group, detailed in panel B of table 141, one might have some question about the 15 cases with touch response to 16 to 35 gm. and pain thresholds of 40 gm. or below, but these cases constitute only 13 percent of the entire group. In the third group, shown in panel C of table 141, there are 15 cases which do not exhibit a superficial pain threshold, but 14 of them do have touch; there are 4 others with superficial pain thresholds, but no touch, or in all not more than 19 cases or 12 percent which might be questioned. In the fourth rubric of the adapted British classification there are 9 cases, or 5 percent, with no evident superficial pain threshold. In the main, then, the British classification was used by the United States examiners in a fashion which at least grossly fits the observations on pain and touch, and it seems doubtful that technical error can explain the discrepancy between the two series.

5. Sensory Evidence of Anatomic Regeneration

Usually some slight evidence of sensory regeneration was noted by examiners, so much so that the observation provides a rather insensitive tool for studying variation in sensory regeneration in relation to the independent variables which may be considered its determinants. In table 142 are contained the available data for all complete sutures in the representative sample. No great confidence can be placed in the absolute level of the percentages tabled there, in view of the considerable center variation noted above in section B, but they may be considered to represent the average conclusions to be expected from careful neurological examinations. Only the sciatic lesions depart from the rather uniform pattern of 85 to 88 percent with sensory regeneration, and even for the sciatic the percentages are 70 to 75.

Table 142.—*Sensory Evidence of Anatomic Regeneration Following Complete Suture, by Nerve*

Nerve	Number of cases	Percentage with sensory evidence
Median	252	88.1
Ulnar	450	86.9
Radial	201	86.6
Peroneal	149	86.6
Tibial	97	84.5
Sciatic-peroneal	168	70.8
Sciatic-tibial	134	74.6

D. DESCRIPTION OF SENSORY RECOVERY FOLLOWING NEUROLYSIS

In view of the multiplicity of the sensory tests and the generally superior sensory recovery following neurolysis, this separate section is devoted to an exposition of the results obtained with neurolyses and to their comparison with sutures. The sample of neurolyses was limited, as in chapter III, to those drawn from rosters chosen for their reliability, and to those obtained from the Peripheral Nerve Registry, provided they fell within the sampling area for each nerve (p. 9). It will be recalled that lesions for which the definitive operation was neurolysis were specially scrutinized for sensory loss immediately prior to operation, in an effort to insure that the analysis could be carried out on limbs with adequate evidence of sensory loss.

1. Pain

The lysed cases are not concentrated at any particular point on the scale, but in the upper extremity the most frequent pain threshold was below 6 gm., i. e., essentially normal. Table 143 provides a summary of all the lysed lesions in the representative sample, although for several of the nerves the samples are quite small. For every nerve except the radial there exists a set of cases with no pain sensation at all, and for every nerve there is an additional set with only deep-pressure pain; these observations seem to indicate that some of the lysed lesions might better have been resected and sutured. None of the following comparisons of two or more nerves yields statistical evidence of probable heterogeneity:

Nerves compared:
- All seven nerves.
- Median v. ulnar v. radial.
- Peroneal v. tibial.
- Sciatic-peroneal v. sciatic-tibial.
- Peroneal v. sciatic-peroneal.
- Tibial v. sciatic-tibial.

Because of the small numbers of injuries representing several of the nerves, great emphasis cannot be placed upon the failure of the observations to distinguish the individual nerves from one another, but it does appear reasonably certain that any variation among them is probably not large.

Table 143.—*Deep-Pressure Pain Response and Superficial Pain Threshold for Lysed Lesions, by Nerve, Autonomous Zone Only*

Threshold [1]	M	U	R	P	T	SP	ST
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No sensation of pain......	2.7	4.3	....	8.3	7.4	18.9	11.5
Deep-pressure pain only..	8.0	9.6	3.3	16.7	14.8	13.5	13.1
Superficial pain, 40 gm...	12.5	15.0	21.2	....	8.0	5.4	10.7
Superficial pain, 30 gm...	7.9	7.5	....	4.6	4.0	2.7	8.9
Superficial pain, 20 gm...	12.5	6.3	10.6	4.6	4.0	5.4	8.9
Superficial pain, 10 gm...	18.9	21.3	17.6	27.1	28.1	24.3	25.0
Superficial pain, 6 gm....	9.5	13.8	10.6	17.9	4.0	16.2	5.4
Superficial pain, <6 gm..	28.0	22.3	36.7	20.8	29.6	13.5	16.4
Total.............	100.0	100.1	100.0	100.0	99.9	99.9	99.9
Number of lesions..	75	94	30	24	27	37	61

[1] About 6 percent of all cases were classified as "hypalgesia, unmeasured," and these have been distributed proportionately over the frequencies for thresholds from 40 gm. to 6 gm.

One would expect somewhat better recovery of pain sensation following lysis than following complete suture; interest lies rather in the magnitude of the discrepancy. Table 144 provides a summary of the comparisons which were made, nerve by nerve, on a more summary grouping of the pain-response scale. Despite occasionally small numbers of cases, the superiority of the lysed cases seems quite clear. For lysed lesions the percentage with superficial pain thresholds of 6 gm. or less is about twice that for sutured lesions, on the average. The advantage stems not from the difference in surgery, of course, but from the very different nature of the underlying lesions; the incomplete (lysed) lesions do better than the complete. However, it is also plain that if surgeons had chosen, instead of neurolysis, resection and suture of the lesions studied here—neurolyses, the ultimate sensory recovery would probably have been less favorable than it actually was. As was noted in connection with table 143, however, one might argue that 10 to 25 percent of the lysed lesions might have done better if resected and sutured.

Table 144.—*Comparison of Completely Sutured and Lysed Nerve Lesions as to Deep-Pressure Pain Response and Superficial Pain Threshold in Autonomous Zone, by Nerve.*

Nerve and operation [1]	Percentage distribution as to pain response					Number of lesions
	None or deep only	30–40 gm.	10–20 gm.	6 gm. or less	Total	
Median..............S..	22.1	22.5	29.0	26.5	100.1	236
L..	10.7	20.4	31.4	37.5	100.0	75
Ulnar...............S..	30.0	24.4	29.6	16.0	100.0	430
L..	13.9	22.5	27.6	36.1	100.1	94
Radial..............S..	20.7	22.1	28.3	28.8	99.9	188
L..	3.3	21.2	28.2	47.3	100.0	30
Peroneal............S..	31.0	21.3	21.3	26.4	100.0	142
L..	25.0	4.6	31.7	38.7	100.0	24
Tibial..............S..	42.2	21.0	23.7	13.2	100.1	95
L..	22.2	12.0	32.1	33.6	99.9	27
Sciatic-peroneal.......S..	50.3	21.4	14.7	13.5	99.9	163
L..	32.4	8.1	29.7	29.7	99.9	37
Sciatic-tibial..........S..	59.0	16.2	16.2	8.7	100.1	129
L..	24.6	19.6	33.9	21.8	99.9	61

[1] S distinguishes sutures from lyses (L).

2. Touch

The results of the examination for the touch response are quite like those for pain, as may be seen from table 145. Every nerve is represented by cases with no touch sensation (or threshold >50 gm.) and by a significant number with normal (<3 gm.) touch response. Variation among nerves never satisfies the criterion of statistical significance:

Nerves compared:
- All seven nerves.
- Median versus radial versus ulnar.
- Peroneal versus tibial.
- Sciatic-peroneal versus sciatic-tibial.
- Peroneal versus sciatic-peroneal.
- Tibial versus sciatic-tibial.

These tests were made on the basis of a summary grouping of various positions on the scale, viz.: deep-pressure threshold of 35 gm. or more, deep-pressure threshold of 25 gm. or superficial threshold of 16 gm., and superficial threshold of 5 gm. or less. The frequencies of table 145 suggest that the nerves of the upper extremity probably do have some advantage over nerves of the lower with respect to the likelihood of no touch sensation (or threshold >50 gm.).

Lysed and sutured lesions differ as to touch response about as they do as to pain, as may be seen from table 146. The advantage of lysed lesions is not always marked (cf. the radial), but on the whole the only tenable conclusion is that lysed lesions have a clear superiority over sutured, presumably because they were so different to begin with. For lysed lesions the percentage with superficial touch thresholds of 3 gm. or less is about twice that for sutured. Again, however, it would appear that a significant proportion of the lysed cases would probably have benefited from suture, had it been possible to distinguish them from the rest.

Table 145.—*Deep-Pressure Touch Response and Superficial Touch Response for Lysed Lesions, by Nerve, Autonomous Zone Only*

Threshold [1]	M	U	R	P	T	SP	ST
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
No sensation, or threshold >50 gm	9.3	10.5	3.3	20.8	14.8	19.4	21.0
Deep-pressure felt with 50 gm / Deep-pressure felt with 35 gm	3.1	2.4	10.7	8.9	......	8.3	......
Deep-pressure felt with 25 gm	3.1	6.0	3.3	4.4	4.1	5.6	12.3
Superficial pressure felt with 16 gm	21.4	24.1	21.0	17.8	20.0	33.3	29.8
Superficial pressure felt with 5 gm	29.1	16.8	21.0	17.8	15.9	16.7	12.3
Superficial pressure felt with 3 gm	15.3	18.0	14.0	17.8	11.8	5.6	3.5
Superficial pressure felt with <3 gm	18.7	22.1	26.7	12.5	33.3	11.1	21.0
Total	100.0	99.9	100.0	100.0	99.9	100.0	99.9
Number of lesions	75	95	30	24	27	36	57

[1] About 5 percent of all cases were classified as "hypesthesia, unmeasured," and these have been distributed proportionately over the frequencies for thresholds from 50 gm. to 3 gm.

3. British Summary of Sensory Regeneration

In general the lysed lesions did very well. In the great majority of cases there was some return of superficial pain and touch, and complete absence of sensibility was relatively uncommon. Table 147 provides the basic data on all the neurolysed lesions classified as to the modified British scale for sensory recovery. Apart from a fairly marked difference between nerves of the upper and lower extremities, there is no very reliable variation among nerves. The following comparisons were made without finding statistical evidence of heterogeneity beyond that expected by chance: M v. U v. R, P v. T, SP v. ST, P v. SP, and T v. ST.

Table 146.—*Comparison of Completely Sutured and Lysed Nerve Lesions as to Deep-Pressure Touch Response and Superficial Touch Threshold in Autonomous Zone, by Nerve*

Nerve and operation [1]	Percentage distribution as to touch response					Number of lesions
	None or 35 gm. or more	16–25 gm.	5 gm.	3 gm. or less	Total	
Median.............S—	22.9	28.6	21.8	26.7	100.0	241
L—	12.4	24.5	29.1	34.0	100.0	75
Ulnar...............S—	29.4	35.6	16.6	18.4	100.0	433
L—	12.9	30.1	16.8	40.1	99.9	95
Radial..............S—	16.2	27.8	20.0	36.0	100.0	187
L—	14.0	24.3	21.0	40.7	100.0	30
Peroneal............S—	32.5	30.2	13.5	23.7	99.9	143
L—	29.7	22.2	17.8	30.3	100.0	24
Tibial...............S—	42.8	30.9	10.7	15.6	100.0	95
L—	14.8	24.1	15.9	45.1	99.9	27
Sciatic-peroneal.......S—	53.8	26.5	8.6	10.8	99.7	163
L—	27.7	38.9	16.7	16.7	100.0	36
Sciatic-tibial..........S—	56.0	26.0	9.4	8.6	100.0	129
L—	21.0	42.1	12.3	24.5	99.9	57

[1] S is used for suture, L for lysis.

Table 147.—*British Summary of Sensory Regeneration for Lysed Lesions, by Nerve*

Summary	M	U	R	P	T	SP	ST
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sensibility absent........	5.2	5.2	0	12.0	7.4	13.2	14.3
Deep pain only..........	3.9	6.2	3.3	16.0	7.4	10.5	6.3
Superficial pain.........	0	1.0	10.0	4.0	0	10.5	6.3
Some superficial pain and touch................	10.4	19.6	10.0	12.0	7.4	7.9	14.3
Superficial pain and touch, overreaction and poor localization...........	20.8	12.4	30.0	12.0	37.0	15.8	27.0
Superficial pain and touch, no overresponse........	29.9	20.6	16.7	32.0	22.2	31.6	17.5
Superficial pain and touch, +2-pt. discrimination..	24.7	25.8	20.0	12.0	11.1	2.6	7.9
Complete recovery.......	5.2	9.3	10.0	0	7.4	7.9	6.3
Total............	100.1	100.1	100.0	100.0	99.9	100.0	99.9
Number of lesions...	77	97	30	25	27	38	63

Lysed and completely sutured lesions generally differ to an extent which seems statistically reliable, but for the radial and the peroneal the differences are small and without statistical significance. Table 148 enables a comparison to be made, nerve by nerve, on the basis of a summary grouping of the British scale. In the median and ulnar comparisons it will be noted that the lysed have not only fewer poor results but also many more good results, but in the sciatic comparisons the advantage is chiefly one of fewer poor results; even the lysed lesions do not often exhibit superior sensory recovery in the sciatic.

Table 148.—*Comparison of Completely Sutured and Lysed Nerve Lesions as to British Summary of Sensory Regeneration, by Nerve*

Nerve and operation [1]	Percentage distribution as to sensory regeneration					Number of lesions
	At most deep pain (0,1) [2]	Superficial pain and touch, with overresponse (2,3,4)	Superficial pain and touch, without overresponse (5)	Superficial pain and touch, with at least some two-point discrimination (6,7)	Total	
Median..........S..	23.0	45.4	13.9	17.6	99.9	244
L..	9.1	31.2	29.9	29.9	100.1	77
Ulnar..........S..	28.5	40.1	18.9	12.5	100.0	441
L..	11.4	33.0	20.6	35.1	100.1	97
Radial..........S..	16.3	33.2	25.5	24.9	99.9	196
L..	3.3	50.0	16.7	30.0	100.0	30
Peroneal..........S..	33.0	39.9	14.5	12.4	99.8	145
L..	28.0	28.0	32.0	12.0	100.0	25
Tibial..........S..	42.3	45.4	10.3	2.0	100.0	97
L..	14.8	44.4	22.2	18.5	99.9	27
Sciatic-peroneal.....S..	50.4	36.6	7.8	5.4	100.2	167
L..	23.7	34.2	31.6	10.5	100.0	38
Sciatic-tibial........S..	55.5	34.1	5.3	5.3	100.2	132
L..	20.6	47.6	17.5	14.2	99.9	63

[1] S is used for suture, L for lysis.

[2] Code numbers refer to categories defined (p. 247).

4. Sensory Evidence of Anatomic Regeneration

When all the evidence of the sensory examination was weighed in an effort to determine whether any anatomic regeneration had occurred in sensory fibers, the examiner almost always came to the conclusion that some sensory fibers had regenerated. Table 149 contains a summary of the resulting data, by nerve. There is comparatively little variation among nerves when sample size is taken into proper account, but the suggestion is strong that the sciatic lesions did less well than the median, ulnar, and radial lesions.

Table 149.—*Comparison of Completely Sutured and Lysed Nerve Lesions as to Presence of Any Sensory Evidence of Anatomic Regeneration Following Operation, by Nerve*

Nerve	Complete suture		Neurolysis	
	Number of lesions	Percentage with sensory evidence	Number of lesions	Percentage with sensory evidence
Median	252	88.1	79	93.7
Ulnar	450	86.9	100	93.0
Radial	201	86.6	30	93.3
Peroneal	149	86.6	25	76.0
Tibial	97	84.5	27	92.6
Sciatic-peroneal	168	70.8	39	76.9
Sciatic-tibial	134	74.6	63	79.4

Table 149 also includes the parallel data on complete sutures already cited in table 142. For none of the individual nerves does the disparity lie outside the range of chance, but for all seven nerves combined the advantage of the lysed lesions is clearly a quite significant one in the statistical sense, and yet a small one clinically. The forces of regeneration are too omnipresent, and regeneration itself too much a matter of degree, for a simple "yes or no" rating of this type to be very discriminating.

E. INFLUENCE OF CHARACTERISTICS OF NERVE INJURY UPON SENSORY RECOVERY

The preceding comparisons of lysed and completely sutured lesions pertain to the most important characteristic of the nerve lesion, namely, its precise anatomic nature and extent, but such comparisons are at best quite imperfect, for one can never know these facts for the lysed lesion as one can for the completely sutured. Other characteristics of injury which remain to be discussed here are the following—anatomic completeness of traumatic lesion preceding complete suture, specific site of lesion, and multiple lesions.

1. Anatomic Completeness of Traumatic Lesion Preceding Complete Suture

On the basis of the operator's report, it will be recalled, each lesion was classified as one of complete division, partial division, or neuroma in continuity, prior to resection and complete suture. These distinctions are somewhat inexact, but the broad groups based upon them should differ greatly as to anatomic completeness of original lesion. Partial divisions were not often seen in the sample of complete sutures, and in most of the comparisons which follow they are either omitted entirely or combined with the neuromas. Only complete sutures in the representative sample were used in this analysis.

Comparisons of neuromas in continuity and complete nerve divisions provide little suggestion of heterogeneity for all nerves generally, although in two (ulnar and tibial) some evidence is found. Table 150 contains a summary of these comparisons, nerve by nerve, with the omission of all cases coded "hypalgesia, unmeasured." The discrepancy noted there for the ulnar is hardly credible as evidence of a real difference between the two types of lesions of which these cases are samples, for the complete sutures have an excess of both good and poor recoveries, the neuromas being more concentrated in the middle of the distribution. The discrepancy noted for the tibial has a fairly small probability (.015) but is intuitively unreasonable in its direction; one would almost be willing to require that any discrepancy favor the neuromas in continuity. Despite these two aberrant tests, therefore, the only possible conclusion from these data is

Table 150.—*Pain Threshold and Anatomic Completeness of Lesion Prior to Complete Suture, by Nerve*

Nerve and completeness of lesion [1]	Percentage distribution of lesions as to pain threshold [2]				Number of lesions
	None or deep-pressure only	20–40 gm.	10 gm. or less	Total	
Median:					
Complete	24	34	42	100	159
Neuroma	25	32	43	100	44
Ulnar:					
Complete	35	31	34	100	291
Neuroma	24	49	26	99	87
Radial:					
Complete	22	25	53	100	111
Incomplete	21	37	42	100	34
Peroneal:					
Complete	33	23	44	100	82
Incomplete	36	36	28	100	47
Tibial:					
Complete	37	29	34	100	59
Incomplete	72	12	16	100	25
Sciatic-peroneal:					
Complete	56	23	21	100	102
Incomplete	50	18	32	100	50
Sciatic-tibial:					
Complete	62	16	22	100	87
Incomplete	58	26	16	100	38

[1] Incomplete lesions include partial divisions and neuromas in continuity.
[2] Cases coded "hypalgesia, unmeasured" are omitted from this table.

that no important variation in pain threshold is associated with the classification of lesions as to anatomic completeness.

In the observations on the touch threshold there is even less suggestion of heterogeneity associated with anatomic completeness of the original lesion, as may be seen from table 151.

Table 151.—*Touch Threshold and Anatomic Completeness of Lesion Prior to Complete Suture, by Nerve*

Nerve and completeness of lesion [1]	Percentage distribution of lesions as to touch threshold [2]				Number of lesions
	None or 35 gm. or more	16–25 gm.	5 gm. or less	Total	
Median:					
Complete	26.3	28.8	45.0	100.1	160
Neuroma	19.1	27.7	53.2	100.0	47
Ulnar:					
Complete	30.9	32.9	36.2	100.0	298
Neuroma	30.3	40.4	29.2	99.9	89
Radial:					
Complete	16.4	23.6	60.0	100.0	110
Incomplete	23.1	25.6	51.3	100.0	39
Peroneal:					
Complete	30.1	31.3	38.6	100.0	83
Incomplete	42.0	24.0	34.0	100.0	50
Tibial:					
Complete	42.4	33.9	23.7	100.0	59
Incomplete	56.0	12.0	32.0	100.0	25
Sciatic-peroneal:					
Complete	57.9	23.4	18.7	100.0	107
Incomplete	50.0	30.0	20.0	100.0	50
Sciatic-tibial:					
Complete	56.7	23.3	20.0	100.0	90
Incomplete	55.3	31.6	13.2	100.1	38

[1] Incomplete lesions include partial divisions and neuromas in continuity.
[2] Cases coded "hypesthesia, unmeasured" are excluded from this table.

Other data on sensory recovery are less satisfactory for analytic purposes by reason of the considerable center variation discussed earlier, but are in keeping with the data presented here on pain and touch, and it may be concluded that the classification of completeness of lesion, based on the surgeon's gross examination at time of resection and suture, is of no prognostic significance for sensory recovery.

2. Site of Lesion

Two related studies were made of site of lesion, the first based on the high-low classification already discussed, and the second on the detailed classification of table 14 (p. 36). The first study was done on the representative cross-section of complete sutures. In the upper extremity high lesions are those involving the elbow, arm, or shoulder (below the brachial plexus) and in the lower extremity the knee and thigh. In addition, there is interest in the relation of each of the two sciatic components to its corresponding lower segment, which has already been discussed earlier and need only be summarized here.

Sensory recovery differs quite dramatically from motor recovery in respect to the role played by gross site; it will be recalled from chapter III that motor recovery was considerably better in low lesions than in high. Except for the advantage enjoyed by peroneal and tibial nerves over their respective sciatic components, none of the comparisons of gross sites yields a discrepancy outside the range of chance. Three sensory indices were employed in this analysis: pain, touch, and the British summary of sensory regeneration. Table 152 provides the data on the pain threshold for median, ulnar, peroneal, and tibial nerves. In none of these comparisons does the discrepancy approach statistical significance, and despite some suggestion that lower lesions generally do a little better a combined probability on the discrepancies presented by all four nerves

Table 152.—*Comparison of High and Low Lesions as to Pain Threshold, Complete Sutures, by Nerve*

Nerve and site	Percentage distribution as to pain threshold [1]				Number of lesions
	At most deep-pressure	Superficial pain threshold		Total	
		20–40 gm.	10 gm. or less		
Median:					
High	26.3	35.1	38.6	100.0	114
Low	20.4	30.6	49.1	100.1	108
Ulnar:					
High	35.5	35.5	29.1	100.1	220
Low	27.6	34.6	37.8	100.0	185
Peroneal:					
High	34.9	29.1	35.9	99.9	103
Low	30.8	23.1	46.2	100.1	26
Tibial:					
High	48.1	25.9	25.9	99.9	27
Low	47.4	22.8	29.8	100.0	57

[1] The few cases with unmeasured thresholds have been omitted.

also lies well within the chance region. To assert that some small difference may not exist would be to go beyond the data, but it is plain that, as tested here, they are consistent with the view that gross site of lesion has no real effect on the recovery of the pain response. It must be recalled from the earlier discussion of table 136, however, that tibial lesions differ significantly from sciatic-tibial, and peroneal from sciatic-peroneal. If the testimony of those comparisons is added to that of table 152, one would conclude that gross site does have a general effect, so that whatever general conclusion one draws about the effect of gross site will depend on the view one takes of the discrepancies between the sciatic components and the segments distal to the sciatic sheath.

The touch threshold varies much less than the pain threshold, as may be seen from table 153, but, of course, the basic observations are more affected by center variation than is true of those on pain. Neither singly nor jointly do the four comparisons included in table 153 meet the criterion of statistical significance used here. It was noted in the discussion of table 137 that peroneal lesions recovered much better than sciatic-peroneal, but that the advantage of tibial lesions was small enough to have easily occurred by chance. The data do not support any general conclusion as to the effect of site upon the recovery of touch, and yet the discrepancy noted between peroneal and sciatic-peroneal has a probability below .001.

Table 153.—*Comparison of High and Low Lesions as to Touch Threshold, Complete Sutures, by Nerve*

Nerve and site	Percentage distribution as to touch threshold [1]				Number of lesions
	None or 35 gm or more	16–25 gm	5 gm or or less	Total	
Median:					
High	22.2	29.1	48.7	100.0	117
Low	25.5	26.4	48.2	100.1	110
Ulnar:					
High	32.6	36.2	31.2	100.0	221
Low	28.0	33.2	38.9	100.1	193
Peroneal:					
High	36.4	29.9	33.6	99.9	107
Low	26.9	23.1	50.0	100.0	26
Tibial:					
High	44.4	25.9	29.6	99.9	27
Low	47.4	28.1	24.6	100.1	57

[1] The few cases with unmeasured thresholds have been omitted.

Sensory observations upon the peroneal are not too reliable, but apart from any prejudice in the attitude of the examiner one would expect this fact to operate equally for peroneal and sciatic-peroneal lesions.

The summary classification of sensory recovery according to the British scale appears in table 154. None of the four comparisons there provides a discrepancy outside the usual chance range, and this is also true of all four taken jointly. As noted in the earlier discussion of table 139, this is also true of the tibial v. sciatic-tibial comparison, but peroneal lesions were rated much more favorably ($P < .01$) than sciatic-peroneal. Again, therefore, the evidence is far from satisfactory but suggestive of some effect favoring lower sites.

Table 154.—*Comparison of High and Low Lesions as to British Summary of Sensory Regeneration, Complete Sutures, by Nerve*

Nerve and site	Percentage distribution as to British summary of regeneration				Number of lesions
	Not more than return of superficial pain	Pain and touch with overreaction and inability to localize	Pain and touch with with no no overresponse	Total	
Median:					
High	24.4	48.0	27.6	100.0	127
Low	26.5	37.6	35.9	100.0	117
Ulnar:					
High	34.2	33.8	32.1	100.1	237
Low	30.9	38.7	30.4	100.0	204
Peroneal:					
High	42.7	33.3	23.9	99.9	117
Low	32.1	28.6	39.3	100.0	28
Tibial:					
High	48.3	44.8	6.9	100.0	29
Low	45.6	39.7	14.7	100.0	68

Site was studied in full detail for all sutures in the entire sample, not merely those in the representative sample and, for the pain threshold, table 155 gives a distribution of results for each site, by nerve. For each nerve a statistical test was made of the homogeneity of all sites in relation to one another. Other hypotheses, involving the relation of one particular site to another, were not formulated in advance and hence not tested. For both the median and the ulnar the observed variation by site is quite significant statistically, although this was not so when high and low lesions were compared in table 154. In part this is because the samples in table 155 are much larger (median lesions by 44 percent and ulnar by 31)

Table 155.—*Specific Site of Lesion and Pain Threshold at Follow-up, Complete Sutures, by Nerve*

Specific site	Percentage distribution as to pain threshold [1]				Number of lesions [2]
	At most deep-pressure	Superficial pain threshold		Total	
		20–40 gm.	10 gm. or less		
Median					
Upper ⅓ arm	33.3	37.5	29.2	100.0	48
Middle ⅓ arm	30.2	33.9	35.8	99.9	53
Lower ⅓ arm	20.0	22.5	57.5	100.0	40
Elbow	19.0	42.8	38.1	99.9	21
Upper ⅓ forearm	22.2	11.1	66.7	100.0	36
Middle ⅓ forearm	26.0	24.0	50.0	100.0	50
Lower ⅓ forearm	25.6	48.7	25.6	99.9	39
Wrist, hand	12.5	37.5	50.0	100.0	32
Total	24.8	31.7	43.6	100.1	319
Ulnar					
Arm, upper ⅓	42.8	35.7	21.4	99.9	70
middle ⅓	29.8	38.8	31.3	99.9	67
lower ⅓	36.9	26.2	36.9	100.0	84
Elbow	31.3	39.1	29.7	100.1	64
Forearm, upper ⅓	33.8	32.3	33.8	99.9	65
middle ⅓	22.1	26.7	51.2	100.0	86
lower ⅓	23.7	35.6	40.7	100.0	59
Wrist, hand	26.5	52.9	20.6	100.0	34
Total	31.2	34.2	34.6	100.0	529
Radial					
Arm, upper ⅓	20.7	28.3	50.9	99.9	53
middle ⅓	23.6	32.2	44.1	99.9	93
lower ⅓	25.4	20.9	53.7	100.0	67
Total	23.5	27.7	48.8	100.0	213

Table 155.—*Specific Site of Lesion and Pain Threshold at Follow-up, Complete Sutures, by Nerve*—Continued

Specific site	Percentage distribution as to pain threshold [1]				Number of lesions [2]
	At most deep-pressure	Superficial pain threshold		Total	
		20–40 gm.	10 gm. or less		
Peroneal					
Thigh, lower ⅓	43.5	34.8	21.7	100.0	23
Knee	34.6	29.0	36.4	100.0	107
Leg, upper ⅓	32.1	25.0	42.9	100.0	28
Total	35.4	29.1	35.4	99.9	158
Tibial					
Thigh, lower ⅓ } Knee }	48.7	23.1	28.2	100.0	39
Leg, upper ⅓ } middle ⅓ }	32.4	32.4	35.3	100.0	34
lower ⅓ } Ankle, foot }	53.1	15.6	31.3	100.0	32
Total	44.8	23.8	31.4	100.0	105
Sciatic-tibial					
Thigh, upper ⅓	65.6	18.7	15.6	99.9	96
middle ⅓	49.0	27.4	23.5	99.9	51
Lower ⅓	57.7	23.1	19.2	100.0	26
Total	59.5	22.0	18.5	100.0	173
Sciatic-peroneal					
Thigh, upper ⅓	53.3	25.0	21.7	100.0	120
middle ⅓	51.5	24.2	24.2	99.9	66
lower ⅓	59.4	25.0	15.6	100.0	32
Total	53.7	24.8	21.6	100.1	218

[1] Unmeasured thresholds omitted.

[2] Braces indicate groupings made for purposes of statistical test on variation by site.

and in part because the high-low groupings serve to obscure some of the variation noted by specific site. For any particular site the samples are often quite small, and it may be for this reason that no uniform numerical pattern emerges from the median and ulnar data, but insofar as any trend may be discerned it appears to be a simple gradient favoring the lower lesions. In all the other nerves the observed variation is quite within the power of chance to produce and any suggestion of a uniform pattern seems confined, again, to the advantage possessed by tibial and peroneal lesions over their sciatic components.

The touch response was studied in parallel fashion and significant variation observed only for the median and the sciatic-tibial. The data appear in table 156 and are confined to these two nerves. For the others the sites seem quite homogeneous in their recovery of the touch response. Even the differences noted for the median and sciatic-tibial are not very

Table 156.—*Specific Site of Lesion and Touch Threshold at Follow-up, Complete Sutures on the Median and Sciatic-Tibial Nerves*

Specific site	Percentage distribution as to touch threshold [1]				Number of lesions[2]
	50 gm. or more including no sensation	16–35 gm.	5 gm. or less	Total	
Median					
Arm, upper ⅓	38.0	22.0	40.0	100.0	50
middle ⅓	31.5	25.9	42.6	100.0	54
lower ⅓	9.8	36.6	53.7	100.1	41
Elbow	14.3	33.3	52.4	100.0	21
Forearm, upper ⅓	19.4	38.9	41.7	100.0	36
middle ⅓	24.0	24.0	52.0	100.0	50
lower ⅓	25.0	37.5	37.5	100.0	40
Wrist, hand	19.4	36.1	44.4	99.9	36
Total	24.1	30.8	45.1	100.0	328
Sciatic-tibial					
Thigh, upper ⅓	65.3	16.8	17.8	99.9	101
middle ⅓	49.1	39.6	11.3	100.0	53
lower ⅓	36.0	44.0	20.0	100.0	25
Total	56.4	27.4	16.2	100.0	179

[1] Cases with unmeasured threshold omitted.

[2] Braces indicate groupings made for purposes of statistical test on variation by site.

large, although like those involving the pain threshold they indicate a somewhat poorer recovery on the part of higher lesions.

Clearly there is a reliable but weak association between specific site of lesion and sensory recovery, but whether it is true of only certain nerves or of all remains in doubt. Only in the median, ulnar, and sciatic-tibial lesions is there statistically reliable evidence of the association, and for these the evidence is by no means uniform: only for the median are both pain and touch significantly related to specific site. In addition, of course, appreciable differences were noted earlier between the tibial and the sciatic-tibial and between the peroneal and the sciatic-peroneal. In general, it would appear that the lower lesions do better than the higher, and that the very highest tend to do least well. Table 157 provides a partial summary of the relationship, with emphasis upon the likelihood of no sensory response whatsoever in the autonomous zone, based on the modified British classification.

Table 157.—*Site of Lesion and Percentage of Cases With Absent Sensibility in Autonomous Zone at Follow-up, Completely Sutured Nerves, by Nerve*

Nerve	Specific site of lesion	Total lesions	Percentage with absent sensibility
Median	Arm, upper ⅓	53	18.9
	middle ⅓	59	13.6
	lower ⅓	43	7.0
	Elbow	22	9.1
	Forearm, upper ⅓	41	7.3
	middle ⅓	55	12.7
	lower ⅓	50	6.0
	Wrist and hand	40	15.0
	Total	363	11.6
Ulnar	Arm, upper ⅓	77	18.2
	middle ⅓	69	11.6
	lower ⅓	91	16.5
	Elbow	70	8.6
	Forearm, upper ⅓	74	8.1
	middle ⅓	91	9.9
	lower ⅓	68	13.2
	Wrist and hand	41	9.8
	Total	581	12.2
Radial	Arm, upper ⅓	57	5.3
	middle ⅓	108	6.5
	lower ⅓ plus elbow	102	8.8
	Total	267	7.1

Table 157.—*Site of Lesion and Percentage of Cases With Absent Sensibility in Autonomous Zone at Follow-up, Completely Sutured Nerves, by Nerve*—Con.

Nerve	Specific site of lesion	Total lesions	Percentage with absent sensibility
Peroneal	Thigh	25	16.0
	Knee	123	16.3
	Leg, ankle and foot	37	18.9
	Total	185	16.8
Tibial	Thigh, lower ⅓	13	7.7
	Knee	28	21.4
	Leg, upper ⅓	15	13.3
	middle ⅓	27	3.7
	lower ⅓	25	24.0
	Ankle and foot	10	20.0
	Total	118	15.3
Sciatic-peroneal	Thigh, upper ⅓	132	26.5
	middle ⅓	73	23.3
	lower ⅓	33	9.1
	Total	238	23.1
Sciatic-tibial	Thigh, upper ⅓	103	31.1
	middle ⅓	54	16.7
	lower ⅓	28	7.1
	Total	185	23.2

3. Multiple Lesions

The foregoing analysis is concerned almost exclusively with single lesions to a nerve trunk, but there were a handful of cases, here termed "multiple lesions," in which a single nerve sustained more than one injury. These cases are too few for refined statistical study, but those in which at least one of the lesions on the nerve was completely sutured are listed in table 158 as to pain and touch thresholds, and British sensory recovery. In an effort to determine whether the performance of multiple lesions, even in these few cases, was sufficiently inferior to meet a criterion of statistical significance, a rough comparison was made with other lesions on the basis of the frequencies presented in table 139. The result appears in table 159 and leads to the conclusion that the multiple lesions probably do not recover as well as single lesions. The percentage lying along the upper half of the scale is 32 for multiple lesions in contrast to an expectation of 54 percent, and the discrepancy has a probability of about .02 in a one-tailed test on the hypothesis that multiple lesions may not be better but are no worse than single. Although the effect of a secondary lesion upon sensory recovery is less dramatic than that upon motor recovery (see p. 119), it is nevertheless real.

Table 158.—*Pain and Touch Thresholds and British Sensory Recovery Following Multiple Lesions to Single Nerves, and With One Lesion Completely Sutured*

Case number	Nerve	Pain threshold gm.[1]	Touch threshold gm.[2]	British summary [3]
1074	Median......	20................	16	Pain and touch, no over-reaction.
2043	Ulnar.......	No sensation........	25	Unknown.
2053	Median......	Deep-pressure only...	>50	Absent sensibility.
2111	Tibial.......	No sensation........	>50	Do.
3194	Ulnar.......	10................	5	Pain and touch, 2-pt.
3275	Tibial.......	40................	>50	Superficial pain and touch.
3286	Median......	30................	>50	Deep pain.
3302	Ulnar.......	40................	>50	Do.
3372	Radial.......	40................	5	Superficial pain.
3408	.....do......	<6................	<3	Complete recovery.
3446	Ulnar.......	Deep-pressure only...	>50	Deep pain.
3801	Median......	Hypesthesia.........	16	Pain and touch, 2-pt.
3857	.....do......	.....do............	Hypalgesia	Pain and touch, no over-reaction.
4051	Ulnar.......	Deep-pressure only...	16	Do.
4063	.....do......	.....do............	>50	Deep pain.
4081	Median......	<6................	<3	Pain and touch, 2-pt.
4107	Sciatic-peroneal.	10................	16	Deep pain.
4289	Peroneal.....	No sensation........	>50	Absent sensibility.
4297	Ulnar.......	.....do............	>50	Do.
4346	.....do......	.....do............	>50	Do.
4379	Median......	Deep-pressure only...	16	Do.
4464	.....do......	10................	5	Superficial pain.
5026	Ulnar.......	40................	5	Pain and touch, no over-reaction.
5271	Sciatic-peroneal.	10................	16	Do.
5414	Ulnar.......	No sensation........	>50	Absent sensibility.
7707	.....do......	10................	16	Pain and touch, over-reaction.
8715	.....do......	Deep-pressure only...	16	Deep pain.
8725	.....do......	10................	25	Superficial pain.
8783	Median......	<6................	5	Pain and touch, over-reaction.

[1] These are abbreviated statements of the rubrics given in full on p. 243.

[2] These are abbreviated statements of the rubrics given in full on p. 244. The first rubric there "No sensation or >50 gm." is here abbreviated as ">50 gm."

[3] These are abbreviations for the classes described in detail on p. 247.

Table 159.—*Modified British Summary of Sensory Recovery for Multiple Lesions, at Least One Completely Sutured, All Nerves Combined*

Modified British summary		Number of cases	
Code	Interpretation	Observed	Expected [1]
0.....	Sensibility absent	7	3.6
1.....	Deep pain only	6	4.5
2.....	Superficial pain	1	1.1
3.....	Some superficial pain and touch	5	3.8
4.....	Superficial pain and touch, overreaction and poor localization.	3	6.6
5.....	Superficial pain and touch, no overresponse	3	4.6
6.....	Superficial pain and touch, plus 2-pt. discrimination	2	3.6
7.....	Complete recovery	1	.2
	Total	28	28.0

[1] For each set of cases involving a particular nerve the expected distribution of that number of cases was calculated from the distribution of all sutures on that nerve, and these expected values were then added together to provide a total for all 28 lesions.

F. INFLUENCE OF ASSOCIATED LESIONS

Although the decision to limit the statistical study of pain and touch response to the observations on the autonomous zone should obviate most of the influence of an associated nerve lesion upon the examiner's evaluation of the sensory recovery of another, it was considered wise to examine the data on the median and ulnar from this point of view. Also, there is practical interest in the possible influence of associated injuries to bones and arteries, and of prolonged infection. It should be recalled, however, from the study of motor regeneration, that both bone injury and prolonged infection are confounded with time from injury to operation and no attempt has been made here to disentangle these variables. Although the original study of associated injuries extended to all the indices of sensory recovery, only the analysis of the pain response is in every case presented here. Finally, two sampling considerations should be borne in mind: (1) The study of associated nerve injuries was confined to the representative sample of complete sutures; and (2) other associated injuries were analysed on the basis of all complete sutures or all neurolyses in the entire study.

1. Associated Nerve Injury

One nerve lesion was considered to have another associated with it only if both were on the same limb. It was not required of an associated nerve lesion that it be sutured, but only that it be a *bona fide* injury as determined by clinical signs. As noted in chapter II, the classification of associated lesions in the upper extremity extended to median, ulnar, radial, musculocutaneous, and axillary; "pure" nerve lesions are those in which none of these nerves was also injured. In the analysis here, however, associated lesions involving the axillary and musculocutaneous were not used, so only when the median, ulnar, or radial nerve on the same limb was also injured is a lesion said to be a "combined" lesion here, i. e., to have an associated nerve injury. Table 160 provides a summary of the data on this question, from which it may be concluded quite definitely that the presence of an associated ulnar injury has no effect upon the sensory recovery of the median, and that the sensory response of the ulnar is not influenced by the presence of a median or radial injury.

Table 160.—*Presence of Associated Nerve Injury and Pain Response in Autonomous Zone at Follow-up, Complete Sutures on the Median and Ulnar Nerves*

Associated nerve injury	Percentage distribution as to pain threshold [1]					Number of cases
	At most deep pain	30–40 gm.	10–20 gm.	6 gm. or less	Total	
Median						
None	26.0	19.0	26.0	29.0	100.0	100
Ulnar only	18.5	26.1	28.3	27.2	100.1	92
Total	22.4	22.4	27.1	28.1	100.0	192
Ulnar						
None	32.2	23.4	30.0	14.3	99.9	273
Median or radial	31.1	23.5	25.0	20.5	100.1	132
Total	31.9	23.5	28.4	16.3	100.1	405

[1] Cases with unmeasured hypesthesia are omitted.

2. Associated Bone or Joint Injury

In the entire series of 3,656 nerve injuries there are 41 percent with injuries to bones or joints on the same limb, and generally at the same site; for the radial the percentage is much higher, and for the sciatic considerably lower. On the average a definitive suture was delayed about 50 days by the presence of such associated injury or by other factors in turn associated with the orthopedic injury. Only complete sutures are studied here.

Both time and site are confounded with associated bone or joint injury, but it has not seemed necessary to refine the analysis to take these factors into account since their influence would tend to reinforce any effect of bone and joint injuries, and no apparent effect was noted.

For each of the major nerves the pain threshold was studied in relation to the presence of associated bone or joint injury and to the general character of its healing process. Table 161 exemplifies these analyses with the data on the median nerve; only small, insignificant variation can be seen there. Similar tests were done for "pure" and "combined" nerve lesions with the same result. For all other nerves except the peroneal the situation is essentially the same and presentation of further data seems unnecessary. For all complete sutures on the peroneal, however, a moderately large discrepancy was observed but discounted as a chance aberration on the ground that its direction seemed unreasonable: pain thresholds of 10 gm. or less were found in 25 percent of the cases with no associated bone or joint injury in contrast to 45 percent of those with some such injury.

The touch threshold was also analysed in relation to the presence and character of any associated bone or joint injury and no significant evidence of any deleterious influence was found. Table 162 presents the observations on the median as a sample of the available material.

The British summary of sensory regeneration was also employed as a sensory index in an effort to test the relationship between bone and joint

Table 161.—*Presence and Character of Any Associated Bone or Joint Injury, and Pain Threshold in Autonomous Zone at Follow-up, Complete Sutures on Median Nerve*

Presence and character of associated bone or joint injury	Percentage distribution as to pain threshold [1]				Number of lesions
	At most deep-pressure pain	Superficial pain felt		Total	
		With 20–40 gm.	With 10 gm or less		
Absent	25.7	31.8	42.5	100.0	179
Present: Normal healing	21.1	32.2	46.7	100.0	90
Other [2]	26.9	30.8	42.3	100.0	52
Total	24.6	31.8	43.6	100.0	321

[1] Cases with unmeasured hypesthesia are omitted.
[2] Requiring operative repair.

injury and sensory recovery following suture, and with results entirely consistent with those already given. The conclusion seems inescapable, therefore, that such associated injuries have no clinically important bearing upon sensory regeneration under the conditions of surgery prevailing in World War II.

Table 162.—*Presence and Character of Any Associated Bone or Joint Injury and Touch Threshold in Autonomous Zone at Follow-up, Complete Sutures on Median Nerve*

Presence and character of bone or joint injury	Percentage distribution as to touch threshold [1]				Number of lesions
	None or 50 gm. or more	16–35 gm.	5 gm. or less	Total	
Absent	23.8	31.4	44.7	99.9	185
Present: Normal healing	23.9	26.1	50.0	100.0	92
Other [2]	28.3	34.0	37.7	100.0	53
Total	24.5	30.3	45.2	100.0	330

[1] Cases with unmeasured hypalgesia are omitted.
[2] Requiring operative repair.

3. Chronic Infection Delaying Repair

Whenever osteomyelitis or soft tissue infection intervened to an extent sufficient to delay repair of a nerve lesion, this fact was noted as a characteristic of the case and a statistical analysis was done to determine whether lesions with such associated infection did as well as those without. As already reported in chapter II, this classification segregates a group of sutures which, on the average, were done about 100 days later than sutures on lesions free of such complications. About 9 percent of all the 3,656 nerve lesions in the series were complicated by chronic infection as defined here. Pain, touch, and the British summary of sensory regeneration were all utilized in the investigation of the possible effect of infection, whether directly or through delay in repair.

The observations on the pain threshold are summarized in table 163, by nerve, and seem at best somewhat equivocal. In view of the paucity of cases with infection, the scale for deep pressure pain and superficial pain was divided into two groups: (a) cases in which there was no pain sensation, deep pressure pain only, superficial pain felt with 20 to 40 gm., or "hypesthesia, unmeasured"; and (b) superficial pain felt with 10 gm. or less. Even this gross dichotomy often fails to provide sufficient cases for any very sensitive test in the statistical sense. A discrepancy favoring lesions free from complicating infection is noted for the median, radial, and sciatic-peroneal only, and one would not be inclined to consider the matter further were it not for the fact that the discrepancy for the radial has a probability of .01 in a two-tailed statistical test. The combined probability from all 7 independent tests is .15, well within the range of chance variation. To the extent that one may require that any effect of chronic infection must be general for all nerves, therefore, the conclusion must be that no influence has been demonstrated. But if one entertains the possibility that any effect may pertain only to certain individual nerves, then greater weight should be placed upon the variation seen in the radial, although, as noted in the introduction to this chapter, sensory tests on the radial are none too reliable. The point of view adopted here is that any effect must be general, and that the observed variation provides no basis for believing that chronic infection exerts any influence upon the ultimate regeneration of pain fibers.

Table 163.—*Presence of Chronic Infection Delaying Nerve Repair and Recovery of Pain Response, Complete Sutures, by Nerve*

Nerve	Infection present		Infection absent		Statistical tests [2]
	Number of cases	Percentage with threshold of 10 gm. or less [1]	Number of cases	Percentage with threshold of 10 gm. or less [1]	
Median	34	23.5	324	40.7	NS
Ulnar	44	34.1	524	32.1	NS
Radial	25	20.0	244	48.4	(**)
Peroneal	18	38.9	163	31.3	NS
Tibial	9	44.4	108	26.9	NS
Sciatic-peroneal	20	10.0	213	21.1	NS
Sciatic-tibial	17	23.5	164	17.1	NS
All tests combined	....	....	....	....	NS

[1] Among all tested, including those classified as "hypesthesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS—Not significant.
**—Significant at .01 level.

Recovery of the touch response was studied in exactly the same fashion, the scale being divided into two groups: (a) those with absent touch response, response to 16 gm. or more, or "hypalgesia, unmeasured"; and those with touch response to 5 gm. or less. As noted for pain, few of the statistical tests involve enough cases to give one confidence that any effect would show through the large sampling fluctuation in percentages entailed by such small numbers with chronic infection. Nevertheless, table 164 provides a summary of the available data, and it may be seen that, although only a single comparison (radial) provides a probability low enough to be of any interest, lesions without such infection have some numerical advantage in every nerve except the tibial, represented by only 9 cases with infection. Also, when the probabilities from the individual tests are combined into a single, overall probability judgment applicable to all nerves, it is found that the aggregate variation is greater than one would expect by chance. One must conclude, therefore, that the presence of chronic infection sufficient to delay repair, or the fact of such delay, or other factors associated with such infection, probably do tend to impair recovery of the touch threshold.

Table 164.—*Presence of Chronic Infection Delaying Nerve Repair and Recovery of Touch Response, Complete Sutures, by Nerve*

Nerve	Infection present		Infection absent		Statistical tests[2]
	Number of cases	Percentage with superficial touch threshold of 5 gm. or less[1]	Number of cases	Percentage with superficial touch threshold of 5 gm. or less[1]	
Median	35	34.3	327	41.9	NS
Ulnar	45	28.9	523	32.3	NS
Radial	25	28.0	242	50.8	*
Peroneal	18	27.8	164	32.3	NS
Tibial	9	33.3	108	26.9	NS
Sciatic-peroneal	21	9.5	213	16.4	NS
Sciatic-tibial	17	5.9	166	16.9	NS
All tests combined					*

[1] Among all tested, including those classified as "hypalgesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS—Not significant.
*—Significant at .05 level.

Although the observations upon which the British summary are based consist chiefly of those on the pain and touch response, in view of the disparity between the analyses on touch and pain it seems useful to present also the data on the British classification in relation to infection. This is done in table 165 which leads to the conclusion reached on the basis of the study of touch. Although, therefore, the observed discrepancies, even when taken collectively, do not uniformly have reliably low probabilities under the test hypothesis of random variation, that based on the British summary lies between .01 and .02. The conclusion seems justified that infection delaying nerve repair, either directly or through the fact of such delay, is somewhat prejudicial to the recovery of sensibility following nerve suture, but that as a general effect it may be confined to the regeneration of touch fibres.

Table 165.—*Presence of Chronic Infection Delaying Nerve Repair and British Overall Assessment of Sensory Recovery, Complete Sutures, by Nerve*

Nerve	Infection present		Infection absent		Statistical tests [2]
	Number of cases	Percentage classified as superior [1]	Number of cases	Percentage classified as superior [1]	
Median	35	22.8	331	30.8	NS
Ulnar	46	26.1	534	32.0	NS
Radial	25	24.0	254	48.8	*
Peroneal	18	38.9	167	24.0	NS
Tibial	10	10.0	109	13.8	NS
Sciatic-peroneal	21	0	217	12.0	NS
Sciatic-tibial	17	0	169	10.1	NS
All tests combined	....	....	....	....	*

[1] Defined as at least recovery of superficial cutaneous pain and touch sensibility throughout autonomous zone, with disappearance of any overresponse. "Superior" thus corresponds to rubrics 5, 6, and 7 on p. 247.

[2] Results of statistical tests (two-tailed) abbreviated as follows:

NS—Not significant.

*—Significant at .05 level.

4. Associated Arterial Injury

About 16 percent of all 3,656 nerve lesions had associated injuries to major arteries on the same limb. It was pointed out earlier that presence of an arterial lesion is confounded with site, being most common in the upper arm and rare in the lower extremity. Any analysis is of necessity confined to the median, ulnar, and radial. The presence of arterial injury did not serve to delay nerve repair.

Although all six sensory indices were studied in relation to arterial injury, for none of them was the observed variation sufficient to conclude that such associated injury has any effect upon sensory regeneration, and the observations on pain were chosen to exemplify the material used in the analysis. Table 166 provides a summary of the analysis, which extends to neurolyses on the median and ulnar as well as to sutures on all three nerves. The pain scale was divided as described earlier in connection with table 163. The observed variation is unusually small even as an example of chance variation.

Table 166.—*Presence of Associated Arterial Injury and Recovery of Pain Response in Autonomous Zone, Complete Sutures and Neurolyses in the Upper Extremity, by Nerve*

Nerve and definitive operation	Arterial injury absent		Arterial injury present		Statistical tests [2]
	Number of cases	Percentage with threshold of 10 gm. or less [1]	Number of cases	Percentage with threshold of 10 gm. or less [1]	
Median:					
Suture	230	40. 0	125	37. 6	NS
Lysis	55	54. 5	31	54. 8	NS
Ulnar:					
Suture	428	32. 9	135	31. 1	NS
Lysis	76	51. 3	28	60. 7	NS
Radial: Suture	239	46. 0	27	48. 1	NS
All tests combined					NS

[1] Among all tested, including those classified as "hypesthesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS = Not significant.

5. Major Plastic Procedure at Site of Nerve Injury

About 11 percent of all 3,656 nerve injuries had associated soft tissue defects at the same site and of sufficient extent to require plastic repair. Such repair was most commonly done at the knee or elbow, or in the forearm and leg, and involved the median, ulnar, peroneal, and tibial nerves. It was associated with an average delay of about 50 days in the nerve repair.

Each of the six sensory indices was studied in relation to the presence of large soft tissue defects requiring plastic repair, but for none of them was the observed variation outside the chance range. The observations on pain, being attended with less extraneous variation on technical grounds, are presented in table 167 to illustrate the findings. Since pain response shows some relation to site of injury, and the confounding is not such as to reinforce any effect of the plastic repair, the comparisons have been confined to the so-called low lesions, i. e., below the elbow and knee.

Table 167.—*Major Plastic Repair at Site of Nerve Injury and Pain Response in Autonomous Zone at Follow-up, Complete Sutures and Neurolyses, by Nerve, Low Lesions Only* [1]

Nerve and definitive operation	Plastic repair		No plastic repair		Statistical tests [3]
	Number of cases	Percentage with threshold of 10 gm. or less [2]	Number of cases	Percentage with threshold of 10 gm. or less [2]	
Median:					
Suture	58	44.8	126	38.9	NS
Lysis	9	55.6	7	28.6	NS
Ulnar:					
Suture	70	38.6	195	36.4	NS
Lysis	11	36.4	22	59.1	NS
Peroneal: Suture	27	44.4	9	22.2	NS
Tibial: Suture	65	32.3	10	10.0	NS
All tests combined	....	....	....	....	NS

[1] Low lesions are below elbow or knee.

[2] Among all examined cases, including those classified as "hypesthesia, unmeasured."

[3] Results of statistical tests (two-tailed) abbreviated as follows:
NS = Not significant.

G. INFLUENCE OF TECHNICAL ASPECTS OF MANAGEMENT

It is extremely difficult to assess the value of therapeutic procedures in the absence of experimental safeguards on the selection of clinical material, but in view of the great practical interest which inheres in the results of various choices which the surgeon may make as to therapeutic procedures, the analysis of sensory recovery has been extended to such details of management as seemed obtainable from the original military records.

In keeping with the policy which dictated the sampling plan for the study the investigation has usually been done not on the representative cross-section but on all complete sutures available in the study, regardless of roster and sampling area. The present section is quite parallel in purpose, method, and scope to the section bearing the same heading in the chapter on motor recovery, and pertains only to complete sutures.

1. Number of Operations

About 19 percent of all 3,416 lesions operated upon in this series had more than one operation. As pointed out earlier, most lesions for which the definitive operation is a complete suture, and on which more than one operation was done, were nevertheless sutured only once.

The role played by multiplicity of operations is a difficult one to forecast because reoperation is performed on various indications, especially poor regeneration, because one expects reoperation to have a beneficial effect, and because the operations which are counted vary greatly in their probable effect. On the whole, however, in a system in which explorations were done quite liberally whenever there was doubt about the progress of regeneration following operation, one would expect the cases with more than one operation to have poorer prognoses.

To obviate any influence of associated nerve injuries, the analysis was confined to so-called "pure" lesions on the median, ulnar, peroneal, and tibial nerves. Neither pain nor touch recovery alone reliably distinguishes sutures with a single operation from those with two or more, but classification by the British summary of sensory recover (table 168) does. The conclusion seems well founded that lesions with one or more operations before or after first suture have a poorer prognosis than those sutured and operated upon but once. The difference is not as large as one might expect, however. To provide a more detailed basis for estimating the extent of such selection, table 169 has been prepared by combining median and ulnar lesions. The advantage of the sutures with but one operation extends over the entire range of the British scale.

Table 168.—*Number of Operations and British Summary of Sensory Recovery, Complete Sutures on Pure Nerve Lesions, by Nerve*

Nerve	One operation		Two or more operations		Statistical tests [2]
	Number of cases	Percentage classified as superior [1]	Number of cases	Percentage classified as superior [1]	
Median	138	31.2	41	22.0	NS
Ulnar	291	34.0	94	21.3	*
Peroneal	100	28.0	45	17.8	NS
Tibial	86	15.1	6	16.7	NS
All tests combined					**

[1] Defined as at least recovery of superficial cutaneous pain and touch sensibility throughout autonomous zone, with disappearance of any overresponse. "Superior" thus corresponds to rubrics 5, 6, and 7 in table 169.

[2] Results of statistical tests (two-tailed) abbreviated as follows:

NS—Not significant.

*—Significant at .05 level.

**—Significant at .01 level.

Table 169.—*Number of Operations and British Summary of Sensory Recovery, Complete Sutures on Pure Median and Ulnar Lesions, Combined*

British classification	Single operation	More than one operation
	Percent	*Percent*
0 Sensibility absent	10.3	15.6
1 Deep pain only	13.1	20.0
2 Superficial pain	5.4	6.7
3 Some superficial pain and touch	12.8	14.8
4 Superficial pain and touch, overreaction and poor localization	25.4	21.5
5 Superficial pain and touch, no overresponse	17.9	14.1
6 Superficial pain and touch, plus 2-pt. discrimination	14.7	7.4
7 Complete recovery	0.5	0
Total	100.1	100.1
Number of lesions	429	135

2. Interval From Injury to Definitive Suture

The pitfalls of any analysis of the possible effect of time have been discussed at length in chapter III and need not be repeated here. At the outset the analysis of sensory recovery was confined to pure lesions on the median, ulnar, peroneal, and tibial, but no more than suggestive evidence of an effect was obtained. In view of the results of the analysis of motor recovery, which was conducted independently and showed time to exert a considerable effect upon the recovery of affected muscles, the study was broadened to include all seven major nerves, regardless of the presence of associated nerve injury, but the selection of cases was confined to the representative sample, i. e., sutures from the Army Registry within the sampling areas for individual nerves and centers. Both pain and touch thresholds were tabulated and studied in systematic detail, but neither for any individual nerve nor for all nerves jointly did there appear to be significant evidence that time exerts any effect upon the recovery of either modality. Table 170 provides the data for pain, table 171 for touch. These data are in marked contrast to those on motor recovery.

Special interest attached to the likelihood of sensory regeneration following sutures done long after injury. Not many lesions were operated upon later than 1 year after injury, but there are perhaps enough to warrant separate review, and in tables 172 and 173 will be found information on definitive sutures performed at long intervals after injury. The material merely suffices to show that sensory regeneration can occur following sutures done after such long intervals.

Table 170.—*Days From Injury to Definitive Suture and Pain Threshold at Follow-up, by Nerve, for Representative Sample*

Days from injury to suture	Pain threshold,[1] by nerve, upper extremity								
	Median			Radial			Ulnar		
	Poor	Fair	Good	Poor	Fair	Good	Poor	Fair	Good
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0–49	3. 8	7. 9	9. 3	7. 1	13. 7	14. 6	13. 1	6. 8	8. 1
50–99	15. 1	17. 1	15. 5	19. 0	17. 6	21. 9	17. 7	19. 2	16. 3
100–149	24. 5	26. 3	25. 8	21. 4	27. 5	22. 9	16. 9	25. 3	30. 4
150–199	18. 9	19. 7	16. 5	23. 8	13. 7	16. 7	23. 1	18. 5	17. 8
200–299	26. 4	19. 7	19. 6	19. 0	15. 7	16. 7	17. 7	19. 9	18. 5
300–399	7. 5	2. 6	7. 2	4. 8	5. 9	6. 3	4. 6	6. 2	5. 2
400–499	1. 9	3. 9	3. 1	0	2. 0	0	3. 1	2. 1	3. 7
500 or more	1. 9	2. 6	3. 1	4. 8	3. 9	1. 0	3. 8	2. 1	0
Total	100. 0	99. 8	100. 1	99. 9	100. 0	100. 1	100. 0	100. 1	100. 0
Number of cases	53	76	97	42	51	96	130	146	135

See footnote at end of table.

Table 170.—*Days From Injury to Definitive Suture and Pain Threshold at Follow-up, by Nerve, for Representative Sample*—Continued

Days from injury to suture	Touch threshold,[1] by nerve, lower extremity											
	Peroneal			Sciatic-peroneal			Tibial			Sciatic-tibial		
	Poor	Fair	Good	Poor	Fair	Good	Poor	Fair	Good	Poor	Fair	Good
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0–49	0	11.1	10.2	7.1	8.6	5.1	2.5	0	20.8	9.1	15.4	0
50–99	25.0	19.4	12.2	20.2	22.9	28.2	10.0	25.0	4.2	15.6	19.2	30.8
100–149	15.9	25.0	22.4	19.0	31.4	28.2	25.0	15.0	16.7	27.3	30.8	30.8
150–199	15.9	16.7	12.2	21.4	11.4	17.9	17.5	20.0	16.7	16.9	7.7	23.1
200–299	22.7	8.3	28.6	17.9	11.4	20.5	25.0	25.0	33.3	19.5	11.5	15.4
300–399	11.4	2.8	4.1	6.0	8.6	0	12.5	5.0	4.2	3.9	11.5	0
400–499	4.5	5.6	8.2	3.6	0	0	2.5	5.0	4.2	3.9	0	0
500 or more	4.5	11.1	2.0	4.8	5.7	0	5.0	5.0	0	3.9	3.8	0
Total	99.9	100.0	99.9	100.0	100.0	99.9	100.0	100.0	100.1	100.1	99.9	100.1
Number of cases	44	36	49	84	35	39	40	20	24	77	26	26

[1] Cases coded "hypesthesia, unmeasured" were dropped, and the threshold divided as follows:

Poor=No sensation or deep pressure only

Fair=Superficial pinprick, 20 to 40 gm.

Good=Superficial pinprick, less than 20 gm.

Table 171.—*Days From Injury to Definitive Suture and Touch Threshold at Follow-up, by Nerve, for Representative Sample*

Days from injury to suture	Touch threshold,[1] by nerve, upper extremity								
	Median			Radial			Ulnar		
	Poor	Fair	Good	Poor	Fair	Good	Poor	Fair	Good
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0–49	2. 2	9. 5	8. 1	4. 2	10. 2	15. 1	12. 1	10. 2	5. 5
50–99	10. 9	18. 9	16. 2	25. 0	15. 3	20. 8	22. 4	16. 2	16. 4
100–149	21. 7	31. 1	23. 4	20. 8	28. 8	23. 6	15. 0	28. 7	26. 7
150–199	23. 9	13. 5	18. 9	25. 0	16. 9	16. 0	19. 6	16. 2	22. 6
200–299	28. 3	18. 9	19. 8	16. 7	15. 3	17. 0	17. 8	18. 0	20. 5
300–399	6. 5	1. 4	8. 1	8. 3	8. 5	4. 7	4. 7	5. 4	5. 5
400–499	4. 3	2. 7	2. 7	0	1. 7	0	5. 6	2. 4	2. 1
500 or more	2. 2	4. 1	2. 7	0	3. 4	2. 8	2. 8	3. 0	. 7
Total	100. 0	100. 1	99. 9	100. 0	100. 1	100. 0	100. 0	100. 1	100. 0
Number of cases	46	74	111	24	59	106	107	167	146

See footnote at end of table.

Table 171.—*Days From Injury to Definitive Suture and Touch Threshold at Follow-up, by Nerve, for Representative Sample*—Continued

Days from injury to suture	Touch threshold,[1] by nerve, lower extremity											
	Peroneal			Sciatic-peroneal			Tibial			Sciatic-tibial		
	Poor	Fair	Good	Poor	Fair	Good	Poor	Fair	Good	Poor	Fair	Good
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0–49	2.4	14.3	8.2	7.4	5.7	10.0	3.0	10.3	9.1	6.3	8.9	17.4
50–99	21.4	16.7	16.3	18.5	18.9	36.7	12.1	17.2	4.5	14.1	22.2	26.1
100–149	21.4	14.3	26.5	19.8	34.0	20.0	24.2	17.2	18.2	25.0	35.6	26.1
150–199	16.7	11.9	14.3	17.3	18.9	16.7	12.1	17.2	22.7	17.2	15.6	13.0
200–299	16.7	28.6	16.3	18.5	15.1	16.7	33.3	24.1	27.3	20.3	8.9	17.4
300–399	9.5	2.4	8.2	8.6	5.7	0	9.1	3.4	13.6	9.4	4.4	0
400–499	2.4	4.8	8.2	3.7	0	0	3.0	3.4	4.5	1.6	4.4	0
500 or more	9.5	7.1	2.0	6.2	1.9	0	3.0	6.9	0	6.3	0	0
Total	100.0	100.1	100.0	100.0	100.2	100.1	99.8	99.7	99.9	100.2	100.0	100.0
Number of cases	42	42	49	81	53	30	33	29	22	64	45	23

[1] Cases coded "hypalgesia, unmeasured" were dropped, and the threshold divided as follows:
Poor=No sensation or threshold >50 gm.
Fair=Threshold 16 to 50 gm.
Good=Threshold <16 gm.

Table 172.—*Pain and Touch Thresholds Following Complete Sutures Done 400 or More Days After Injury, by Nerve*

Nerve	Number of Lesions, by Threshold [1]			
	Poor	Fair	Good	Total
A. Pain threshold				
Median	2	5	6	13
Ulnar	9	6	5	20
Radial	2	3	1	6
Peroneal	4	6	5	15
Tibial	3	2	1	6
Sciatic-peroneal	7	2	0	9
Sciatic-tibial	6	1	0	7
Total	33	25	18	76
B. Touch threshold				
Median	3	5	6	14
Ulnar	9	9	4	22
Radial	0	3	3	6
Peroneal	5	5	5	15
Tibial	2	3	1	6
Sciatic-peroneal	8	1	0	9
Sciatic-tibial	5	2	0	7
Total	32	28	19	79

[1] As defined in tables 170 and 171.

Table 173.—*Sensory Recovery Following Complete Sutures at Intervals Greater Than 700 Days After Injury*

Nerve	Case No.	Pain threshold [1] in gm.	Touch threshold [2] in gm.	British summary [3]
Median	3306	10	<3	Pain and touch, overreaction and poor localization.
Median	3820	Hypesthesia	Hypalgesia	Pain and touch, overreaction and poor localization.
Median	3828	<6	16	Some pain and touch.
Median	3894	30	16	Pain and touch, with overreaction and inability to localize stimulus.

See footnotes on p. 294.

Table 173.—*Sensory Recovery Following Complete Sutures at Intervals Greater Than 700 Days After Injury*—Continued

Nerve	Case No.	Pain threshold[1] in gm.	Touch threshold[2] in gm.	British summary[3]
Median	3906	Hypesthesia	16	Pain and touch, without overresponse.
Median	4253	Deep pressure only.	16	Pain and touch, without overresponse.
Radial	3354	Deep pressure only.	50	Deep pain only.
Radial	3883	Hypesthesia	Hypalgesia	Pain and touch, overreaction and poor localization.
Radial	3912	Hypesthesia	Hypalgesia	Pain and touch, overreaction and poor localization.
Radial	5363	Unknown	Unknown	Pain and touch, overreaction and poor localization.
Ulnar	1175	Deep pressure only.	50	Deep pain only.
Ulnar	2043	No sensation	25	Unknown.
Ulnar	3221	6	5	Pain and touch, 2-pt. discrimination.
Ulnar	3851	Hypesthesia	Hypalgesia	Pain and touch, overreaction and poor localization.
Peroneal	3175	Deep pressure only.	>50	Deep pain only.
Peroneal	3654	Unknown	Unknown	Unknown.
Peroneal	3854	40	>50	Superficial pain.
Peroneal	3908	No sensation	>50	Sensibility absent.
Peroneal	4467	20	16	Pain and touch, no overresponse.
Peroneal	5003	40	16	Some pain and touch.
Sciatic-peroneal.	3802	Hypesthesia	>50	Superficial pain.
Sciatic-peroneal.	3875	No sensation	>50	Superficial pain.
Sciatic-peroneal.	5142	40	>50	Deep pain only.
Tibial	3854	10	>50	Superficial pain.
Sciatic-tibial.	3875	No sensation	>50	Superficial pain.
Sciatic-tibial.	5142	40	>50	Deep pain only.

[1] These are abbreviated statements of the rubrics given in full on p. 243.
[2] These are abbreviated statements of the rubrics given in full on p. 244. The first rubric there "No sensation or >50 gm." is here abbreviated as ">50 gm."
[3] These are abbreviations for the classes described in detail on p. 247.

3. Echelon of Definitive Repair

About 16 percent of all 3,416 nerve lesions operated upon received their definitive operation overseas. The distinction between a Z/I and an overseas suture is far more than a matter of time from injury to suture, for the Z/I sutures include many operations undertaken to improve the regeneration of lesions first sutured overseas.

Complete sutures on median, ulnar, peroneal, and tibial lesions were studied for variation in sensory return in relation to echelon of definitive repair, but with inconclusive results. Table 174 contains the data on the pain threshold, according to which one would conclude that the selective factors distinguishing between overseas and Z/I cases were probably of no consequence. The one clear-cut difference involves the ulnar and betokens some superiority on the part of Z/I sutures, but as a set the four tests shown there lead to the overall conclusion that the echelon-groups differ by no more than chance. The same conclusion is more quickly forthcoming from table 175 on the touch response, and from table 176 on the British summary of sensory recovery. The undoubtedly real selective factors involved in the echelon-grouping simply do not modify the conditions of sensory recovery to such an extent that a small series such as this is, with all its restrictions, can be counted upon to exhibit the variation.

Table 174.—*Echelon of Definitive Suture and Recovery of Pain Response in Autonomous Zone at Follow-up, Pure Lesions on Median, Ulnar, Peroneal, and Tibial*

Nerve	Overseas		Z/I		Statistical tests [2]
	Number of cases	Percentage with pain threshold of 10 gm. or less [1]	Number of cases	Percentage with pain threshold of 10 gm. or less [1]	
Median	17	23.5	160	35.6	NS
Ulnar	57	19.3	322	34.5	**
Peroneal	24	37.5	118	31.4	NS
Tibial	11	54.5	78	24.4	NS

[1] Cases of "hypesthesia, unmeasured" are included in denominator.

[2] Results of statistical tests (two-tailed) abbreviated as follows:

NS—Not significant.

**—Significant at .01 level.

4. Length of Surgical Gap

In view of the wide range of gap and its ready adaptability to an analysis of mean values, the study of sensory recovery in relation to gap was done on the basis of mean gap for cases of defined sensory recovery. The pain

Table 175.—*Echelon of Definitive Suture and Recovery of Touch Response in Autonomous Zone at Follow-up, Pure Lesions on Median, Ulnar, Peroneal, and Tibial*

Nerve	Overseas		Z/I		Statistical tests [2]
	Number of cases	Percentage with touch threshold of 5 gm. or less [1]	Number of cases	Percentage with touch threshold of 5 gm. or less [1]	
Median	17	35.3	161	33.5	NS
Ulnar	56	21.4	321	32.4	NS
Peroneal	24	37.5	118	30.5	NS
Tibial	11	27.3	78	28.2	NS
All tests combined					NS

[1] Cases of "hypalgesia, unmeasured" are included in denominator.
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS—Not significant.

Table 176.—*Echelon of Definitive Suture and British Classification of Sensory Recovery at Follow-up, Pure Lesions on Median, Ulnar, Peroneal, and Tibial*

Nerve	Overseas		Z/I		Statistical tests [2]
	Number of cases	Percentage superior [1]	Number of cases	Percentage superior [1]	
Median	17	35.3	162	28.4	NS
Ulnar	58	25.9	327	31.8	NS
Peroneal	24	41.7	121	21.5	NS
Tibial	11	36.4	80	12.5	NS
All tests combined					NS

[1] Defined as groups 5 to 7 in table 169.
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS—Not significant.

and touch thresholds and the British summary of sensory recovery were all utilized in this analysis, which was not confined to pure lesions and extended to all seven major nerves, but the resulting variation appears to lie well within the power of chance to produce. Table 177 contains the mean values corresponding to the subdivision of the pain scale.

Table 177.—*Mean Length of Surgical Gap and Recovery of Pain Threshold in Autonomous Zone at Follow-up, All Complete Sutures, by Nerve*

Nerve	Sensory recovery [1]				Statistical tests [2]
	Poor		Good		
	Number of cases	Mean gap, cm.	Number of cases	Mean gap, cm.	
Median	196	5.44	128	5.26	NS
Ulnar	353	5.40	170	5.95	NS
Radial	136	5.08	110	4.95	NS
Peroneal	110	6.37	55	6.04	NS
Tibial	80	6.58	30	5.37	NS
Sciatic-peroneal	173	7.12	40	6.73	NS
Sciatic-tibial	139	7.32	29	6.86	NS

[1] Cases classified as poor have no pain sensation or a threshold of 20 gm. or more, or were termed "hypesthesia, unmeasured"; cases classified as good have a threshold of 10 gm. or less.

[2] Results of statistical tests abbreviated as follows:
NS = Not significant.

5. Transposition or Extensive Mobilization as Special Operative Features

Bulb sutures associated with transposition or extensive mobilization were omitted from this study, which extended to all major nerves regardless of presence of associated nerve injury, provided the definitive operation was complete suture. Transposition and extensive mobilization are, of course, confounded with length of surgical gap, but it seemed unnecessary to take gap into account in view of the preceding analysis, and all comparisons were made directly. For comparison with the lesions affected by transposition and extensive mobilization, those with no special operative features of any kind were chosen.

The pain threshold seems entirely unaffected by transposition or extensive mobilization, as may be seen in table 178. Not so the touch threshold (table 179) in the lower extremity; for the two sciatic components the individual discrepancies are large and significant in the statistical sense, and both the tibial and peroneal comparisons yield discrepancies of similar sign if lesser magnitude. In the upper extremity, however, the differences are small and largely of opposite direction. It would appear that no single generalization would adequately cover all major nerves, and that the procedures of transposition and extensive mobilization are without effect in the upper extremity but rather prejudicial to the recovery of touch fibres in the lower extremity.

Table 178.—*Extensive Mobilization and Transposition and Recovery of Pain Response in Autonomous Zone, All Complete Sutures, by Nerve*

Nerve	Lesions with no special features		Lesions with transposition or extensive mobilization		Statistical test [2]
	Number	Percentage with pain threshold of 10 gm. or less [1]	Number	Percentage with pain threshold of 10 gm. or less [1]	
Median	191	37.2	136	42.6	NS
Ulnar	141	29.1	388	32.7	NS
Radial	156	44.9	52	48.1	NS
Peroneal	121	33.1	46	30.4	NS
Tibial	57	33.3	49	24.5	NS
Sciatic-peroneal	131	22.1	88	17.0	NS
Sciatic-tibial	100	18.0	69	17.4	NS

[1] Among all lesions tested, including those classified as "hypesthesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS=Not significant.

Table 179.—*Extensive Mobilization and Transposition and Recovery of Touch Response in Autonomous Zone at Follow-up, All Complete Sutures, by Nerve*

Nerve	Lesions with no special features		Lesions with transposition or extensive mobilization		Statistical tests [2]
	Number	Percentage with touch threshold of 5 gm. or less [1]	Number	Percentage with touch threshold of 5 gm. or less [1]	
Median	195	39.5	137	39.4	NS
Ulnar	139	28.1	389	32.9	NS
Radial	154	44.8	54	55.6	NS
Peroneal	120	34.2	48	31.2	NS
Tibial	56	37.5	50	20.0	NS
Sciatic-peroneal	130	20.8	89	9.0	*
Sciatic-tibial	100	23.0	70	4.3	**

[1] Among all lesions tested, including any classified as "hypalgesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS=Not significant.
*=Significant at .05 level.
**=Significant at .01 level.

Since the classification used in table 179 for the touch response is quite gross, there may be interest in the detailed distribution, over the entire coded range of touch response, for lesions with and without extensive mobilization or transposition. These data appear in table 180 for both sciatic components combined.

Table 180.—*Extensive Mobilization and Transposition and Recovery of Touch Response in Autonomous Zone at Follow-up, Complete Sutures on Both Sciatic Components* [1] *Combined*

Touch threshold	Lesions with no special features	Lesions with transposition or extensive mobilization
	Percent	*Percent*
Hypalgesia, unmeasured	3.0	1.3
No sensation, or >50 gm	42.6	57.2
Measured threshold: 50 gm	9.6	5.7
Measured threshold: 25 gm	6.5	9.4
Measured threshold: 16 gm	16.5	19.5
Measured threshold: 5 gm	11.7	1.9
Measured threshold: 3 gm	4.8	2.5
Measured threshold: <3 gm	5.2	2.5
Total	99.9	100.0
Number of lesions	230	159

[1] That is, sciatic-tibial and sciatic-peroneal nerves are here added together.

6. Bulb Suture

Bulb-stretch preparatory to end-to-end anastomosis was not coded as an operation, but as a special operative feature. On the average the surgical gap in such cases was 2 to 3 times that noted in lesions with no operative features, but as already noted there is little or no evidence of an effect of gap upon sensory recovery. The proportion of complete sutures preceded by bulb sutures is not large, but if all 7 major nerves are studied there are about 120 bulb sutures distributed among them. The sampling is not confined to pure lesions but extends to all complete sutures.

None of the several sensory indices (pain, touch, and British summary) provides convincing evidence that sensory regeneration is affected by bulb suture, and the observations on the pain threshold (table 181) may be taken as fairly representative.

Table 181.—*Bulb Suture and Recovery of Pain Response in Autonomous Zone at Follow-up, All Complete Sutures, by Nerve*

Nerve	Lesions with no special features		Lesions first treated by bulb suture		Statistical tests [2]
	Number	Percentage with pain threshold of 10 gm. or less [1]	Number	Percentage with pain threshold of 10 gm. or less [1]	
Median	191	37.2	23	30.4	NS
Ulnar	141	29.1	25	32.0	NS
Radial	156	44.9	26	38.5	NS
Peroneal	121	33.1	10	30.0	NS
Tibial	57	33.3	10	10.0	NS
Sciatic-peroneal	131	22.1	12	25.0	NS
Sciatic-tibial	100	18.0	11	18.2	NS

[1] Among all examined cases, including those classified as "hypesthesia, unmeasured."
[2] Result of statistical tests (two-tailed) abbreviated as follows:
NS—Not significant.

7. Character of Nerve Ends at Definitive Suture

The prognostic significance of the surgeon's description of nerve ends, following resection and freshening, was sought in the eventual sensory recovery of pure lesions on the median,ulnar, peroneal, and tibial, but none was found. Pain, touch, and British summary were studied for each nerve, but with generally negative results as illustrated in table 182 for pain.

Table 182.—*Surgeon's Description of Nerve Ends at Definitive Suture and Recovery of Pain Response in Autonomous Zone at Follow-up, Pure Lesions on the Median, Ulnar, Peroneal, and Tibial*

Nerve	Both distal and proximal ends normal		Other		Statistical tests [2]
	Number	Percentage with pain thresholds of 10 gm. or less [1]	Number	Percentage with pain thresholds of 10 gm. or less [1]	
Median	97	29.9	30	46.7	NS
Ulnar	199	36.7	62	33.9	NS
Peroneal	68	36.8	31	22.6	NS
Tibial	44	27.3	21	23.8	NS

[1] Among all examined lesions, including those classified as "hypesthesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS—Not significant.

8. Tension Upon Suture Line

The observations on tension are technically less satisfactory than most observations concerned with the details of management, as already noted. Only pure lesions on the median, ulnar, peroneal, and tibial nerves were studied as to the possible effect of tension upon sensory recovery. Pain, touch, and the British summary of sensory recovery were all included in these studies, but for none of the sensory indices was the variation associated with differences in tension of a magnitude which achieved statistical significance. The data on pain are presented in table 183 as representative of the findings. The lesions classified as having no tension are those in which the operator's report specifically stated that tension was minimal; cases in which the operator made no reference to tension were not used in the analysis.

Table 183.—*Surgeon's Description of Tension on Definitive Suture Line and Recovery of Pain Response in Autonomous Zone at Follow-up, Pure Lesions on the Median, Ulnar, Peroneal, and Tibial Nerves*

Nerve	No tension		Moderate or severe tension		Statistical test [2]
	Number	Percentage with pain threshold of 10 gm. or less [1]	Number	Percentage with pain threshold of 10 gm. or less [1]	
Median	74	35.1	19	36.8	NS
Ulnar	187	34.8	35	25.7	NS
Peroneal plus tibial	111	29.7	18	50.0	NS

[1] Among all examined cases, including those classified as "hypesthesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS=Not significant.

9. Suture Material

As was observed in the initial study of motor recovery, there at first appeared to be marked differences in sensory return when lesions were grouped according to the material used in the definitive suture. Lesions sutured with silk appeared no different from those sutured with fine tantalum wire, but both were definitely superior to those on which the plasma glue technique was employed. Table 184 presents a summary of these initial comparisons on definitive sutures for "pure" lesions. As was shown in chapter III, however, the plasma glue series is not comparable with the tantalum and silk series in two major respects: (a) plasma glue sutures were generally done at longer intervals after injury; and (b) definitive plasma glue sutures were more often second or subsequent sutures.

Table 184.—*Suture Material at Definitive Operation and Sensory Recovery, Pure Lesions Only, by Nerve*

Nerve	Tantalum		Silk		Plasma glue		Statistical tests [2]
	No. of lesions	Percent superior [1]	No. of lesions	Percent superior [1]	No. of lesions	Percent superior [1]	
A. Pain threshold							
Median	106	*34.9*	38	*47.4*	25	*8.0*	**
Ulnar	257	*35.4*	80	*22.5*	29	*27.6*	NS
Peroneal	91	*29.7*	42	*42.9*	+	+	NS
Tibial	59	*27.1*	27	*29.6*	+	+	NS
B. Touch threshold							
Median	107	*31.8*	38	*52.6*	25	*8.0*	**
Ulnar	258	*30.2*	77	*32.5*	29	*27.6*	NS
Peroneal	91	*34.1*	42	*33.3*	+	+	NS
Tibial	59	*27.1*	27	*25.9*	+	+	NS
C. British summary							
Median	108	*32.4*	38	*36.8*	25	*4.0*	**
Ulnar	262	*32.8*	80	*28.7*	30	*10.0*	*
Peroneal	94	*25.5*	42	*28.6*	+	+	NS
Tibial	60	*16.7*	28	*14.3*	+	+	NS

[1] Superior is defined as follows:

Pain: superficial pain felt with 10 gm. or less, among all tested, including any with "hypalgesia, unmeasured."

Touch: superficial pressure felt with 5 gm. or less, among all tested, including any with "hypesthesia, unmeasured."

British summary: Both superficial pain and touch present, no overresponse.

[2] Results of statistical tests abbreviated as follows:

NS=Not significant.

*=significant at .05 level.

**=significant at .01 level.

+Too few cases to tabulate.

Since sensory recovery is unrelated to interval from injury to suture, the only controls which appear necessary are that the groups be defined by the suture materials used at the first operation and examined at the New York Center where all the plasma glue patients were seen. Controlled comparisons of this nature were made for median and ulnar nerves, and are summarized in table 185. Since it has already been shown that associated nerve lesions do not affect examiners' evaluations of sensory recovery, table 185 is not confined to pure nerve lesions as is table 184, and there is actually a net gain in the number of plasma glue median sutures available for study. The use of these additional controls does not dissipate all the evidence of poorer sensory return following plasma glue suture, for the touch response of the median nerve continues to be inferior, but otherwise all the differentials of table 184 appear greatly reduced in table 185, and to such an extent that the only tenable conclusion is that sensory recovery following plasma glue suture is probably no different from that seen after sutures with tantalum and silk.

Table 185.—*Suture Material at First Operation and Sensory Recovery, All Median and Ulnar Lesions Studied at New York Center*

Nerve	Tantalum or silk		Plasma glue		Statistical tests [2]
	No. of lesions	Percent superior [1]	No. of lesions	Percent superior [1]	
A. Pain threshold					
Median	72	31.9	29	20.7	NS
Ulnar	114	26.3	27	22.2	NS
Total	186	28.5	56	21.4	NS
B. Touch threshold					
Median	72	26.4	29	6.9	NS
Ulnar	114	21.1	28	28.6	NS
Total	186	23.1	57	17.5	NS
C. British summary					
Median	71	54.9	29	69.0	NS
Ulnar	115	52.2	28	50.0	NS
Total	186	53.2	57	59.6	NS

[1] As in table 184.
[2] Results of statistical tests abbreviated as follows:
NS=Not significant.

10. Use of Cuff

About one-third of the definitive sutures were protected by cuffs, almost always those made of tantalum foil. In only about 7 percent of the cases was it unknown whether a cuff was employed. All seven major nerves were studied for variation in sensory recovery associated with the use of cuffs, and the selection was not limited to pure lesions. Pain, touch, and the British summary of sensory recovery were utilized in these comparisons, and in each index the observed variation appeared to exceed that expected from a random process. Table 186 provides a summary of the observations on pain, and although for only 1 of the 7 nerves is the discrepancy statistically significant, it will be noted that in every comparison there is a differential in the same direction. When all seven tests are taken in combination it is clear that the evidence in favor of the cuff is statistically quite significant.

Analysis of the touch response also provides fairly strong evidence in favor of the cuff (table 187). In one of the individual comparisons the discrepancy between the percentages with superior touch response attains statistical significance, and although for the ulnar the direction of the difference is counter to the rest, when all 7 tests are combined the overall probability is found to be $<.01$.

The evidence from the British summary of sensory recovery is even more definite. Table 188 distributes each nerve-cuff group according to a coarse grouping of the British scale. Almost uniformly the sutures accomplished with the aid of cuffs look better at both ends of the scale.

Table 186.—*Use of Cuff at Definitive Suture and Recovery of Pain Response in Autonomous Zone at Follow-up, by Nerve*

Nerve	No cuff used		Cuff used		Statistical tests [2]
	Number of lesions	Percentage with pain threshold of 10 gm. or less [1]	Number of lesions	Percentage with pain threshold of 10 gm. or less [1]	
Median	211	35.1	119	43.7	NS
Ulnar	322	30.1	194	33.5	NS
Radial	145	43.4	104	48.1	NS
Peroneal	125	29.6	38	36.8	NS
Tibial	71	25.4	35	34.3	NS
Sciatic-peroneal	125	14.4	97	28.9	*
Sciatic-tibial	99	14.1	71	22.5	NS
All tests combined					**

[1] Among all examined cases, including those classified as "hypesthesia, unmeasured."

[2] Results of statistical tests (two-tailed) abbreviated as follows:

NS—Not significant.

*—Significant at .05 level.

**—Significant at .01 level.

Table 187.—*Use of Cuff at Definitive Suture and Recovery of Touch Response in Autonomous Zone at Follow-up, by Nerve*

Nerve	No Cuff used		Cuff used		Statistical tests [2]
	Number of lesions	Percentage with touch threshold of 5 gm. or less [1]	Number of lesions	Percentage with touch threshold of 5 gm. or less [1]	
Median	213	35.7	121	45.5	NS
Ulnar	323	31.6	193	29.5	NS
Radial	143	44.1	105	52.4	NS
Peroneal	125	26.4	39	38.5	NS
Tibial	71	21.1	35	31.4	NS
Sciatic-peroneal	125	10.4	98	22.4	*
Sciatic-tibial	99	13.1	73	20.5	NS
All tests combined	....	....	....	....	**

[1] Among all examined lesions, including those classified as "hypalgesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS—Not significant.
*—Significant at .05 level.
**—Significant at .01 level.

As noted in chapter III, the decision to employ a cuff is probably related to characteristics of the case which have a bearing upon nerve regeneration. When a controlled motor comparison of cases with and without cuff was done by restricting the analysis to lesions with most favorable prospects for recovery (no associated injuries, short gaps, and fairly early time of operation), the advantage of cases with cuff disappeared. Accordingly, the same selection was made here and tables 186 and 187 were repeated. Unlike motor recovery, sensory recovery is not appreciably affected by these restrictions; a larger sampling variation is introduced by the fact of smaller numbers of cases, but no systematic shift appears in either the group with, or the group without, cuffs. In consequence, lesions with tantalum foil again appear to have recovered more fully than those without, although the margin of advantage is less certain and more variable in this smaller amount of material. Table 189 contains these data; statistical tests were done only on the totals for all nerves since each nerve is represented by so few cases, and both for pain and touch lead to the rejection of the hypothesis that cases with cuff are no better than those without.

Table 188.—*Use of Cuff at Definitive Suture and British Classification of Sensory Recovery at Follow-up, by Nerve*

Nerve and use of cuff	Percentage distribution as to British classification of sensory recovery: No sensation or deep pain	At most superficial pain and touch with overreaction and inability to localize	At least superficial pain and touch with disappearance of overresponse	Total	Number of lesions
Median:					
No cuff	23.9	49.1	27.1	100.1	218
Cuff	21.7	46.7	31.7	100.1	120
Ulnar:					
No cuff	31.4	38.7	29.9	100.0	328
Cuff	24.1	47.2	28.6	99.9	199
Radial:					
No cuff	21.5	34.2	44.3	100.0	149
Cuff	10.2	40.7	49.1	100.0	108
Peroneal:					
No cuff	39.1	38.3	22.7	100.1	128
Cuff	25.6	43.6	30.8	100.0	39
Tibial:					
No cuff	50.0	38.9	11.1	100.0	72
Cuff	25.0	52.8	22.2	100.0	36
Sciatic-peroneal:					
No cuff	55.1	37.0	7.9	100.0	127
Cuff	45.0	39.0	16.0	100.0	100
Sciatic-tibial:					
No cuff	59.0	35.0	6.0	100.0	100
Cuff	49.3	36.0	14.7	100.0	75

11. Use of Stay Suture

Among all complete sutures, 67 percent were performed without resort to the stay suture, 22 percent with the stay suture, and in 11 percent the operation report was unclear or silent on the subject. As was noted in the roster-comparisons appearing in chapter II, stay sutures were much less often placed on sutures in the representative sample than on other sutures. To avoid this source of bias, therefore, the study of stay suture was confined to the representative sample of sutures, all of which are from the Army Registry and within the sampling area. Only the nerves of the upper extremity were studied, and the British summary of sensory recovery was used to provide the criterion. As may be seen in table 190, this limited study provides no evidence of any effect upon sensory return.

Table 189.—*Percentage of Sutured Lesions With Superior Pain and Touch Thresholds*[1] *in Relation to Use of Tantalum Cuff, by Nerve, for Lesions Selected*[2] *for Favorable Outcome*

Nerve sutured	Number of lesions		Percentage with superior pain threshold			Percentage with superior touch threshold		
	No cuff	Cuff	No cuff	Cuff	P[3]	No cuff	Cuff	P[3]
Median	11	21	27.3	57.1	......	38.5	45.5	......
Ulnar	31	33	29.0	39.4	......	28.1	28.1	......
Radial	23	18	26.1	38.9	......	30.4	61.1	......
Peroneal	18	10	11.1	30.0	......	27.8	27.3	......
Tibial	10	10	20.0	50.0	......	20.0	50.0	......
Sciatic-peroneal	25	19	16.0	26.3	......	16.0	15.8	......
Sciatic-tibial	26	17	23.1	23.5	......	15.4	23.5	......
Total	144	128	22.2	38.3	$<.01$	24.5	34.9	.034

[1] As defined in tables 186 and 187.
[2] Having no associated injuries, short gaps, and moderate intervals from injury to suture.
[3] Probability obtained in statistical test of percentages.

Table 190.—*British Summary of Sensory Recovery and Use of Stay Suture at Definitive Suture, Nerves of the Upper Extremity*

Nerve	Stay suture	Number of lesions	Percentage with superior sensory return[1]
Median	None	217	*30.4*
	Any	49	*34.7*
	Total	266	*31.2*
Ulnar	None	360	*30.0*
	Any	77	*28.6*
	Total	437	*29.7*
Radial	None	169	*55.0*
	Any	52	*42.3*
	Total	221	*52.1*

[1] Defined as groups 5, 6, and 7 in table 169, i. e., at least return of superficial pain and touch without overresponse.

12. Training of Surgeon

Trained neurosurgeons performed about 45 percent of the definitive operations, general surgeons with wartime training in neurosurgery about 33 percent, and surgeons with essentially no special neurosurgical training the remaining 22 percent. The analysis of variation in sensory recovery associated with these differentials in neurosurgical training was done on pure lesions managed by complete suture. Pain recovery, touch recovery, and the British summary of sensory recovery were all employed as measures of functional sensory return, but for none of them was any evidence found that neurosurgical training, thus defined, was associated with differentials in sensory recovery. Table 191 presents a summary of the pain data to exemplify this analysis.

Table 191.—*Neurosurgical Training and Recovery of Pain Response in Autonomous Zone Following Definitive Suture on Pure Nerve Lesions, by Nerve*

Nerve	Neurosurgical training						Statistical tests [2]
	Trained neurosurgeon		General surgeon with neurosurgical training		Essentially untrained in neurosurgery		
	Number of cases	Percentage with pain thresholds of 10 gm. or less [1]	Number of cases	Percentage with pain thresholds of 10 gm. or less [1]	Number of cases	Percentage with pain thresholds of 10 gm. or less [1]	
Median	73	30.1	53	47.2	51	27.5	NS
Ulnar	129	27.9	150	33.3	100	36.0	NS
Peroneal	56	33.9	54	35.2	32	25.0	NS
Tibial	37	29.7	36	25.0	17	29.4	NS

[1] Among all examined cases, including those classified as "hypesthesia, unmeasured."
[2] Results of statistical tests (two-tailed) abbreviated as follows:
NS = Not significant.

13. Summary

Despite the difficulties inherent in arguing from the fact of group differences to the effect of specific forms of treatment when treatment groups are defined by clinical considerations alone, sensory recovery at follow-up has been used as a criterion for exploring the possible influence of the variety of details on treatment abstracted from operation reports in military records of treatment. In general the results obtained here differ greatly from those presented in the motor chapter, so much so in fact that the difficulty is not one of interpreting variation in the light of treatment differences but rather one of determining whether the observed variation is within the limits of a random process. The following characteristics appear not to be associated with significant variation in sensory recovery:

Days from injury to definitive suture.
Echelon (Z/I or overseas) of definitive suture.
Length of surgical gap at definitive suture.
Resort to bulb suture as a preliminary procedure prior to definitive suture.
Operator's gross evaluation of nerve ends after freshening.
Operator's report of tension on definitive suture-line.
Suture material.
Use of stay suture.
Level of formal neurosurgical training of operator.

In marked contrast to the analysis of motor recovery, it is extremely significant that the analysis here yields no evidence that time from injury to suture influenced sensory recovery in any way.

The only elements of surgical treatment which were found to be associated with variation in sensory recovery, by the criterion of statistical significance used here, are:

a. Transposition and mobilization of nerves in the lower extremity were followed by considerably poorer recovery of touch sensibility, but appeared to have no effect upon recovery of pain. In the upper extremity no such variation was seen.
b. Sutured nerves about which tantalum foil cuffs were placed appear to have definitely superior recovery of both pain and touch sensibility, even after some effort at insuring the inherent comparability of the treatment groups in the light of factors present at suture which might be considered to have prognostic value.

Chapter VI

PAIN AND RELATED PHENOMENA, INCLUDING CAUSALGIA

James C. White and *Bertram Selverstone*

A. INTRODUCTION

In the belief that painful phenomena are of intrinsic importance, a separate study was made of their frequency and association with other characteristics, notably those of treatment and other aspects of follow-up status. True causalgia is rare in this series but of sufficient clinical interest to warrant some discussion and the presentation of individual cases. The rest of the chapter is concerned with disagreeable phenomena of lesser importance and greater frequency, e. g., complaints of unpleasant sensations and pain on use or pressure.

Causalgia, a term coined by S. Weir Mitchell, should include only cases of intense pain, burning in character, radiating diffusely up the injured extremity, and often brought on by extremes of temperature and psychological stimuli, as well as by the lightest touch or even breath of air over the injured part. Unfortunately, many modern writers have not conformed to this concept. The authors of this chapter have agreed to restrict their use of the term causalgia to the sense originally proposed by Mitchell and not to allow it to become a catch-all for many poorly understood varieties of burning pain. When such a limitation is applied, it is found that nearly all the wounded suffering from this condition were relieved by sympathectomy. The number of patients with true causalgia found in the present study was too few to warrant statistical analysis and will therefore be discussed separately below.

B. CAUSALGIA

1. Description of Causalgia Syndrome

Clinical Picture. In 1864 Mitchell, Morehouse, and Keen (55) gave their classical description of this syndrome. Its name we apparently owe to Silas Weir Mitchell (54), as he wrote: "Perhaps nothing can better illustrate the extent to which these statements may be true than the cases of burning pain, or as I prefer to term it, causalgia, the most terrible of all the tortures which a nerve wound may inflict." These three physicians, while in charge of nerve injuries at a military hospital near Philadelphia during the War Between the States, emphasized that the peculiar burning, often agonizingly severe and persistent pain is referred in a diffuse fashion throughout the distal portion of the injured extremity, but never to the chest or abdomen. As they observed, it usually results from penetrating wounds with partial injury to a nerve, most often the median or sciatic. Thirty years later J. K. Mitchell, who had reexamined some of his father's veterans of the Civil War, found (53) that the causalgic syndrome was still present in a few, and that severe burning pain, not related to psychological stimuli but to thermal changes and use of the part, was often a cause of long-continued incapacity and suffering.

Weir Mitchell and his colleagues stressed the peculiar emotional factors which characterize the causalgic state, citing the increase in pain which is manifested by the victims with a multitude of psychic stimuli: the stirring music of a military band, jarring noises in the war, even the rattling of a newspaper. In World War II White, Heroy, and Goodman (84) listed an even greater variety of emotional stimuli that aroused intense suffering. These included:

Loud or unexpected noises; annoying radio programs.
Children crying; arguments with other patients.
Jarring of the bed.
Exciting movies; stirring music; watching a baseball game; going too fast in an automobile.
Prospect of a hypodermic injection.
Laughing.

Other homeostatic factors of interest comprised:

Exposure to cold, damp, or very hot weather.
Cold air on the painful extremity.
Physical exertion.
Defecation or urination.
Drinking anything cold.

Many of the psychological irritants, such as present-day jarring radio programs, exciting movies, and the clatter of aeroplane motors flying too close to the hospital roof, have added to the patient's suffering since Mitchell's day. Boyd (7) has summed up these factors nicely by his statement that causalgia is characteristically aggravated by "disturbing the patient's environment."

Foerster (23), who coined the term hyperpathia, intended that it should be used to designate the peculiar features of pain seen in the causalgic state. His definition of hyperpathia, given below in full (p. 336), emphasizes the accompanying defects in sensory conduction which make it difficult for the subject to determine the nature or type of painful stimulation, as well as the delayed and explosive nature of the pain, and the prolonged afterdischarge.

Unhappily recent writers have used the term causalgia to describe any type of persistent hyperalgesia whose cause is difficult to understand, much as dermatologists tend to classify many forms of resistant chronic dermatitis as eczema. As an extreme example, Macfarlane (47) has included such unrelated conditions as spinal injuries, postamputation neuralgias, painful osteoporosis, and meralgia paraesthetica. No wonder that he has been surprised that so few of these conditions react favorably to sympathectomy! Such use of the term as a catchall for all forms of poorly understood pains in the extremities is to be deplored.

We believe that causalgia is a distinct clinical entity, provided the use of the term be restricted to penetrating injuries of nerves which give rise to intense burning pain, influenced by environmental and psychological factors as originally observed by Mitchell. The characteristic pain is likely to start within a few hours after infliction of the wound. Painful states of this sort fall into a consistent group and are strikingly influenced by the sympathetic discharge from the hypothalamus.

In addition to the victim's desire to retire into a quiet room where he can escape the emotional stimuli of the open ward, there are other characteristic features. The sufferer from severe causalgia is more comfortable if he protects his hand by wrapping it in a damp cloth or by soaking it in cool water. He is very susceptible to either extreme heat or cold. Trophic changes are frequently seen, and the subject may be unable to wash the painful part or cut his nails. With total disuse because of pain, the trophic changes soon set in. There is a glossy texture to the skin, and the fingers acquire a tapering shape. Contractures and osteoporosis then appear, resulting in irreversible changes if pain is not relieved in time. In addition, if unrelieved, the patient rapidly will lose morale and is likely to become a narcotic addict. Because of the striking psychological changes and aggravation of the burning pain by emotional stimuli, physicians who have had no experience with causalgia have often made a diagnosis of psychoneurosis or malingering. Mitchell, et al. (55) pointed this out, stating that "surgeons, who have happened to encounter a single one of the worst of them, have been so surprised at the character of the suffering as to suspect that such an extreme hyperaesthesia must be due, at least in some measure, to a desire on the part of the patient to magnify his pains."

Nerves Involved. Injuries to certain nerves are far more likely to result in causalgia than others. In the 64 cases we have been able to study in detail there has been the following numerical incidence:

Median	33
Ulnar	2
Sciatic	17
Posterior tibial	10
Peroneal	2

It is possible that the incidence of causalgia following ulnar and peroneal nerve injuries is somewhat higher than the figures given above, as there are 11 combined median and ulnar lesions in this series which have all been included under the median and 2 combined posterior tibial and peroneal lesions listed under the tibial nerve. No other nerves appear to be responsible for this type of pain, although they often give rise to severe dysaesthesia following injury and partial recovery.

Diagnosis. To summarize and simplify matters a bit, we agree with Boyd (7), who has written one of the best recent British descriptions of causalgia, that the diagnosis depends on the following factors:

a. The appropriate injury of a peripheral nerve.

b. Diffuse burning pain (hyperpathia), paroxysmal in character and aggravated "by disturbing the patient's environment."

c. Temporary relief by blocking the regional sympathetic ganglia with procaine and permanent benefit following adequate sympathectomy.

2. Historical Considerations

At a lecture delivered at the Peter Bent Brigham Hospital, Boston, on October 20, 1953, Sir James Paterson Ross of St. Bartholomew's Hospital, London, pointed out that, although Mitchell deserves the credit for naming causalgia and the general recognition of the syndrome, the condition had been described by a number of others dating back to the 18th century. Alexander Denmark cited one of Wellington's troopers who suffered the characteristic agonizing burning pain following a wound at the Battle of Badajoz in 1812. After the arm was amputed for pain, its dissection showed the median nerve involved in a neuroma. Other examples were recorded by John Abernethy, who described a case following venisection and mentioned an earlier description of the pain by Percival Pott, which followed partial division of a nerve. Mr. Pott was surgeon to St. Bartholomew's Hospital in the middle of the 18th century. In 1838 John Hamilton of Dublin also reported a peculiar train of symptoms following partial injury of nerves. Other early cases were mentioned by Charles Bell in 1812 and by Antonio Scarpa in 1832. In 1864 James Paget gave an even better description in which he said that "glossy fingers appear to be a sign of peculiarly impaired nutrition and circulation due to injury of nerves . . . and are always associated, I think, with distressing and hardly manageable pain and disability." These cases, however, were not the result of pentrating wounds and no mention was made by Paget of aggravation by environmental factors. The references to these early accounts will be found in a previous paper by Ross (64).

The epochal papers of Mitchell and his associates (54, 55) have been mentioned above. Most of the graphic descriptions in the first account published with Morehouse and Keen must have been written by Mitchell, as he repeats many of them in his second book. Following the War Between the States little interest was shown in this condition for many years. In and after World War I Leriche (39) began to use periarterial sympathectomy and stellectomy in the treatment of severe brachial neuralgias. Spurling (74) and Kwan (37) seem to have been the first to use present forms of upper thoracic sympathetic ganglionectomy. Spurling's bootlegger and Kwan's Chinese soldier had both suffered gunshot wounds with partial injury to the brachial plexus. Spurling's patient was relieved for a number of hours after the chill that followed intravenous injection of typhoid vaccine had subsided, just as was observed in World War II after a malarial chill. It is of interest to point out that during the stage of defervescence sympathetic activity is decreased, whereas during the actual period of the chill, when vasoconstrictor and pilomotor activity is increased, the pain has been greatly intensified. Neither of these men derived any benefit from extensive neurolysis of the brachial plexus or from resection of a portion of the axillary artery, but both responded in a most gratifying manner to upper thoracic sympathectomy.

In World War II Mayfield found an incidence of causalgia of somewhat over 5 percent in nerve injuries treated at the Percy Jones Army Hospital. Others, as shown in table 192, have found it as low as 2 percent. Sympathectomy, following favorable results of preliminary diagnostic block with procaine, soon manifested its value in giving immediate relief. Impressive evidence in favor of this form of therapy is given in section 4 below and is summarized in Mayfield's monograph on causalgia (49), in Shumacker's review (72), and in White, Smithwick, and Simeone's volume on the autonomic nervous system (85).

Table 192.—*Published Cases of Causalgia in World War II and Its Incidence After Wounds of Nerves*

Authors	Cases of causalgia		Total number of wounds involving nerves	Percentage of wounds with causalgia	Result of sympathectomy: Percentage distribution		
	Total	Sympathectomized			Excellent	Fair	Failure
Doupe, Cullen, and Chance (22)	7	5	......	......	100	......	......
Mayfield and Devine (50)	15	12	737	2	100	......	......
Ulmer and Mayfield (80)	75	70	1, 477	5	95. 7	......	......
Speigel and Milowsky (73)	9	7	275	3. 3	100	......	......
Rasmussen and Freedman (62)	100	40	......	......	62. 5	10	27. 5
Allbritten and Maltby (1)	67	30	......	......	93	......	7
Kirklin, Chenoweth, and Murphey (36)	52	48	......	......	69	29	2
Shumacker (72)	......	57	......	......	80. 7	17. 5	1. 8
White, Heroy, and Goodman (84)	......	13	400	3. 3	100	......	......

3. Treatment

The statistics in the following section demonstrate the permanent effectiveness of present therapy. When a patient with a lacerated or penetrating wound develops the classical causalgic syndrome, surgical intervention on the sympathetic nervous system should be undertaken at a relatively early date, before the reaction to persistent agonizing pain can produce serious contractures from inability to move the painful part, narcotic addiction, or psychological deterioration. In the early years of World War II these unfortunate individuals were often branded as malingerers or psychoneurotics, but it was soon found that psychotherapy had little to offer and appropriate interruption of sympathetic pathways gave immediate and dramatic relief. Neurosurgeons working in the Army and Navy hospitals soon came to realize that neurolyses and other local procedures on the injured nerves were useless. According to Mayfield (49), resection of the neuroma with suture of the nerve was often successful. In his paper he cites 28 successful cases and relatively few failures. Our findings have not confirmed this. Furthermore, early resection is rarely an advisable procedure, as the injury to the nerve is usually a minor one, and far better return of sensory-motor function is likely to be obtained if the neuroma is left intact. The conclusion arrived at and thoroughly justified by experience was that demoralizing pain should be relieved by sympathectomy first and injuries to the nerves and adjacent structures dealt with later.

The first logical procedure is chemical blocking of the regional sympathetic ganglia with a local anesthetic agent. The cervicothoracic or stellate ganglion should be infiltrated when the arm is involved, the lumbar chain for causalgia in the lower extremity. When the pain follows a wound of the sciatic nerve high up in the thigh or buttock care must be taken to carry the infiltration upwards to include the first lumbar and lowest thoracic ganglia. The surgeon who is inexperienced in these techniques may refer to the description in White, Smithwick, and Simeone's textbook (85). If he has any uncertainty concerning the position of his needle he will find it helpful to check its position by a lateral film of the spine, as first suggested by White and Gentry (83). Relief of causalgic pain generally coincides with ganglionic block and may last for many hours. When relief is clear-cut, but brief, it is best to proceed with sympathectomy. On the other hand, when relief persists for a longer time, it is advisable to try a series of blocks in the hope that the early mild case of causalgia will improve progressively. This occurred, with the result that no sympathectomy was necessary, in 40 [18] of 344 cases reported by Mayfield (49) and in 2 of the 64 cases summarized below.

If sympathectomy is necessary it is important that it be carried out at a level sufficiently high to denervate the actual area of injury of the peripheral mixed nerve. In the arm denervation will be complete after any of the standard upper thoracic operations. This is best accomplished by Smithwick's "preganglionic" sympathectomy because this operation leaves intact the nerve supply to the pupil and upper eyelid, thereby sparing the individual the minor disfigurement of a Horner's sign. While minor

[18] Many of these were early cases with injections carried out in overseas hospitals soon after the onset of pain.

degrees of vasoconstrictor and sudomotor activity can often be demonstrated within a year, there has been no tendency for causalgic pain to recur.

To relieve causalgia in the lower extremity it is only necessary to remove the second and third lumbar ganglia if the injury has involved only the ankle or foot but, as Ulmer and Mayfield (80) pointed out, this will not suffice for wounds at higher levels. It is therefore advisable to include the first lumbar ganglion for injuries below the midthigh and to resect the chain up through the diaphragm in case of wounds to the buttock.

The technique of these operations also is described in White, Smithwick, and Simeone's monograph (85) and in many other current publications.

4. Statistics From Present Study

Difficulties were encountered in attempting to extract cases of true causalgia from the code. Owing to confusion in terminology it has been necessary to review the individual records of patients who were listed under the following headings:

Sympathectomy for pain before separation from service.
Sympathectomy for pain after separation from service.
Good data on course of causalgia.

We have also included a number of the senior author's personal cases at the U. S. Naval Hospital at St. Albans, New York, some of which are not included in the population studied in this chapter.

Working in this somewhat unsatisfactory fashion, we have been able to obtain records of only 64 veterans for study, 35 who have had some form of sympathectomy for causalgia in the arm, 29 in the leg.[19] We could find no instances in which crippling causalgia can still be said to exist in any veteran examined after an appropriate form of sympathectomy. Residual complaints have been restricted to sensibility to heat or cold, paraesthesiae, cutaneous hyperalgesia, and moderate discomfort on use or pressure, but never severe enough to prevent use of the extremity. The early intense hyperpathia with accompanying psychological phenomena is no longer present. We have no late observations on individuals with inadequate operations who were still suffering severely when separated from the service.

The major statistical reports of early results published during and shortly after World War II are summarized in table 192. It is unfortunate that all of these men have not been followed and doubly so that many of them were not examined by the centers, so that only meager information could be obtained from Veterans Administration examinations. Late results are given in table 193 for the upper and lower extremities of 64

[19] It is obvious that some of the patients originally diagnosed causalgia and treated by sympathectomy have not been traced. Mayfield (49) in his questionnaire to neurosurgeons serving with the Army Medical Corps in the war received reports of 350 cases. This represents the incidence amongst a much larger number of peripheral nerve injuries, and it is questionable whether all of these men had typical causalgia.

individuals treated by operations on the paravertebral sympathetic chains and a small group by other procedures.

Table 193.—*Summary of Results in Causalgia*

Result	35 cases upper extremity	29 cases lower extremity
Satisfactory relief following sympathectomy maintained at 2 to 8 years	20	10
Good early result, but less than 2-year follow-up	1	5
Moderate degree of overresponse or hypersensitivity to heat or cold	6	9
Lasting relief following repeated blocking of sympathetic ganglia with procaine hydrochloride	1	2
Relief following excision of neuroma and suture	2	0
Failures:		
Inadequate sympathectomy	1	1
No sympathetic block, or test preceding ganglionectomy failed to give significant relief	1	1
Periarterial sympathectomy	2	0
Excision of neuroma and suture	[1] 3	[2] 3
Cause unknown	0	1

[1] One of these patients was later relieved by sympathectomy, another failed to benefit by a subsequent periarterial sympathectomy. These are also listed above under the appropriate headings.

[2] Sympathectomies subsequently performed in these 3 cases resulted in 2 successes and 1 failure in an individual who did not respond to preliminary paravertebral test block with procaine. These are also included above under the appropriate headings.

These statistics show that, when appropriate sympathectomy has been performed in properly selected cases, there has been only a single failure to obtain immediate and enduring relief. On reexamination after intervals of 10 months to 8 years, 56 of these veterans (including 3 treated by repeated chemical blocking) have made no mention of serious residual discomfort; 15 of these have had some variety of annoying complaint such as mild spontaneous pain, often related to cold or damp weather, or discomfort on use of the hand or pressure on the foot, but this has never been incapacitating. In table 193 the latter appear on the third line and their present disabilities are summarized in table 194. The majority of residual complaints may be classified as "overresponse," such as occurs so frequently after any damage to a nerve with incomplete sensory reinnervation. A few have mentioned transitory mild burning discomfort on direct exposure to heat and in case 23 this is still brought on by emotional excitement. (See histories of cases 17, 20, and 23 in table 195.) The intense burning pain with emotional correlation has never returned.

Table 194.—*35 Cases of Causalgia, Upper Extremity*

Procedure and case number	Nerve [1]	Level [1]	Good result	Improved	Failure	Comment
A. Appropriate sympathectomy						
1	M (p)	Arm	5 years			
	U (c)	U/3				
2	M (p)	Axilla	9 months			
	U (p)					
3	M (c)	Forearm	2½ years			Causalgia "cured" at discharge.
	U (p)					
4	M (c)	Arm		2½ years		Causalgia developed after median and ulnar suture. Slight palmar sensitivity following sympathectomy.
	U (c)	U/3				
5	M (c)					
	U (p)	Elbow	4½ years			
	R (c)					
6	M (p)	Arm	5 years			
	U (c)					
7	M (p)					
	U (c)			2½ years		Mild overresponse persists in sutured ulnar area.
	R (c)					
8	M (c)					
	U (p)	Arm		5½ years		Complained of sensitivity to cold.
	R (c)					

See footnotes at end of table.

Table 194.—*35 Cases of Causalgia, Upper Extremity*—Continued

Procedure and case number	Nerve [1]	Level [1]	Good result	Improved	Failure	Comment
A. Appropriate sympathectomy—Con.						
9	M (p)	Axilla	5½ years			
	U (c)					
10	M (p)	Arm	3½ years			
	U (c)	M/3				
11	M (p)	Arm		2¾ years		Residual palmar sensitivity.
	R (c)					
12	M (p)	Arm	5 years			
	U (p)					
13	M (p)	Arm	4 years			Stiff joints and poor nerve recovery. Works in shoe factory.
	U (c)	U/3				
14	M (p)	Arm	3 years			Stiff joints and feeling of coldness. Grocery clerk.
	U (p)					
15	M (c)	Forearm	2 years			Prefers fishing and playing pool to regular work.
		L/3				
16	M (c)	Axilla	3 years			No handicap in work as gate tender.
	R (c)					
Personal cases						
17	M (p)	Arm		8 years		Occasional mild burning. Milkman.
18	M (c)					
	U (p)	Axilla	5 years			Changed job to salesman because of paralysis.
	R (c)					
	M. C. (c)					

19	M (p)	Forearm M/3	5 years			Moderate overresponse and limitation in use of hand. Salesman.
20	M (p) U (c)	Arm M/3	8 years			Slight burning in fingers. Accountant.
21	M (p) U (p) R (p)	Arm M/3	8 years			Shipping clerk. Only complains of a mild throbbing sensation when working hard or in cold damp weather.
22	M (p)	Forearm U/3		3 years		Residual paresis with overresponse. Watchman.
23	M (p) M. C. (c)	Arm U/3		7¾ years		Industrial student.
24	M (p) R (c)	Forearm	8 years			Working with limited elbow movement. Salesman.
25	M (p)	Hand	7 years			Barber.
26	M (p) U (p) M. C. (p)	Axilla	3 years			Working at his former job.
27	U (p)	Arm		8 years		Although major part of pain is gone his hand burns slightly in very hot or cold weather, on strenuous exertion, and when hand is pressed or rubbed. Much less severe than preop. Bookkeeper and does much typing.
Failure because of technical error						
28	M (p) U (p)	Axilla			9 months	Surgeon failed to find sympathetic chain.
29	M (p)	Elbow			3 years	Poor selection. Diagnosis of causalgia is questionable and pain not well relieved by procaine block.

See footnotes at end of ta ble.

Table 194.—*35 Cases of Causalgia, Upper Extremity*—Continued

Procedure and case number	Nerve [1]	Level [1]	Good result	Improved	Failure	Comment
B. Procaine block						
30	M (p) U (c)	Arm U/3	1 year			No later information.
C. Excision and neurorrhaphy						
13 [2]	M (p) U (c)	Arm U/3			+	Resection neuroma in continuity and suture severed nerve.
31 [2]	M (p) U (p)	Forearm			+	Resection neuromas in continuity and suture.
32	M (c)	Forearm L/3			+	Median suture.
33	M (p) U (c)	Arm M/3	4½ years			Median—lysis. Ulnar—suture.
34	U (c)	Elbow		3 years		Ulnar—suture. Still has slight burning after neurorrhaphy.

D. Periarterial sympathectomy						
31 [3]	M (p)	Forearm			+	Severe hyperalgesia in area supplied by both nerves.
	U (p)					
35	M (p)				+	
	R (p)					

[1] p=partial severance of nerve or neuroma in continuity c=complete severance of nerve or neuroma in continuity. U/3, M/3, and L/3 denote upper, middle, and lower thirds of arm or forearm.

[2] This patient was subsequently relieved by sympathectomy. (See above.)

[3] Case 31 had a periarterial sympathectomy as well as resection of a neuroma in continuity, but neither operation relieved his pain.

Table 195.—*29 Cases of Causalgia, Lower Extremity*

Procedure and case number	Nerve [1]	Level [1]	Perfect result	Improved	Failure	Comment
A. Appropriate sympathectomy						
36	Sciatic (p)	Buttock		1 year		First sympathectomy incomplete. Second sympathectomy with resection of ganglia. Uncomfortable only in very cold weather.
37	Sciatic (p)	Thigh	5 years			
38	T. sciatic (c) P. sciatic (p)	Thigh		4½ years		Shooting pains several times daily, but not interfering with work.
39	Post. T. (p)	Leg	4 years			
40	P. (p)	Leg		2¾ years		Minimal residual discomfort.
41	P. (c)	Thigh		2⅔ years		Minimal discomfort, not like preoperative pain—overresponse.
42		Leg M/3		3 years		Tennis professional with overresponse in sole. Changed job to store clerk.
43	P (p) Post. T. (c)	Thigh U/3		7 months		Inadequate operation report and question whether sympathectomy was carried sufficiently high. Burning relieved, but aching subsided slowly and incompletely.
44	Post. T. (p)	Knee Heel		4 years		Mild residual overresponse.
45	Plantar (p)	Foot	5 years			
46	Post. T. (p)	Buttock		5½ years		Walks well, but cannot run because of residual overresponse.

47	Sciatic (p)	do.	1 year.			
48	Post. T. (c) P. (p)	Thigh U/3		$3\frac{1}{2}$ years		Sole sensitive when barefoot.
49	Post. T. (c)	Leg	1 year.			
50	Sciatic (c)	Thigh U/3	2 years.			
51	Post. T. (p) P. (c)	Thigh	$4\frac{3}{4}$ years.			
52	Sciatic (c)	Thigh M/3	3 years.			
53	Post. T. (p)	Leg		5 years		Mildly sensitive sole without limitations of walking.
54	Sciatic (c)	Thigh L/3	10 months			Pain-free at discharge.
55	Sciatic (p)	Thigh U/3	$4\frac{1}{2}$ years			Sympathectomy limited to resection L3 and L4 ganglia. Works as stitcher.
56	do.	Thigh			4 years	Failure despite resection L1–L3 ganglia with path. verification and high SR. Good response to preoperative procaine block. Works at former job as writer.
57	T. Sciatic (p) P. Sciatic (p)	Buttock		3 years		Moderate residual overresponse in sole and spontaneous pain. In college.
58	T. Sciatic (p) P. Sciatic (p)	Buttock		3 years		Despite purported T10–L2 sympathectomy there are islands of low SR and sweating. He complains of mildly sensitive sole, but can walk unlimited distance. Auto salesman.

See footnotes at end of table.

Table 195.—*29 Cases of Causalgia, Lower Extremity*—Continued

Procedure and case number	Nerve [1]	Level [1]	Perfect result	Improved	Failure	Comment
Personal cases						
59			4½ years			First sympathectomy L1–L3 proved incomplete and gave no relief. Second stage transabdominal resection resulted in complete loss of sweating and gave good results. He remains partially incapacitated because of concomitant bone injuries.
60			3 years.			
Technical error						
61	Sciatic (c)	Thigh U/3			2¾ years	Failure of T11–L2 ganglionectomy, but he had not responded to procaine block.
62	Post. T. (p) P. (c)	Buttock			5 years	Lumbar sympathetic chain merely cut between L2 and L3 ganglia. Has had to change from sales manager to clerk.
B. Procaine block						
63	Post. T. (p)	Leg L/3	4 years			Only complaint that foot tires after walking more than 1 mile.
64	Post. T. (p) P. (p)	Knee	3½ years			"Can do everything that anyone else can do."

C. Excision neuromas and neurorrhaphy						
41 [2]	P. (c)	Thigh			+.	Neurorrhaphy.
53 [2]	Post. T. (p)	Leg			+.	Excision neuroma in continuity and suture.
61 [2]	Sciatic (c)	Thigh U/3			+.	Neurorrhaphy.

[1] p=Partial severance of nerve or neuroma in continuity.
c=Complete severance of nerve or neuroma in continuity.
T. signifies tibial and P. peroneal nerve. U/3, M/3, and L/3 denote upper, middle, and lower thirds.

[2] These individuals were subsequently treated by sympathectomy. (See above.)

Insofar as we have been able to ascertain, none of these individuals is now unable to work because of pain, although a tennis professional with a sensitive foot is unable to engage in his former occupation, and several others have changed to less active jobs. Another veteran with a posterior tibial nerve injury (case 59, St. Albans Naval Hospital series) remains incapacitated because of severe injuries to the bone and soft parts in his arm as well as in his formerly painful leg. We have encountered only one failure for which there is no certain explanation (case 56), a man who had characteristic pain, a good response to diagnostic block, and removal of the lumbar chain through the first lumbar ganglion for a wound of the sciatic nerve in the midthigh. Possibly he might have been relieved if the dissection had been carried up through the diaphragm. He remains a cripple from severe injuries to both legs in addition to considerable persistent discomfort. Fortunately he is a well-adjusted individual and was a writer before the war, so that he has been able to continue in his former occupation without too serious handicap. Of the 12 other failures, 2 were due to inadequate sympathectomies and 2 others to improper selection of cases for operation in which there had been a poor response to preliminary procaine block. One of these individuals, in addition, did not have proper clinical evidence for a diagnosis of causalgia. Two failures resulted from periarterial sympathectomy, as one might expect. There were 6 other failures, which are not attributable to sympathectomy but followed excision of the neuromas and suture. In the 3 of these in whom a proper sympathectomy was later carried out, the causalgia was relieved. It is of interest that in the 8 individuals who were treated by excision of the neuroma and suture, only 2 were benefited.

These poor results from excision of intraneuronal scars with suture of apparently healthy nerve ends are not in accord with Mayfield's findings, as he stated that this operation is a satisfactory alternative to sympathectomy. In addition, it should be pointed out that it is inadvisable to resect a neuroma in continuity in the early stages for pain, unless the scarring is so severe that the nerve fibers in the injured area are entirely interrupted. The reason for this statement is that reinnervation and recovery of function may never be as complete as if the nerve were left alone or a simple neurolysis were performed. It is very rarely an effective procedure; out of 8 trials 6 resulted in failure, with only a single really satisfactory result and moderate improvement in one other. Neurolysis alone, performed prior to sympathectomy in 24 of these individuals, never gave any appreciable relief.

5. Typical Case Histories

These are case histories of 7 patients treated by one of us (J. C. W.) at the U. S. Naval Hospital, St. Albans, during the last year of the war. It has been possible to follow these individuals with severe causalgia over periods from 5 to 8 years since their sympathectomies. Early results in these patients, together with those in 9 other cases of causalgia, were reported shortly after the end of the war (84).

§ *Case 17.* Pfc., USMC, 21 years: On Okinawa on May 1, 1945, this private received multiple wounds in the head, right thigh, and left upper arm from a "booby trap." Within a few hours he noticed the onset of burning pain in the left hand, together with a sense of partial numbness in the second and third fingers. All his wounds healed uneventfully. On June 18, 1945, at another hospital the median nerve was explored and minor adhesions freed, without the least benefit. On admission to the U. S. Naval Hospital at St. Albans, on July 16, 1945, he complained of constant diffuse burning pain in the entire hand and lower forearm, which was increased by cold, sudden noises, and any form of apprehension. He could not tolerate the minor disturbances on the open ward, and he kept his hand constantly moist with a wet towel or by immersion in a basin of lukewarm water. He was suffering so much that he begged for early relief. Accordingly, diagnostic paravertebral procaine block was performed on the day after his admission. The nervous apprehension caused by this procedure resulted in such severe throbbing pain that it was necessary for a hospital corpsman to drip lukewarm water over the lower arm and hand while the needles were being inserted in his back. However, within a minute of the time the infiltration of procaine began the discomfort disappeared, and a few minutes later the cold extremity became warm and dry. That evening he went to the movies for the first time, but noticed some recurrence of his pain. Left thoracic preganglionic sympathectomy was performed 2 days later, followed by complete relief. He got up on the first postoperative day and was able to move out on the open ward and use his hand without discomfort. Shortly thereafter he began to play volley ball and other strenuous games, and was then discharged from the Marine Corps to enter civilian work.

This was the first and also the most severe case of causalgia seen in the St. Albans Naval Hospital series. Exactly 8 years after his sympathectomy he came to be examined by one of us. His report is as follows: "In general I am completely relieved, certainly over 99 percent. I have two complaints at the present time: First, on very hot days, especially if the sun is on my left hand, I get a very slight but annoying burning pain in the palm in the same place where I used to have the severe pain I find that I can make this much better by holding a piece of ice in my palm. I can usually do this all right because I am a milkman and have ice in the truck." His other complaint consists of a Tinel paraesthesia in the median distribution when he strikes the upper part of his arm near the site of his wound. After discharge from the service he first tried glass blowing, but had to give this up because he could not tolerate extreme heat on his left hand. In his present job as a milkman he does not find his injured arm any handicap in his work. On neurological examination his left face and arm remained dry. There was no Horner's sign. His left hand was as well developed and well calloused as the right. There was no motor impairment, but a slight although definite hypalgesia over the distribution of the median nerve.

Case 18. Maj., USMC, 25 years: This officer was struck by shell fragments at Okinawa on May 4, 1945, from which he sustained a compound fracture of the surgical neck of the left humerus and other injuries of lesser importance. The missile, which entered his axilla, partially divided the axillary artery and ulnar nerve, and severed the median. Severe causalgic pain developed immediately throughout his entire hand. On admission to St. Albans he was in poor general condition and still had an unhealed wound in his left axilla. This soon began to extrude clots of blood so that it was necessary to ligate the axillary artery on September 15, 1945 to prevent serious hemorrhage. This operation permitted evaluation of the nerve injury, but median suture in the presence of sepsis was out of the question. It was of interest that this patient, in addition to noticing an increase in his burning pain on cold and psychic stimuli, complained bitterly of the throbbing pain in his hand during any slight argument or whenever his children cried. Following diagnostic block, thoracic sympathectomy was performed on September 27, 1945, and produced an excellent result. His median nerve was sutured on March 6, 1946, a month after final healing of his wound, together with lysis of the swollen ulnar nerve. In this patient, as in others personally observed in the St. Albans series, there was no vasodilatation in the cutaneous area of the median nerve, where the postganglionic sympathetic fibers had degenerated from the injury to the nerve trunk (skin temperature of first 3 fingers averaging 72° F. but 90° in fifth finger). He remained free of pain at the end of a year.

Five years later he had changed his former occupation of civil engineer to salesman. He had had no treatment since discharge. His complaints were limited to poor sensation, some loss of muscle strength, a feeling of coldness at all times, fatiguability on long use, and stiff joints. He considered that he was only slightly handicapped and that the arm had been "repaired as well as possible under the circumstances." He said he was "clumsy with the left hand, tending to drop objects quite frequently." Motor examination showed perceptible movement only in the flexor profundus indicis and opponens with good recovery of flexor carpi ulnaris, but none in distal ulnar muscles. There was also no recovery of radial and musculocutaneous nerves.

Case 20. Pfc., USMC, 19 years: received multiple wounds in the right upper and lower arm at Okinawa on May 10, 1945, with partial median and complete ulnar paralysis. His burning pain began 5 hours after he was wounded. Next to case 17 this patient had the most severe causalgia of the St. Albans series. When he was admitted in July the burning pain involved the entire hand. This became much worse in the cold and quite unbearable on any psychological disturbance, so that he lay in a quiet, darkened room with his arm immobile on the bed and usually protected by moist towels. He complained particularly of the aggravating effect of loud noises, jarring of the bed, exciting movies, of cold draughts of air over his hand, or cold, rainy weather. The patient stated that each night when he got quieted down and relaxed his pain largely disappeared and he was able to sleep well, but it would appear again soon after he awakened. At the time of his admission he unfortunately had a complicating infectious hepatitis, so that we did not dare submit him to general anesthesia and operation until his jaundice cleared. During this period of waiting his causalgia was relieved three times by paravertebral procaine infiltration of the upper thoracic ganglia, only to recur within a few hours on each occasion. Finally sympathectomy was performed on September 19, 1945, and his causalgia disappeared from this date.

A week later the nerves in his arm were widely exposed and a long gap in the ulnar repaired by transplantation and suture. There was a complete injury to the ulnar nerve and surrounding adhesions of the median, which undoubtedly gave rise to the causalgic syndrome. In the forearm there were only fine adhesions to each trunk. It is again of interest to note that, whereas vasodilatation of the median area was complete following preganglionic sympathectomy (skin temperature of the first 3 fingers in a room at 67° F. being between 86.5° and 90°), the temperature in the hemianesthetic ring finger measured 90° on the median and 86° on the ulnar side, and in the completely denervated little finger, where there was complete degeneration of the postganglionic sympathetic fibers, was reduced to 74°. He was under observation on the service for 1 year and remained free of his former burning pain.

In August 1953, this veteran gave a carefully considered answer to a routine questionnaire. He states that "the terrible burning pain I had before the sympathectomy was performed has remained dormant with a few exceptions. I have this same severe burning sensation in my first three fingertips while exposed to hot sun such as experienced at the beach. I also experience this sensation on hot, humid days and while exercising excessively. The cold weather has little effect other than the usual stiffness in my fingers." He also experiences a moderately annoying degree of gustatory sweating in the sympathectomized side of his face when he eats spicy foods. There has apparently been little recovery following the extensive neurolysis, transposition, and suture of his ulnar nerve, although there has been useful recovery of the median following the neurolysis and resection of the lateral neuroma. He works as a salesman with some handicap in typing or handling heavy suitcases, and says that he is handicapped in most sports because he cannot grip well.

Case 21. Pfc., USMC, 19 years: On February 28, 1945, at Iwo Jima this Marine was wounded by gunshot. The bullet, which traversed the lower third of his right arm, caused a partial injury of the median and ulnar nerves, nicking the brachial artery as well. Eleven days later the resulting aneurysm was operated upon at Pearl Harbor. Immediately afterward he began to complain of burning pain deep in the hand, made worse by cold, touching the extremity, or by excitement such as that caused by watching a baseball game or by a close call in an automobile. On arrival at St. Albans he had a cold hand without any radial pulse, the characteristic signs of median and ulnar paralysis, and severe ischemic fibrosis of the flexor muscles in his forearm. On August 21, 1945, a week after his admission, following temporary relief obtained by paravertebral procaine block, his moderately severe causalgia was relieved by preganglionic sympathectomy. Although the relief of his burning pain and hyperesthesia was complete and the hand became totally dry, there was little increase in temperature in the anesthetic median and ulnar areas. After this operation he was hospitalized for a period of 6 months for plastic procedures to release scar tissue contractures in his forearm and elbow. No operation on the injured nerves was necessary because of their spontaneous regeneration. It was of interest that with early return of sensation he developed the usual mild cutaneous sensitivity that often accompanies nerve regeneration, but without any trace of his previous burning pain. This has been a common finding in other cases.

This patient, after a letter of inquiry, sums up his status 8 years after sympathectomy as follows: "I am feeling well with hardly any pain at all, except for a burning sensation in my lower arm and hand when I am exerting myself or in rainy weather and cold weather. It is not an extreme pain, but more of a burning and throbbing sensation. In rainy and cold weather my hand turns dark purplish blue, from lack of circulation, I imagine, but in nice weather my hand is its natural color . . . The results of the operation have been very effective . . . Under emotional stress I notice no pain . . . When I am exerting myself, such as working or participating in sports, I perspire freely on the left side of my body only. When I eat spicy, highly seasoned foods such as pickles, peppers, spaghetti, etc., I perspire freely on my right side from the top of my head down to my waist.[30] At the present time, and since my discharge, I am working for the . . . . . Company in the Shipping Department. I am handicapped insofar as I am limited in the type of job I can do, as I cannot do any heavy lifting and cannot rotate my arm from the elbow down or cannot clench my fist tightly; also I cannot move my fingers individually."

Case 23. Pvt., USMC, 22 years: This man was injured by fragments of mortar shell explosion in the upper arm on 9/16/44 at Pelelieu. There was complete paralysis of the musculocutaneous and partial of the median nerve. Severe causalgic pain appeared in the area of its palmar distribution the day after he was wounded. He described this pain as intense burning and throbbing in the thenar side of his hand, which was increased by any light touch or rub, or by any sudden noise, mental upset, fright, anger, or excitement. Instead of being aggravated by cold, this patient complained particularly of hot weather, when he had to protect his hand by ice or cold, wet packs. The most striking feature of all was the relation of his pain to any attempt to swallow cold liquids. This began a month

[30] This form of gustatory hyperhidrosis has been described by Haxton (32).

after his wounding and forced him to limit his fluid intake to sips of warm milk. Brachial plexus block with procaine at another hospital had failed to relieve his pain, but the result from paravertebral infiltration of the sympathetic ganglia in our hands was excellent. For the first time he was able to drink a tumbler of cold water. Preganglionic thoracic sympathectomy, performed on 11/14/45, gave a most satisfactory result. At the end of 13 months he had no further complaints and was very happy to be able to drink cold liquids, especially beer. In spite of residual biceps paralysis, he had good use of his arm, which had recovered normal sensation in the hand and a fair degree of elbow flexion through compensatory movement by the brachioradialis muscle.

In answer to a follow-up letter in July 1953, he reported: "To begin with, I can honestly say that the result of the operation has stood up. The pain I have at present is negligible when compared to the pain I experienced prior to the operation. When the skin is pressed or rubbed, pain is brought about. All the things you mentioned such as emotional excitement, changes of the weather, fatigue bring on pain. Of these, hot humid weather and fatigue cause the more intense burning sensation . . . I have overcome enough of the paralysis to follow a vocation chosen prior to entering service in World War II. I am now employed as a commercial artist . . . Today I can hardly believe that I once begged a field doctor at one of the hospitals in the Pacific to amputate my arm because the burning pain was so intense . . . I had 15 months of hell's fire in my extremities and you quenched it. The pain I now have on occasion is as nothing to what I had then."

Case 24. Pfc., USMC, 23 years: A machine-gun bullet passed through the left forearm on 1/5/45, causing partial paralysis of the median and radial nerves. Five hours later, on recovering from anesthesia for débridement of the wound, he began to suffer from causalgic pain through his hand. Neurolysis and partial suture of both partially paralyzed nerves had been performed 4 months prior to his admission to St. Albans, and this had resulted in some improvement in his burning pain, but he still complained of severe stabbing, shooting pain in his wrist and hand. This was made definitely worse by cold weather, but was not related to emotion. We regarded this as a somewhat atypical case of causalgia, but we obtained satisfactory relief by diagnostic procaine block. Preganglionic sympathectomy, performed on 9/5/45, was followed by a complete remission of all his complaints. There was only partial vasodilatation in the residual hypesthetic territory of the median nerve.

In answer to a recent follow-up letter the patient has given us the following report of his status nearly 8 years after operation: "Relief following sympathectomy has stood up. No pain during hot or cold weather. No pain due to fatigue, emotional excitement, pressure or rubbing of abnormal areas. Skin tone: Excellent. Tautness and blue coloring of fingers completely vanished. Sensitivity: No sensation in areas affected by ulnar and radial nerves; however, if fingers touch an extremely hot object (hot water, hot dish, door handle exposed to bright sun, etc.) feeling is intensified, almost to the point of touching a hot stove . . . In general, the operation you performed has made me much more comfortable, and has enabled me to lead a perfectly normal life within the limitations of my left arm disability . . . Everything that was to have been rectified, has been rectified . . . I swim well, and can swing a baseball bat or golf club effectively, making allowance for lack of mobility in left elbow and wrist."

Case 27. Pfc., USMC, 22 years: On 3/11/45 a shell fragment caused a partial injury of the right ulnar nerve at the internal condyle. The patient began to notice causalgic pain as soon as he recovered from an accompanying cerebral concussion. When he was admitted to St. Albans he suffered from moderately severe burning pain and hyperalgesia in the ulnar area of his hand, aggravated by cold and the usual psychological factors. The first attempt to block his upper thoracic sympathetic ganglia resulted in vasodilatation, but failed to produce satisfactory drying of the skin or any Horner's sign; furthermore, his pain was not relieved. Following a second, effective diagnostic block and throughout the 5 months he was under observation following surgical preganglionic denervation he remained free of pain.

In July 1953, he wrote a good description of his present state and then came to Boston for examination. These are his statements: "I have come a long way since the operation you performed on me in 1946. Although a major part of the pain is gone, I still get a burning pain in my hand. I usually get this pain when the weather changes, very hot and very cold weather, fatigue and when the little finger is pressed or rubbed. Strenuous exertion may cause the burning to become really disagreeable, otherwise I can forget it. My elbow is still very sensitive and at times I get a very sharp pain in my back where the sympathectomy was performed. Because of this I am unable to lift anything that is too heavy or carry anything for more than a couple of blocks. I am at present a traveling auditor for a freight forwarding company. I do a tremendous amount of writing and typing which causes my arm and hand at times considerable pain. It has not, thank God, prevented me from doing my work. The only time I'm handicapped is traveling. I have three pieces of luggage to worry about."

On neurological examination he was found to have good motor recovery. He could feel a fine von Frey hair as well in the autonomous zone of the little finger as in normal areas, but a 2-gram pinprick caused distinct dysesthesia.

In summary, this man at 8 years shows the reaction of overresponse with mild burning at times, but this is never related to emotional stimuli nor is it incapacitating.

6. Summary

a. In patients who have true causalgia with burning pain which is aggravated by psychological factors and exposure to heat or cold, appropriate sympathectomy is nearly certain to give relief. Mild degrees of overresponse may remain, and a few individuals have persistent discomfort on exposure to heat.

b. It is advisable to do a preliminary procaine block, particularly in any atypical case. A few cases of causalgia respond so favorably to the first block that the pain can be relieved without operation by a series of injections with local anesthetic solution.

c. In the severe case of causalgia sympathetic surgery should be undertaken at an early date, before immobility of the painful part can lead to irreparable orthopedic deformities, or the individual can develop serious loss of morale or narcotic addiction.

d. Periarterial sympathectomy and neurolysis are both useless.

e. Excision of neuromata and suture, although occasionally effective, are inadvisable. Delay for a period long enough to make certain that useful regeneration will not take place spontaneously is unjustifiable and a favorable response is at best uncertain.

C. OTHER PAINFUL PHENOMENA

1. Definitions

Since examiners in the various centers were found to have interpreted rather differently the meanings of terms used to describe painful and other unpleasant phenomena, exact definitions have been formulated. Where substantial semantic conflict has been found, additional exclusions have been made, under statistical control.

Complaints of actual pain have been studied in three categories:

a. *Spontaneous pain* is considered to be constant or intermittent pain in the injured limb, present even at rest. It is often particularly annoying in damp or cold weather. It may represent overresponse to unrecognized stimuli, but this is by no means certain. Spontaneous pain may occur when there are fibrotic changes in joints, tendons, or other tissues, in the absence of nerve injury. Old soldiers have for generations complained of their wounds with changes in weather.

b. *Hyperesthesia* (or more strictly, hyperalgesia) should refer only to pain evoked by stimuli which, when applied to the normal subject, would be below threshold. This is a rare phenomenon; in the great majority of nerve injuries elevated thresholds can be demonstrated with graded hairs and pins. Since most examiners took "hyperesthesia" to mean an exaggerated, disagreeable response to tactile or painful stimuli, whatever the threshold, we have eccepted this definition although reluctantly.

c. *Pain on use or pressure* is self-explanatory.

This chapter includes also certain sensory complaints other than pain. These phenomena may be a source of considerable annoyance in some "sensitive" individuals. They have been classified as follows:

(1) *Paresthesia* includes peculiar sensations such as "tingling" or "crawling" which are not painful.

(2) *Gross sensory loss* implies a feeling of numbness or "wooden" sensation. Ordinarily, this complaint is associated with a demonstrable reduction in sensation to algesiometer, von Frey hairs, or both.

(3) *Feeling of coldness* may in some cases be a major complaint.

(4) *Bizarre sensory pattern.*

(5) *Ulceration.*

In the course of examination for threshold of pain sensation in the autonomous zone of the injured nerve, examiners were asked to indicate the presence of "hyperpathia" or "dysesthesia." Considerable confusion has arisen in connection with these terms:

(1) *Dysesthesia.* According to strict etymology, the Greek prefix "dys" has severa meanings: painful, abnormal, or impaired. It is not surprising, therefore, that dysesthesia was construed at some examining centers to be synonymous with paresthesia and at others as a disagreeable quality to any stimulus. We have grouped individuals who appeared to be in actual pain on local (often minimal) stimulation under this heading and have eliminated those considered to exhibit dysesthesia when other definitions have been used.

(2) *Hyperpathia.* The term hyperpathia was coined by Foerster, who proposed this designation "for certain characteristics of the so-to-speak pure pain sensation which is experienced under pathologic conditions following a nerve suture when pain only is appreciated and all other modalities of sensation are absent. These characteristics are: absence or impairment of correlation between intensity of stimulus and intensity of sensation with a relatively high threshold; a considerable latent period between stimulus and response; or explosive appearance of pain at stimuli above threshold; an abnormal exceedingly unpleasant character to the pain leading to vigorous defensive movements and reactions in the vasomotor and vegetative spheres; a long persistence of pain after cessation of the stimulus in which pain-free intervals may alternate several times with painful periods; a defective appreciation of the extent and location of the area stimulated; poor discrimination as to the application of two or more stimuli simultaneously, with irradiation of the pain; lack of features which enable the subject to determine the nature or type of painful stimulus." Most of the centers used this term to connote intensely disagreeable sensations and evidence of profound discomfort on stimulation of the injured extremity. The word, as used by Foerster, would include the most severe forms of overresponse as well as cases of causalgia.

The categories of "hyperpathia" and "dysesthesia" have been studied together, for statistical reasons.

The raw data concerning the unpleasant sensory and related sequelae of nerve injury may be summarized as follows among the 2,962 nerve injuries with some follow-up:

Nature of complaint	*Number of nerves*
A. No complaints	228
B. Complaint of spontaneous pain	902
C. Painful overresponse:	
1. Manifested by complaint of pain on use or pressure	1,035
2. Manifested by complaint of hyperesthesia	529
3. Manifested by "dysesthesia" or "hyperpathia" on examination for pain threshold	667
D. Causalgia	(64)[31]
E. Complaints of unpleasant phenomena other than pain:	
1. Paresthesia	1,080
2. Coldness	1,000
3. Gross sensory loss	1,241
4. Bizarre sensory pattern	48
5. Ulceration	150

[31] The sixty-four cases of causalgia in World War II, reviewed in section B, were not all drawn from this population. Since causalgia often results from nerve injuries so minor that neither neurolysis nor nerve suture is done, it is impossible from our data to find the true incidence of the condition.

In all there were 5,985 complaints and 667 instances of evoked overresponse on examination. In 973 instances there were 3 or more complaints. It will be noted that in only 8.3 percent of the cases was there no complaint.

An attempt has been made to determine which, if any, of the characteristics of the injury or of its treatment may be responsible for the persistence of pain or of other unpleasant sensory phenomena. The effects of the agent and site of injury, associated damage to arteries or bones, time of operation, operative findings and technique, and of other obvious features have been sought by means of statistical analysis, independent of the clinical impressions of the authors. The relation of unpleasant sensory phenomena to motor, sensory, and autonomic recovery has been sought and an attempt has been made to determine whether they have a bearing on occupational disability of the veteran. No significant difference has been found between patients with single and those with multiple nerve lesions in the incidence of painful and related phenomena. These two groups have therefore been combined. However, center variation in the observations on painful phenomena has required that all analyses be made separately for each center.

2. Relation to Characteristics of Injury

In a group of median and ulnar nerve injuries, unselected except by center, only 49 of 453 wounds had been caused by cutting instruments. Spontaneous pain occurred in only 18 percent of the cutting injuries as compared with 34 percent of the missile wounds (table 196). This difference, which depends upon only 49 instances of cutting injury, has a probability of about .04 and agrees with clinical experience with civilian injuries. Overresponse, as judged either by complaint or by examination (the latter is not shown in table 196) or paresthesia, appears to be no more common after missile wounds than after wounds produced by cutting instruments. Perhaps because the series is small, especially after subdivision by center, extensive soft tissue damage, requiring plastic repair, is not reliably associated with persistent pain. An associated injury to bones or joints appears to be of little or no importance in determining whether persistent pain will follow a nerve injury, except in the case of the median nerve, where such complaints are somewhat more common in men with complex wounds of this type. Even when infection severe enough to delay nerve repair has been present, no consistent increase is noted in the incidence of painful or other unpleasant phenomena.

As might be expected, associated arterial injury is not associated with an increased incidence of spontaneous pain or hyperesthesia. Pain on ordinary use is also found no more frequently in patients with arterial injury, but observations were not made on the possible effect of prolonged exertion in the presence of arterial injury. Painful overresponse to examination for pain threshold after median and ulnar injuries is somewhat more common in patients with associated arterial damage, but the evidence is suggestive only. Persistent paresthesia seems clearly related, however, to arterial injury complicating wounds of the median nerve (table 197). Some suggestion of such an effect is found for the radial nerve, and a rather more questionable effect for the ulnar. It is possible, therefore, that impaired blood supply, in the case of the median nerve at least, may be associated with persistent paresthesia.

The possible effect of the level of injury on the incidence of persistent pain has been studied in median, ulnar, and sciatic nerves with negative results.

Table 196.—*Prevalence of Painful Phenomena and Agent of Injury, Median and Ulnar Sutures* [1]

Complaints	Agent		
	Gunshot	Cutting instruments	Total
	Percent	*Percent*	*Percent*
Spontaneous pain	34.4	18.4	32.7
Paresthesia	44.1	51.0	44.8
Hyperesthesia	19.3	16.3	19.0
Pain on use or pressure	38.9	36.7	38.6
Number of lesions studied	404	49	453

[1] Median and ulnar sutures studied in New York center, and ulnar sutures in Philadelphia.

Table 197.—*Prevalence of Paresthesia and Associated Arterial Injury, by Nerve, All Centers, Complete Sutures Only*

Nerve	Arterial injury					
	Present		Absent		Total	
	Number of lesions	Percent paresthesia	Number of lesions	Percent paresthesia	Number of lesions	Percent paresthesia
Median	128	54.7	237	35.4	365	42.2
Radial	30	43.3	250	32.4	280	33.6
Ulnar	136	47.1	448	38.8	584	40.8

3. Relation to Treatment of Injury

Persistence of pain is apparently unrelated to the interval between injury and operation or to the necessity for multiple operations. Only one questionable exception to this rule was found: overresponse to examination for pain threshold occurred in 47 percent of men whose median nerve had been repaired more than once and in only 34 percent of men with a single definitive neurorrhaphy.

In most cases, the operator evaluated the amount of scarring of nerve ends and measured the surgical defect just prior to suture. Neither factor exerted a discernible effect upon the persistence of painful phenomena at follow-up examination. Curiously enough, patients who had undergone preliminary bulb suture actually were less likely to have pain or related complaints than were patients who had had only a definitive nerve suture. In attempting to explain this unexpected finding, it was thought that poorer sensory recovery would probably be found in such cases, and might be correlated with a decreased incidence of pain. Actually, as shown in chapter V, sensory recovery was apparently not adversely affected by bulb suture. Extensive mobilization or transposition of the nerve had no significant association with the prevalence of pain. Tantalum, silk, and plasma glue as suture materials were equally likely to be associated with pain at follow-up examination, and the use or removal of tantalum cuffs similarly provided no useful correlation.

The data do not give a clear picture of the effect of sympathectomy in the treatment of pain following nerve injuries. Sympathectomy is known to be of value chiefly in the treatment of causalgia, which, in the coding system used for this study, is not clearly separable from other painful phenomena. Residual spontaneous pain caused by changes in the joints, for example, will still be coded in a patient whose causalgia has been relieved by sympathectomy. Then, too, causalgia is rare in patients whose nerve injury, as in the majority of this group, has been treated by nerve suture. For these reasons causalgia and its treatment are discussed in a separate section of this chapter, on the basis of a review of case records.

4. Relation to Other Follow-up Characteristics

A correlation clearly exists between sensory complaints and complaints of impairment of motor function. Only 3 percent of men with sensory complaints were free of motor complaints, while as many as 21 percent of the small group without sensory complaints had no motor complaints (table 198). When a relationship is sought, however, between the various subjective indices of motor impairment (loss of coordination or power, fatigability on long use, easy fatigability, cramps, stiff joints) and spontaneous pain or overresponse, results are not striking. Only "easy fatigability" shows a reliable correlation. Of patients complaining of spontaneous pain or overresponse, 51 percent had this motor complaint. In the absence of sensory complaints, only 23 percent complained of easy fatigability.

Suprisingly little correlation can be found between motor recovery (as judged by the British Summary) and persistent pain. In the upper limb there is no clear relationship. In the sciatic nerve and its branches, spontaneous pain was somewhat less common in men with good motor function than in those whose motor power remained grossly impaired. Neither overresponse nor paresthesia shows any similar relationship to motor recovery.

Table 198.—*Relationship Between Motor and Sensory Complaints Following Complete Suture, All Centers and All Nerves Combined*

Motor complaint	Number of lesions	Percentage with sensory complaint
None	97	62.9
Any	1,877	92.7
Total	1,974	91.2

Complaints of pain and related abnormalities bear no discernible relationship to return of sensation as judged by the British Summary. It was necessary to seek further for correlation between overresponse and sensory recovery, since absence of overresponse is a criterion of good sensation in the British Summary. Thresholds of pain and of touch were therefore studied in relation to the history or finding of overresponse. No relation can be found between pain threshold and painful overresponse. Touch threshold, however, seems to be pertinent. After neurorrhaphy, patients whose touch thresholds remain poor or fair are less likely to exhibit overresponse on examination than those with good touch recovery. After neurolysis, on the other hand, it is the group with poor return of touch thresholds who are likely to show painful overresponse. Apparently overresponse is more closely related to recovery of touch threshold than pain threshold, but the relationship is complex and not explained in terms of these data.

Complaints of pain bear no apparent relation to those of "adverse reaction to heat or cold" or to excessive sweating. Curiously, there is no clear evidence that change in occupation or even the presence of an occupational handicap is associated with either complaints of pain or evidence of overresponse to examination for pain threshold.

Chapter VII

Autonomic Recovery

Bertram Selverstone and *James C. White*

A. INTRODUCTION

Recovery of autonomic function has been assessed and compared in the various nerves by means of certain simple subjective and objective criteria. An attempt has been made to determine which characteristics of the injury itself and of its treatment may influence the degree of functional recovery to be expected. The effects of level of injury, associated injuries to major arteries, bones, and joints, time of operation, length of gap, suture material, and other features of the nerve wound and of its operative treatment have been viewed in the light of statistical analysis divorced, insofar as possible, from the preconceptions of the authors. An attempt has been made also to study the relations among the indices which have been used to assess autonomic recovery and to determine the relation of recovery of autonomic functions to those of sensation and motor power.

At follow-up, each veteran was asked a number of questions designed to elicit complaints which might have resulted from failure of normal autonomic recovery. The only complaint studied which is clearly attributable to impairment of autonomic recovery was that of loss of sweating. Although data are available concerning the complaint of excessive sweating, such data are indicative only of reinnervation of sweat glands; an excessive amount of secretion has no known relation to autonomic recovery unless it is clearly limited to the distribution of a specifically injured nerve, as in the auriculotemporal syndrome. The present data were not gathered with this point in mind. In the authors' opinion this complaint of excessive sweating in a wounded veteran most often results from general autonomic stimulation related to anxiety. Data have also been accumulated concerning the complaint of abnormal sensitivity to extremes of temperature. Here again, there is no clear relationship between this complaint and autonomic recovery. While in certain experimental animals sympathectomy may be followed by an abnormally intense vasoconstrictor response because of sensitization of arteriolar walls to circulating epinephrine and sympathin, recent work summarized by White, Smithwick, and Simeone (85) indicates that the phenomenon is barely detectable in man. Obvious cooling of the extremities is, however, a common finding after a major nerve injury with incomplete recovery. Doupe (20) has discussed this phenomenon in humans, but suggests that a more important mechanism is the reduced metabolism of paretic striated muscle.

Objective criteria of autonomic recovery depend upon determinations of skin resistance by the methods of Richter (63) and, less often, of sweating by the starch-iodine method of Minor (52) or the quinizarin test of Guttmann (31). Plethysmographic studies for return of vasomotor activity were not undertaken. There is, however, no evidence for disassociation between sudomotor and vasomotor recovery, and individuals with clearly elevated skin resistance or absence of sweating in the distribution of an injured nerve may be classified as failures insofar as autonomic recovery is concerned.

Certain differences, both anatomical and physiological, will be recalled between sympathetic innervation and that of the somatic motor and sensory systems. The sympathetic fibers in the mixed peripheral nerves are unmyelinated or poorly myelinated fibers of small diameter, corresponding to conduction times of 0.5 to 1.0 meter per second. The peripheral structures chiefly influenced by these impulses are the blood vessels of the muscles and more especially of the skin, the sweat glands and the arrectores pilorum, which produce the phenomenon of "gooseflesh" in man. Chemical mediation of autonomic impulses both at ganglia and at end-organs, although less important in man than in lower animals, may permit singularly widespread activity by a few residual or regenerating axons. Furthermore, the peripheral distribution of the autonomic impulses is far more diffuse than that of the somatic impulses.

When a peripheral nerve is severed, its autonomic fibers undergo Wallerian degeneration in a manner similar to somatic fibers. Suture is followed by more or less regeneration in accordance with the classically accepted pattern for motor and sensory axons. There is no evidence to suggest, in their reaction to injury or in their ability to regenerate, that individual autonomic axons differ in any significant way from those of the somatic system. It is likely, however, because of the overlap of their peripheral innervation, that recovery of a relatively small proportion of the interrupted autonomic fibers of a nerve may produce complete recovery, both of symptoms and of measurable functional activity.

B. DESCRIPTIVE DATA ON AUTONOMIC RECOVERY

As in the earlier chapters, the tables for this section were confined to the representative sample. All seven major nerves were studied, but certain combinations of injured nerves and cases with sympathectomy were dropped. In the selection of combinations of injured nerves emphasis was placed upon pure lesions and upon median lesions accompanied by other nerve lesions; in addition, all sciatic lesions studied here involved both branches. Peroneal lesions with associated tibial lesions were also included.

The criteria chosen as indicative of partial or complete persistence of loss of autonomic function after nerve injury are as follows:

(1) Complaint of "loss of sweating." The assumption must be made that a randomly selected majority of patients have factual bases for this complaint.

(2) Evidence of increased skin resistance in
   (a) the total area of innervation of the nerve, or
   (b) the assumed autonomous area of its distribution.
(3) Evidence of absence of sweating in
   (a) the total area of the nerve, or
   (b) the assumed autonomous area of its distribution.

Table 199 contains the data on these indices for sutured nerves. The complaint of loss of sweating appears to be much less common in association with pure radial nerve injuries than with injuries of the median, ulnar, sciatic, tibial, or peroneal nerves. This observation is consistent with data indicating that elevation of skin resistance is much less frequent with pure radial than with other major nerve lesions. It may not be concluded from these data, however, that a high degree of recovery of impaired autonomic function occurs after lesions of the radial nerve. It seems likely that radial lesions may be associated with relatively little initial disturbance of autonomic function. Proof of this hypothesis would require preoperative studies similar to those which have been carried out in these follow-up examinations. Such data are not available. An alternative explanation, not susceptible of proof or disproof here, would suppose a specific tendency for autonomic overlap from median and/or ulnar distributions in the presence of radial autonomic paralysis.

Table 199.—*Percentage of Cases With Evidence for Impaired Autonomic Recovery After Suture of Various Nerves*

Nerves injured	Complaint of "loss of sweating"	Increased skin resistance		Objective loss of sweating	
		Total area	Autonomous area	Total area	Autonomous area
Median only	5.4	10.3	25.3	9.1	22.7
Ulnar only	2.4	13.1	31.6	11.5	17.3
Radial only	1.2	1.7	8.6	0	20.0
Median plus ulnar, radial, or both	8.5	19.0	32.1	16.0	24.0
Peroneal only	3.6	11.5	21.8	25.0	33.3
Sciatic-peroneal	9.9	24.1	27.7	37.9	27.6
Tibial only	9.1	9.4	26.4	47.4	15.8
Sciatic-tibial	11.7	23.6	31.5	36.0	24.0
Peroneal plus tibial	9.7	9.1	18.2	50.0	33.3

Autonomic status is objectively superior in patients whose nerve injury was such as to have required lysis rather than suture. This conclusion emerges clearly from a consideration of the data concerning elevated skin resistance in table 200. Complaint of loss of sweating is no more frequent after suture than after lysis, however, nor do the relatively fragmentary data derived from sweating tests disclose a difference between the two groups. Results of neurorrhaphy for an initially complete nerve wound do not differ from those after resection of a neuroma in continuity. Associated injury to radial or ulnar nerves does not affect the observed degree of recovery after median nerve injury; autonomic recovery following peroneal suture, similarly, is unaffected by the presence of associated tibial lesions. It would therefore appear, for nerves heavily supplied with autonomic fibers (i. e., other than the radial), that associated nerve injury is without effect on autonomic recovery.

Table 200.—*Percentage of Cases With Elevated Skin Resistance at Follow-up Examination, After Nerve Suture or Lysis*

Nerves injured	Total area		Autonomous area	
	Complete suture	Lysis	Complete suture	Lysis
Median and ulnar (all cases)	13.8	7.5	30.2	18.8
Radial (all cases)	1.6	0	9.5	0
Peroneal and tibial (all cases)	10.5	0	26.4	9.8
Sciatic (one or both divisions)	23.9	10.9		

C. INFLUENCE OF CHARACTERISTICS OF INJURY

Certain characteristics of the patient and of his original nerve injury have been studied in order to determine whether they exert a significant effect upon the indices of autonomic function discussed in the previous section. All complete sutures on the median, ulnar, tibial, and sciatic-tibial nerves entered into the analysis except those in men with sympathectomies.

Gross site of injury appears to have some relation to the chance of autonomic recovery, an elevated SR being more often found in a high suture than a low. Some suggestion of the same effect is also contained in the small amount of data derived from tests of sweating but complaints of loss of sweating do not vary by site.

Associated injuries to bones and joints bear no consistent relation to any of the indices of autonomic recovery. More surprising, perhaps, is the observation that the presence of associated soft tissue defects sufficiently extensive to require plastic procedures do not significantly affect recovery of autonomic function. Infection severe enough to delay operation was uncommon but, insofar as data are available, it does not appear to exert a significant effect.

Median and ulnar injuries were studied in order to determine whether associated major arterial ligations might influence autonomic recovery. No effect was noted upon the indices employed in this study.

The age distribution of these men, most of whom had been wounded in battle, is not wide enough to permit definite conclusions concerning the effect on age on autonomic recovery. No evidence for such an effect has been observed.

When wounds caused by shell fragments and other missiles were compared with those relatively few injuries produced by cutting instruments, no significant difference was found in autonomic recovery.

D. INFLUENCE OF TECHNICAL ASPECTS OF MANAGEMENT

Certain technical features have long been considered, *a priori*, to be of importance in the result to be expected from a neurorrhaphy. The validity of these preconceptions has been subjected to statistical analysis in all the complete neurorrhaphies on the median, ulnar, tibial, and sciatic-tibial lesions in the series except those of men with sympathectomies. It must be emphasized that the results reported in this chapter are based upon evidence for autonomic functional recovery alone; they do not necessarily reflect the quantitative aspects of anatomic regeneration.

The training of the surgeon credited with a neurorrhaphy was found to be uncorrelated with the result of the procedure. This observation must be interpreted in the light, however, of the special circumstances surrounding this entire group of cases, described on pages 44–45.

Surprisingly enough, features as discouraging as a delay for as much as 6 to 12 months between injury and operation, the recognition of excessive tension on the suture line, or the necessity for transposition, extensive mobilization or even a preliminary bulb suture are not correlated with evidence of impaired autonomic recovery. On the other hand, the observation at operation that the condition of the nerve ends was "poor" or "very poor," although it is not associated with an increased incidence of complaints of diminished sweating, is correlated with elevated skin resistance at follow-up study. A similar situation is noted with respect to the adverse effect of multiple operations upon autonomic recovery. In the sciatic-tibial nerve at least, excessively long gaps are also associated with an increased incidence of elevated skin resistance at follow-up examination.

The materials and technique of the actual nerve suture showed certain positive correlations of interest. While the use of a stay suture has no discernible effect on autonomic recovery, skin resistance studies indicate that the use of a tantalum cuff is significantly advantageous. The choice of suture material appears to have no effect upon the reestablishment of normal skin resistance. As first analyzed, the data showed proportionately many more instances of increased skin resistance among plasma glue cases, but when the comparisons were refined, as in the earlier chapters, to take account of important differences in the cases to begin with, the inferiority of the plasma glue cases no longer seemed statistically significant.

408980—57——24

It appears desirable to reiterate that the several indices of autonomic recovery provide only a gross indication of the anatomic regeneration of autonomic fibers. The relatively diffuse character of the chemical stimulation of autonomic end-organs by the nerve impulse (13) may make it possible for regeneration of a few axons to be associated with functional recovery indistinguishable from that produced by complete regeneration.

E. AUTONOMIC RECOVERY AND OTHER EVIDENCE OF REGENERATION

Objective evidence of autonomic recovery is closely correlated with some aspects of recovery of somatic function. There is a suggestion that patients with the best sensory return complain least often of loss of sweating, but this association is not marked. The British summary of sensory return, however, is quite significantly associated with recovery of normal skin resistance. Sweating tests, although done on relatively few patients, confirm this observation. The correlation between the British summary of motor recovery and recovery of normal skin resistance is high for the median and ulnar nerves, but not for the tibial and sciatic-tibial, perhaps because the observations are few in number.

F. RELATION BETWEEN SUBJECTIVE AND OBJECTIVE EVIDENCE OF AUTONOMIC RECOVERY

The complaint of loss of sweating, a considerable body of objective evidence derived from measurements of skin resistance, and a limited series of observations of objective evidence of sweating constitute the principal data. Information is also available with regard to complaints of increased sweating and of adverse reaction to heat and cold, but has not been used in the analysis since no clear relationship is known to exist between these complaints and recovery of autonomic function.

The complaint of loss of sweating, which should be the most valid subjective index, was found to be significantly correlated with elevated skin resistance, but the relationship is not an intimate one. For example in the ulnar nerve, where the number of observations is large and the association of greater reliability, the complaint was registered by 12 percent of the men with increased SR in contrast to 5 percent of those with normal or decreased SR. A complaint of adverse reaction to extremes of temperature as might be expected was not found to be related in any way to SR.

The meaning of the complaint of increased sweating is not entirely clear. The recording of this subjective complaint does not specify whether it was limited to the specific area of autonomic denervation. The complaint may have resulted from sympathetic discharge in areas of the injured extremity supplied by other nerves or even to generalized sweating associated with emotional tension. However, an initial impression that this complaint might be related to a need for psychotherapy, as indicated by the examiner's opinion or by the patient's estimate of himself as unemployable, is not borne out by statistical analysis. Furthermore, men who were considered by examiners to be in need of psychotherapy were no more likely to complain of excessive sweating than the group as a whole. As would be expected, the complaint occurs less often in patients with increased than in those with normal or decreased skin resistance. In addition, there is a slight suggestion that the complaint occurs more often in men with decreased skin resistance.

Increased skin resistance is known from many experimental observations to be a reliable index of loss of autonomic function. No data from this study have cast doubt on this observation. Decreased skin resistance, on the other hand, is not significantly correlated with any of the listed complaints, nor with objective tests of sweating. Objective absence of sweating is, however, significantly correlated, as expected, with increased skin resistance. Sweating tests also offer some confirmation of the observation noted above, that there is often an objective basis for the complaint of loss of sweating.

Chapter VIII

FUNCTIONAL RECOVERY AND OCCUPATIONAL ADJUSTMENT

Gilbert W. Beebe

A. INTRODUCTION

In earlier chapters, which are concerned chiefly with evaluating various determinants of regeneration, methodological requirements place a premium upon objectivity and reliability as characteristics of any index of regeneration. In comparison with the strength of a particular muscle, or the measured stimulus required to elicit a pain response, a clinical opinion as to the level of overall functional recovery must seem subjective and somewhat unreliable. Also, there is considerable clinical interest in the individual modalities themselves. For these reasons the earlier chapters are organized along the lines of individual modalities, or groups thereof, and contain no summary information about the overall level of functional recovery, except as it may correlate with a particular index of regeneration. And yet it is precisely here that the greatest clinical interest lies, and no study of regeneration would be complete if it portrayed recovery solely in terms of the individual modalities, to the neglect of practical function.

The complexity of the functions ruled over by the peripheral nerves makes the assessment of overall functional recovery a difficult task, and any scheme one may propose will necessarily seem arbitrary. It was fortunate that the study group included at the start the late Dr. Frederic H. Lewey, who was quite aware of the divergent requirements which would be placed upon the observations and who had a special interest in the problem of describing practical function. Dr. Lewey was an advocate of the work-furlough as a rehabilitative procedure, and expressed keen interest in the occupational readjustments necessitated by peripheral nerve injuries. In addition to providing the scales used in evaluating functional recovery, Dr. Lewey advocated collection of systematic information on occupation before and after injury, evaluation of the role of the peripheral nerve injury in any occupational change, and formulation of a clinical opinion as to the extent of any present occupational handicap attributable to the peripheral nerve injury.

The present chapter is essentially descriptive in nature, containing summary information on the final level of practical function attained by men with various peripheral nerve injuries. Although the individual nerves themselves are distinguished here, and complete sutures are differentiated from neurolyses, in general there is no effort to explain why function is superior in this group of cases and inferior in that. It was believed that no such analysis could be as penetrating as those already presented earlier in the study of the individual modalities. Following this brief introduction there is first a section on the methods developed by Dr. Lewey for the assessment of functional recovery, followed by a section in which these classifications are used to describe the sample as a whole, nerve by nerve. A fourth section deals with the interrelations among motor, sensory, and overall functional recovery. There is next a section on the relation between the clinical assessments of functional recovery developed by examiners working in the peripheral nerve study centers on the one hand and the Veterans Administration disability ratings on the other. Consideration is then given to the occupational changes which have occurred, and to the opinions of examiners as to the role played by peripheral nerve injuries in bringing them about. In a final section appear the examiners' opinions as to the extent of any present occupational handicaps suffered by the examinees in their work, whether they had changed jobs or not.

B. METHODS OF EVALUATING FUNCTIONAL RECOVERY AND OCCUPATIONAL ADJUSTMENT

The variety and complexity of functional recovery make its classification an extremely difficult matter. Such questions as—Is a sensory deficit more important than a motor? Is one movement more important than another?—do not always have satisfactory answers. With full realization of these difficulties, Dr. Lewey undertook to classify practical function in the upper extremity according to the following scheme:

0. Amputation.
1. Useless limb.
2. Of use only as a holder.
3. Can grasp larger objects.
4. Some opposition.
5. Good opposition.
6. Picks up pin with visual aid.
7. Picks up pin blindly.
8. Many skilled but awkward acts.
9. Good practical function.

Each upper extremity was located at a particular point on this scale as a rough indication of the level of its functional capacity, whether the injury involved the median, ulnar, radial, or combinations of these nerves. In addition, note was made of any orthopedic deformity or of any adverse functional overlay, except that only one of the latter could be chosen for any one injured limb.

In the lower extremity the scale was more abbreviated, the categories being:

0. Amputation.
1. Will not bear weight.

2. Walks less than one block.
3. Walks less than one-quarter mile.
4. Unlimited walking; can't run.
5. Can run or dance.

In addition, any one of the following limitations might be noted by the examiner for each injured extremity:

Limited by pain.
Limited by weakness.
Limited by ulceration.
Orthopedic deformity.
Adverse functional overlay.

In some instances the lower extremity was evaluated with a brace, and when such was the case it was specifically noted.

A limited exploration was made of center variation in the employment of the above classification of specific functional capacity. A sample of peroneal and ulnar sutures was chosen on the basis of the following criteria:

1. Only a single nerve was injured in the affected limb.
2. The nerve had been completely severed.
3. The operation was a complete suture.

The first of these criteria effectively excluded sciatic cases, since these are almost always combined lesions. The second criterion was unnecessarily restrictive and excessively reduced the number of cases available for study. There remained 238 ulnar and 62 peroneal sutures for study after these restrictions had been made. Only insignificant variation among centers was noted in the peroneal material but, of course, the test is weak. The centers do differ in their classification of ulnar cases, but only because a single center often used "good practical function" where others would have used "many skilled but awkward acts." Apart from this discrepancy, center variation did not appear impressive.

In addition to the above scales of specific functional status, Dr. Lewey developed for the study group a scale of "overall functional evaluation" having 11 positions. The sensory contribution to practical function is quite variable, as is the anatomic regeneration of individual muscles. One muscle may recover well, but be of little importance in functional recovery in comparison with another which may be very weak. A movement of the greatest importance may be accomplished only by virtue of a tendon transplant. With such considerations in mind, Dr. Lewey undertook to specify, nerve by nerve, the relative functional deficit represented by specific findings, so that each limb affected by nerve injury might be scaled in a roughly uniform way over the range from 0 to 100 percent, at the decile values. The specific criteria which he prepared for this classification, and used by each center, are as follows:

Radial Nerve

1. The partial loss of triceps seen in high radials does not impair function.
2. The brachioradialis is of little importance because of compensation by the biceps.

3. This is true of supinator as well.
4. A complete wrist drop allows 40 percent function.
5. Wrist o. k. but complete finger and thumb drop allows 60 percent function.
6. If fingers can be opened around large object (ash tray 4 in. in circumference) but thumb not abducted—80 percent function.

Ulnar Nerve

1. The complete high ulnar with weak fourth and fifth flexors and clawing of fourth and fifth fingers has a hand in which small objects are still easily grasped between thumb and first two fingers. In grasping large objects, only the radial half of the hand grips, and the fourth and fifth fingers are in the way and liable to injury (because of anesthesia)—60 percent function.
2. The fourth and fifth fingers are still useless in gripping, but can be extended out of the way—70 percent.
3. Fourth and fifth fingers cannot only be extended out of the way but have good grip—80 percent.
4. Gradings above 80 percent depend on the extent of intrinsic muscle function in separating and adducting fingers and upon the degree of sensory recovery.

Median Nerve

1. The complete high median with absent sensation, with poor flexion of thumb and index finger, weak grip, and absent opposition of the thumb, has a functional rating of 20 percent.
2. The median with good flexion of thumb and index finger—absent opponens, absent sensation—is rated between 25 percent and 40 percent depending upon the success in compensating for absent opponens with the short flexor and abductor of the thumb.
3. With good opposition so that the hand is mechanically nearly perfect, but with little sensory recovery—function is 50 percent.
4. With good return of pain and touch points and thresholds, there may still be no ability to use the hand in fine work without visual guidance—function is 60 percent.
5. Ratings above 60 percent depend on the degree of further sensory return, which permits action without visual aid.

Combined Nerve Lesions

From what has been said, a reasonable grading of combined lesions can be arrived at on the basis of the functions which are possible.

Practical function of the arm is 0 percent, regardless of the muscles functioning, until the fingers can be used to grip lightly (10 percent). Function approaches 25 percent as all movements but opposition are regained. It is as high as 40 percent when opposition is performed, but, of course, such a figure would be reduced by weakness of flexion of elbow, of dorsiflexion of wrist, by stiff fingers, etc. It is also limited when the fingers curl on flexion because of absent lumbricals, and the finger pads do not meet the opposing thumb. Even with a mechanically good hand, function will be only 50 percent if sensation in the critical median area is poor.

The recoveries from *brachial plexus injuries* are graded in the same manner, depending upon the actual movements which the hand can perform.

Sciatic Nerve

In the case of the leg, function is rated logically on the man's ability to walk, and this may vary widely in different individuals with the same degree of anatomical regeneration. It is very poorly correlated with motor strength and sensation. Thus, with a complete sciatic paralysis, the patient may have developed a stiff ankle in a position of dorsiflexion and be able to walk a mile with minimal difficulty. On the other hand, an injury of the tibial nerve at the ankle may give rise to paresthesias on weight bearing which make it difficult to walk a block. The proposed functional ratings given below are therefore arbitrary and not as logical as those which can be formulated for the hand.

1. With no movement present below the knee and a complete anesthesia of the dorsum and sole of the foot, the patient will usually walk well with brace which maintains dorsiflexion of the ankle. If he can walk a mile under these conditions, his functional rating is 60 percent. If he is clearly limited to a few blocks, it is 50 percent. If he experiences difficulty in walking 1 block, it is 40 percent. If even standing is uncomfortable, it is 30 percent or less. When a brace is unnecessary, because of operative fusion or spontaneous partial fixation of the ankle, function can be rated at 70 percent.
2. Walking is more effective when plantar flexion of the foot occurs forcefully; 10 percent can be added to the functional ratings given above.
3. If sustained dorsiflexion of the foot is possible while walking, no brace is necessary and an additional 10 percent is added (thus 70 percent if man can walk a mile). It does not matter whether this dorsiflexion has occurred by actual recovery of tibialis anticus function or by effective tendon transfer.
4. Ratings between 70 percent and 100 percent depend primarily upon the skills of dancing and running, climbing being possible in addition to unlimited walking. Toe movements, active inversion and eversion of the foot, and sensory disturbances are important only in the extent to which they limit walking or standing.

Center variation was also explored for overall functional evaluation, and in the fashion already described for specific functional capacity. More center variation was observed here than in the classification of specific functional capacity, although only for the ulnar was the variation outside the usual bounds of chance. The median ratings for the ulnar, by center, are 60, 66, 71, 76, and 76. Undoubtedly, variation among examiners contributes heavily to the total variation seen in these ratings.

Occupational adjustment was approached on the basis of the following elements of the history:

1. Previous work done, and industry in which work was performed.
2. Present work done, and industry in which work is performed.
3. Change in occupation, and role of nerve injury in this.
4. Handicap in present occupation.

Although quite specific occupational facts were obtained and recorded, coding and related statistical processing have been confined to the following summary characterization, best described as a socioeconomic scale:

Professional and semiprofessional.
Farmers, farm managers, and farm laborers.
Proprietors, managers, officials.

Clerical and sales people.
Craftsmen and foremen.
Operatives.
Service (except protective) workers.
Protective service workers.
Students.
Occupation not yet established.
Laborers, except farm.

Specific occupation and industry were converted to the above on the basis of 1948 census procedures (81).

Change in occupation, and the examiner's estimate of the role played by the peripheral nerve injury, were classified as follows:

0. Never employed, including man still student without work history.
1. Never employed before, but has occupation now.
2. No change in preservice occupation, including man in student status now expecting to resume former occupation.
3. Changed to new occupation, including training for new one, apparently *not* because of nerve injury.
4. Change to new occupation, including training for new one, apparently because of nerve injury, at least in considerable part.
5. No occupation now, and not in training for one, regards self as unemployable because of nerve injury.
6. Same as category 5, except that it is apparently *not* because of nerve injury that man regards himself as unemployable.

No specific criteria were developed for the above classification, which each examiner applied in accordance with his own evaluation of the history.

Occupational handicap was also rated rather subjectively by the examiner on the basis of the history, modified, of course, by the objective findings as to function. A 4-point scale was used, as follows:

0. No handicap apparent.
1. Some handicap, not severe.
2. Severe handicap.
3. Man regards self as unemployable.

Those without established occupations were not, of course, rated in this way. No criteria were developed to guide examiners in their use of this scale.

C. VARIATION IN FUNCTIONAL REGENERATION

For the reasons stated earlier it was not considered useful to extend the analysis beyond these few elementary characteristics: nature of definitive surgery, nerve involved, and relation between the two rating scales for function. In the descriptive parts of chapters III through VII, it may be recalled, care was taken to confine the selection of cases to men falling within the sampling area as defined in chapter I. Here, however, since the selective factors involved in this distinction did not appear to be of especially great importance in the analyses of chapters III through VII, the distinction was dropped. Moreover, since it is the function of the *limb* which is being described, it seemed essential to limit the sampling to limbs with single nerve injuries, or to specify the associated nerve lesions. In the thigh the sampling was confined to *complete* sciatic lesions, i. e., those in which both sciatic trunks were sutured. Also, a special study was done of the influence of associated ulnar upon median injuries, and vice versa.

There was great variation in the specific functional capacity of the upper extremities, depending on which nerve was involved and whether the lesion required suture or lysis. Within the set of lesions affecting a single nerve, variation was greatest for the median, and the most severe limitations were imposed by injuries to this nerve. Table 201 provides a summary of data on specific functional capacity of upper extremities, by nerve and by type of definitive surgery, for pure lesions only. The latter restriction greatly reduces the number of lysed lesions available for study, since many entered the larger series only in association with sutured lesions on adjacent nerves. Amputation is excluded from the scale there because no upper limb with a single nerve lesion was amputated; a single patient with an amputation in the upper extremity was seen at follow-up. The relevant particulars of this case (3380) are as follows:

A severe bullet wound in the region of the left elbow completely severed the brachial artery, fractured the distal end of the humerus and the olecranon process of the ulna, and produced complete median and ulnar nerve paralyses. The brachial artery was ligated, and the median nerve sutured; at exploration the ulnar was seen to have a neuroma in continuity. A Volkmann's contracture developed, and led to an arthrodesis to the wrist about 7 months after injury, and eventually to amputation at the level of the wrist, about 17 months after injury.

Despite their limited number, the superior performance of limbs with lysed lesions is plain. About half of the limbs with median lesions requiring suture were capable of "many skilled but awkward acts" or had "good practical function," in contrast to about 90 percent of the radial and 85 percent of the ulnar. About a fifth of the limbs with median lesions requiring suture were classified as "can grasp larger objects" or "some opposition." Orthopedic deformity varied little by nerve, being noted in 17.6 percent of limbs with median sutures, 14.9 percent with radial, and 17.1 percent with ulnar.

The scales for overall functional evaluation vary by nerve in the fashion already described, and are not necessarily comparable. Since the contribution of each nerve to function is unique, the only surely common ground is found in specific functional tasks such as those just analysed. However, in preparing his scales for overall functional evaluation, Dr. Lewey had as his objective a rating which expressed the function of the limb as a percentage of the normal function of the extremity. In these terms, then, even relatively poor anatomic regeneration in the radial might be consistent with fairly good function, although this would not be true of a poor median nerve recovery. The overall functional evaluation of the

Table 201.—*Specific Functional Capacity of Upper Extremities With Pure Nerve Lesions by Nerve Involved and by Type of Definitive Surgery*

Specific functional capacity	Median	Radial	Ulnar
A. Complete sutures			
	Percent	*Percent*	*Percent*
Useless limb	1.3	1.4	0.6
Only a holder	3.1	1.0	.8
Grasps larger objects	10.7	3.4	3.9
Some opposition	10.7	0	1.4
Good opposition	4.4	0	0.8
Picks up pin, visual aid	14.5	0.5	.8
Picks up pin, blindly	6.3	1.9	5.8
Many skilled but awkward acts	25.8	41.8	44.8
Good practical function	23.3	50.0	41.2
Total	100.1	100.0	100.1
Number of cases	159	208	362
B. Neurolyses			
	Percent	*Percent*	*Percent*
Useless limb	4.8	6.3	0
Only a holder	0	0	0
Graps larger objects	0	6.3	0
Some opposition	0	0	0
Good opposition	0	0	0
Picks up pin, visual aid	14.3	0	0
Picks up pin, blindly	9.5	0	4.9
Many skilled but awkward acts	23.8	0	29.3
Good practical function	47.6	87.5	65.9
Total	100.0	100.1	100.1
Number of cases	21	16	41

upper extremity is summarized in table 202. The general picture is one of greater variability than characterizes the classification of specific functional capacity, but with no essential change in the interrelations among the several nerves. Also, limbs with lysed lesions again appear at a definite advantage in relation to those with sutures.

The relation between the two scales, one of specific functional capacity and the other of overall functional evaluation, may be of value in interpreting the foregoing data on the upper extremity. Tables on this relationship were run as a preliminary and exploratory measure before the present chapter was planned, and were not confined to pure nerve lesions.

Table 202.—*Overall Functional Evaluation of Upper Extremities With Pure Nerve Lesions, by Nerve and by Type of Definitive Surgery*

Overall functional evaluation, percent	Sutures			Lyses		
	Median	Radial	Ulnar	Median	Radial	Ulnar
0	1.3	1.5	0.3	4.8	6.3	0
10	0	0.5	0.3	0	0	0
20	2.6	0	0.8	0	0	0
30	6.4	0.5	0.6	0	0	0
40	12.2	3.9	3.4	0	0	0
50	20.5	4.9	6.2	14.3	0	4.8
60	17.3	11.7	19.4	14.3	0	9.5
70	18.6	17.1	23.0	38.1	12.5	11.9
80	15.4	39.0	34.8	19.0	25.0	31.0
90	5.1	18.5	10.7	9.5	56.3	38.1
100	0.6	2.4	0.6	0	0	4.8
Total	100.0	100.0	100.1	100.0	100.1	100.1
Number of cases	156	205	356	21	16	42

Despite this limitation, arising out of the possibly unequal influence of associated nerve injuries upon the two functional classifications, these preliminary tables are of considerable value in exhibiting their interrelationship, nerve by nerve. Tables 203 through 205 embody these data, for complete sutures only. The correlation may be described as rather high, but no numerical measure of it would seem useful. It is apparently highest for the radial and about the same for median and ulnar. In general, there is more scatter along the scale of functional evaluation for a group of cases with a specific functional capacity than vice versa. For example, in the ulnar there are 170 cases with "good practical function," of which 18 percent were given ratings of 70 percent of normal function, 50 percent given ratings of 80 percent, and 21 percent given ratings of 90 percent. Conversely, of the 143 limbs rated at 80 percent of normal function, 36 percent were considered capable of "many skilled but awkward acts" and 59 percent considered to have "good practical function." The relationship is weakest for limbs classified as capable of many skilled but awkward acts or as having good practical function.

In the lower extremity there were too few pure lesions treated by lysis to justify presentation, and, accordingly, in table 206 the summary of data on specific functional capacity is limited to complete sutures. The table does not extend to the limitations which examiners found, but pain and weakness were most commonly reported. Ulceration was seen in some sciatic cases, and deformity occasionally in all three groups. Since

Table 203.—*Relation Between Specific Functional Capacity and Overall Functional Evaluation, Complete Sutures on Median Nerve*

Specific functional capacity	Overall functional rating, percent											Total
	0	10	20	30	40	50	60	70	80	90	100	
Amputation	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
Useless limb	16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	16
Useful only as holder	6	14	10	3	.....	.....	.....	.....	.....	.....	.....	33
Can grasp larger objects	.....	2	8	13	10	4	2	1	.....	.....	.....	40
Some opposition	.....	.....	4	10	17	11	5	1	1	.....	.....	49
Good opposition	.....	.....	1	1	1	3	1	1	2	.....	.....	10
Picks up pin, visual aid	.....	.....	1	1	2	12	15	3	1	1	.....	36
Picks up pin, blindly	.....	.....	1	2	1	4	5	2	.....	.....	.....	15
Many skilled but awkward acts	.....	.....	1	4	14	11	12	17	15	.....	.....	74
Good practical function	.....	.....	.....	.....	2	7	7	8	19	9	2	54
Total	23	16	26	34	47	52	47	33	38	10	2	328

Table 204.—*Relation Between Specific Functional Capacity and Overall Functional Evaluation, Complete Sutures on Radial Nerve*

Specific functional capacity	Overall functional rating, percent											Total
	0	10	20	30	40	50	60	70	80	90	100	
Amputation	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Useless limb	11	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	11
Useful only as holder	2	6	2	1	.....	.....	.....	.....	.....	.....	.....	11
Can grasp larger objects	.....	1	1	1	1	1	1	.....	4	.....	.....	10
Some opposition	.....	.....	.....	.....	2	1	.....	.....	.....	.....	.....	3
Good opposition	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Picks up pin, visual aid	.....	.....	.....	.....	.....	.....	1	1	.....	.....	.....	2
Picks up pin, blindly	.....	.....	.....	.....	.....	2	2	.....	2	.....	.....	6
Many skilled but awkward acts	.....	.....	.....	1	7	7	21	23	36	10	.....	105
Good practical function	.....	.....	.....	.....	3	1	6	15	48	32	5	110
Total	13	7	3	3	13	12	31	39	90	42	5	258

Table 205.—*Relation Between Specific Functional Capacity and Overall Functional Evaluation, Complete Sutures on Ulnar Nerve*

Specific functional capacity	Overall functional rating, percent											Total
	0	10	20	30	40	50	60	70	80	90	100	
Amputation	...	...	...	...	...	...	...	...	...	...	...	...
Useless limb	12	...	...	...	...	...	1	...	...	...	...	13
Useful only as holder	11	11	9	3	2	...	2	...	...	...	...	38
Can grasp larger objects	...	2	8	9	3	5	9	1	...	...	...	37
Some opposition	...	1	3	8	9	7	4	1	...	...	...	33
Good opposition	...	...	1	1	1	1	...	1	...	...	...	5
Picks up pin, visual aid	...	...	3	1	1	4	6	1	2	...	...	18
Picks up pin, blindly	...	...	1	...	4	3	8	9	5	...	...	30
Many skilled but awkward acts	...	...	2	3	14	12	53	66	51	4	...	205
Good practical function	...	...	...	1	2	6	8	31	85	35	2	170
Total	23	14	27	26	36	38	91	110	143	39	2	549

it was desired to evaluate functional capacity with the benefit of all therapeutic and rehabilitative procedures, not merely surgery, the stated performance depends to some extent upon braces. No effort was made to determine the precise contribution of the brace *per se*, but it is of interest to note that the numbers of limbs evaluated with braces are 54 for peroneal lesions, 2 for tibial, and 88 for sciatic, among the totals shown in table 206.

Table 206.—*Specific Functional Capacity of Lower Extremities With Pure Lesions Treated by Suture*

Functional capacity	Peroneal	Tibial	Sciatic [1]
	Percent	*Percent*	*Percent*
1. Will not bear weight	0	0	1.6
2. Walks less than one block	0	0	2.4
3. Walks less than one-quarter mile	20.4	11.7	21.4
4. Unlimited walking; can't run	46.9	50.0	56.3
5. Can run or dance	32.7	38.3	18.3
Total	100.0	100.0	100.0
Number of limbs	113	60	126

[1] Both sciatic branches sutured.

Amputation is omitted from the scale there because none occurred in the limbs on which the table is based; a single amputation of the lower extremity was seen in all the patients brought in for follow-up examination:

Case 4673. A complete sciatic lesion in the upper third of the left thigh incurred in a truck accident 19 June 1943 during Z/I maneuvers. Compound fracture of femur, with extensive muscle damage. The right femur was also fractured, but without nerve injury. He had skeletal traction with Kirschner wire in the distal third of each tibia, with the limbs in Thomas splints. On 10 July 1943 the fracture of the right femur was manipulated to correct angulation, but without success. Skeletal traction of right extremity maintained until 10 October, of left until November. On 10 November skin grafts were applied to the posterior surface of left leg, and thigh and legs replaced in suspension splints. On 4 February 1944 Keller operation was performed on right great toe because of persistent hallux rigidus. During February patient was allowed up with weight bearing on right lower extremity but not on the left. Knee motion was improving in both legs, but there was no return of sciatic function in the left. On 18 April 1944 the left sciatic nerve was explored, and an extensive nerve gap visualized. Following the exploration, the patient was allowed up with weight bearing on the right leg, and ischial caliper on the left. On 7 September 1944, first stage nerve grafts of both left sciatic branches were placed. Each gap was 15 cm. in length. On 15 January 1945 the grafts were explored, found to be completely avascular, and removed. Second grafts were placed at that time. There was no evidence of regeneration prior to discharge and hopes were pinned on procedures to stabilize the knee to permit walking. Discharge occurred on 14 April 1945 without further surgery. No regeneration had taken place and the left knee was partially ankylosed. On 12 March 1948 amputation was performed above the knee, the indications being ulcers and osteomyelitis.

Another case, from Woodhall's Walter Reed Hospital series and adequately followed to the point of amputation, but not included in the allocation pattern for the follow-up study, may be of interest here:

> *L. B.* This patient made a parachute landing after his plane was shot down on a bombing mission, and sustained a compound comminuted fracture of the right femur in its lower one-third. The injury occurred on 4 April 1944. He was taken prisoner and treated by a civilian physician and a beef-bone intramedullary graft was placed in this extremity. This procedure was done on 15 May 1944.
>
> He arrived at the Walter Reed General Hospital on 25 October 1944, and at this time showed a complete ankylosis of the right knee joint in extension, atrophy of the quadriceps and calf muscles, a decubitus ulcer over the lateral aspect of the right lower leg and complete motor and sensory paralysis of the sciatic nerve. Clinically, the fractured femur appeared to have solid union. Physiotherapy was instituted in order to get knee flexion and, on 29 November 1944, the right sciatic was explored and a huge defect was found; a bulb suture was performed. On 29 December 1944, quadricepsplasty was done on the right thigh and following this the patient developed about 90 degrees of flexion. On 29 March 1945, the bulb suture was resected and an end-to-end anastomosis carried out under considerable tension. By June 1945 it was possible to start him on physiotherapy, but thereafter he developed an ulcer on the right heel. On 26 November 1945, a graft of the right heel was carried out, with the donor site being from the left thigh. Following this, he became ambulatory, with a brace for the right leg.
>
> At no time was there very good circulation in this leg and, in May 1946, a series of paravertebral blocks was carried out in order to enhance his circulation. In the latter part of 1946, there were muscle twitches seen in the gastrocnemius-soleus muscle group and the Tinel's sign had descended to the region of the ankle.
>
> While on pass, in February 1947, the patient slipped and sustained a complete simple fracture of the lower-third of the right femur below the point of original injury. He was put in traction and, although the fracture showed signs of healing, he developed progressive cyanosis of the right leg, with a large pressure ulcer over the right gastrocnemius muscle. Primarily because of this vascular complication, amputation was done on 15 April 1947. A supracondylar amputation was done and following this, he received his prosthesis and began to walk satisfactorily.

The overall functional evaluation was made on somewhat more limbs than the determination of specific functional capacity, and it is of passing interest to note that the percentage ratings on limbs which examiners classified as unknown as to specific functional capacity are about the same as the ratings on limbs which were specifically classified in this way. Table 207 provides a summary of the overall ratings, which were least favorable for the complete sciatic lesions and most favorable for the pure tibial lesions. As may be seen there, sciatic lesions were generally rated at 40 to 70 percent of normal, peroneal at 50 to 90 percent, and tibial at 60 to 90 percent. The median ratings are 60 percent of normal for the sciatic, 66 for the peroneal, and 76 for the tibial, on Dr. Lewey's scale.

Although the scale for specific functional capacity is rather abbreviated for the lower extremity, it lends additional meaning to both scales for the lower extremity to exhibit the correlation between them, as is done in table 208 for all peroneal, tibial, and sciatic-peroneal lesions treated by complete suture, whether or not other nerves were injured in the same limb. Men rated at 70 percent or more of normal almost always had no limitation on their walking, and about 60 percent of the men rated at 80 percent or better were able to run or dance. There is, however, rather considerable variation in the overall percentage ratings on limbs capable of specific functional acts. For example, about one-third of the men able to run or walk are rated at 70 percent or less of normal. A small number of men classified as able to run or dance nevertheless have low overall ratings. This fact points up a deficiency in the scale, for a man may be able to dance, in his own peculiar and limited fashion, and yet be limited in his walking. Those who are classified as able to run or dance, and have low overall ratings, are quite limited in their ability to run or dance.

Table 207.—*Overall Functional Evaluation of Lower Extremities With Pure Lesions Treated by Suture*

Evaluation, percent	Peroneal	Tibial	Sciatic [1]
	Percent	*Percent*	*Percent*
0	0	0	0.7
10	0	0	0
20	0	0	2.8
30	1.6	0	3.5
40	9.3	5.0	12.6
50	14.0	3.8	17.5
60	23.3	18.8	26.6
70	20.2	18.8	27.3
80	17.8	41.3	6.3
90	13.2	12.5	2.8
100	0.8	0	0
Total	100.2	100.2	100.1
Number of limbs	129	80	143

[1] Sciatic lesions are those with complete suture of both branches.

The average man with combined nerve lesions on a single limb, has, of course, greater impairment than the man with but one of these lesions. Combined lesions are quite common in the present material, but any useful exploration of the functional deficit attributable to a second lesion must be restricted to well-defined lesions, and only the complete sutures satisfy this requirement. The effect of the second lesion will vary with the identity of the two nerves, but it would take a large sample indeed to provide adequate information on all the combinations of interest. From the present material the median and ulnar were chosen for an exploration along these lines.

Pure median and pure ulnar nerve lesions treated by complete suture were isolated and the limbs compared, both as to specific functional capacity and overall functional evaluation, with limbs in which both

Table 208.—*Relation Between Specific Functional Capacity and Overall Functional Rating, Lower Extremities With Complete Sutures, by Nerve* [1]

Specific functional capacity	Overall functional rating, percent											
	0	10	20	30	40	50	60	70	80	90	100	Total
Peroneal												
Will not bear weight	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Walks less than one block	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Walks less than one-quarter mile	1	.....	.....	1	6	10	13	1	1	1	.....	34
Unlimited walking; can't run	.....	.....	1	1	7	3	19	25	11	4	.....	71
Can run or dance	.....	.....	.....	1	1	3	4	4	16	11	1	41
Total	1	.....	1	3	14	16	36	30	28	16	1	146
Tibial												
Will not bear weight	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Walks less than one block	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Walks less than one-quarter mile	.....	.....	.....	.....	4	2	6	1	.....	.....	.....	13
Unlimited walking; can't run	.....	1	.....	.....	1	4	11	15	12	6	.....	50
Can run or dance	.....	.....	.....	1	1	1	2	3	13	9	.....	30
Total	.....	1	.....	1	6	7	19	19	25	15	.....	93

Sciatic-peroneal

Will not bear weight	......	......	......	......	1	1	......	......	......	......	......	2
Walks less than one block	2	......	1	......	......	1	......	......	......	......	......	4
Walks less than one-quarter mile	......	......	2	1	11	21	11	3	......	......	......	49
Unlimited walking; can't run	......	......	......	......	4	7	43	44	9	2	......	109
Can run or dance	......	......	......	1	3	1	4	9	12	3	......	33
Total	2	......	3	2	19	31	58	56	21	5	......	197

[1] These are not pure lesions, but all those evaluated on both scales.

median and ulnar nerves had been sutured. Injury to any nerve other than the median and ulnar was cause for exclusion from the comparison, the results of which appear in tables 209 and 210. A high-low distinction is maintained there because combined median and ulnar nerve lesions are much more common in the arm than in the forearm, and because of the general influence of site of lesion upon the recovery of specific modalities. Although the distinction as to gross site impairs considerably the stability of any estimates one might make of the effect of the second lesion, it does not obscure the fact that the effect is real for both the median

Table 209.—*Effect of Associated Nerve Lesions Upon Specific Functional Capacity, Upper Extremity by Gross Site, Complete Sutures Only*

Specific functional capacity	Pure median	Pure ulnar	Median and ulnar
	Percent	*Percent*	*Percent*
High lesions			
Useless limb	4.3	0.7	5.3
Useful only as holder	4.3	1.4	21.1
Can grasp larger objects	6.4	2.0	17.5
Some opposition	6.4	1.4	22.8
Good opposition	2.1	0.7	0
Picks up pin, visual aid	10.6	0	7.0
Picks up pin, blindly	14.9	7.5	5.3
Many skilled but awkward acts	34.0	46.3	15.8
Good practical function	17.0	40.1	5.3
Total	100.0	100.1	100.1
Number of men	47	147	57
Low lesions			
Useless limb	0	0.5	0
Useful only as holder	2.7	0.5	24.0
Can grasp larger objects	12.5	5.1	8.0
Some opposition	12.5	1.4	16.0
Good opposition	5.4	0.9	4.0
Picks up pin, visual aid	16.1	1.4	12.0
Picks up pin, blindly	2.7	4.2	0
Many skilled but awkward acts	22.3	43.9	28.0
Good practical function	25.9	42.1	8.0
Total	100.1	100.0	100.0
Number of men	112	214	25

Table 210.—*Effect of Associated Nerve Lesions Upon Overall Functional Evaluation, Upper Extremity, by Gross Site, Complete Sutures Only*

Overall functional evaluation, percent	Pure median	Pure ulnar	Median and ulnar
	Percent	*Percent*	*Percent*
High lesions			
Useless limb	4.3	0.7	10.3
10	0	0	8.6
20	4.3	0.7	15.5
30	6.4	0.7	19.0
40	12.8	3.5	13.8
50	21.3	5.6	20.7
60	10.6	18.8	8.6
70	14.9	23.6	1.7
80	19.1	36.1	1.7
90	6.4	9.0	0
100	0	1.4	0
Total	100.1	100.1	99.9
Number of men	47	144	58
Low lesions			
Useless limb	0	0	4.0
10	0	0.5	12.0
20	1.8	0.9	16.0
30	6.4	0.5	16.0
40	11.9	3.3	20.0
50	20.2	6.6	8.0
60	20.2	19.9	12.0
70	20.2	22.3	8.0
80	13.8	34.1	4.0
90	4.6	11.8	0
100	0.9	0	0
Total	100.0	99.9	100.0
Number of men	109	211	25

and the ulnar, and generally quite large, but larger when the median is the second lesion. For example, among high lesions the percentages with no more than good opposition are 23.5 for pure median lesions and 6.2 for pure ulnar, but 66.7 for combined. For low lesions the figures are somewhat similar: 33.1 percent for pure median, 8.4 for pure ulnar, and 52.0

percent for the combined lesions. If the comparison is made at the upper end of the scale of specific functional capacity, say at the level of good practical function, then for high lesions one finds such performance in 17.0 percent of the limbs with pure median lesions, 40.1 with pure ulnar, but only 5.3 percent with combined. In low lesions the figures differ but the internal pattern is similar. If the overall functional evaluation is employed to gauge the effect of the second lesion, estimates of the same order of magnitude are obtained. In general, it seems plain that the bulk of the better-than-average results observed after sutures on pure median or pure ulnar lesions are not observed following suture of combined lesions, and that in their stead one finds an excess not of average or nearly average results but of very poor results. Men who, with but a single lesion, might be expected to perform at least at the level of many skilled or awkward acts, with combined lesions are found capable of no more than opposition or grasping larger objects.

D. OVERALL FUNCTIONAL EVALUATION IN RELATION TO MOTOR AND SENSORY RECOVERY

Dr. Lewey's criteria for the overall functional evaluation are expressed in terms of specific motor and sensory capabilities, and no further refinement upon them can come from the intercorrelation of the summary motor, sensory, and functional assessments, subject as they are in practice to some error of observation. However, the application of these criteria can be usefully illuminated by such correlations, and in addition the summary form of the modified British motor and sensory assessments provides a facile tool for exhibiting, perhaps more dramatically than do the criteria, the sources of functional impairment.

Chief interest lies in the complete picture of motor, sensory, and functional recovery, but it has seemed best to approach this objective by first examining the correlations in each of the three pairs of variables: motor and functional, sensory and functional, and finally motor and sensory.

Tabulations were confined to complete sutures on "pure" nerve lesions, which effectively excluded the sciatic cases, as well as men with injuries to both upper or both lower extremities.

Motor recovery

The relation between motor recovery and the overall functional evaluation is shown in table 211, by nerve. Each scale has been broadly grouped into three classes, which omits some of the detail of the relationship but not at the cost of obscuring the picture in any way. In the form in which the tests were made, the relationship is a highly significant one statistically in every nerve except the tibial where the amount of material is small and the result hardly inconsistent with the notion of an overall relationship regardless of nerve. Were the relationship not a marked one, of course, it would reflect upon the validity of one or both of the assessments. It is the strength of the relationship, not its presence, which is of particular interest. The difference between the median on the one hand, and the radial and ulnar on the other, is noteworthy: in the median function depends less intimately upon motor recovery than is true in the radial and ulnar, presumably because of the greater importance of sensory recovery in median function and because the correlation between motor and sensory recovery is none too high.

Table 211.—*Relation Between Motor Recovery and Overall Functional Evaluation Following Complete Suture, by Nerve, Pure Lesions Only*

Level of motor recovery [1]	Percentage distribution as to overall function, as percentage of normal				Number of cases
	0–50	60–70	80–100	Total	
Median					
At most proximal muscles acting against gravity	75.0	15.0	10.0	100.0	20
Some action in intrinsics, without synergic or isolated movements	45.9	40.0	14.1	100.0	85
Synergic or isolated movements possible	21.3	36.2	42.6	100.1	47
Total	42.1	35.5	22.4	100.0	152
Radial					
At most proximal muscles acting against gravity	22.2	48.9	28.9	100.0	45
Some action in intrinsics, without synergic or isolated movements	9.8	25.0	65.2	100.0	112
Synergic or isolated movements possible	......	15.6	84.4	100.0	45
Total	10.4	28.2	61.4	100.0	202
Ulnar					
At most proximal muscles acting against gravity	16.7	73.3	10.0	100.0	30
Some action in intrinsics, without synergic or isolated movements	11.4	46.5	42.1	100.0	271
Synergic or isolated movements possible	......	13.2	86.8	100.0	53
Total	10.2	43.8	46.0	100.0	354

See footnote at end of table.

Table 211.—*Relation Between Motor Recovery and Overall Functional Evaluation Following Complete Suture, by Nerve, Pure Lesions Only*—Continued

Level of motor recovery [1]	Percentage distribution as to overall function, as percentage of normal				Number of cases
	0–50	60–70	80–100	Total	
Peroneal					
At most perceptible contraction in proximal muscles	37.5	48.2	14.3	100.0	56
Proximal muscles acting against gravity, at most perceptible contraction in intrinsics	22.6	25.8	51.6	100.0	31
All important muscles, at least acting against resistance	5.1	53.8	41.0	99.9	39
Total	23.8	44.4	31.7	99.9	126
Tibial					
At most perceptible contraction in proximal muscles	15.8	42.1	42.1	100.0	19
Proximal muscles acting against gravity, at most perceptible contraction in intrinsics	12.1	33.3	54.5	99.9	33
All important muscles, at least acting against resistance	......	30.4	69.6	100.0	23
Total	9.3	34.7	56.0	100.0	75

[1] The three groupings correspond to the following rubrics in the classification on p. 75: Upper extremity—(0+1+2) v. (3+4) v. (5+6); lower extremity—(0+1) v. (2+3) v. (4+5+6).

Sensory recovery

As may be seen from table 212, which is arranged in the same fashion as the motor table, the correlation between sensory recovery and the overall functional evaluation is much poorer than motor and functional. One would not want to insist upon a correlation between sensory and functional as a condition of the validity of the individual assessments, but the suggestion is that at least a weak correlation is probably characteristic of each nerve. Only for the median and ulnar nerves, however, is the association of table 212 a significant one statistically ($P<.01$ in each case). For the median the association is somewhat closer than for the ulnar. In the median, the chance of a poor functional classification (0 to 50 percent of normal) ranges from 74 to 16 percent, depending on level of sensory recovery; in the ulnar the range is from 13 to 3.5; the chance of a good functional classification (80 percent or more of normal) ranges from 14 to 32 in the median, and from 29 to 62 in the ulnar. The variation is thus large at the low end of the functional scale for the median, and at the high end for the ulnar.

Table 212.—*Relation Between Sensory Recovery and Overall Functional Evaluation Following Complete Suture, by Nerve, Pure Lesions Only*

Level of sensory recovery [1]	Percentage distribution as to overall function, as percentage of normal				Number of cases
	0–50	60–70	80–100	Total	
Median					
Not more than superficial pain	73.8	11.9	14.3	100.0	42
Some touch, overresponse still present	41.7	38.3	20.0	100.0	60
Overresponse has disappeared	16.0	52.0	32.0	100.0	50
Total	42.1	35.5	22.4	100.0	152
Radial					
Not more than superficial pain	17.0	19.1	63.8	99.9	47
Some touch, overresponse still present	10.5	31.6	57.9	100.0	57
Overresponse has disappeared	7.1	30.6	62.2	99.9	98
Total	10.4	28.2	61.4	100.0	202
Ulnar					
Not more than superficial pain	13.2	57.9	28.9	100.0	114
Some touch, overresponse still present	13.4	39.4	47.2	100.0	127
Overresponse has disappeared	3.5	34.5	61.9	99.9	113
Total	10.2	43.8	46.0	100.0	354
Peroneal					
Not more than superficial pain	28.0	54.0	18.0	100.0	50
Some touch, overresponse still present	19.5	41.5	39.0	100.0	41
Over response has disappeared	22.9	34.3	42.9	100.1	35
Total	23.8	44.4	31.7	99.9	126
Tibial					
Not more than superficial pain	8.8	44.1	47.1	100.0	34
Some touch, overresponse still present	9.7	32.3	58.1	100.1	31
Overresponse has disappeared	10.0	10.0	80.0	100.0	10
Total	9.3	34.7	56.0	100.0	75

[1] The three groupings correspond to rubrics (0+1+2) v. (3+4) v. (5+6+7) in the classification on page 247.

Table 213.—*Relation Between Motor and Sensory Recovery Following Complete Suture, by Nerve, Pure Lesions Only*

Motor recovery [1]	Percentage distribution by sensory recovery [1]				Number of cases
	A	B	C	Total	
Median					
A	30	50	20	100	20
B	29	41	29	99	85
C	23	32	45	100	47
Total	28	39	33	100	152
Radial					
A	33	22	44	99	45
B	23	33	44	100	112
C	13	22	64	99	45
Total	23	28	49	100	202
Ulnar					
A	63	27	10	100	30
B	31	40	29	100	271
C	21	21	58	100	53
Total	32	36	32	100	354
Peroneal					
A	54	25	21	100	56
B	42	39	19	100	31
C	18	38	44	100	39
Total	40	33	28	101	126
Tibial					
A	58	21	21	100	19
B	33	58	9	100	33
C	52	35	13	100	23
Total	45	41	13	99	75

[1] The A, B, and C groupings are precisely those of tables 211 and 212.

Motor and sensory

The correlation between motor and sensory recovery is not remarkable, as may be seen from table 213. Whatever the forces of regeneration may be, they do not appear to act uniformly upon motor and sensory fibers.

The primary importance of motor recovery dictates the form of the final tables in this set. For a given level of motor recovery, the influence of sensory recovery is shown upon the overall functional evaluation, for each nerve individually. Two tables were prepared, one showing the percentage of poor functional results (50 percent or less of normal), the other showing the percentage of good functional results (80 percent or more). The tibial has been omitted from these tables because of small numbers; among the denominators for the 9 cells only 4 exceed 10 cases, and none exceeds 20. Otherwise, the only attempt to cope with the irregularity induced by small numbers has been to place an asterisk (*) beside any percentage based on less than 10 cases. In the first (table 214) it is

Table 214.—*Percentage of Cases With Poor Functional Assessments, by Levels of Motor and Sensory Recovery*

Level of sensory recovery [1]	Percentage with poor function, by level of motor recovery [1]		
	A	B	C
Median			
A	*100	76	54
B	80	37	27
C	*25	28	0
Ulnar			
A	16	14	0
B	*25	14	0
C	*0	5	0
Radial			
A	33	12	*0
B	10	14	0
C	20	6	0
Peroneal			
A	33	31	*0
B	29	17	13
C	58	*17	0

[1] The A, B, and C groupings are precisely those of tables 211 and 212; a poor functional evaluation is one in the range of 0 to 50 percent of normal.

*Based on less than 10 cases.

easily seen that poor function in the median depends almost equally upon motor and sensory recovery. For none of the other nerves does sensory recovery play a major role independently of motor recovery. On an over-all basis for all nerves combined, it does appear that, for fixed motor recovery, poorer sensory recovery is associated with a poorer functional assessment, however.

The influence of variable sensory recovery (motor fixed) upon the chance of having a good functional assessment (80 percent or more of normal) is evident from table 215. Motor and sensory contribute about equally to median function, but for the other nerves the influence of sensory recovery seems slight indeed.

Table 215.—*Percentage of Cases With Good Functional Assessments, by Levels of Motor and Sensory Recovery*

Level of sensory recovery [1]	Percentage with good function, by level of motor recovery [1]		
	A	B	C
Median			
A	*0	8	36
B	10	14	40
C	*25	20	48
Ulnar			
A	16	25	82
B	*0	47	82
C	*0	53	90
Radial			
A	47	73	*67
B	0	65	90
C	30	61	86
Peroneal			
A	7	39	*29
B	36	50	33
C	8	*83	53

[1] The A, B, and C groupings are precisely those of tables 211 and 212; a good functional assessment is one in the range of 80 to 100 percent of normal.

*Based on less than 10 cases.

E. RELATION BETWEEN FUNCTIONAL RECOVERY AND COMPENSATION RATINGS BY VETERANS ADMINISTRATION

Systematic information on VA compensation ratings was not sought, but in connection with the study of follow-up bias it was planned to use the VA rating as a means of comparing examined and not examined men. In this study the VA ratings were obtained for matched groups of 84 each (examined and not examined) from the New York allocation, the matching being done on the particular nerve injured, type of injury, type of operation, site of injury, and presence of associated injuries. It was thus possible to study the VA ratings in relation to the study examiners' ratings of overall disability for 84 men, with the result shown in table 216. Although the effective sample size is not large, it covers all major nerves and all operative procedures except graft; 52 were men with injuries to the upper extremity and 32 men with injuries to the lower. No significant association (P=.08) was found between the two classifications on the basis of the data in table 216. It was at first thought that the lack of correlation might result from the concentration of cases in the region of 60 to 80 percent on Dr. Lewey's scale, and a second sampling was undertaken to investigate this possibility.

Table 216.—*VA Disability Ratings and Follow-up Examiners' Overall Functional Evaluations, New York Sample Representing All Major Nerves*

VA disability rating, percent	Overall functional evaluation												
	0	10	20	30	40	50	60	70	80	90	100	Unknown	Total
100	...	...	...	...	...	...	...	...	...	...	...	...	...
90	...	...	...	...	...	...	...	...	1	...	...	...	1
80	...	...	...	...	...	1	1	2	3	...	...	2	9
70	1	...	...	...	...	1	1	...	2	1	...	3	9
60	...	...	...	...	...	1	1	9	5	...	...	2	18
50	...	...	...	1	...	1	1	2	4	2	...	3	14
40	...	...	...	...	...	1	7	5	3	3	...	...	19
30	...	...	...	...	1	...	...	1	1	3	...	3	9
20	...	...	...	...	...	...	...	1	2	...	...	...	3
10	...	...	...	...	...	...	...	...	...	...	...	...	...
0	...	...	...	...	...	...	...	...	...	...	...	...	...
No. claims filed	...	...	...	...	...	...	...	...	...	...	...	2	2
Total	1	...	...	1	1	5	11	20	21	9	...	15	84
Mean rating	70.0	...	...	50.0	30.0	60.0	49.1	52.5	55.2	42.2	...	56.2	52.6

In the second study of the relationship between VA ratings and follow-up examiners' ratings, pure median and pure peroneal lesions were chosen from the allocations of all five centers and with no residuals of any associated injuries, and a deliberate effort was made to give adequate representation to the entire scale. Although the latter objective was not completely realized, the resulting sample was a marked improvement over the first sample in this respect. Table 217 provides a summary of the resulting observations, which also provides no real evidence of an association between the two classifications.

Table 217.—*VA Disability Ratings and Follow-up Examiners' Overall Functional Evaluations, Pure Median and Pure Peroneal Lesions*

VA disability rating, percent	Overall functional evaluation			
	0 to 50	60 to 70	80 to 100	Total
Median				
100, 90	....	....	....	....
80, 70	3	5	1	9
60, 50	4	4	5	13
40, 30	14	7	11	32
20, 10	....	2	....	2
0	....	....	1	1
Total	21	18	18	57
Mean rating	43.8	46.7	38.9	43.2
Peroneal				
100, 90	....	....	....	....
80, 70	....	....	....	....
60, 50	7	3	9	19
40, 30	6	10	5	21
20, 10	2	2	5	9
0	....	....	....	....
Total	15	15	19	49
Mean rating	44.7	37.3	38.4	40.0

The foregoing studies were made as statistical operations after the follow-up examiners had completed their work, and no attempt has been made to review the cases individually to uncover the source of the discrepancy. However, certain other observations, made during the course of this and other studies participated in by the NRC Follow-up Agency, have some bearing on the probable reasons why the two ratings fail to agree. In some related work on men with peripheral nerve injuries it was noted that VA ratings were appreciably higher for men with combined nerve lesions than for men with pure lesions. In another study (15) on peripheral vascular injuries, a high correlation was found between VA ratings and the number of different sources of disability (vascular, nerve, bone, soft tissue, etc.) noted by follow-up examiners. Finally, in connection with the bias studies described earlier (pp. 22–27) the chairman of the present study group used Dr. Lewey's scale to rate both examined and not examined men with pure ulnar lesions, using only the appropriate reports of VA examinations undertaken for rating purposes. For the 26 men seen by the follow-up examiners of the New York center the chairman was kept in ignorance of the center's overall functional ratings based on its own examinations. Nevertheless, statistical analysis showed a high correlation between the two ratings of overall function, one by the New York examiner who saw the patient, the other by the study group chairman who saw only the last VA rating examination made before the research examination in New York. In 9 of the 26 cases the ratings were the same, and in 24 they were within 10 percent (one step on the scale); the overall correlation was +.8. This suggests not only that the New York ratings were reasonable and reproducible, but also that the VA examination contained the bulk of the information required to satisfy Dr. Lewey's classification. One can only conclude, from these various facts, that the VA percentage rating does not closely reflect the recorded findings of the rating examination in the same way that Dr. Lewey's classification does. At the same time, it would appear that VA percentage ratings do closely reflect the various components of disability insofar as these may be traced to the different structures involved in the original injury. This is consistent with the view that the percentage rating is a compound of actual disability found at examination and of the characteristics of the injury as noted in the original records underlying the claim.

F. OCCUPATIONAL CHANGES

As explained earlier, occupational changes were approached by asking the examiner to obtain specific occupation (job and industry) before service and at follow-up, and to determine whether any change seemed attributable to the nerve injury. The gross data on the latter point are exhibited in table 218 for all lesions with follow-up except the few with more than one lesion on a single nerve. For the sample as a whole, change in occupation was the rule for men with previously established occupations, and the great majority of the changes appeared to examiners to have resulted, at least partly, from the nerve injuries. A control group would be necessary to delineate the precise role of the nerve injury, but the clinical opinion is quite clear: The peripheral nerve injury contributed to a change in occupation in 49 percent of the cases, and to an apparent inability to work in another 7 percent. An investigation on the median failed to show that

Table 218.—*Change in Occupation, All Peripheral Nerves With Single Lesions at Follow-up*

Change in occupation	All lesions	Lesions of men with prior occupation
	Percent	*Percent*
Never employed	6.6	0
Employed now, but not before	7.1	0
No change	20.5	23.8
Changed, not for nerve injury	16.0	18.5
Changed, because of nerve injury	42.2	48.9
No occupation; unemployable because of nerve injury [1]	6.0	6.9
No occupation; unemployable for other reason [1]	1.6	1.9
Total	100.0	100.0
Number of lesions	2,489	2,148

[1] In the man's own opinion.

handedness was definitely associated with occupational change, although there was a suggestion that men with high lesions were more likely to regard themselves as unemployable if the dominant hand was affected.

The directional shift of occupational change was chiefly from the ranks of operatives into clerical and sales occupations. Table 219 gives the distributions by broad socioeconomic class, both before service and at follow-up, for all men and for those with established occupations before service. The categories for which losses occurred are, in addition to the operatives, farmers of all kinds, craftsmen and foremen, and nonfarm laborers; in all others gains were registered. In addition, there were many changes within these broad categories, especially from jobs requiring more to those requiring less strength or fine coordination of movement.

The identity of the injured nerve seems not to affect the gross picture of occupational change. When attention is confined to pure nerve lesions treated by complete suture, as in table 220, changes attributed to nerve injuries are somewhat more common for men whose lower extremities were involved, but otherwise the particular nerve involved seems unimportant. Table 220 is confined to the more common occupational groups prior to service, and shows, in addition to the percentage changing occupation (in the narrow sense) because of nerve injury, the percentage whose changes (for any reason) placed them in an entirely different occupational category. Men with median, ulnar, or radial injuries were least likely to change their jobs if their work involved clerical or sales activities. Although their number is not large, nonfarm laborers more often changed jobs than men in other occupational groups, as did operatives, craftsmen, and foremen.

Table 219.—*Percentage Distribution by Socioeconomic Class, Before Service and at Follow-up*

Socioeconomic category	All cases		Cases with previously established occupation	
	Before service	At follow-up	Before service	At follow-up
Professional, semiprofessional	2.8	3.3	5.9	6.9
Farmers of all kinds	4.0	4.7	1.8	2.2
Proprietors, managers, officials	2.5	3.0	5.7	6.7
Clerical and sales	15.2	18.1	27.1	31.8
Craftsmen and foremen	17.0	20.2	13.2	15.5
Operatives	31.1	36.9	20.3	23.8
Service, except protective	1.9	2.3	3.9	4.5
Service, protective	1.5	1.8	2.9	3.4
Students	13.2	0	13.8	0
Occupation not established	2.6	0	0.9	0
Laborers, nonfarm	8.2	9.7	4.3	5.1
Total	100.0	100.0	99.8	99.9
Number of lesions	2,576	2,169	2,450	2,088

Since only the distinction between upper and lower extremity seems to be associated with the chance of occupational change, in table 221, giving the precise change in socioeconomic category, the individual nerves are grouped in accordance with this distinction. Also, only the most common preservice occupational categories are shown there. For both upper and lower extremity cases, it was unlikely (12 and 7 percent) that a man would remain a craftsman or foreman; he tended to shift to the other two categories. Similarly, the entrance into the category of the craftsman and the foreman was not common for men previously in clerical or sales work, or for former operatives. Men in clerical and sales work were least inclined to leave their socioeconomic category, and yet the numbers who did are large (60 percent for upper extremity and 42 percent for lower). Behind the summary frequencies of table 221 is a welter of detail which can at best be exemplified:

A coal miner with a median lesion becomes a clerk in the VA.

A machine operator with a median lesion becomes a mail carrier for the U. S. Government.

A blacksmith's helper with a median lesion becomes a chauffeur.

A printer's apprentice with a radial lesion becomes a postal clerk for the U. S. Government.

After a radial lesion, a man who was formerly a special tool grinder, doing handwork, changes to toolgrinding requiring no hand work.

A welder in a U. S. Navy yard, with an ulnar lesion, becomes a stockkeeper at the yard.

A truck driver, with an ulnar lesion, becomes a clerk in a bank.

Table 220.—*Change in Occupation Because of Nerve Injury (A), and Change in Socioeconomic Category for Any Reason (B), by Occupation Prior to Service, and by Nerve Injured, Pure Lesions Treated by Complete Suture*

Nerve and change in status	Previous occupation				
	Clerical and sales	Craftsmen and foremen	Operatives	Nonfarm laborers	Total [1]
Median					
Number of men	25	30	49	15	137
Percent A	28.0	60.0	55.1	66.7	50.4
Percent B	16.0	53.3	38.8	60.0	40.1
Radial					
Number of men	30	33	54	17	155
Percent A	26.7	54.5	63.0	52.9	48.4
Percent B	23.3	54.5	42.6	35.3	37.4
Ulnar					
Number of men	56	61	118	24	297
Percent A	26.8	62.3	46.6	54.2	44.4
Percent B	16.1	52.5	33.1	50.0	34.0
Peroneal					
Number of men	13	14	41	14	99
Percent A	53.8	57.1	53.7	57.1	54.5
Percent B	15.4	50.0	41.5	42.9	41.4
Tibial					
Number of men	15	16	21	7	63
Percent A	26.7	56.3	61.9	85.7	55.6
Percent B	13.3	50.0	47.6	85.7	46.0
Sciatic [2]					
Number of men	33	38	74	26	205
Percent A	48.5	47.4	59.5	69.2	57.6
Percent B	24.2	47.4	43.2	69.2	46.8

[1] Includes all other occupations not shown separately.
[2] Complete sciatic lesions, i. e., both branches sutured.

Table 221.—*Change in Socioeconomic Category for Any Reason, Men With Pure Lesions Treated by Complete Suture in Most Common Preservice Occupational Categories*

Occupational category at follow-up	Preservice occupation			
	Clerical, sales	Craftsmen, foremen	Operatives	Nonfarm laborers
Upper extremity				
Professional, semiprofessional	4.0	4.5	1.8	6.7
Farmers of all kinds	0.0	0.0	0.0	0.0
Proprietors, managers, officials	12.0	7.6	6.4	6.7
Clerical and sales	40.0	34.8	24.8	16.7
Craftsmen and foremen	8.0	12.1	18.3	6.7
Operatives	24.0	27.3	32.1	30.0
Service, except protective	0.0	7.6	11.0	16.7
Service, protective	8.0	4.5	1.8	0.0
Laborers, nonfarm	4.0	1.5	3.7	16.7
Total	100.0	99.9	99.9	100.2
Number of cases	25	66	109	30
Lower extremity				
Professional, semiprofessional	3.8	3.6	4.8	3.3
Farmers of all kinds	0.0	7.1	1.6	3.3
Proprietors, managers, officials	11.5	3.6	12.7	0.0
Clerical and sales	57.7	42.9	30.2	36.7
Craftsmen and foremen	7.7	7.1	11.1	16.7
Operatives	19.2	32.1	31.7	33.3
Service, except protective	0.0	0.0	3.2	0.0
Service, protective	0.0	3.6	0.0	0.0
Laborers, nonfarm	0.0	0.0	4.8	6.7
Total	99.9	100.0	100.1	100.0
Number of cases	26	28	63	30

Since the occupational changes which men made, although frequent, appear not to have been quite specific to the identity of the injured nerve, it is not surprising to find, at follow-up, no important differences in the distributions by broad socioeconomic category. Table 222 provides the data for these comparisons, and is confined to pure lesions and complete sciatic lesions.

Table 222.—*Percentage Distribution of Cases by Socioeconomic Category at Follow-up, by Nerve, for Pure Lesions Treated by Complete Suture*

Socioeconomic category	Nerve: Median	Radial	Ulnar	Peroneal	Tibial	Sciatic [1]	Total
Professional, semiprofessional	5.1	6.0	5.8	3.3	2.6	5.4	5.2
Farmers of all kinds	1.3	2.0	1.2	2.5	0.0	2.3	1.6
Proprietors, managers, officials	5.8	10.5	3.8	4.9	6.6	8.5	6.6
Clerical and sales	26.3	24.5	25.1	23.8	26.3	26.9	25.5
Craftsmen and foremen	12.2	10.5	16.2	12.3	19.7	10.8	13.3
Operatives	22.4	20.0	26.6	28.7	27.6	20.8	23.9
Service, except protective	5.8	4.5	2.9	1.6	1.3	.8	2.8
Service, protective	3.2	2.5	3.2	2.5	0.0	1.5	2.4
Student	14.1	13.0	11.6	13.9	13.2	19.2	14.2
Occupation not established	.6	.5	.6	.8	1.3	1.5	.9
Laborers, nonfarm	3.2	6.0	3.2	5.7	1.3	2.3	3.6
Total	100.0	100.0	100.2	100.0	99.9	100.0	100.0
Number of cases	156	200	346	122	76	260	1,160

[1] Complete lesions; both trunks sutured.

G. OCCUPATIONAL HANDICAPS

Even after changing their occupations because of nerve injuries a majority of the men continued to have at least some handicap in their new work. For the sample as a whole at follow-up, examiners considered only 29 percent to have no apparent handicap; they regarded 57 percent as having less than a severe handicap, and 8 percent a severe handicap, in addition to the 7 percent who regarded themselves as unemployable. Table 223 presents the basic data on occupational handicap by nerve, for pure lesions treated by complete suture. Men with median or complete sciatic lesions were considered by examiners to be the most handicapped, and men with ulnar or tibial the least. When the examiners' assessments as to occupational handicap were studied in relation to overall functional evaluation, some correlation, by no means close, was found. In the main, those with the greatest handicaps had the poorest functional recovery, but this was by no means uniformly true. An occupational handicap is a two-sided matter, depending at least as much upon the requirements of the work as upon the capabilities of the man. After all the occupational changes which men were able and willing to make, there remained a few with fairly good practical function, by average standards, who nevertheless seemed to examiners to be severely handicapped in their work.

Although it is not possible here to display the detail required to show the relation between specific occupation and handicap in its performance, some of the information which is useful may be obtained from an analysis by broad occupational category, as in table 224, which is confined to the three most common occupational groupings. Severe handicaps were rare for men who were able to work at occupations in these three categories, but some handicap was usual, and especially so for men with median, radial, or ulnar lesions working as craftsmen, foremen, and operatives as contrasted with clerks and salespeople. The occupational category has no such influence upon the handicap of men whose injuries involved the lower extremities.

Table 223.—*Percentage Distribution of Cases by Occupational Handicap at Follow-up, by Nerve, Pure Lesions Treated by Complete Suture*

Nerve	Occupational handicap					Number of men
	None apparent	Present			Total	
		Not severe	Severe	Unemployable [1]		
Median	26.7	56.2	8.9	8.2	100.0	146
Radial	31.2	59.7	4.8	4.3	100.0	186
Ulnar	32.6	61.5	3.4	2.5	100.0	322
Peroneal	34.5	54.0	5.3	6.2	100.0	113
Tibial	44.9	47.8	5.8	1.4	99.9	69
Sciatic [2]	24.2	58.4	6.1	11.3	100.0	231

[1] In the man's opinion.
[2] Complete lesions; i. e., both branches sutured.

H. FUNCTIONAL CAPACITY OF MEN WHO REMAINED IN SERVICE

From the some 3,000 cases originally considered for allocation, 22 men were found to be back on duty with the Armed Forces. Letters were written to their commanding officers, or theater surgeons, requesting that they be examined and that some statement be made concerning their fitness for duty. Fourteen replies were received. Although this group is a small one, and their examinations not comparable in completeness to those carried out in the study centers, a brief description of the post-injury course of these individuals seems indicated.

There were 4 officers, all of whom had been members of the Regular Army at the time of their initial injury, 9 noncommissioned officers, and 1 enlisted man, all of whom had continued in service following hospitalization for their peripheral nerve wounds. It was evident that these officers

Table 224.—*Occupational Handicap and Socioeconomic Grouping at Follow-up, by Nerve, for Pure Lesions Treated by Complete Suture, Employable Men Only*

Nerve and socioeconomic grouping	Percentage distribution by occupational handicap				Number of men
	None	Not severe	Severe	Total	
Median					
Clerical, sales	50.0	47.4	2.6	100.0	38
Craftsmen, foremen	7.1	85.7	7.1	99.9	14
Operatives	24.2	69.7	6.1	100.0	33
Radial					
Clerical, sales	43.5	54.3	2.2	100.0	46
Craftsmen, foremen	31.6	57.9	10.5	100.0	19
Operatives	23.5	76.5	0	100.0	34
Ulnar					
Clerical, sales	45.9	51.8	2.4	100.1	85
Craftsmen, foremen	20.0	72.7	7.3	100.0	55
Operatives	20.7	75.9	3.4	100.0	87
Peroneal					
Clerical, sales	32.0	68.0	0	100.0	25
Craftsmen, foremen	42.9	57.1	0	100.0	14
Operatives	38.7	54.8	6.5	100.0	31
Tibial					
Clerical, sales	50.0	45.0	5.0	100.0	20
Craftsmen, foremen	33.3	58.3	8.3	99.9	12
Operatives	45.0	45.0	10.0	100.0	20
Sciatic [1]					
Clerical, sales	31.7	61.9	6.3	99.9	63
Craftsmen, foremen	38.5	61.5	0	100.0	26
Operatives	22.7	77.3	0	100.0	44

[1] Complete lesions; both branches sutured.

and men were compelled by personal motives having to do with furthering and continuing their careers in the Armed Forces.

The peripheral nerve injuries included 2 of the sciatic nerve, 3 of the common peroneal nerve, 3 of the radial nerve, (1 combined with a median nerve division), 3 of the ulnar nerve and 3 of the median nerve. All nerve injuries were initially selected as instances of complete nerve division and were treated by nerve suture in neurosurgical centers in England or in the Zone of Interior at time intervals ranging from 1 to 11 months. They were hospitalized until, in the opinion of their physicians, maximal hospital benefit had been achieved. Except in terms of motivation, there was no obvious dissimilarity between this small sample and the major group.

The neurological review of the two patients with sciatic nerve division suggested a marked difference in anatomical reinnervation. Letters from these patients or their superior officers describe excellent or at least adequate functional rehabilitation.

The first patient was injured by shell fragments on 14 January 1944, with evidence of complete sciatic nerve division in the upper third of the thigh. Nerve suture was done in April of 1945 and subsequent roentgenography of the suture site disclosed displacement of the tantalum sutures. He was reoperated upon in November of 1945, suture line disruption was proved, and it was necessary to remove 15 cm. of the proximal and distal nerve segments to attain reasonably good nerve ends. Examination in 1951 disclosed complete foot drop, weak plantar flexion, and hypalgesia over the sensory domain of the sciatic nerve. In spite of this evidence of poor anatomical regeneration, and the adverse factors responsible for it, the following note was received.

> "I would like to say that in spite of the rather severe nature of my nerve injury, I was retained on active service in the Army and have been able to perform my regular duties without the loss of even a day's duty due to any trouble with my wound. I would estimate that I have gotten about 60 percent return of function of my sciatic nerve."

The man was then serving with the 7th Infantry Division in Korea.

The second patient sustained a shell fragment wound of the upper third of the thigh on 10 April 1945. He was operated upon in November 1945, a 9-cm. gap was recorded as a result of resection of pathologic nerve ends and sciatic nerve suture was performed. In 1951 there was "partial" foot drop, normal plantar flexion, and slight hypesthesia over the lateral aspect of the foot. The evidence for fairly adequate anatomical regeneration seems to be present. His examining physician writes:

> "This officer states that there is no limitation placed upon him as a result of his old injury for usual activities. He states that he has taken prolonged marches with soldiers without difficulty. However, his left leg will not 'react as fast' as the right leg. (The patient) is well pleased with the results that he has had. It also seems to me that he has had a splendid result and has probably reached maximum benefit from surgery."

In the group of 3 patients with injury to the common peroneal nerve, close scrutiny of the hospital records of 1 case shows that complete nerve division was not present and that but one fascicle was sutured. This patient returned to full duty with evidence of good anatomical and functional regeneration. The second patient with complete nerve division and subsequent suture of the common peroneal nerve still showed complete foot drop and sensory changes in 1951. He was on duty in the United

States and no detailed comment about his fitness is available. The third patient, on limited duty at present in Japan, was wounded in June 1944 and operated upon in July 1944. From the neurological examination, anatomical regeneration was grossly inadequate. The following comment was appended to the examination report:

> "From a functional standpoint, this man has had a good recovery from a serious injury in that he can walk with minimal objective evidence of disability and minimal subjective discomfort from pain."

Two of the 3 patients with radial nerve division did well and the third patient had a double nerve injury. The first patient was wounded by a shell fragment in July 1944 and was operated upon in September 1944. A 3-cm. defect was found and a relatively easy peripheral nerve suture was accomplished. Anatomical regeneration was good with full return of extension of wrist and fingers with the exception of the extensor hallucis longus. The extent of his regeneration is attested to by an accompanying letter.

> "Subjectively (the patient) suffers little disability. He is able to play the piano, shoot a pistol and to use the typewriter efficiently. His only adverse sensations connected with use of the limb occur when he plays the piano for any length of time. He then feels that his lateral forearm muscle group becomes unduly and rather easily fatigued. In addition, he reports that a mild blow over the wound produces a 'shooting, tingling sensation' down the course of the radial nerve in the forearm. He is able, however, to perform all of his duties without disability."

The officer was then on duty with the 3d Infantry Division in Korea.

The second patient is on duty in Hawaii and his examiner described "fair" return in muscles innervated by the radial nerve and "good" functional return. No further information is available. The third patient received a shell fragment wound of the elbow in November 1944 and nerve divisions of the radial and median nerve were sutured in February 1945. Anatomical and functional return in the radial musculature was described but residual paralysis of intrinsic muscles of the hand innervated by the median nerve was reported, together with the return of diffuse pain appreciation in the distal half of the index finger. The examining physician writes from a station in Europe:

> "Patient's overall functional usefulness of his right arm is limited about 50 percent. He can do crude, unskilled light work involving the right hand, but is unable to do heavy work, skilled work or fire a gun. Patient works as a motor pool supply sergeant, and can do all that is required in his job, except for heavy lifting."

Upon review, one median nerve injury proved to be a partial nerve suture. The patient was reported on full duty as a member of the military police in Europe. The neurological examination in the other two instances of median nerve injury were incomplete but suggested no return of intrinsic muscle power and only return of pain appreciation in the sensory domain. Both patients were on full duty, 1 overseas and 1 in the United States. Excerpts from the accompanying letters state "can do full duties" and "grossly appears normal."

The ability of patients with ulnar nerve division to carry on military duties in spite of inadequate anatomical regeneration is further noted in the three patients in this group. The first patient sustained ulnar nerve division above the wrist in September 1944, and was sutured in February 1945 following a 4-cm. resection of pathologic nerve ends. In 1951, there was complete loss of all sensory modalities over the autonomous zone of this nerve and atrophy and paralysis of all intrinsic muscles innervated by the ulnar nerve. His examining physician in Europe writes:

> "He is at present assigned to an Engineer's Service Bn. He has successfully completed a course of training at Equipment Operators School and serves now as an equipment operator. This work requires considerable manual dexterity in manipulation of machine controls. His commanding officer registered surprise when told of the nature of the man's wound because there has never been a question of (the patient's) efficiency or usefulness. His service is unlimited."

The second and third patients showed evidence of anatomical regeneration only in some return of the appreciation of pain in the autonomous zone. There was no motor return following injuries in the lower forearm. Letters from their examiners follow:

> "In my opinion this officer is fit to perform his duties, but would be handicapped in combat requiring active use of the right arm. His immediate superior officer feels that this officer is fully qualified in his present job."

He was with the 3d Air Division in Europe.

> "(The patient) is able to perform all his duties properly, including fine movements required in maintenance of material."

In summary the reports upon the physical status of these men are admittedly inadequate. They serve to demonstrate the fact that resolute individuals, with proper motivation, can resume useful military duties in spite of any type of common peripheral nerve injury.

Chapter IX

RECOVERY FOLLOWING INJURY TO THE BRACHIAL PLEXUS

Frank E. Nulsen and *Harry W. Slade*

A. INTRODUCTION

Because the resulting patterns of functional disturbance are so variable and complex, injuries to the brachial plexus seem most adequately approached via the case study and are given separate consideration here for that reason. Each brachial plexus case must be reviewed in detail if one is to draw any conclusion about the degree of motor or sensory recovery that has occurred, and whether this improvement may be attributed to therapy. In all, 117 cases were selected from the follow-up material as having sufficiently clear and consistent longitudinal data on motor and sensory status, and sufficiently detailed operative reports, to permit their inclusion for analyis.

All cases were characterized by a sufficiently severe and lasting paralysis to result in the undertaking of surgical exploration, in the earliest at 6 weeks, and in 95 percent at 3 months or more, after injury. The indication for exploration, in retrospect, will be discussed but the point to be made here is that all cases in this study were obtained from surgical rosters and had therefore suffered major plexus injuries with sufficient, lasting dysfunction to be subjected to surgery. In addition, an initial total paralysis of the arm was so universally reported, except in 3 stab wounds, that a classification of cases according to nerve elements suffering major damage was achieved by arbitrarily considering an element uninvolved when it gave evidence of good motor and sensory function by 2 months after injury. Accordingly, the data on spontaneous recovery in this series can be expected to be less favorable than often reported, because all examples of very early recovery have been discarded from the analysis. In addition to these 3 stab wounds, trauma was by stretch in 5, and by high velocity missiles in the remaining 109 cases. In 10 of this last group a variable amount of initial nerve damage was compounded by subsequent pressure upon nerves by growing arterial aneurysms.

Depending upon the location of the nerve lesions and the evidence for continuing dysfunction at 2 months, the patients were classified into the following groups:

I. Damage confined to superior trunk or roots (C5, C6)—19 cases.
II. Damage confined to middle or inferior trunk or roots (C7, C8, T1)—3 cases.

III. Damage to all trunks or roots—11 cases.
IV. Damage confined to lateral cord—8 cases.
V. Damage confined to posterior cord—6 cases (3 cases IV plus V).
VI. Damage confined to medial cord—15 cases (3 cases V plus VI).
VII. Damage to all cords—49 cases.

The disproportionately low number of cases in group II probably derives from the likelihood of fatality from arterial or pulmonary damage in association with such injuries.

B. REGENERATION

Group I

Major involvement at the root or trunk level, which was essentially confined to the C5 and C6 roots, occurred in 19 cases. Only 5 of these patients showed a major permanent deficit in function secondary to loss of either shoulder abduction or elbow flexion. Suture of C5 or of upper trunk was responsible for restoration of shoulder abduction in 9 of 12 such cases. Suture of both C5 and C6 was associated with recovery of elbow flexion in 4 of 5 cases. Two failures resulted from grafts. Suture made a significant contribution in 10 of the 14 recoveries, while spontaneous regeneration appeared responsible for the other 4 good results.

One might suppose that the C5, C6 root sensory loss would be disabling. Actually such loss was invariably incomplete early after injury and rapidly became inconsequential in hampering function of the hand, presumably as the result of overlapping sensory innervation.

Group II

In 3 cases damage was ultimately confined to the lower roots with good motor function above the elbow and none below. Sensation was preserved in at least the medial or working portion of the hand. Suture of lower roots in 2 cases and lysis in 1 did not result in the recovery of any finger movement, and the extremity remained virtually useless.

Group III

All roots showed prolonged evidence of dysfunction in 11 cases. Damage was by stretch in 5 instances. All of these were explored and resection of scar with suture of one or more nerves was done in 2. In no instance was there recovery below the shoulder level.

The remaining 6 were injured by high velocity missiles. Among 5 who were subjected to suture of one or more elements, biceps and deltoid recovery resulted with upper root sutures, but in every instance the absence of motor function below the elbow was by itself a total functional limitation. One satisfactory recovery occurred in a lysis case in which distal muscles began to function in the third month, and proximal muscles began 4 months after injury.

Group IV

Eight cases had primarily lateral cord involvement. One showed late spontaneous recovery, beginning in biceps at 4 months, while of 7 sutures only 1, done with plasma glue, failed to give useful recovery in the biceps. This appraisal may be overly optimistic since strong elbow flexion can result purely from brachioradialis action and the degree of participation by the biceps is hard to define. At any rate, these sutures made some contribution to the biceps action which resulted in satisfactory function.

Loss of the contribution of the lateral cord to median nerve function might be expected to result in some paralysis of median flexors and loss of median sensation. Actually such motor loss was incomplete—even initially each median flexor retained a useful degree of strength. Median sensory loss was also unlikely to be total and in only 2 instances was there a persistent deficit sufficient to cause inability to pick up small objects blindfolded. In pure lateral cord damage, therefore, the deficit is chiefly in biceps paralysis with a high expectation of recovery after suture when this does not occur spontaneously.

In 3 cases where the posterior cord was also involved (but medial cord intact), good results were obtained from 2 lateral cord sutures, while the third recovered spontaneously. A real limitation in function remained in only 1 case on the basis of finger extensor paralysis. (See group V.)

Group V

Major damage limited to the posterior cord was seen in 6 instances, of which only 2 were subjected to suture. In both instances there was a failure to develop useful finger extension while wrist dorsiflexion, elbow extension, and deltoid function were good in 1 and absent in the other. A "pure" axillary lesion suture with plasma glue did not result in deltoid function. In the 3 cases subjected to lysis only, satisfactory recovery, including even the distal finger extensors, occurred in 2, while 1 failed to recover below the triceps level.

In all 3 cases failing to develop useful extension of wrist and fingers, it should have been possible to utilize intact flexor muscles to provide this missing extensor function by tendon transfer. This was done in 1 case only and with a partially satisfactory result.

Of the 3 cases with recovery from associated lateral cord involvement (discussed under group IV), 1 showed good spontaneous recovery while 2 were subjected to posterior cord suture. Failure in distal recovery only (finger extensors) was treated by flexor tendon transfers in 1 with an excellent result, while the second had the correctible permanent deficit of an inability to open his fingers.

Three additional cases had posterior cord and medial cord damage. The latter by itself prevented the recovery of a useful hand so that it is of only academic interest that 2 posterior cord sutures resulted in good elbow and wrist extensor function. Tendon transfers were quite properly not undertaken.

Group VI

Lasting disturbance of medial cord function is of itself inconsistent with useful function of the hand and therefore of the extremity. A total ulnar nerve deficit is combined with loss of that component of median nerve supply necessary for intrinsic hand muscle function. The preservation of median sensation (through lateral cord) and of fair median forearm muscles avails little in the face of this total loss of intrinsic hand muscle action.

Of 15 patients with damage confined to the medial cord, 7 had complete suture of this structure with no recovery of intrinsic muscle function in any instance. Despite varying degrees of action in proximal ulnar muscles and occasional recovery of ulnar sensation, functional ratings remained below 30 percent for this group. Four patients correctly subjected to lysis only (as proved by subsequent proximal motor recovery) again failed to develop useful intrinsic muscle action.

More favorable results were seen, not as a result of treatment, but because only incomplete damage occurred to this element so vital for hand function. Damage was total for only the ulnar component of the medial cord in 3 patients in whom suture gave low-grade ulnar sensory return and fair proximal muscle function. In these high lesions with median sparing, clawing of the last 2 fingers was not likely to be pronounced and, in one instance, voluntary function returned to the abductor digiti quinti and first dorsal interosseous. A final case, subjected to lysis only, showed useful recovery with the assistance of a tendon transfer for opposition.

In the face of good sensation in the median area or working part of the hand, and some action in the forearm flexors and intact extensors, some mechanical device should be provided for abducting fingers and opposing the thumb, functions absent with intrinsic muscle loss. Partial correction of this deficit to the point of useful function was shown to be possible in 4 instances (3 additional from group VII) where this motor loss was not total. Either the fingers functioned sufficiently well so that a concentrated effort could be made to achieve thumb opposition, utilizing an extensor tendon rather than a weakened flexor, or opposition was good and tendon work could be utilized to overcome clawing of fingers.

Group VII

Since medial cord damage by itself is, in general, an obstacle to the development of useful hand (and therefore arm) function, it can be anticipated that in this group with major damage to all 3 cords, suture will seldom be responsible for a practical degree of recovery. Such sutures of 1 or more cords were performed in 41 of 49 cases in this group and in only 6 of the sutured cases could function be rated above 30 percent (hand can be positioned as a weight and can hold some objects forced into it). The degree of recovery possible when all 3 cords are sutured is of some theoretical interest. In 1 case in which all 3 divided cords were sutured at 6 months after injury, final evaluation 5 years later assessed deltoid at 50 percent, biceps at 30 percent, triceps at 25 percent, wrist extensors at 10 percent, and finger flexors at 10 percent. All of the muscles above the elbow would have functioned usefully (and strength could have been increased with training), had there been some mechanism for opening fingers and opposing thumb. However, with this major link in arm function missing, the recovery was of little practical advantage.

The 6 good cases were all characterized by early recovery of some intrinsic hand muscle function as evidence of relatively intact medial cord function. In 1 case a suture of the lateral cord gave the usual good return in biceps with increasing strength in median flexors and improvement in median sensation (never totally lost), resulting in 80 percent overall function owing to coincident spontaneous recovery in medial and posterior cords. In 4 cases sutures of the posterior cord gave varying degrees of extensor function, always with triceps recovery (and deltoid, if affected). Two with no wrist or finger extension were subjected to flexor tendon transfers. In one, very good extension resulted with an overall functional rating of 80 percent, in the other, extension of fingers was weak because of incomplete recovery of the flexors utilized, but function was nevertheless considered 60 percent. The remaining 2 posterior cord sutures achieved fair wrist extension and overall function could probably have been raised from 40 percent to 70 percent or better had strong flexor muscles been utilized for extension. The final favorable result in this group of 6 had suture of both lateral and posterior cords with the usual optimal regeneration in each. Extension of wrist but not of fingers recovered and function was judged as 40 percent. Again the final assessment of flexor strength suggests finger extension could have been accomplished by tendon transfer.

In the 8 cases in which operative treatment consisted in lysis only, 3 recovered useful arms spontaneously while 2 did so by virtue of tendon work. Both failed to recover finger extension and good thumb opposition, although intrinsic muscles were functioning and the fingers were not clawed. In each instance, flexors were sufficiently strong to permit establishment of finger extension and strengthening of opposition by tendon transfers with overall function of 70 or 80 percent.

Three of the lysed cases failed to regain useful arms. In 1, a lesion in continuity of the medial cord was left alone and its failure to recover was sufficient to prevent useful function (suture would have accomplished no more). In 2, the only significant residual deficit was in extensor function of wrist and fingers, a situation which could presumably have been improved by flexor tendon transfers.

The foregoing data are summarized in table 225 where results are classified in terms of useful function of the arm and hand as a whole. The conclusion that only 28 of 89 sutures contributed to useful function discounts many "successful sutures" because the resulting motor recovery was negated in multiple nerve damage by a missing link necessary for use of the extremity. Further, the contribution of 8 of these sutures to useful function was made possible by the addition of a missing link through

Table 225.—*Operative Treatment and Overall Result of Injury-Group*

Injury-group	Total cases	Number sutured	Useful arms: Total	Useful arms: Aided by suture	Useful arms: Aided by tendon transfer	Poor function: Deficit	Poor function: Number of cases	Poor function: Possible rehabilitation
I	19	14 incl. 2 grafts	14	10	....	Shoulder abduction	3	Shoulder fusion.
						Elbow flexion	2	Elbow fusion.
II	3	2	0	0	....	All forearm and hand	3	Hand prosthesis.
III	11	7	1	0	....	All forearm and hand	4	Hand prosthesis.
						All movement	6	None.
IV	8	7	7	6	....	Elbow flexion	1	Elbow fusion.
IV–V	3	3	2	2	1	Finger extension	1	Tendon transfer.
V	6	3	3	1	1	Shoulder abduction	1	Shoulder fusion.
						Finger extension	2	Tendon transfer.
V–VI	3	2	0	0	....	Hand extensors	3	Hand prosthesis.
VI	15	10	4	[1] 3	1	Hand muscles	10	Tendon transfer, fusion.
						Part hand muscles	1	Tendon transfer.
VII	49	41	11	6	9	Elbow flexion	1	Elbow fusion.
						Finger extensors	4	Tendon transfer.
						Part hand muscles	4	Tendon transfer.
						Hand muscles	5	Tendon transfer, fusion.
						All forearm and hand	22	Hand prosthesis.
						All movement	2	None.
Total	117	89	42	28	12		75	In 67 cases.

[1] All were partial sutures of ulnar or median component.

tendon transfers. Had such measures been more universally applied, only 8, rather than 75 of the 117 patients, need have had virtually useless extremities and only 24 of the 89 sutures would have been of no practical value. These possibilities for rehabilitation are discussed below.

Table 226 has been prepared by combining the data on all 89 sutured cases, whenever an accurate follow-up observation for strength of movement or sensation was obtained, and such function was clearly the result of suture and not of regeneration through a neighboring element of the plexus. Multiple sutures in one patient were particularly useful in this regard. In occasional single sutures, the recovery of certain muscles, not having dual innervation, was considered to have occurred by this avenue, when the timing of recovery was consistent with suture and inconsistent with spontaneous recovery.

Data on median sensation are limited almost entirely to multiple lesions because of overlapping innervation with single nerve injury at any point above the formation of the median nerve. A greater median sensory deficit results from lateral cord than from medial cord division, but even in the former the loss was total in only two instances. Useful sensory recovery is considered present either when reduced pain and touch thresholds were described or when, for the median, the patient could pick up small objects blindfolded. Low-grade recovery indicates lesser but definite perception in the appropriate fingertips. Useful shoulder abduction implies the ability to abduct the arm 90°. When only the deltoid is involved, such shoulder abduction can occur without its recovery but the rating indicates function of deltoid at least sufficient to contribute to strong abduction. In the case of elbow flexion, the ability to raise the forearm against gravity plus resistance was considered useful. In root or upper trunk sutures all such flexion was the result of regeneration through suture. In lateral cord sutures considerable flexion could be provided by the unaffected brachioradialis when a "useful recovery" indicated the observation of a strong contraction of the biceps as a major contribution to elbow flexion. Triceps and finger extensors offered fewer problems in isolated innervation—action against gravity plus resistance was considered useful. For the wrist and finger flexors the same criteria for useful function were used. Ulnar flexors could be considered the result of isolated medial cord regeneration through suture while median flexors, receiving contributions from both lateral and medial cords, could only be included with dual lesions. The intrinsic hand muscles should behave as a group with medial cord damage and are separated only because of four examples in which only the median or only the ulnar portion of the medial cord was sutured. Useful median intrinsic function implies ability to pick up small objects between thumb and finger. Useful ulnar function indicates ability to abduct the fourth and fifth finger sufficiently to grasp objects.

Study of table 226 suggests that suture of the upper trunk or its roots, of the lateral cord, and of the posterior cord, carries with it a reasonably high expectation of useful recovery in the appropriate muscles of the shoulder and upper arm. The triceps does less well (46 percent) but even a low-grade recovery in this particular muscle can be of some benefit. It is worthy of note that useful recovery in wrist extensors and flexors does occur, but by no means presages extension of functional innervation to finger flexors and extensors—a very rare occurrence. With the limitation in distal recovery already so well defined, it is not unexpected that useful recovery in intrinsic hand muscles was never observed. Conceivably, low-grade recovery might have been found more often if electrical tests had been generally utilized to demonstrate minimal innervation.

Table 226.—*Motor and Sensory Recovery Attributable to Suture of a Component of the Brachial Plexus*

Specific motor or sensory involvement	Total cases	Recovery			
		Useful		Low-grade	None
		Number	Percent		
Median sensation	19	3	16	3	13
Ulnar sensation	34	6	18	9	19
Shoulder abductors	20	11	55	1	8
Elbow flexors or biceps	30	24	80	2	4
Triceps	35	16	46	10	9
Wrist extensors	31	4	13	5	22
Wrist flexors	61	13	21	11	37
Finger extensors	32	0	0	2	30
Median finger flexors	16	1	6	3	12
Ulnar finger flexors	36	2	6	6	28
Median intrinsic hand muscles	37	0	0	3	34
Ulnar intrinsic hand muscles	37	0	0	3	34

The results of suture might have been better had it been accomplished earlier after injury. However, there is a sufficient number of relatively early sutures (38 by 4 months) to suggest that while the percentage of proximal muscles recovering and their actual strength might well be improved by more uniformly early suture, the limitations are absolute on the recovery of finger flexors and extensors and intrinsic hand muscles. The limitations apply even when regeneration occurs without suture. (See below.)

The achievement of a reasonable degree of distal skin sensation through suture is worthy of note and illustrates the marked variability between limitations on sensory and motor recovery. The possibility of such recovery through suture is of considerable importance in a pure median lesion but is of minor advantage in plexus lesions. Here, those lesions requiring suture to improve sensation include such a major permanent deficit in distal motor function, with so little possibility for substitutive tendon transfers, that such sensation contributes little to overall performance.

Probability of spontaneous regeneration may be studied in table 227. Although all of these 117 cases were surgically explored, and at least 1 element sutured in 89, the assumption is made that lysis does not affect the already instituted regenerative process. Therefore, in both the lysis cases and the single suture cases with multiple nerve involvement, a large number of examples are available for an analysis of this spontaneous process. It has been arbitrarily assumed that a recovery manifest before 2 months speaks for a major degree of neurapraxia, or minor injury, and these frequent early recoveries are not included in the tabulation. When recovery is first seen more than 2 months after injury, a definite permanent residual deficit is the result, although the mechanism of such recovery as does occur may be unclear. Observations were not tabulated when the timing of recovery suggested a contribution by suture or when an absence of negative observations before 2 months failed to disprove the possibility of very early recovery.

Table 227 shows, as might be anticipated, a higher recovery rate than obtains after suture. There remains the same serious limitation on distal motor recovery without a comparable infrequency of distal sensory return. This suggests that in partial lesions from missiles sensory axons fare better than motor, a discrepancy not observed in stretch injuries. While in most

Table 227.—*Motor and Sensory Recovery Occurring Spontaneously or After Lysis Following Brachial Plexus Injury* [1]

Specific motor or sensory involvement	Total cases	Recovery			
		Useful		Low-grade	None
		Number	Percent		
Median sensation	47	23	49	11	13
Ulnar sensation	44	20	45	10	14
Shoulder abductors	35	23	66	5	7
Elbow flexors or biceps	52	41	79	3	8
Triceps	37	28	76	4	5
Wrist extensors	38	12	31	10	16
Wrist flexors	27	7	26	4	16
Finger extensors	40	8	20	7	25
Median finger flexors	28	2	7	2	24
Ulnar finger flexors	48	13	27	18	17
Median intrinsic hand muscles	45	5	11	10	30
Ulnar intrinsic hand muscles	44	5	11	9	30

[1] Functions recovering within 2 months of injury are not included in this analysis.

nerve injuries sensory recovery when clearly attributable to function of a given nerve suggests adequate motor recovery, in these high lesions it is frequently an accompaniment of recovery in proximal muscles only and does not preclude distal motor failure.

As one proceeds distally, the major decrement in proportion of recoveries is seen to begin below the elbow but never results in the level of improbability defined for finger motions of any kind after suture. A marked, and doubtless artificial, difference between median and ulnar flexors arises from a difficulty in analysis. Since the median flexors receive innervation from both lateral and medial cords, observations about them enter this table only when they were totally involved by damage to both medial and lateral cords. Because one of these cords was so often sutured, such spontaneous recovery as was recorded for these muscles could derive from only one-half their potential nerve supply.

A practical question concerns the timing of this spontaneous recovery— By what interval after injury does it occur if it is to occur at all? In the case of sensation, a large number of careful longitudinal observations is not available, nor is sensory recovery a primary concern in plexus injuries since it is never the limiting factor in function. It does appear that fingertip sensation can appear as late as a year after injury and still develop to a remarkable extent. In proximal muscles, down to and including the wrist flexors, recovery can begin as late as is consistent with regrowth of axons, e. g., up to 4 months for biceps and 7 months for wrist flexors, and still result in adequate function although an earlier trace of function carries a greater certainty of good strength.

Much shorter time intervals obtain for the first evidences of recovery in the distal muscles, if such recovery is to progress to useful function. In none of these cases with useful recovery to finger flexors and extensors or to hand muscles was action in these muscles delayed beyond 3 months after injury. This constant behavior is useful in the early clarification of prognosis although the reasons for it are uncertain. Since one may assume that regeneration, which would require up to 18 months for hand muscles, cannot contribute significantly to the useful distal function that develops early, if ever, how is it possible for neurapraxia to persist so long? One explanation would be an "alienation" of voluntary function continuing long after the potential for neuromuscular function exists. With more frequently encountered distal nerve lesions, it is not unusual to see an absence of voluntary function in intrinsic muscles of hand and foot and in extensors of foot and toes for weeks after nerve stimulation results in muscle contraction. In the personal experience of one of us, 4 plexus injuries with hand muscle paralysis which ultimately showed adequate recovery in these muscles all showed good contractions of these muscles on median and ulnar nerve stimulation when first done from 3 weeks to 6 weeks after injury. Clinical recovery soon followed in this group, but could well have been delayed additional weeks had patients not seen this proof of function. A possibility is that the duration of a block in neuromuscular conduction is actually short in all cases—possibly less than 2 weeks—that neurapraxia is compounded by alienation of voluntary function, and that nerve stimulation would very early (in the first month) define those brachial plexus lesions which will develop finger movement. In other words, the evidence suggests that distal muscles can recover only in the presence of intact axons suffering from temporary dysfunction.

C. DISCUSSION

Intelligent management of the brachial plexus injury depends upon answers to these questions:

1. How much spontaneous recovery is probable in a given injury and by what time does the end result become clearly defined?
2. To what extent does surgery of the brachial plexus assist in defining prognosis?
3. Under what circumstances does suture of plexus elements contribute to function and when should it be undertaken?
4. When are tendon transfers of value and how early can the indications for them be defined?
5. What additional rehabilitative measures should be considered in a given case?

1. Spontaneous Recovery

Most writers on this subject are in agreement that much of the initial total paralysis after brachial plexus injury can be a transient affair (neurapraxia) and that preservation of sensation is likely to be followed by early motor recovery (17). However, the time limits of neurapraxia are not stated beyond "up to a few weeks (70)." Nor has there been any clear definition of the time limit by which a further practical increment in functional recovery by any mechanism, including regeneration occurring spontaneously or after suture, can no longer be expected. Brooks (10) has gone so far as to state that the end result of recovery can be clearly anticipated by 9 months. On the other hand, Barnes (3) in a review of 63 cases, has made observations similar to ours; he concludes that, while proximal motor recovery can begin as late as 6 months and progress to good strength, distal muscles not working by 2 months will never regain useful function. A review of the management of the present series shows that no time limitation for recovery was generally accepted. As a result, patients with useless hands were continued on elaborate programs of physiotherapy up to 2 or 3 years so as to have joints and muscles in good condition when recovery should finally occur. This impression of long intervals necessary for clarification of recoverability has led to the advice that all plexus injuries should be explored to secure an early definition of prognosis.

With the general experience in more distal nerve lesions that paralysis of a muscle can exist for as long as 6 or even 9 months, and yet be replaced by a degree of action that contributes to function, it would seem logical to project such data to the brachial plexus injury and to assume that the same adequate regenerative process with longer distances to grow migh require as much as 18 months to set up intrinsic hand muscle function—that paralysis here should not be written off as permanent until such elapsed time since injury or suture. Further basis for optimism was found in the concept that any function in a given area was likely to be followed by more function, regardless of time, so that even 5 years after injury electromyographers who found motor units in a noncontracting muscle urged resumption of intensive physiotherapy.

The data collected in this study seem sufficiently significant to disprove many of these viewpoints, although it must be recognized that they were not proposed on the basis of fact but reflect a sincere desire to postpone, beyond any possible time limit for recovery, the discontinuation of any therapy that might improve a disabling situation. It is apparent that there is an absolute limit to the distance below a lesion at which regeneration of axons can contribute a useful degree of motor recovery. Any finger movements developing to a useful extent, whether from forearm muscles or intrinsic hand muscles, have achieved an end point in recovery long before they could be affected by axon regrowth. From the data available, it is established that such distal muscle recovery is heralded by some motor function within 3 months of injury. It can be further proposed (but not proved) that more frequent early clinical observations among these cases might have shortened this time limit—that an even further shortening could be achieved by general use of nerve stimulation which has demonstrated (in a number of cases perhaps not significant statistically) the presence of distal muscle contractions by 1 month if useful function is to result. Certainly the permanently useless hand, found as an end result in 65 of these cases, was defined at 3 months by the persistence of distal motor paralysis.

Early clarification of the potentials for hand function should result in a realistic pessimism. It is precisely in this same area where nerve surgery will not alter the outcome. It is an area of indispensable function whose absence can largely negate the value of proximal motor function achieved spontaneously or by suture.

The proximal muscles can, paradoxically, follow a slower schedule of recovery than distal muscles and progress to useful function because here the slow-going process of axonal regrowth can be effective. Examples of ultimately useful recovery begin as late as 4 months for deltoid, 5 months for biceps, 6 months for triceps, and 7 months for wrist extension. When the early definition of hand function has been favorable, these findings have an important bearing on management while the degree of proximal function has less significance in the face of a useless hand.

2. Surgery To Determine Prognosis

Some writers (3, 17) maintain that even when surgery fails to improve nerve regeneration it has been useful in cases of severe paralysis as a means of defining prognosis for recovery so as to permit more intelligent management. However, Brooks (10) has demonstrated that, except in the case of gross nerve disruption, the surgeon's description of lesions in continuity bears little relation to subsequent regeneration. Similar experience is described in the section of this monograph which deals with the neuroma in continuity. Furthermore, it has now become clear from our data that prognosis for hand function becomes established no later than 3 months by simple motor examination, which should ideally include electrical stimulation of the various peripheral nerves. The more slowly determined status of proximal muscles might well call for earlier definition by exploration, provided there will be a useful hand for these muscles to position. Since these are the same muscles whose function can be established by suture, it seems proper to dismiss this question by stating that the only necessary surgery is that which can improve function. Those elements which do not yield function through suture need not be inspected for their degree of continuity, even if this were always helpful, since their status is very clearly defined by distal physiologic events.

A further means has been found for the demonstration of root avulsion in stretch injuries, namely, the performance of a cervical myelogram. When this demonstrates extravasation of the dye into extraspinal pockets, the impossibility for recovery is defined for certain roots. While this test is of negative value only, it permits definition of the hopeless prognosis at a very early date.

3. Surgery of the Plexus as a Therapeutic Measure.

One question to be considered is whether neurolysis, or the release of external constricting scar, influences nerve function. When recovery follows such procedures, a cause and effect relationship is often presumed (24, 27, 76). Davis and Martin (17) have gone so far as to imply that lysis is important even with partial nerve function because "subsequent extensive scar tissue formation tends to impair to various degrees many originally uninjured portions of the plexus and gives rise to disseminated and incomplete motor and sensory disturbances." Certainly this external scarring can be so dense as to make the surgeon believe he must be performing a useful function in liberating the encased nerve. However, the absence of one well-documented case where there has been a clear regression of function, without further external trauma or growth of an aneurysm, forces the conclusion that peripheral nerve function does not deteriorate from progressive scarring, logical as this idea might seem. The causal relationship of neuroloysis to subsequent recovery is more difficult to evaluate. However, whenever good longitudinal data on motor and sensory status are available, such increments in function have occurred at a time consistent with the usual schedule for regeneration obtaining with reference to the date of injury rather than the date of surgery. One is therefore inclined to agree with the statement of Barnes (3): "It is important to appreciate it is intraneural damage and not extraneural scarring caused by associated soft tissue injury which is the barrier to recovery." The assumption is therefore made that, when surgery of the plexus is performed, only resection and suture alter the course of regeneration.

Before any discussion of what can be accomplished by suture, it should be stressed that this procedure should never be elected at surgical exploration in the absence of gross evidence for nerve discontinuity, unless sufficient time has elapsed to establish that the lesion is inconsistent with recovery. In early resections of lesions in continuity only histologic study will determine whether this was done in the face of a high degree of axonal continuity. Resection has clearly been unwisely undertaken when it destroys partial distal function which will never return (4 cases in this series).

Except for those who believe nerve function is favorably influenced by lysis, it is generally agreed that plexus surgery is of no benefit in stretch injuries (10, 27, 76). Neither has suture of disrupted nerve ends nor resection and suture of the segment most damaged ever been reported to yield function. Such was the case in two stretch injuries in this series in which suture was undertaken.

Opinions concerning the efficacy of nerve suture in the plexus after open wounding show considerable variance. Most enthusiastic reports deal with isolated cases subjected to early operation and suture of one element only, where subsequent improvement was not clearly attributable to the suture. Wider experience has led to conclusions such as that of Brooks (10) that "exploration of open wounds of the brachial plexus is rarely profitable or justifiable." These conclusions from the British experience with World War II injuries actually are based on only 11 sutured cases of which only 1 derived useful recovery consisting in shoulder abduction and elbow flexion after suture of the upper trunk.

In this series the possible contribution of suture to function is defined by noting those muscles capable of recovery (table 226). Suture of the following elements carries a high expectation of useful innervation: upper trunk or either of its roots for supraspinatus, deltoid, and biceps; lateral cord for biceps and a partial contribution to median forearm flexors; posterior cord for deltoid, triceps, and, with luck, wrist extensors. Suture of both lateral and posterior cords has resulted in a useful extremity when followed by tendon transfers for extension. While recovery of sensation to fingertips can occur through suture, the distal motor loss with those plexus injuries causing total sensory loss is so disabling as to negate the value of sensation gained by suture. Suture of the isolated median nerve injury below the plexus for its sensory contribution is another matter.

Suture of the lower roots or of the medial cord is not capable of contributing to useful function except when the damage is partial. If either the ulnar half or the median half of the cord is functioning, suture of the damaged element has been of value.

In considering the individual patient or his extremity as a whole, the value of suture, undertaken to achieve proximal function, is questionable in the face of permanent distal loss. If one reviews the 89 cases subjected to suture, designating those who achieved a functioning arm rather than just some new muscles after surgery, the number is discouragingly small—28. At the same time, one has the feeling that rehabilitation possibilities were missed, measures whose application would have turned more of these proximal recoveries to practical use in the overall function.

Despite the certain limitations on recovery from suture of the inferior portions of the plexus, the situations where surgery can contribute are clearly defined, and in these same situations the contribution is probable rather than possible.

An early time for plexus surgery is urged by some writers (17, 27) on the basis that: (a) earlier suture is accomplished when badly damaged nerves are discovered (with better regeneration as a result); and (b) exploration is technically easier and less likely to result in damage to normal nerves before dense scarring has occurred. At the other pole are those (76) who feel that suture has so little to offer, in comparison with spontaneous recovery, that no part of the plexus should be even handled until its potential for recovery has been clarified by 6 to 9 months of observation.

The material under consideration presents one urgent argument for early exploration of injuries at the cord (rather than the root) level, namely, the rather frequent finding of a traumatic aneurysm of the axillary artery in proximity to nerve elements and causing an increasing involvement of axons with the passage of time. Ten such aneurysms were found in this series. The nerves showing dysfunction were doubtless affected by the initial wound but were directly impinged upon and often thinned out by the aneurysm. In 3 of these cases a partial nerve deficit progressed with the passage of time but in the remaining 7 the paralysis was present from the time of wounding. However, there is still evidence in the similar operative findings for the two groups that the growing aneurysm caused structural damage to nerves, quite probably superimposing axonal disruption upon an initial neurapraxia. In the absence of progressing paralysis, because of masking neurapraxia, these aneurysms were still recognized by increasing axillary mass or bruit in 5 cases. However, in the remaining 2, the aneurysm was an unanticipated finding when surgery was undertaken solely for purposes of plexus exploration. The medial cord was involved in 8 cases and served by itself to prevent functional recovery, whether sutured or simply lysed. The lateral head of the median was involved in 5 of these cases. Surprisingly, in 5 instances the posterior cord was affected. In 2, where the medial cord was intact, posterior cord suture permitted useful recovery with the assistance of tendon transfers.

In summary, 8 of the 10 aneurysms ended up with useless arms, while 2 had serious residual deficits. In the 2 cases with poor end results who developed paralysis late (at 10 days and 17 days) earlier intervention would clearly have been "arm saving." It is certainly possible that the other 8, none of whom suffered actual nerve division from the original wounding, would have fared far better with early attention to the aneurysm, which was delayed from 1 to 7 months. Since aneurysm was found unexpectedly in 2 instances (both at 5 months) there may be an argument for exploring all cord lesions early on the possibility of finding this progressively destructive lesion. However, the unexpected aneurysm remains a rarity and is probably diagnosable if looked for repeatedly in every plexus cord lesion by combining careful palpation and auscultation of the wounded area with the neurological evaluation in all patients routed to the "nerve specialists."

If suture will make a significant contribution to function, its early performance will both shorten the period of dysfunction and improve the ultimate result, although any proximal muscles capable of useful recovery after suture do not appear to show a critical reduction in strength up to 6 months of delay in suture. Good proximal recovery was seen after 8 months delay but the proportion of recoveries decreased at 6 months. In addition, the technical difficulty of exploration increases with the passage of time. The following views as to timing of brachial plexus exploration seem tenable. (a) If paralysis is limited to proximal muscles, explore the appropriate roots or cords early because the finding of any gross discontinuity and its correction by suture will give the best possible result. However, any lesion in gross continuity must be left alone with the necessity for a second operation to resect and suture if recovery does not occur in 3 to 6 months, depending on the distance for regrowth to muscle. (b) If paralysis involves those distal muscles which will be uninfluenced by surgery, and proximal muscles whose isolated recovery will contribute little, surgery can be deferred for 3 months to determine whether distal recovery, even with tendon transfers, is consistent with hand function. In other words, the question must be settled whether a gain in proximal motor function will be useful to the patient.

4. The Use of Tendon Transfers

The literature on tendon transfers for the improvement of motor deficits is extensive and is particularly well reviewed by Bunnell (12), Littler (43), and Brooks (9). Nevertheless, this often all-important link in therapy is seldom stressed in writings about the overall management of nerve injuries. Failure to institute these important rehabilitation measures in this series stemmed from such factors as the extensiveness of motor deficit, false optimism concerning the possibility of late improvement in function from nerve regrowth until elapsed time forced a halt to all therapy by closing of hospitals or discouragement of patients, plus lack of realization of the neurosurgeon concerning feasible alternatives to nerve function, coupled with unavailability of surgeons skilled in these procedures in many centers where nerve injuries were treated.

Examples of the situations where tendon transfers are of benefit have been given and are summarized in table 225. The clearest indication is the isolated failure of wrist and finger extensor recovery. This indication existed in 3 cases of primary posterior cord damage and in 12 more cases of multiple nerve involvement where reasonable recovery occurred in the other elements. Actually, only 6 of these 15 cases were given the benefit of this procedure with good results in 5. The remaining cases might have been given useful hands with the occasional requirement that the procedure be accompanied with a wrist fusion, where weakened flexor tendons were inadequate to extend both wrist and fingers.

The other opportunities for striking improvement of hand function have occurred with partial loss of intrinsic hand function in partial medial cord lesions. Three cases with such incomplete loss and inadequate thumb opposition were given this function by tendon transfer while an apparent indication was neglected in 2 others. In 2 cases with good forearm flexors and sensation, both extensor and opposition transfers were done with achievement of both satisfactory finger extension and thumb opposition. Two additional men with partial medial cord lesions, with clawing of fourth and fifth fingers, were enabled to open these fingers by tendon transfers to stabilize the metacarpophalangeal joints.

So much for the clear indications for tendon transfer. In 10 pure medial cord lesions and in 5 multiple lesions, the residual deficit was total loss of intrinsic hand muscle function in the face of good sensation and working forearm muscles. However, too few of these forearm muscles were considered sufficiently strong to provide both opposition of thumb and stabilization of curled fingers to oppose the thumb. In these situations it would appear that appropriate joint fusions combined with tendon transfers would have resulted in at least a thumb-to-finger pincers action for handling objects, as a marked improvement over the useless clawed hand which could be employed only as a paper weight.

In considering the possibilities for tendon substitutions, sources for failure should be stressed. Experience with procedures proven feasible, and with technical details of such surgery, is essential to success, as well as the recognition that minimal residual weakness in muscles serving as motors causes a major reduction in their effectiveness. In three failures in this series, either another strong muscle should have been chosen or, failing such choice, the weakened muscle might have contributed to function with its load reduced by joint fusions.

As to timing, where such a good guess can be made as to permanent deficits in hand function at 3 months, and partial function reaches a limit in improvement soon thereafter, there seems little reason why these procedures cannot be recognized as essential to function and undertaken by 6 months.

5. Other Rehabilitative Measures

Maintenance of unrestricted joint movement by physiotherapy and avoidance of overstretching of inert muscles by splinting are necessary considerations in management during a temporary period of motor paralysis. The great difficulty in many plexus injuries has been the institution of these measures without any plan by doctor or patient as to their duration. On the one hand is seen the frequent patient whose major energies over a 2-year period or more were devoted to the nursing of what was to be always a useless extremity. In such individuals the attention of well-wishing therapists served only to increase frustration and pain complaints and to block the direction of energy to a realistic adjustment and compensation for a permanent handicap. If we can now accept the evidence that the prognosis for function, at least for the all-important distal muscles, becomes defined by 3 months, there should be little reason for inability to define what will be useful therapy at a relatively early period. On the other hand, one finds patients (at least eight in this study) in whom concentration on such rehabilitation measures might have allowed real use of an arm, either by themselves or with the assistance of tendon transfers.

In particular, the less frequent recovery of shoulder abduction in comparison with elbow flexion appears not to depend upon any less frequent motor recovery. Rather, restricted shoulder joint movement coupled with overstretching of paralyzed muscles appears to account for this difference in results, presumably remediable by greater attention to shoulder mobility and splinting in abduction.

Pain rarely constituted a barrier to rehabilitation in these patients with major nerve damage. True causalgia, relieved by sympathectomy, was found in only two cases with minimal involvement of medial or lateral cord. Prolonged and distressing pain, often requiring narcotics and not relieved by sympathetic blocking, was an occasional but by no means constant manifestation in total nerve involvement. Such discomfort frequently had the characteristics of phantom limb pain, with referral to totally anesthetic areas of the extremity. Late follow-up indicated that this pain had gradually subsided over a period of months without relation to any specific therapy except in two instances where amputation was followed by marked pain relief.

Loss of shoulder abduction was an isolated handicap in 4 cases. (See table 225.) Considerable improvement in the ability to position the arm has been obtained by both shoulder fusions and tendon procedures (2, 16, 48, 58), none of which was utilized in these cases.

Loss of elbow flexion as observed in four cases might have been corrected by a number of procedures. British authors (2) indicate that the Steindler operation has not worked favorably. Seddon (69) has had dramatic success in securing flexion by utilizing the lower portion of the pectoralis major as a motor for the biceps. Fortunately, this is usually spared in superior plexus injuries involving biceps. Hendry (34) suggests another alternative which he claims is superior to elbow fusion; the performance of a posterior bone block at the elbow which checks extension at a given limit but still allows a range of further passive flexion for use in placing the hand on a table while sitting, etc. Again such measures did not receive serious consideration in these patients.

There were some 32 patients in this group who had sufficient proximal function to provide good movement at shoulder and elbow but such total or near total paralysis of forearm and hand that no combination of tendon transfers and fusions could have given even a useful pincers. Accordingly, the arm was of little use despite this excellent proximal action. One possibility for achieving function of the arm would have been to amputate the hand with substitution of a prosthesis having a pincers action controlled by the opposite shoulder. Certainly patients with forearm amputation at initial injury ended up with a far more useful arm simply because this amputation, which physicians disliked suggesting and patients were loath to accept, had occurred fortuitously. As a result, prompt training in the use of a prosthesis was immediately undertaken. Another alternative for the flail hand, provided there are mobile joints and enough proximal forearm innervation to allow at least weak pronation and supination, is suggested by Hendry (34). Flexor and extensor tendons are fused to bone above the wrist in such a way that when supination causes the hand to dorsiflex (by gravity) the fingers close, while turning the arm into pronation drops the wrist with opening of the fingers. It is claimed that patients can attain fair facility in handling light objects and will prefer such a mechanism to a hand prosthesis.

Finally, there were 8 patients (5 were stretch injuries) with such total paralysis of entire arm and shoulder that amputation below the shoulder joint might actually have resulted in better rehabilitation. Even if one neglects the long period during which active treatment to regain arm function was fruitlessly pursued and considers the end result, he is still impressed by the amount of energy which the patient must devote to nursing this dead weight, which not only has no function but interferes with many activities by being in the way. The 4 patients who accepted such amputation expressed no regrets, but rather satisfaction at being freed of this encumbrance and, in 2 instances, attributed to the procedure a marked relief in pain.

Such then are some of the rehabilitation measures that might have been more widely applied had there been a clearer realization of the early ability to predict the limitations in nerve regeneration in each case and the available measures for at least partially substituting for nerve function. Reference to table 225 indicates that, of the 75 poor results, 20 could have achieved relatively useful arms through tendon transfers and joint fusions, 15 might have had at least a pincers action for grasping objects instead of clawed hand, and 32 more could have put their wounded extremity to some use by substituting a prosthesis for an inert forearm. This leaves only 8 unsalvageable situations, 5 of them stretch injuries where high amputation might be indicated, and was actually of considerable benefit in 4. It must be remembered that how much a patient will use his hand can be vastly affected by providing only one missing link in its function.

D. CONCLUSIONS

1. Suture of upper plexus elements carries a high probability of restoring useful function to muscles of shoulder and upper arm, except in stretch injuries.

2. The major disability in brachial plexus lesions occurs when its lower roots or medial cord elements are involved with loss of hand function.

3. Such deficits are not improved by surgery of the plexus. Recovery of hand function must depend upon spontaneous recovery which becomes

defined by 3 months, since it cannot be assisted by axonal regeneration.

4. When such deficits are incomplete, yet disabling, tendon transfers, sometimes in combination with joint fusions, may permit useful function. These procedures, when indicated, can be correctly planned and undertaken as early as 3 months and never later than 6 months after injury.

5. An understanding of the time limitations upon useful recovery should lead to earlier utilization of all possible accessory rehabilitative measures with improvement in results and in 75 percent curtailment of time necessary for active treatment.

Chapter X

CASE STUDY OF THE BEST AND POOREST RESULTS FOLLOWING PERIPHERAL NERVE SUTURE

Barnes Woodhall

A. INTRODUCTION

Although the statistical analysis of the factors influencing the regeneration of peripheral nerve injuries may show trends of indisputable significance, it cannot illustrate the ideal case where all factors are so blended that they produce the maximum return of function of which each nerve may be capable. This method may readily portray those factors that mitigate against good regeneration; the obverse can then only be surmised by the absence of such adverse factors. Whether this is a valid assumption or not, it is a fact that the experienced observer can peruse a succession of individual case reports and form substantial opinions concerning the probable cause of adequate or poor neural regeneration. This approach has been taken with a moderately large group of case histories in which regeneration was recorded as developing to a point that might be termed maximal, and with a similar group in which little or no regeneration was noted after a period of many years.

Ten examples of maximal regeneration and a like number with virtually no evidence of regeneration were selected from each of the 7 nerve groups (median, ulnar, radial, tibial, peroneal, sciatic-tibial, and sciatic-peroneal), a total of 140 cases. They were chosen primarily on the basis of the two modified British summaries, one of motor recovery and the other sensory. The specific criteria, of course, varied by nerve, and as shown in table 228. Use of these motor and sensory criteria produced more than 10 examples in each group. Autonomic recovery and overall functional evaluation, therefore, were used to make the final selection of 10 cases from among those eligible under the motor and sensory criteria for each group. Thus, an example of very poor recovery in the median nerve might have: (1) a complete absence of sensibility; (2) an elevated skin resistance in the total area of nerve supply; (3) an overall functional evaluation of 30 percent or less; and (4) either no motor recovery or at most just perceptible contraction in proximal muscles. An example of very good recovery would include: (1) perception of superficial pain and touch throughout the autonomous sensory zone plus some two-point discrimination; (2) normal skin resistance; (3) an overall functional evaluation of 80 percent or more; and (4) contraction against resistance on the part of all important muscles, both proximal and distal, plus capacity for some synergic and isolated movements.

Table 228.—*Motor and Sensory Criteria Employed in Choosing Examples of Good and Poor Recovery Following Complete Suture, by Nerve*

Nerve	British motor	British sensory
	Good recovery	
Median, ulnar, and radial	At least all important proximal and distal muscles acting against resistance plus capacity for some synergic and isolated movements.	At least return of superficial pain and touch, plus some 2-pt. discrimination in autonomous zone.
Peroneal	At least all important proximal and distal muscles acting against resistance.	At least return of superficial pain and touch throughout autonomous zone.
Tibial	Same as peroneal	At least return of some superficial pain and touch in autonomous zone.
Sciatic-peroneal	At least proximal muscles acting against gravity, perceptible contraction in intrinsics.	At least return of superficial pain and touch throughout autonomous zone, with overreaction and inability to localize.
Sciatic-tibial	Same as sciatic-peroneal	At least return of some superficial pain and touch in autonomous zone.
	Poor recovery	
Median	At most perceptible contraction, proximal muscles only.	At most deep cutaneous pain sensibility in autonomous zone.
Ulnar	No contraction at all	Same as median
Radial	Same as median	At most return of some superficial pain and touch, autonomous zone.
Peroneal	Same as ulnar	Same as median.
Tibial	Same as median	Same as median.
Sciatic-peroneal	Same as ulnar	No sensibility in autonomous zone.
Sciatic-tibial	Same as median	Same as sciatic-peroneal.

The extent of neural regeneration has been charted against the major variables that are assumed to influence regeneration, in particular those that are capable of assessment, that is, location of wound in the extremity, time of definitive treatment after injury, extent of the neural defect, existing neural pathology, and presence of complicating factors such as infection, concomitant vascular, bone, and extensive soft tissue injury, and surgical error. Much use has been made of illustrative case material and indeed it is from this that the reader may form his own opinions. The author has chosen to retain these case reports in their original form, and in consequence, tense, style, etc., are not uniform. A summary case report was not required by the protocol, and in most centers was not routine. In the Philadelphia center, however, Dr. Lewey early insisted upon their preparation and for this reason it is largely from the Philadelphia cases that the illustrative material has been drawn. Finally, an effort has been made to draw together and summarize the pertinent data of this case study.

B. UPPER EXTREMITY

1. Median Nerve

The salient features of 10 examples of median nerve recovery at its best are abstracted in table 229, and the details of several then follow. Associated nerve lesions are shown only if suture was required; incomplete, lysed lesions are omitted.

Case Report 4452

HISTORY OF INJURY

This soldier was wounded in action in Italy on April 8, 1944, by a shell explosion, receiving multiple perforating wounds of his left forearm in its lower third and also of his left face. He showed some impairment of his left median nerve with loss of flexion of the 1st, 2d, and 3d fingers, and anesthesia of the palm of the hand and superior half of the 1st, 2d, and 3d fingers. On October 2, 1944, neurorrhaphy was done on the left median nerve at Wakeman General Hospital. In the middle third of the forearm the median nerve showed a lateral neuroma adherent to the adjacent muscle tissue; after an attempt to enucleate this tumor mass without damage to the nerve, only a few shreds of nerve were left, and it showed no response to electrical stimulation. It was therefore resected to a gap of 3 cm. and sutured with silk. Seven months postoperatively the patient had 75 percent function in all median muscles, except the opponens which had 50 percent and the flexor pollicis brevis which had none. At 9 months all median muscles showed 75 percent function. This was the patient's status at discharge on August 16, 1945.

INTERVAL HISTORY

The patient has had no treatment since discharge, but he has noted the return of ability to adduct his index finger. There has been increased sensation in the palmar surface of the 1st, 2d, and 3d fingers, and all hand motions are stronger. His chief complaint is diminished sensation in the first three fingers, difficulty in picking up small objects, and a drawing up of his forearm in cold weather. He has pain with use and rapid fatigue

Table 229.—*Characteristics of Median Nerve, Cases With Good Recovery*

Characteristics of case	Case numbers									
	3925	[1] 4266	[1] 4366	[1] 4452	5081	5086	5224	5245	5326	5332
Lesion										
Pathology	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.
Site	Wrist	Forearm, middle ⅓	Arm, lower ⅓.	Forearm, middle ⅓.	Forearm, upper ⅓.	Forearm, lower ⅓.	Forearm, middle ⅓.	Arm, lower ⅓.	Wrist	Arm, lower ⅓.
Associated lesions and complications.	Artery	Fracture	Artery		Plastic repair.	Ulnar N., tendon.		Fracture	Fracture, artery, plastic repair.	Artery.
Definitive suture										
Days after injury	1	130	130	170	220	1	210	60	130	130.
Tension	None	None	None	None	None	None	Moderate	None	None	None.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Done	Not done	Not done	Not done.
Suture material	Plasma	Tantalum	Tantalum	Silk	Silk	Silk	Tantalum	Tantalum	Tantalum	Tantalum.
Surgical gap, cm	1	3	6	3	4	1	9	7	2	5.
Follow-up examination										
British motor [2]	Complete recovery.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.
Pain threshold, gm	<6	<6	10	30	6	<6	30	6	10	20.
British sensory [3]	Complete recovery.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.
Skin resistance	Normal	Normal	Normal	Normal	Normal	Normal	Decreased	Elevated	Normal	Elevated.
Overall function, percent.	90	90	80	60	80	80	90	90	80	80.

Relative power [4]										
3-Fl. poll. long	Not affected.	15	100	100	100	Not tested	Not tested	Not tested	Not tested	?.
4-Fl. prof. ind	Not affected.	35	15	100	90	90	80	30	70	40.
5-Opponens	100	35	80	14	70	80	60	80	90	75.
6-Abd. poll. brev	100	28	20	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested	Not tested.

[1] Case reported in text here.

[2] The rubric abbreviated here as "synergic and isolated" is "Return of function in both proximal and distal muscles so that all important muscles can act against resistance, and some synergic and isolated movements are possible."

[3] The rubric abbreviated here as "pain and touch, 2-pt." is "Superficial cutaneous pain and touch throughout autonomous zone, no overresponse, and two-point discrimination in autonomous zone."

[4] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

only with heavy work. Before the war he was a pipefitter's helper. He changed his occupation because he was afraid of damaging his hand. He is now a trucker for the railway express and is slightly handicapped by the inability to do heavy lifting and he also takes time off sometimes because of his arm. His compensation is 30 percent, and he is satisfied with this.

CENTER EXAMINATION March 3, 1950

The patient is left handed. Distance of the injury is 9¼ inches[22] and there is a "hot spot" present. The injured hand shows some atrophy of the thenar eminence and the middle phalanx of the index and middle fingers is smaller than normal. The forearm is diminished ¼ inch in circumference. The injured hand is slightly cooler than normal but pulses are equal and full. There is no limitation of motion at the wrist or elbow but there appears to be some flexion contracture of all fingers. The patient is able to pick up a pail of water and to button his shirt, but he is unable to pick up a pin with his eyes closed and he now uses his right hand for most manipulations.

In a typical median distribution the patient is able to feel 30 gm. pain and 16 gm. touch; because of calluses, the threshold for the normal part of the hand is 20 gm. pain and 3–5 gm. touch. There is no split sensation and there is good localization, but on the thumb two-point discrimination is 2.5 cm. and on the index finger 7 cm., compared with 2 cm. on other fingers. Position sense is slightly impaired in the median distribution. Deep pressure is almost absent on the index finger and impaired on the thumb and middle fingers. Skin resistance is about normal in the median area of the hand and normal to slightly increased in the ulnar area.

Quantitative muscle evaluation is as follows: Flexor carpi radialis, palmaris longus, and flexor carpi ulnaris 100 percent; flexor pollicis longus 100 percent; flexor pollicis brevis 100 percent; flexor digitorum profundus to all fingers 100 percent; flexor digitorum sublimis to the index finger 100 percent, to the little finger 100 percent; opponens 14 percent; abductor pollicis brevis not tested. Flexor digitorum sublimis to the middle finger had a rheobase of 35, a chronaxie of 0.36; the opponens had a rheobase of 110, a chronaxie of 0.12.

Functional evaluation. This patient has good practical function in his hand and arm; by testing, all muscles show almost 100 percent function, and his sensation is not greatly diminished. If it is true that this patient was left handed and therefore if it was his dominant hand that was injured, he may be slightly handicapped by loss of very fine and skilled movements and also by some lack of sensitivity. Because this was a low median nerve injury, only two muscles (abductor pollicis brevis and opponens) should have been affected, and these as well as sensory function in the hand show a fair degree of return of strength and practically a good degree of function.

---

[22] Measured from the carpal crease in all cases of upper extremity injury.

Case Report 4366

HISTORY OF INJURY

This soldier was accidentally shot by a guard in Luxembourg on October 18, 1944. The rifle bullet penetrated his left upper arm in the lower third of the medial aspect, severing the brachial artery and the median nerve. There was also a fracture of the proximal phalanx of the right index finger. At debridement the same day the median nerve was seen to be severed 2½ inches above the elbow, while the ulnar and medial antebrachial cutaneous nerves were intact. The brachial artery was ligated and the median nerve approximated; penicillin was placed in the wound. Six weeks later the patient had osteotomy performed on the right index finger. On March 3, 1945, neurorrhaphy was performed on the left median nerve at Kennedy General Hospital. At the site of approximation there was a 2-cm. neuroma and there was no electrical response in the nerve. The median nerve was resected 5.5 cm. to good fibrils, sutured with tantalum and wrapped in a tantalum foil. Five months postoperatively there was good function in the pronator teres, flexor carpi radialis, palmaris longus, and flexor pollicis longus. At discharge on December 17, 1945, the pronator teres showed 75 percent function, the flexor carpi radialis 75 percent, the flexor digitorum sublimis and flexor pollicis longus 25 percent, the flexor indicis proprius and the opponens 0; there was some sensory return with spread.

INTERVAL HISTORY

The patient has had no treatment since discharge but his wrist and finger movements have increased in strength. He complains primarily of inadequate sensation and also of limitation in fine hand movements. Before the war the patient was a steam-shovel operator and he has returned to the same job since the war. He is limited because of fatigue in his injured arm to 50 percent of his previous earnings. The patient's compensation is 50 percent and he is not satisfied.

CENTER EXAMINATION November 9, 1949

The patient is right handed. Distance of the injury is 14 inches. There is no marked atrophy, but the forearm is diminished 1 inch in circumference. Pulses are full and strong, and the hands equally warm and moist. Wrist extension is limited to 115 degrees, and there is a slight impairment in flexion of the 2d and 3d fingers. The patient is able to pick up a pin between his thumb and index finger, but is unable to do so with his eyes closed. He is able to pick up approximately 40 pounds weight.

Throughout the entire hand the patient is able to feel 6 gm. pain and 5 gm. touch. Deep pressure and position sense are unimpaired. Skin resistance is not noticeably different from that in the normal hand. There is no split sensation.

Quantitative muscle evaluation is as follows: Flexor carpi ulnaris, flexor carpi radialis, and palmaris longus 100 percent; pronator teres 100 percent; flexor pollicis longus 100 percent; flexor pollicis brevis 70 percent; flexor digitorum profundus to the index finger 15 percent, to the middle finger 95 percent, to the ring and little fingers 100 percent; flexor digitorum sublimis to the index finger 60 percent, to all other fingers 100 percent; opponens 80 percent. The opponens shows a rheobase of 85, a chronaxie of 0.28.

Functional evaluation. This patient has excellent motor function in his arm, and our testing shows the sensory function to be quite good. However, he complains that he is unable to perform fine movements with his hand and that he is limited by his lack of sensation. We might, therefore, list him as possessing many skilled but awkward movements with some limitation through lack of sensation.

Case Report 4266

HISTORY OF INJURY

On September 16, 1944, this soldier was wounded in action in Germany, receiving a rifle bullet in the upper third of his left forearm with fracture of the left ulna and anterior dislocation of the left radius. There was no return of function below the pronator teres, and on February 1, 1945, neurorrhaphy was performed on the left median nerve. There was a 2-cm. neuroma in continuity 3 inches below the elbow, and there was no electrical response on stimulation. The nerve was resected 3 cm. to good tubules, sutured with tantalum, and a tantalum foil placed about the site of suture. At discharge on December 12, 1945, there was good function in the forearm muscles, no function in the median intrinsics, but some perception of light touch and deep pain.

INTERVAL HISTORY

The patient has had no treatment since discharge other than a brief period of physiotherapy. He has noted return of function in the long flexor of his thumb, increased strength of grip, and improved sensation in his fingers. His chief complaint is in diminished maneuverability of his hand, but he can perform all functions with the hand. He has no complaint of pain. He works as a clerk for the Government and does not feel handicapped by his injury. His compensation is 50 percent, of which 40 percent is for his hand injury.

CENTER EXAMINATION August 5, 1949

The patient is right handed. There is slight diminution in substance of the forearm but no gross deformities. There are trophic changes over the median area of the palm and in the nails of the thumb and index finger, and there is loss of pulp in these fingers. The distance of the injury is 10½ inches from the carpal fold, and at this site the tantalum cuff is palpable. There is no "hot spot." The left ulna is ¼ inch shorter than the right. There is no joint limitation. He has a very strong grip and is able to lift a chair with ease although this strength fades out after several minutes. He can pick up a pencil with his eyes shut, or a pin with his eyes open; he is able to pick the correct coin out of his pocket.

In a typical median distribution he perceives 2 gm. pain and 3 gm. touch, with a very minimal amount of hypersensitivity. There is no split sensation on the palm, and less than 1 cm. on the backs of the fingers. Deep pressure is felt with mild discomfort and referred each time to another digit. Two-point discrimination on the thumb is 4 mm. compared with a normal of 2, on the index finger 12 mm. compared with a normal of less than 2. Skin resistance is very slightly increased over the median distribution. Photographs were made of the hand showing opposition and also the trick movement of short abduction.

Quantitative muscle evaluation gave the following results: Flexor carpi radialis, palmaris longus 100 percent; pronator teres 75 percent; flexor digitorum profundus to the second finger 35 percent, to the third finger 100 percent; flexor digitorum sublimis to the second finger 80 percent, to the third finger 100 percent; flexor pollicis longus 15 percent; flexor pollicis brevis 100 percent; opponens 35 percent, with substitution; abductor pollicis brevis 28 percent, with substitution. Percutaneous stimulation of the median nerve at the elbow gave good response in all median muscles. The flexor pollicis longus had a rheobase of 185, a corrected chronaxie of 4.0; the opponens had a rheobase of 85, a chronaxie of 2.4. Electromyography was done on the opponens; on supermaximal stimulation this muscle gave spikes of 2.4 inches compared with a normal of 4.0 inches.

Functional evaluation. This patient has excellent functional return, both motor and sensory. He is practically not handicapped. This is a high grade of motor and sensory return. The intrinsic actions of opposition and short abduction are present, but assisted by trick movements.

The ten examples of poor recovery are summarized briefly in table 230. The cases chosen for detailed presentation follow.

Case Report 4004

HISTORY OF INJURY

On October 29, 1944, this patient suffered multiple shell-fragment wounds resulting in bilateral wrist drop and left ulnar and median paralysis from shoulder injuries. By December 27, 1944, the right wrist drop had cleared and only median motor and sensory paralysis persisted on the left. On June 6, 1945, the left brachial plexus was explored and the median nerve was found to be severed 3 cm. distal to the site of its formation from the lateral and medial head. In addition, there was an accessory lateral head which came from the anterolateral trunk to join the median nerve in the upper one-third of the arm; this also was severed. After resection of neuromata there was a gap of 6 cm. (accessory head not stated), the proximal end of which looked good but the distal end contained gelatinous material. The nerves were sutured with black cotton. The other nerves responded well to electrical stimulation. He was given a disability discharge on October 8, 1945, at which time he had not yet shown evidence of return of function in the median distribution.

Table 230.—*Characteristics of Median Nerve Cases With Poor Recovery*

Characteristics of case	Case number									
	1083	1171	2039	2191	3842	4004 [1]	4110 [1]	4307 [1]	4336 [1]	4514
Lesion										
Pathology	Complete division.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.
Site	Arm, upper ⅓.	Arm, upper ⅓.	Wrist	Arm, upper ¼.	Wrist	Arm, upper ⅓.	Arm, middle ⅓.	Arm, upper ⅓.	Forearm, upper ⅓.	Arm, middle ⅓.
Associated lesions and complications.	Ulnar nerve.	Ulnar and radial nerves, artery.	Ulnar nerve, initial suture to tendon, frostbite, infect., pl. repair.	Ulnar nerve, artery.	Infection, plastic repair.		Ulnar nerve, fracture, artery.	Artery	Radial nerve, infection.	Musculocutaneous nerve.
Definitive suture										
Days after injury	600	110	560	200	160	220	300	130	220	100.
Tension	None	Severe	?	Moderate	None	Mild	Severe	Mild	None	None.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Done	Not done	Not done	Not done.
Suture material	Silk	Tantalum	Tantalum	Silk	Plasma	Cotton	Tantalum	Silk	Tantalum	Tantalum.
Surgical gap, cm	4	9	5	9	3	6	>12	6	6	4.
Follow-up examination										
British motor	Proximal only, perceptible.	Proximal only, perceptible.	No contraction.	Proximal only, perceptible.	No contraction.	No contraction.	Proximal only, perceptible.	No contraction.	No contraction.	No contraction.
Pain threshold, gm	40	Deep only	?	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.
British sensory	Deep pain only.	Deep pain only.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.

Skin resistance	Elevated	Elevated	Mixed	Elevated	Elevated	Elevated	Elevated	Elevated	Not tested	Not tested.
Overall function, percent.	0	0	30	0	40	20	0	0	0	20.
Relative power [2]										
3-Fl. poll. long	Not tested	0	Not affected	0	Not affected	0	0	0	0	0.
4-Fl. prof. ind	Not tested	0	Not affected	0	Not affected	0	Perceptible	0	0	0.
5-Opponens	0	0	?	?	0	0	0	0	0	0.
6-Abd. poll. brev	Not tested	0	Against resistance, unmeasured.	0	Perceptible	0	Perceptible	0	0	Not tested.

[1] Case reported in text here.

[2] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

INTERVAL HISTORY

This patient has had no treatment since discharge. A prewar turret lathe operator, he is now in college studying industrial engineering. His complaints include spontaneous pain, occasional paresthesias, coldness, ulcerations, and pain with use of the left arm. In his right arm he complains of numbness in the medial aspect of his right hand and arm. His compensation is 60 percent.

CENTER EXAMINATION March 24, 1948

The injury is 29 inches above the distal palmar crease.

Sensory examination. There is no return of sensation in the median area.

Motor examination. He has no function in proximal or distal median muscles.

Electrical examination. There was no reaction to direct stimulation of the median muscles. Intraneural stimulation at the wrist gave no reaction in the median intrinsics.

POINTS OF SPECIAL INTEREST

This is a high median injury sutured 7½ months after injury in which there has been no return. Intervention was delayed after injury because of the feeling that the median was returning spontaneously. However, at exploration the nerve was seen to be completely severed, and there is no evidence of anomalous innervation. Reexploration of the suture line was recommended to the patient.

Case Report 4307

HISTORY OF INJURY

In 1943 this patient had an episode of what was called cerebrospinal meningitis, which by description is strongly suggestive of multiple sclerosis. On June 12, 1944, he received a penetrating wound in the left side of the neck and ruptured left ear drum. No sequelae. On July 30, 1944, the patient was wounded in the left axilla by a high explosive shell. The left brachial artery and vein were found severed and were ligated 2 hours later. The left median nerve was found to be fully severed and was approximated with black silk at the same time. A neurorrhaphy on the left median nerve was performed on December 13, 1944, 4.5 months after injury. The nerve was resected 6 cm. and sutured with black silk.

CENTER EXAMINATION

Examination shows very little function in the median nerve, either motor or sensory, but there is a bizarreness of functional deficits in the ulnar and radial areas as well, and these again suggest that he may have an overlay of stigmata of multiple sclerosis. He cannot open his hand very widely, and the use of the hand is limited to picking up small and quite light objects; functionally, he can do practically nothing with the arm. He has been able to continue at his previous skilled job, but as a result of his injury he can put in only half the time that he could previously and therefore his wages are cut in half; despite this, he leads a very active life and is able to support both his wife and his mother. This is a typical median nerve injury with repair 4.5 months after wounding but with practically no return of function; the part played in this poor result by multiple sclerosis is debatable.

Case Report 4110

HISTORY OF INJURY

Patient was injured by shell fragments in France on June 22, 1944. He sustained a compound comminuted fracture of his right humerus in the middle third, and there was some damage to the right biceps muscle group and the brachial artery and plexus. Clinically, a median and ulnar nerve palsy was noted. October 8, 1944, bulb suture of the median was carried out. December 20, 1944, skin grafts were performed over the right hand to burns incurred while on furlough. April 20, 1945, the median and ulnar nerves were sutured at the Newton Baker General Hospital with anterior transplantation of the ulnar nerve. October 4, 1945, arthrodesis of the right wrist was performed with excision of the distal head of the radius and the proximal row of carpal bones. April 27, 1946, discharged for disability, with no functional return, elbow partially ankylosed, operative fixation of wrist, anesthesia in forearm and hand, and significant vascular insufficiency.

CENTER EXAMINATION September 10, 1948

Patient was right handed and 23 years of age at the time of injury. The suture was carried out 16 in. from the distal palmar crease. The diameter of his arm 4 in. above the olecranon was 11 in. on the injured side and 12¼ in. on the normal side. Four inches below the olecranon it was 8⅞ in. on the injured side and 11⅜ in. on the normal side. The radial pulse is only faint at the wrist on the right side. There is definite limitation of joint function. He can extend the elbow to only 133 degrees and flex it to only 62 degrees. There is no movement at the wrist whatsoever secondary to the arthrodesis. There is no pronation or supination and only slight voluntary movement of no more than 15 degrees range in the fingers. All the interphalangeal joints are limited in motion and there is almost a complete flexion contracture of the fingers of the hand. The hand is definitely colder than normal, particularly from the middle of the upper arm down. There is marked tapering of all the fingers with loss of substance of the pulp. The nails of the 4th and 5th fingers are distorted and contain a horny growth. There is marked callus over the distal interphalangeal joint and the dorsal surface of the ring finger. All in all, this is the worst appearing hand we have seen since we began examining patients at this center.

Sensory examination. Deep pressure sense is absent in all of his finger-tips. Position sense is absent in all his fingers. There is no split sensation. For all practical purposes the entire hand, with the exception of a small area on the posterior surface of his hand, is anesthetic to 40 gm. of pain and 20 gm. of touch. Skin resistance is markedly increased all over the abnormal hand.

Motor examination. Clinically, he has a pronator teres, poor flexor carpi radialis, poor palmaris longus, and poor flexor indicis proprius. The remainder of the median innervated muscles are absent. He has a poor flexor carpi ulnaris and a poor flexor digitorum profundus, 4th and 5th. The remainder of the ulnar innervated muscles are absent. On percutaneous stimulation at the wrist, it would seem that he has some abductor digiti quinti and some abductor pollicis. On percutaneous stimulation of the median nerve at the wrist, it would seem that he has some flicker of muscle fibers in the thenar eminence.

POINTS OF SPECIAL INTEREST

This injury is complicated by the extreme vascular insufficiency, partially ankylosed elbow and a wrist which was fixed. This arthrodesis was done when the forearm was shortened in order that the contracted fingers might have a more useful arc of motion. It is also of interest to note that prior to this surgical procedure an amputation was deemed the treatment of choice since it was unlikely that a favorable result could be obtained. Another factor further complicating this injury was a severe burn which necessitated skin grafting over the dorsum of the fingers. There is nothing that we can possibly offer this man in the way of treatment.

Case Report 4336

HISTORY OF INJURY

This soldier was wounded in action on Angaur Island in the Southwest Pacific on September 30, 1944, by shell fire, receiving multiple wounds on the lateral side of his right arm, antecubital fossa, and forearm. Four days after injury he was noted to have dry gangrene of the tip of his right 2d, 4th, and 5th fingers. On October 7, 1944, on the hospital ship U. S. S. *Bountiful*, when the cast was removed from his arm, it was noted that the forearm appeared gangrenous, and incision and drainage were carried out in this region, removing much necrotic muscle tissue from both the flexor and extensor surfaces; it appeared at this time that "he had a divided radial nerve trunk in the lower third of the forearm which was sutured with #40 silk." The gangrene and other wounds gradually healed under immobilization, hot soaks, and chemotherapy. Because of the poor circulation in this extremity, and because of a causalgic type of pain, sympathetic block was tried on February 6, 1945, at Percy Jones General Hospital; the results, judged by skin temperature reading and relief of pain, were satisfactory, and on February 12, 1945, a right dorsal sympathectomy was performed with very good results. At this time there had been a hyperalgesic return of sensation in the ulnar distribution with questionable return in the abductor digiti quinti; there was good action in the radial nerve except for the extensors of the thumb, which digit was too stiff to function;

the entire median nerve was functionless. On May 16, 1945, at Percy Jones General Hospital, neurorrhaphy was performed on the right median nerve. The nerve was found to end in a dense neuroma distal to the branches to the pronator teres, but proximal to the pronator teres muscle; the nerve was transplanted anteriorly to the pronator, resected 6 cm. to healthy tubules, and sutured partly with silk and partly with tantalum. On electrical stimulation there was a very weak response in the pronator teres only. Carpectomy was performed on the right wrist on March 13, 1946, all carpal bone except the pisiform being removed and the wrist placed in 30 degrees dorsiflexion. This latter procedure resulted in increased abduction and short flexion of the thumb. On September 12, 1946, a contracting cicatrix of the right elbow was excised and replaced with a direct skin flap. He then had further plastic work done, apparently to the dorsum of the forearm and wrist, and plans were made for a number of further procedures to improve the function of the hand; these latter procedures were repeatedly postponed by red tape and the patient applied for his discharge. He was finally discharged on September 21, 1947, and at this time action was noted in all the radial muscles, in the flexor carpi ulnaris, flexor digitorum profundus to the 4th and 5th fingers, abductor digiti quinti, and short flexor of the thumb.

INTERVAL HISTORY

The patient has had no treatment since discharge and has noted little, if any, improvement in his arm. He notices no pain in the arm. Before the war he managed a service station; now he is a factory worker, despite his statement that his right arm is utterly useless. His compensation is 90 percent.

CENTER EXAMINATION October 14, 1949

The patient is right handed. Distance of the injury is 16 inches. The right extremity is shortened 3 inches. The forearm is diminished 2 inches in circumference, and there is marked atrophy of the entire forearm and hypothenar eminence. The fingers of the right hand are cold, there is no abnormal sweating and no radial pulse is palpable on the right. The wrist is fixed at 30 degrees dorsiflexion; all of the fingers are clawed; the thumb is adducted and flexed over the index finger. The pulp of the fingers is markedly reduced, and the fingernails are overgrown and curved. The patient is unable to perform any functional tests with this arm.

In the median zone 40 gm. pain are not felt as such, and he is anesthetic to 35 gm. touch; in the ulnar zone he is hypersensitive to 6 gm. pain, but feels 16 gm. touch normally. Deep pressure produces painful paresthesias in the ring and little fingers, and is not felt at all in the thumb, index, and middle fingers; no position sense is present in any of the five fingers.

The only muscles in the entire arm that show clinical function are the biceps and triceps, which are normal, and the abductor pollicis longus which showed a trace of function, as does the extensor digitorum communis. Percutaneous stimulation of the radial nerve produced some response in the brachioradialis, extensor carpi radialis, and extensor pollicis; percutaneous stimulation of the median nerve at the elbow produced no response; percutaneous stimulation of the ulnar nerve at the elbow produced a moderate response of the flexor digitorum profundus to the 4th and 5th fingers, abductor digiti quinti, adductor pollicis, and 1st dorsal interosseus. The abductor digiti quinti had a rheobase of 130, a chronaxie of 2.8, slow; the extensor carpi radialis had a rheobase of 75, a chronaxie of 0.8, prompt; the opponens had no determinable rheobase.

Functional evaluation. The arm is functionless.

POINTS OF SPECIAL INTEREST

This patient had a long and involved history. It was eight months before operation could be performed on the median nerve, and this resulted in no return of function. Throughout this long hospital course there were excellent studies, including electrical ones, done on the arm.

2. Ulnar Nerve

Table 231 contains a summary of the 10 cases representing maximal recovery in this series from which the following cases have been chosen for detailed presentation.

Case Report 8704

HISTORY OF INJURY

October 25, 1948. This patient had an accidental wound to the left elbow in November 1944 with division of the ulnar nerve. In May 1945 operation showed a lesion in continuity. There was a gap of 5 cm. after its removal, and the nerve was transplanted by sectioning rather than by retunneling. By October 1945, 5 months postsuture, the ulnar sensory area still showed a complete anesthesia and analgesia but there was definite innervation in the abductor digiti quinti and the adductor pollicis, as well as the flexor of the 5th finger. EMG showed the abductor digiti quinti at 25 percent. There was no tetanus at 20. Since discharge, the patient notes that he has improved in his ability to extend the 4th and 5th fingers and that he has obtained a much stronger grip. The 5th finger has become more sensitive but still feels very different from the other fingers. There are no major complaints, the patient is able to work outdoors without undue coldness of the hand, but he does notice some cramping in the flexors of the 4th and 5th fingers after prolonged use of the hand. He has learned to be a plumber and does not believe that he is significantly disabled by his hand at the present time.

CENTER EXAMINATION

Examination shows an amazingly normal appearing hand with good filling out of the hypothenar and the abductor spaces. The hand has a very good strong grip and can be used for all types of small and large test objects. The 4th and 5th fingers are extended fully when the hand is placed around large objects, and there is only slight diminution in the ability to lift very heavy things, such as chairs. All of the ulnar flexors and all of the intrinsic muscles work strongly and there is perfect lumbrical function. Even the abductor of the 5th finger is working. The abductor digiti quinti pulls 6 lbs. as opposed to 7 on the normal side, and the 1st dorsal interosseus pulls 4 lbs. as opposed to 4 lbs. on the normal right side. Chronaxies are 0.4 msec. for the abductor digiti quinti and 2.8 msec. for the 1st dorsal interosseus. Tetanus could not be obtained. EMG shows .4 mv. from the abductor digiti quinti on the injured left side as opposed to .5 mv. on the right side. A handprint was taken to show the recovery of the hypothenar eminence. From a sensory standpoint, pain thresholds are 30 gm. over the volar surface of the hand but 6 over the dorsal surface, and the sensory loss is probably entirely due to callus. Touch is felt at 5 gm. throughout. There has been a fair recovery of two-point discrimination which can be felt at ¼ in. There is no split sensation. Pressure and position sense are normal. Sweating is slightly reduced on the 5th finger but definitely present.

POINTS OF SPECIAL INTEREST

(1) This is the best result from ulnar nerve suture that we have seen. Even two-point discrimination has recovered on the sensory side, and there has been a complete functional and anatomical recovery on the motor side.

(2) The completeness of recovery suggests that the delay of 6 months between injury and operation was not significant.

(3) This bears out our theory that lesions in continuity regrow better than complete severance lesions.

(4) Regrowth of the ulnar nerve is probably better when it is not deprived of its blood supply by rethreading a large portion of the nerve through a second canal alongside the median nerve. Here we simply sectioned the flexor carpi ulnaris muscle and lifted only a small portion of the nerve from its bed.

(5) The excellent strength recorded is biased by patient's occupation (plumber).

Case Report 4394

HISTORY OF INJURY

This soldier was wounded in action in France on November 10, 1944, a machine gun bullet perforating his left elbow, fracturing his left radius and ulna. The patient was captured by the Germans, was given some surgical care, and contracted infectious hepatitis. He was liberated by the American Army 5½ months later, at which time he showed paralysis of his left ulnar nerve below the flexor carpi ulnaris. On July 12, 1945, this nerve was repaired at Halloran General Hospital. The nerve was found to end in a neuroma buried in dense scar in the upper third of the left forearm; on electrical stimulation proximal to the injury there was slight contraction of the flexor carpi ulnaris and the flexor digitorum profundus to the 4th and 5th fingers. The nerve was resected 4.8 cm. to good fascicles proximally

Table 231.—*Characteristics of Ulnar Nerve Cases With Good Recovery*

Characteristics of case	Case number									
	1217	[1] 4247	[1] 4394	5180	5312	5394	7745	[1] 8704	[1] 8788	[1] 8835
Lesion										
Pathology	Complete division.	Neuroma in continuity.	Complete division.	Partial division.	Neuroma in continuity.	Complete division.	Complete division.	Neuroma in continuity.	Partial division.	Complete division.
Site	Arm, middle ⅓.	Forearm, middle ⅓.	Forearm, upper ⅓.	Forearm, lower ⅓.	Elbow	Elbow	Arm, lower ⅓.	Elbow	Forearm, middle ⅓.	Arm, upper ⅓.
Associated lesions and complications.		Median N., plastic repair.	Fracture			Fracture, plastic repair.	Fracture			Median N., possible artery.
Definitive suture										
Days after injury	260	250	240	100	110	40	210	170	5	70.
Tension	None	None	None	None	None	None	None	None	None	None.
Bulb suture	Done	Not done	Not done	Not done	Not done	Not done	Done	Not done	Not done	Not done.
Suture material	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Not reported.	Tantalum	Tantalum	Not reported.	Tantalum.
Surgical gap, cm	6	4	5	2	5	>5	9	5	1	6.
Follow-up examination										
British motor [2]	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Complete recovery.	Synergic and isolated.	Synergic and isolated.	Complete recovery.	Synergic and isolated.	Synergic and isolated.
Pain, threshold, gm	20	20	6	10	20	30	20	6	30	10.
British sensory [3]	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2 pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.

Skin resistance	Elevated	Normal	Normal	Not tested	Decreased	Elevated	?	Not tested	Not tested	?.
Overall function, percent.	100	30	90	90	100	90	90	90	90	50.
Relative power [4]										
2-Fl. dig. prof. 4 and 5	Against resistance, unmeasured.	?	100	Not affected	90	30	66	100	Not affected	20.
3-Abd. dig. V	Movement not against resistance.	11	25	50	90	50	22	70	11	22.
5-1st dors. inteross	Movement not against resistance.	16	35	Not tested	100	50	22	45	20	22.

[1] Case reported in text here.

[2] The rubric abbreviated here as "synergic and isolated" is "Return of function in both proximal and distal muscles so that all important muscles can act against resistance, and some synergic and isolated movements are possible."

[3] The rubric abbreviated here as "pain and touch, 2-pt." is "Superficial cutaneous pain and touch throughout autonomous zone, no overresponse, and two-point discrimination in autonomous zone."

[4] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

but only fair ones distally with considerable fibrosis, and sutured with tantalum. Two months later the patient had an excision of the head of the radius and a separation of synostosis. Following this operation the patient showed a transient radial paralysis, but a tdischarge on January 11, 1946, there was full radial nerve function, 75 percent function in the flexor carpi ulnaris, beginning return of sensation but no other motor function in the ulnar nerve.

INTERVAL HISTORY

Patient has had no treatment since discharge and the only improvement he has noted has been some increase in strength and sensation. His major complaint is of pain in his elbow in cold weather. He experiences no other pain, does not have rapid fatigue and otherwise is asymptomatic. The patient has continued at his prewar job as a commercial chemist and his earning capacity is approximately the same. His compensation is 50 percent, and he is satisfied.

CENTER EXAMINATION December 8, 1949

Distance of the injury is 11 inches and there is no hot spot. Patient is right handed. There is some atrophy of the first dorsal interosseus, hypothenar eminence, and interossei spaces. The forearm is diminished ¼ inch in circumference. Both pulses are equal and full and the hands are of approximately the same temperature and moisture. Elbow extension is limited to 155 degrees, but wrist motion is unimpaired; there is slight flexion contracture of the short flexor of the 5th finger. Patient is able to pick up a pin, battery, and all other test objects, including heavy ones, and the only impairment in function is his lack of ability to adduct the 3d, 4th, and 5th fingers.

The patient's sensory limitation is very slight. He is able to feel 6 gm. pain throughout the entire hand, and only in the little finger and a small portion of the heel of the hand is his sensation of touch restricted, being able to feel only 10 gm. touch on the heel of the hand and 5 gm. touch on the little finger, compared with a normal of 3 gm. touch. Skin resistance shows no consistent difference between the two hands. There is no split sensation. Deep pressure is unimpaired in all fingers except the little finger, where it produces a painful paresthesia. Position sense is unimpaired.

Quantitative muscle evaluation is as follows. Flexor carpi ulnaris, radialis and palmaris longus 100 percent; flexor digitorum profundus to the ring finger 100 percent, to the little finger 50 percent; abductor digiti quinti 25 percent; abductor digiti quinti 0; first dorsal interosseus 35 percent. The abductor digiti quinti had a rheobase of 45, chronaxie 0.8; first dorsal interosseus rheobase 85, chronaxie 1.2 (both reactions were prompt, the abductor digiti quinti showing slight fasciculation and the first dorsal interosseus marked fasciculation). Electromyography was done on the abductor digiti quinti.

Functional evaluation. This patient has a remarkably good hand, with only slight limitation to testing and functionally no limitation as to either strength or skill. The only noticeable defect is the inability to adduct the 3d, 4th, and 5th fingers. This injury does not appear to handicap him at all in his profession.

POINTS OF SPECIAL INTEREST

This was a fairly typical ulnar injury at the elbow, but 8 months elapsed between injury and repair of the nerve, with the patient receiving little attention during the 5 months that he was a prisoner-of-war. It was noted at operation, at which 5 cm. of the nerve were resected, that the distal stump showed considerable fibrosis. Despite this, patient has had a practically normal return of sensation, and has good function in all intrinsic muscles except the interossei, and even his chronaxie is not too abnormal. He has a remarkably useful hand.

Case Report 8788

HISTORY OF INJURY

On August 17, 1945, this patient put his fist through a window and received lacerating wounds of the ventromedial surface of the left forearm at the junction of the lower and middle thirds and partial severance of the flexor carpi ulnaris, the extensor carpi ulnaris, palmaris longus, flexor digitorum profundus, and complete severance of the ulnar nerve except for two fascicles. There were also two smaller lacerations lower down on the radial side of the forearm with partial severance of the flexor pollicis longus and brachioradialis. On August 22, 1945, at the 33d General Hospital, the wounds were debrided, tendons were repaired, and anastomosis of the ulnar nerve was done. Nearly $\frac{5}{16}$ in. had to be severed from each end of the ulnar nerve for anastomosis. On October 16, 1945, shortly after admission to Cushing General Hospital, there was no function of the abductor digiti quinti and the dorsal and palmar interossei of the left hand. There was just barely perceptible function of the abductor pollicis. There was complete anesthesia and analgesia over the ulnar distribution of the left hand. On December 14, 1945, the patient had function in the abductor pollicis and the abductor digiti quinti. Sensation remained unimproved but the patient was said to be ready for disability discharge.

CENTER EXAMINATION October 26, 1948

The patient complains chiefly of aching pain in the forearm with heavy lifting. He complains also of paresthesias, numbness in the ulnar area, coldness in the hand, adverse reaction to cold weather, hypersensitivity, easy fatigability, and some loss of muscle power. The patient is assessed at 50 percent and estimates that his earning ability is limited to about that loss. He is now a laborer in the woolen industry and is unable to handle his former duties as wool spinner in the same industry.

The distance of injury is 9 in.

Sensory examination reveals thresholds of 30 gm. to pain and 16 gm. to touch in the ulnar autonomous zone. There is moderate split of sensation.

Pressure and position senses are normal. Two-point discrimination is markedly diminished in the ulnar zone. There is slight sweating over the 5th finger and the ulnar half of the 4th finger.

Motor examination reveals 11 percent to 20 percent function in the ulnar-innervated intrinsic muscles of the hand. Chronaxies are 8.0 msec. in the abductor digiti quinti, and 10.0 msec. in the first dorsal interosseus.

The patient is able to perform all hand functions except adduction of digit 5. The thumb is opposed to digit 5 with the eyes shut and there is a good grip, with all the fingers but the 5th. Joint ranges are normal. This case represents only a fair result from a midforearm ulnar nerve suture. The patient is handicapped chiefly by a lack of strength. The patient states that work furlough was more helpful to him than physiotherapy. Function is 90 percent.

Case Report 8835

HISTORY OF INJURY

October 23, 1948. This patient sustained a complete median and ulnar paralysis by virtue of a machine gun bullet wound just below the axilla. The brachial artery was involved. (Ed.—This is questionable on review of case.) Injury occurred 8 November 1944 and operation was carried out 25 January 1945. Both nerves were completely divided and gaps of 6 cm. and 4½ cm. were overcome for the ulnar and median nerves, respectively. The ulnar nerve had to be transplanted by rethreading through the median tunnel. There was no tension. By December 1945 (11 months later), there was 50 percent power in the flexors of the fingers. There was some median sensory recovery but none in the ulnar. The patient was discharged at this time and unfortunately none of the surgeons was consulted regarding the possibility of a tendon transfer to give satisfactory opposition of the thumb, it being assumed that the partial opponens action would progress satisfactorily.

INTERVAL HISTORY

Since discharge, the patient believes that he has learned to pick up objects more satisfactorily and that the grip of his hand has greatly improved. He does notice some improvement in the sensation to the fingertips. He complains only of clumsiness in the use of his right hand and notices no pain, but is disturbed by coldness of the hand when he is outdoors in the winter. He has, of course, had to switch over to the left hand for writing and for eating. He is continuing his education and hopes to be a salesman, in which work he will circumvent his handicap.

Examination shows that in spite of the good regeneration to the opponens muscle, full opposition is not actually carried out, but instead the thumb is kept close to the hand, and opposition is against the side of the index finger in a fairly effective manner. The patient can pick up a paper clip in this way and does so with considerable facility. The thumb cannot be opposed past the 4th finger. In other words, the function of opposition has been learned to about a 30 percent level. He shows a striking recovery in all forearm muscles and only the deep flexor to the 4th finger is definitely weak. There is certain function in the opponens and the abductor pollicis brevis muscles, although the actual movements do not result in opposition or abduction from the hand. Abduction of the 5th finger is done with good strength and the 1st dorsal interosseus and adductor pollicis have clearly recovered. There is also striking recovery of lumbrical function so that all fingers are well extended instead of retaining the clawed appearance of most combined median and ulnar nerve injuries. Intraneural stimulation confirms our clinical impression about intrinsic muscle function for both the median and the ulnar nerves, and opposition is particularly strong. Sensory recovery is good and about equal for the median and the ulnar to threshold testing (10 gm. for pain, 5 gm. for touch). Split sensation is quite striking in the median distribution but not in the ulnar distribution. Two-point discrimination is practically absent. Pressure and position sense are normal. The 5th finger does not sweat as much as the others, and subjectively the patient feels his sensation is less good in the 5th. Electromyography shows abductor digiti quinti .16 on the right as opposed to .43 mv. on the left. Opponens is .25 on the right as opposed to .45 mv. on the left.

Following are the points of interest:

(1) This is the most ideal recovery from a high median and ulnar injury that we have seen from both a motor and sensory standpoint. The usefulness of the hand is striking and the good result is largely due to the cooperation and intelligence of the patient, following early good surgery.

Patient demonstrates that even with the most ideal median and ulnar regeneration, combined median and ulnar injuries should always have a tendon transfer to provide opposition of the thumb. This is definitely indicated in this patient now and is recommended.

Case Report 4247

HISTORY OF INJURY

This soldier was wounded in action in Germany on November 25, 1944, by a shell explosion, one fragment perforating the lower third of his right forearm on the ulnar aspect. He suffered complete right median and ulnar nerve paralysis. Plastic work was done on the large skin defect at the site of injury. It was felt that there was some slight return of function in some of the median muscles and in the median sensory distribution, but virtually nothing in the ulnar distribution. On August 3, 1945, at Nichols General Hospital, neurorrhaphy was performed on the right median and ulnar nerves. A 4-cm. neuroma was found in continuity in the ulnar nerve, was resected, and the nerve sutured with tantalum; the median nerve was found completely divided in the middle forearm, resected to a gap of 4 cm., and sutured with tantalum. It was noted that the median suture line was 8 cm. distal to that of the ulnar. Three months later Tinel's sign had advanced 20 cm. in both nerves; at 6 months there was some return of sensation in both the median and ulnar distributions. With this status the patient was discharged on February 26, 1946.

INTERVAL HISTORY

Patient has had no treatment since discharge, but has noticed considerable increase of strength in his hand and a return of sensation to the dorsum of the ulnar area. He suffers no real pain in the hand and his only complaint is of rapid fatigue and weakness. Before the war patient made $40 a week in a canning factory; he has no job at present. His compensation is 50 percent but the patient feels this is inadequate.

CENTER EXAMINATION June 28, 1949

Patient is right handed. There is some atrophy of the thenar eminence; the patient holds his fingers in a flexed position. The hand is equally warm as compared to the normal hand, but much drier, and pulses are equal and full. He shows no true opposition, but he is able to pick up a pencil between his thumb and the side of his index finger. He is unable to pick up a heavy chair although he is able to pick up a stool.

The patient is able to feel 20 gm. pain and 5 gm. touch in all areas, except the ball of the thumb where he is able to feel 10 gm. pain. There is considerable splitting of sensation in both the median and ulnar distribution, the median averaging 3 cm. and the ulnar 2 cm. Position sense is about 50 percent of normal. Deep pressure in all five fingers produces a disagreeable sensation which spreads somewhat up the fingers. Two-point discrimination is described as being normal on the thumb but considerably diminished on the other fingers. Skin resistance is somewhat increased in the ulnar area, markedly increased in the median area.

Quantitative muscle evaluation is as follows. Flexion of the wrist 100 percent, with the flexor carpi ulnaris being the weakest of the three muscles; flexor pollicis longus 100 percent; flexor pollicis brevis 40 percent; flexor digitorum sublimis to the index finger 100 percent, to the middle finger 100 percent, to the ring finger 70 percent, to the little finger 50 percent; flexor digitorum profundus to the index finger 100 percent, to the middle finger 65 percent, to the ring finger 95 percent, to the little finger 65 percent; opponens 15 percent (trick); abductor pollicis brevis 0; abductor digiti quinti 11 percent; adductor digiti quinti 0; 1st dorsal interosseus 16 percent (trick); adductor pollicis 11 percent. On percutaneous stimulation of the ulnar nerve at the elbow a good response was found in the abductor digiti quinti and in the lumbricales, a fair response in the first dorsal interosseus and adductor pollicis, no response in the adductor digiti quinti. Percutaneous stimulation of the median nerve at the wrist showed some response in both the opponens and the abductor pollicis brevis. Electromyography was done on the opponens and the abductor digiti quinti.

Functional evaluation. This patient appears not to be making as good use of his hand as his muscle power warrants, and indicative of this is his disinterest in getting a job. For grading purposes he has some skilled but awkward use of the hand.

POINTS OF SPECIAL INTEREST

This was a combined median-ulnar injury in the forearm, with suture of both nerves. The patient typically has no useful function in his opponens, even though electrical stimulation shows that there is some regeneration.

The 10 examples of poor recovery are summarized in table 232. One case was chosen for presentation in detail:

Case Report 2218

HISTORY OF INJURY

This soldier was wounded by machine gun and mortar fire on July 4, 1944, incurring injuries to the left arm and right side of the chest. In the first recorded examination, on July 14th, there was a gunshot wound perforating the left midarm, the entrance being on the anterior aspect of the arm. He had loss of function of the ulnar nerve below the wound, both motor and sensory, and this was accompanied by severe burning pain in the 4th and 5th fingers. There was also some pain in the palm of the hand in the median nerve distribution. A diagnosis of severe causalgia involving the left median nerve was established and, on July 26, 1944, a sympathectomy of the left upper extremity was carried out. On July 30th, the operative wound was reported to be healed and 1 week later the causalgic-type pain in the arm appeared to be subsiding. On August 7th, the wound in the middle and upper third of the left arm, on its medial aspect, was explored and the median nerve was found to be bound down in scar tissue but not severed. A so-called neurolysis was carried out and stimulation of the nerve ends showed fair contractions in the forearm musculature. The ulnar nerve was found completely severed and the statement was made in the operative note that there was considerable distance between the freshened nerve ends. The ulnar nerve was transplanted anteriorly at the elbow and sutured with tantalum. A tantalum sling suture was also used. Complicating factors of a chest wound and a subphrenic abscess kept this soldier in the hospital for a long time and he was eventually evacuated to the States on November 13, 1944. Neurological examination at that time reported some return of sensation in the ulnar nerve but no evidence of motor return. Regeneration of the median nerve had come along nicely with motor power in the intrinsic muscles of the hands supplied by the median nerve and normal median nerve sensation. On January 20, 1945, there was no return of motor or sensory power in the ulnar nerve but Tinel's sign was found at the wrist, approximately 35 cm. from the anastomosis site. Following a series of neurological studies, which in general suggested poor regeneration in the ulnar nerve, this patient received a disability discharge from the Army on January 24, 1946.

Table 232.—*Characteristics of Ulnar Nerve Cases With Poor Recovery*

Characteristics of case	Case number									
	1059	1090	2039	[1] 2218	3065	3346	3803	3884	4065	5414
Lesion										
Pathology	Complete division.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.
Site	Arm, lower ⅓.	Arm, upper ⅓.	Wrist	Arm, upper ⅓.	Elbow	Arm, upper ⅓.	Forearm, lower ⅓.	Forearm, middle ⅓.	Arm, upper ⅓.	Arm, lower ⅓.
Associated lesions and complications.	Irreparable median N., fracture, infection, artery.	Median and radial N., fracture.	Median N., infection, plastic repair, frostbite.		Fracture, separated suture line.	Median and radial N., infection, artery.	Artery	Median N., infection, artery, plastic repair.	Median and radial N., artery.	Double nerve div. on ulnar, only one repaired,[2] plastic repair.
Definitive suture										
Days after injury	270	90	560	30	110	240	200	360	460	190.
Tension	None	None	Severe	?	?	Moderate	Moderate	None	None	Severe.
Bulb suture	Done	Not done	Not done	Not done	Not done	Done	Not done	Not done	Not done	Not done.
Suture material	Tantalum foil sleeve (Weiss).	Tantalum	Tantalum	Tantalum	Plasma	Silk	Tantalum and plasma.	Plasma	Tantalum	Tantalum.
Surgical gap, cm	8	6	7	?	?	9	?	?	6	5.
Follow-up examination										
British motor	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.
Pain threshold gm	Deep only	No sensation.	?	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.

British sensory	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.
Skin resistance	?	Decreased	Mixed	Elevated	Elevated	Elevated	Mixed	Elevated	Elevated	Elevated.
Overall function, percent.	30	10	30	30	60	10	70	20	0	50.
Relative power: [3]										
2-Fl. dig. prof. 4 & 5	0	0	Not affected	0	0	0	Not affected	0	0	0.
3-Abd. dig. V	0	0	0	0	0	0	0	0	0	0.
5-1st dors. inteross.	0	Not tested	0	0	0	0	0	0	0	0.

[1] Case reported in text here.

[2] Second lesion was in m/3 forearm with an 8 cm. gap and 20 cm. scarred nerve. It was not repaired.

[3] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

INTERVAL HISTORY

The patient apparently has had no treatment for either the chest or nerve injuries since discharge. He has continued to complain of aching pain in the ulnar aspect of the left hand. He has noticed no return of sensation in the 4th and 5th fingers and no return in muscles innervated by the ulnar nerve. He feels that the grip in his left hand is stronger than it was at his last examination 2 years ago. He still cannot use it for finer movements. There is some increase of the pain in cold weather. No information is available concerning his occupational disability.

CENTER EXAMINATION April 16, 1948

Motor. The left upper extremity measures 3 cm. less in the forearm than does the right. There is atrophy of the left hypothenar eminence and marked atrophy of the ulnar side of the hand. There is atrophy of the dorsal interosseus spaces. There is weakness of the flexor pollicis longus. There is marked weakness of flexion of the fingers, especially of the 4th and 5th fingers. Flexion of the distal phalanx is entirely absent. There is weakness of the flexor carpi ulnaris although contraction can be felt at the wrist. There is weakness of the extensors of the fingers and of the wrist. The patient cannot make a cone with his fingers and the newspaper test is positive. Fingers are held flexed at the first interphalangeal joint and extended at the metacarpal phalangeal joint in a sort of clawhand. Abduction of the 5th finger cannot be performed. Abduction of the other fingers cannot be performed. The thumb has only a weak degree of opposition. The little finger cannot be opposed at all. There is marked atrophy in the first interosseus space.

Sensory. There is complete loss of pinprick and cotton test touch sensation in the ulnar distribution, including the little finger. There is hypesthesia and hypalgesia in the index finger and thumb and in the forearm extending on the ulnar side up as high as the elbow. These areas include the lower third of the forearm. The isolated area of innervation of the radial nerve is well preserved.

Electrodiagnostic studies carried out on the ulnar nerve, sutured 1,330 days previously, and upon the median nerve which had undergone neurolysis at the same time-period, showed the following changes:

Abductor minimi digiti: Rheobase 5.3. Chronaxie less than 1 msec. Tetanus ratio over 3. Response to faradic current was present. Repetitive stimuli curve was descending. Supermaximal about 1.5 over the threshold for tetanus repetitive stimuli.

Abductor pollicis brevis: Rheobase 1.7. Chronaxie 7 msec. Faradic current present. Tetanus ratio 3.1. Repetitive stimuli descending. Supramaximal about 1.2 over the threshold per tetanus repetitive stimuli.

3. Radial Nerve

The 10 examples of good radial recovery are summarized in table 233. A single case was chosen for detailed presentation.

Case Report 4281

HISTORY OF INJURY

This soldier was wounded in action in France on September 3, 1944, when a rifle bullet penetrated the lower third of his left arm, fracturing the humerus; at debridement 7 hours later the radial nerve was found to be divided. He had a complete left radial paralysis below the triceps, and on February 6, 1945, at England General Hospital, a neurorrhaphy was performed on the left radial nerve. A large neuroma was found at the site of the fracture; the nerve was resected to fairly good tubules in the proximal stump, fair tubules in the distal stump, and sutured with tantalum. Seven months later he had good function in the triceps and supinator and fair function in the brachioradialis, but no return in the other radial muscles. At 7½ months function was noted in the extensor carpi radialis longus and brevis and a flicker in the extensor digitorum communis; at 9 months function was also noted in the extensor carpi ulnaris, extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus. Because a tantalum cuff had been placed about the nerve at the first operation, the site of suture was explored on January 29, 1946; the nerve was found bound down in dense scar tissue and adherent to callus of the bone; it was lysed externally and internally and the tantalum foil removed. The anastomosis was found slightly swollen, but the nerve gave good response on stimulation. The patient was discharged on March 4, 1946.

INTERVAL HISTORY

The patient has had no treatment since discharge and the only improvement that he has noticed in the arm is some increase in strength. He complains of spontaneous pain at the site of suture (or at the site of fracture), and also pain in damp weather and when he uses the hand. Before the war he was a helper in a machine shop, but now he works as an operator at a water plant, with a cut in earning of about 15 percent. His compensation is 40 percent.

CENTER EXAMINATION August 29, 1949

The patient is right handed. The distance of the injury is 15½ inches. There is no noticeable atrophy of the forearm or hand and no trophic changes of the skin or nails. Pulses are equal and full and the hands are equally warm and moist. Supination is limited to midposition when the elbow is extended, and appears to be performed exclusively by the biceps. There is 20 degrees limitation of elbow extension. He has some disability in picking up a stool and can barely lift the chair; otherwise he shows excellent use of the hand, and has no difficulty in opening his hand wide.

In a typical radial distribution on the dorsum of the hand he can feel 10 gm. pain and 16 gm. touch, compared with the normal of 5 gm. touch; there is a small area on the distal phalanx of the dorsum of the thumb in which he cannot feel 40 gm. pain. Deep pressure is slightly diminished on

Table 233.—*Characteristics of Radial Nerve Cases With Good Recovery*

Characteristics of case	Case number									
	1219	1226	1240	2102	2161	3026	3331	[1] 4281	5097	5282
Lesion										
Pathology	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.
Site	Arm, lower ⅓.	Arm, middle ⅓.	Arm, lower ⅓.	Arm, upper ⅓.	Arm, upper ⅓.	Arm, lower ⅓.	Elbow	Arm, middle ⅓.	Arm, middle ⅓.	Arm, middle ⅓.
Associated lesions and complications.		Fracture	Unar N					Fracture	Fracture	
Definitive suture										
Days after injury	30	100	1	150	50	50	120	150	180	40.
Tension	?	None	?	None	None	None	None	None	None	None.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done.
Suture material	Tantalum	Tantalum	Not reported.	Tantalum	Silk	Tantalum	Silk	Tantalum	Tantalum	Tantalum.
Surgical gap, cm	?	5	?	4	2	3	4	3	3	3.
Follow-up examination										
British motor [3]	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Complete recovery.	Complete recovery.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.
Pain threshold, gm	6	<6	<6	<6	<6	10	40	10	10	30.
British sensory [3]	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Complete recovery.	Complete recovery.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.
Skin resistance	Normal	Normal	Not tested	Normal	Normal	Normal	Mixed	Normal	Decreased	Normal.
Overall function, percent.	90	100	100	90	80	90	70	90	80	90.

Relative power [4]											
3-Ext. car. rad.	Against resistance, unmeasured.	43.	Against resistance, unmeasured.	Against resistance, unmeasured.	100.	78.	30.	50.	80.	90.
4-Ext. dig.	Against resistance, unmeasured.	44.	Against resistance, unmeasured.	Against resistance, unmeasured.	75.	56.	33.	35.	70.	80.
7-Ext. poll. long.	Against resistance, unmeasured.	15.	Movement not against resistance.	Against resistance, unmeasured.	80.	Movement not against resistance.	25.	25.	65.	50.

[1] Case reported in text.

[2] The rubric abbreviated here as "synergic and isolated" is "Return of function in both proximal and distal muscles so that all important muscles can act against resistance, and some synergic and isolated movements are possible."

[3] The rubric abbreviated here as "pain and touch, 2-pt." is "Superficial cutaneous pain and touch throughout autonomous zone, no overresponse, and two-point discrimination in autonomous zone."

[4] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

the thumb, normal on all the other fingers. Position sense, similarly, is slightly diminished in the thumb, normal in the other fingers. Two-point discrimination in the autonomous zone is 38 mm. compared with a normal of 19. There is no split sensation. Skin resistance is slightly diminished over the injured area.

Quantitative muscle evaluation is as follows. Triceps 100 percent; extensor carpi radialis 50 percent; extensor carpi ulnaris 25 percent; extensor digitorum communis 35 percent, being very weak in the extensor of the third finger; abductor pollicis longus 25 percent; extensor pollicis longus and brevis 25 percent. The extensor carpi radialis had a rheobase of 145, a chronaxie of 0.6. EMG was done on the abductor pollicis longus; on supramaximal stimulation the injured muscles show spikes of 2.5 in. compared with a normal of only 2.0 in. and it was felt that this low normal value is the result of a poor contact with the muscle.

Functional evaluations. This right-handed patient does not feel much handicap by his left radial injury, and is able to perform almost all acts with the arm except for heavy lifting.

POINTS OF SPECIAL INTEREST

This radial nerve was repaired 5 months after injury and shows an extremely good functional return, both motor and sensory.

The 10 examples of poor radial recovery are summarized in table 234. Individual case reports follow.

Case Report 4065

HISTORY OF INJURY

October 3, 1944, WIA Germany. Severe perforating shell fragment wound right axilla and shoulder severing axillary artery and radial nerve, and partially severing median and ulnar nerves. October 4, 1944, 203 General Hospital, radial nerve found completely severed, sutured with tantalum. Ulnar nerve 80 percent severed and a 1-inch portion missing, nerve not sectioned or repaired, but tantalum sutures left as a guide. Axillary artery ligated. March 14, 1945, O'Reilly General Hospital, neurorrhaphy of ulnar nerve. Much scarring and troublesome bleeding.

Ulnar stimulation elicited no motor response. Stimulation of the median nerve elicited fair response in pronator and flexors of wrist. No lesion identified in median although a considerable portion was scarred. The ulnar nerve found severed with neuroma at proximal end and glioma at distal end. Resected to healthy funiculi, gap 3 cm. and with considerable tension was sutured with #40 tantalum. Blood supply to both ends of nerve good, proximal posterior portion of sheath was poor.

January 11, 1946, Halloran General Hospital, ulnar neurorrhaphy. Stimulation of proximal portion of previous suture gave good ulnar sensation, no motor function. Suture site was resected, and resutured with .003 tantalum with a good approximation obtained. Median nerve found bound down in scar and neuroloysis done. Stimulation above the scarred portion gave good motor response in median muscles. September 3, 1946, no return of proximal ulnar muscles. Tinel's sign is half way down the arm. Some return of deep median sensation, no return of ulnar sensation. November 14, 1946, discharge.

INTERVAL HISTORY

He has had no treatment since discharge. He uses his arm only as a holder. He has occasional spontaneous pain and complete numbness of the right hand. At present he is unemployed and the VA is looking for a job for him, as he wants to work. His compensation is 90 percent.

CENTER EXAMINATION July 28, 1948

Distance of the injury is 20 in. and the patient is right handed. The right hand is definitely cold to palpation, and no radial or ulnar pulses are felt. The right forearm circumference is 1½ in. less than the left and the right arm is ¼ in. less than the left.

Sensory examination. Ulnar—he has no return of sensation. *Median*—he feels 40 gm. pain and 20 gm. of touch. Split sensation is present. Position sense is about 70 percent of normal. Skin resistance is considerably increased over the entire palm of the hand. The entire hand has a shiny, puffy appearance, and his thumb is kept in the simian position.

Motor examination. He has limitation of extension and rotation at the elbow. He has a very good deltoid, trapezius, biceps, triceps, brachioradialis, and a fair flexor carpi radialis. There are no thumb movements nor intrinsic hand motions.

Stimulation of the ulnar nerve at the wrist and elbow shows complete lack of nerve function. However, in contrast to the clinical examination above, stimulation of the median at the wrist shows a good short flexor of the thumb and a questionable opponens. Stimulation of the radial at the midarm shows good extension of the wrist and nothing in the thumb.

Functional evaluation. At the present time, he has an almost useless right arm, but he is not too willing to do much about it. He uses the arm only as a holder and tendon work would definitely give him some use in extension and abduction of the thumb. With the intact musculature he has around the elbow and shoulder, he could certainly make some use of his hand. The patient flatly refused surgery.

SPECIAL POINTS OF INTEREST

This patient had a suture of his partially severed (75 percent) median nerve and suture of completely severed radial nerve overseas 1 day after injury. The ulnar nerve was 80 percent severed, and unsuccessfully sutured 5 months later. The ulnar was subsequently resutured 14 months after injury and resulted in complete failure. He has had some return of sensation in the median area, and a fair return in the radial.

Table 234.—*Characteristics of Radial Nerve Cases With Poor Recovery*

Characteristics of case	Case number									
	1006	1171	2094	3022	3042	3825	[1] 4065	[1] 4109	4516	[1] 8785
Lesion										
Pathology	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Partial division.	Complete division.	Complete division.
Site	Arm, lower 1/3.	Arm, upper 1/3.	Arm, middle 1/3.	Arm, upper 1/3.	Arm, upper 1/3.	Arm, lower 1/3.	Arm, upper 1/3.	Arm, middle 1/3.	Arm, lower 1/3.	Arm, middle 1/3.
Associated lesions and complications.	Infected fracture.	Median and ulnar N., artery.	Median and ulnar N., fracture.	Median and ulnar N., infection, artery.	Median, ulnar, and musculocutaneous N.,	Fracture, suture-line separation, resuture.	Median, ulnar, and musculocutaneous N., artery.	Fracture	Median and ulnar N., fracture.	Ulnar N., fracture, infection.
Definitive suture										
Days after injury	140	110	160	200	80	400	1	200	250	120.
Tension	?	Severe	None	Severe	None	None	None	Moderate	Moderate	None.
Bulb suture	Not done	Not done	Done	Done	Not done	Not done	Not done	Only coaptation suture, not done.	Not done	Not done.
Suture material	Tantalum	Tantalum	Silk	Tantalum	Silk	Plasma	Tantalum	Not reported.	Tantalum	Tantalum.
Surgical gap, cm	3	3	>4	7	5	5	2	5	6	14.
Follow-up examination										
British motor	No contraction.	Proximal only, perceptible.	No contraction.	No contraction.	Proximal only, perceptible.	No contraction.	Proximal only, perceptible.	Proximal only, perceptible.	Proximal only, perceptible..	Proximal only, perceptible.
Pain threshold, gm	Deep only	Deep only	Deep only	40	Deep only	Hypalgesia	Deep only	30	40	Deep only.

British sensory [2]	Deep pain	Deep pain	Deep pain	Superficial pain and touch.	Deep pain	Superficial pain and touch.	Deep pain	Superficial pain.	Superficial pain and touch.	Deep pain.
Skin resistance	Not tested	Decreased	Normal	Decreased	Elevated	Normal	Not tested	Elevated	Not tested	Not tested.
Overall function, percent.	80	0	0	20	0	?	0	80	20	0.
Relative power [3]										
3-Ext. car. rad	0	0	0	0	0	0	60	Movement not against resistance.	0	Perceptible.
4-Ext. dig	0	0	0	0	0	0	Not tested	Movement not against resistance.	0	Perceptible.
7-Ext. poll. long	0	0	0	0	0	0	0	Perceptible:	0	0.

[1] Case reported in test.

[2] The rubric abbreviated here as "superficial pain and touch" is "Return of some degree of superficial cutaneous pain and touch sensibility within autonomous zone."

[3] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

Case Report 4109

HISTORY OF INJURY

The patient sustained shell fragment wounds in his right arm in France on June 13, 1944. It was noted immediately that he had a partial palsy of his radial nerve. The wound was debrided on June 19, 1944. January 5, 1945, because of poor distal tubules, a modified bulb suture was performed.[23] Operator noted that further surgery was indicated when the nerve was stretched. No further surgery was carried out. November 7, 1945, discharged, and it was noted that he had an inability to extend his fingers.

CENTER EXAMINATION September 9, 1948

Patient is right handed and was 27 years of age at the time of his injury. The suture line was 18 in. from the distal palmar crease. The diameter of his arm 4 in. below the olecranon was 10½ in. on the injured side and 11½ in. on the normal side. Deep pressure was present in the tips of all of his fingers as was position sense. The pulses were equal and full bilaterally. No trophic changes were noted in the fingers. He could flex his elbow to 42 degrees and extend it to 167 degrees. He could flex his wrist to 120 degrees and extend to 105 degrees. There was slight limitation of supination. The metacarpal-phalangeal and the interphalangeal joints were entirely within normal range. Over the back of the hand, slightly more medial than the usual snuffbox area, pain threshold was 30 gm, and touch greater than 50. On stimulation of the most radial portion of this zone there was some radiation up the back of the thumb. Skin resistance in the autonomous area was somewhat increased.

Clinical examination. There was a trace of extension of the fingers and of the wrist. There was a trace of long extensor of the thumb and no abductor of the thumb. The radial nerve was stimulated above the elbow by means of a percutaneous bipolar stimulus. No abduction of the thumb was noted and no extensor of the thumb was noted. There was definitely a trace of extensor communis and extensors to the wrist present.

On performance test, the patient had no difficulty in grasping one's arm and finds the hand entirely useful for most purposes except heavy lifting. He is able to do his job as an electrical maintenance man without any difficulty.

POINTS OF SPECIAL INTEREST

Despite the inadequate type of operative procedure done, i. e., a (modified—Ed.) bulb suture, the patient had a good return of function. There is possibly no more than 30 percent of normal to the long extensors of the wrist and fingers. However, the hand is entirely useful and because of the

[23] From the operation report "* * * a modified type of bulb suture was performed which consisted of suturing the ends together. The distal end had good tubules, the proximal end still had considerable scar tissue. These ends were brought into opposition." Since an end-to-end anastomosis was performed, and no subsequent surgery was done, the operation was coded as a complete suture. (Ed.)

unimportant area of anesthesia remaining, the patient has no difficulty. This man's hand can definitely be improved by means of tendon work. However, he showed no inclination to have this type of operation performed.

Case Report 8785

HISTORY OF INJURY

On May 14, 1945, this soldier sustained a shell fragment wound of the right midarm, with immediate complete paralysis of the ulnar nerve and paralysis of the radial nerve below the brachioradialis. Operation was performed on September 19, 1945, with suture and anterior transplant of both the radial and ulnar nerves. The median nerve was exposed and was found intact with all motor functions present. The radial nerve ended blindly at the fracture site (midhumeral) and the ulnar nerve was separated at this site. The radial nerve was transplanted beneath the biceps tendon, freshened to about a 11–14 cm. gap, with bleeding in proximal end only, and was sutured without tension. The ulnar nerve was sectioned to 8 cm., transplanted anteriorly, with bleeding from the distal end, and was sutured without tension. In transplanting the radial nerve, it was necessary to sacrifice branches to the brachioradialis. In August 1946, there was no definite evidence of radial nerve function, electrical stimulation being unsatisfactory due to transplantation; ulnar nerve stimulation gave flexor carpi ulnaris action and action in the deep flexors to digits 4 and 5; there was also some sensory recovery to the tip of the 5th finger. At that time, the question of tendon transplant for extension was being considered. He was discharged in November 1946.

CENTER EXAMINATION October 21, 1948

The patient complains of almost complete inability to use the right arm and hand. There is numbness, hypersensitivity, and pain, especially in cold weather. There has been an abscess under the old scar for the past month; this is said to be a lighting up of an old osteomyelitis. In October 1948, an abscess was treated with penicillin. He is assessed at 80 percent and estimates a 60 percent loss of earning ability. Before injury he ran a service station but has recently had to give this up because of the abscess. He states that he is occasionally disturbed over the situation.

Sensory examination reveals a pain threshold of 40 gm. and a touch threshold of 75 gm. in the ulnar area. In the radial area, there is no response to 40 gm. pain and 75 gm. touch. Pressure in the ulnar area gives diffuse pain. There is poor position sense in the 5th finger. There is no sweating over the 5th finger, which is atrophic.

Motor examination reveals only barely perceptible motor action in affected radial innervated muscles. Proximal ulnar muscles function at about one-half strength, distal muscles at 10 to 15 percent. Ulnar percutaneous stimulation results in no function of lumbrical, fair function of abductor digiti quinti and 1st dorsal interosseus. Ulnar chronaxies are high. Radial chronaxies were unobtainable because of high rheobases. Median function was unimpaired.

No radial function is possible. Elbow motion is restricted between 60 and 150 degrees. There is no supination, with pronation limited to 30 degrees. Wrist and finger joints are limited in motion and there is mild flexor tendon shortening. The patient has good flexion of the fingers for grasping objects placed therein and he opposes the thumb to either of the first two fingers with good strength. However, because of the complete absence of any extensor mechanism of wrist or fingers, he finds it totally impossible to make use of this function. This patient has had an average ulnar regeneration and the ulnar deficit does not constitute a significant part of his disability. The radial nerve was sutured over a huge gap by transplantation and extensive mobilization; as might be expected, this did not give useful functional recovery, although it is of academic interest that the wrist and finger extensors have visible but not useful function. Appropriate tendon transplants are indicated and should have been done prior to discharge.

4. Summary

A survey of these cases of upper extremity nerve injury indicates again the well-established fact that good neural regeneration tends to develop in simple, uncomplicated instances of nerve injury where the influence of known adverse factors is minimal. Inadequate neural regeneration, on the other hand, is almost invariably found in the more severe and complicated extremity wounds. Exceptions to this generalization may exist and the various adverse factors show varying degress of inhibition. These are discussed briefly.

Location of Injury

Good regeneration in these 20 cases of median and ulnar nerve injury was associated with injury levels in the lower third of the arm or below with 2 exceptions, cases 8835 and 1217. Reasonably good intrinsic muscle function was attained and functional regeneration in selected cases is described in the case reports. Poor regeneration in 20 cases of median and ulnar nerve injury was generally associated with injury levels in the arm or elbow; of the 6 exceptions, 3 were at the level of the wrist. Little or no intrinsic muscle reinnervation was found in these cases.

The question of level of injury does not enter into a consideration of neural regeneration in radial nerve cases since all cases were selected from injuries at the arm level. With this exception, peripheral nerve injuries at a high level tended to do more poorly than those at a low or forearm level.

Time after Injury

On the average, in the 30 examples of good regeneration in upper extremity injuries, the definitive suture was done 117 days after injury; in the 30 cases of poor regeneration the average time was 229 days. Good neural regeneration was obtained, however, in 6 cases operated upon at time periods of 210 days or more, or 7 months post-injury. Regeneration failed to occur in 8 cases operated upon at time periods of 110 days or less after injury. In 4 cases of suture performed on the day of injury, 1 failed to secure neural regeneration and 3 succeeded. Within the limits of this study, time of operation after injury within the first year appeared to have some adverse effect upon the course of neural regeneration.

Nerve defect and suture line tension

The extent of the nerve defect and subsequent suture line tension tended to be greater in cases exhibiting poor neural regeneration than those with a favorable outcome. These factors reflect the magnitude of the inflicting force and are often associated with severely complicated wounds. Many instances of poor regeneration were found with small nerve defects where the cause of failure obviously rested elsewhere. The largest nerve gap found in the 30 favorable cases measured 9 cm. and the average was 4 cm.

Suture material

Since the majority of these cases were sutured with tantalum, no definite conclusions could be established. There were 5 plasma glue sutures, however, 4 of which failed and 1 succeeded.

Complications

Associated lesions or other complications also appeared to affect regeneration adversely. These included fracture, arterial damage, multiple nerve injury, severe soft tissue injury including frostbite, and infection. Technical errors such as suture line separation and failure to recognize nerve-tendon anastomosis were also responsible for a number of poor results.

Among the 30 cases of adequate regeneration, there were 9 with associated fractures, 4 with one other nerve injury and 4 with a major vessel ligation. On the contrary, among the 30 cases of poor or no regeneration, there were 28 examples of severe complicating injuries or technical errors. These included 10 fractures, 12 major vessel ligations, 20 multiple nerve injuries, 5 extensive soft tissue injuries, 10 with chronic infection delaying suture, 2 recognized suture line-separations, and 1 example of suture of nerve to tendon. Of extreme significance appear the adverse influences, respectively, of tissue ischemia secondary to vessel ligation and the appearance of multiple nerve injuries in a single extremity. In the former instance, peripheral nerve tissue is damaged not only by the inflicting force of nerve division but also by that of generalized tissue ischemia. In the latter instance, the effector mechanism is frequently irreparably damaged.

C. LOWER EXTREMITY

1. Peroneal Nerve

The 10 examples of good peroneal recovery are summarized in table 235 and individual cases follow. For the peroneal and tibial nerves, associated nerve lesions are shown only if suture was required, but for the sciatic

Table 235.—*Characteristics of Peroneal Nerve Cases With Good Recovery*

Characteristics of case	Case number									
	2012	2129	2166	[1] 4214	5040	5048	5303	[1] 7701	[1] 8751	[1] 8832
Lesion										
Pathology	Partial division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Partial division.	Partial division.	Complete division.
Site	Knee	Knee	Leg, upper ⅓.	Knee	Knee	Leg, upper ⅓.	Knee	Knee.	Knee	Knee.
Associated lesions and complications.	Fracture	Incomplete tibial N.	Fracture, plastic repair.	Tibial N	Tibial N	Fracture				
Definitive suture										
Days after injury	70	120	290	90	90	120	40	40	5	90.
Tension	None	Mild	None	None	None	None	None	None	None	None.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done.
Suture material	Tantalum	Silk	Silk	Silk	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum.
Surgical gap, cm	?	7	5	7	5	4	>1	3	?	6.
Follow-up examination										
British motor [2]	Intrinsics, resistance.	Intrinsics, resistance.	Intrinsics, resistance.	Synergic and isolated.	Intrinsics, resistance.	Intrinsics, resistance.	Intrinsics, resistance.	Synergic and isolated.	Synergic and isolated.	Synergic and isolated.
Pain threshold, gm	<6	<6	<6	<6	40	6	10	<6	Deep only	20.
British sensory [2]	Pain and touch, no overreaction.	Pain and touch, no overreaction.	Pain and touch, no overreaction.	Pain and touch, no overreaction.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, 2-pt.	Pain and touch, no overreaction.	Pain and touch, no overreaction.
Skin resistance	Normal	Normal	Normal	Not tested	Decreased	Normal	Elevated	Not tested	Not tested	Not tested.
Overall function, percent.	90	60	60	80	80	60	70	90	90	80.

Relative power[4]										
1—Tib. ant.	90.	15.	Movement not against resistance.	100.	15.	40.	25.	100.	60.	60.
2—Ext. dig. long.	10.	Movement not against resistance.	Movement not against resistance.	55.	Perceptible	20.	10.	20.	75.	50.
3—Ext. hall. long.	25.	Movement not against resistance.	Movement not against resistance.	50.	Perceptible.	25.	Perceptible.	Perceptible.	50.	85.
5—Peron. long.	90.	Movement not against resistance.	Movement not against resistance.	100.	10.	20.	25.	100.	100.	80.

[1] Case reported in text.

[2] The rubric abbreviated here as "Intrinsics, resistance" is "Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance". The rubric abbreviated as "synergic and isolated" is the same, plus capacity to perform some synergic and isolated movements.

[3] The rubric abbreviated as "pain and touch, no overreaction" is "Return of cutaneous pain and touch sensibility throughout the autonomous zone, with disappearance of any overresponse". That abbreviated as "pain and touch, 2-pt." is the same, plus some recovery of two-point discrimination within autonomous zone.

[4] Numerical entry gives percentage of normal power.

nerves both complete and incomplete (lysed) lesions are shown and are distinguished.

Case Report 7701

HISTORY OF INJURY

On July 7, 1944, this soldier was hit in the left knee by a rifle bullet. He noticed immediate inability to use the left foot. There was foot-drop. On August 23, 1944, at the 83d General Hospital, a neuroma in continuity [24] was excised from the left common peroneal nerve and end-to-end anastomosis was performed. A tantalum cuff was used. By February 1945, there was beginning return of sensory function with beginning extensor and peroneal function. On November 30, 1945, there was 50 percent to 75 percent function in the tibialis anticus and the extensors, and 75 percent to 100 percent function in the peronei.

CENTER EXAMINATION October 26, 1948

The patient complains of aching of the left leg and foot, especially in cold weather, coldness, hypersensitivity of foot, pain with use and easy fatigability. He has had some physiotherapy in the past two winters. He was a truck driver but is unable to handle the work so he now works in a drug store. He feels he is handicapped 50 percent, but is assessed at 30 percent.

Sensory examination shows a pain threshold of 2 grams with hyperalgesia in some parts of the autonomous zone, and a pain threshold in excess of 40 gm. in other parts. Touch threshold is 5 gm. over most of the autonomous zone. Pressure and position senses are normal. There is very slight split of sensation. Sweating is present.

Motor examination shows normal function in the tibialis anticus and peroneus longus, 20 percent function of extensor digitorum longus, and perceptible function of extensor hallucis longus. EMG was done.

The patient states that all foot functions are possible. Joints have normal ranges. Action of the foot is perfect—there is no foot-drop or limp. A brace is necessary only in icy weather. The patient cannot lift heavy weights or stand for many hours, but walking is relatively unlimited and he can run a short distance (90 percent function).

This is an excellent result from a low peroneal suture done early overseas.

Case Report 8751

HISTORY OF INJURY

On March 29, 1945, this soldier was wounded by mortar-shell fragments. He sustained a wound of the lateral aspect of the left popliteal space with the wound of exit on the mesial aspect. There were multiple retained foreign bodies, and the peroneal nerve was almost completely severed. There was foot-drop on the left. On April 3, 1945, at the 98th General Hospital in England the nerve was operated upon. An end-to-end anas-

[24] Coded as a partial division on review of operation report (Ed.).

tomosis with tantalum wire was done. A tantalum foil cuff was then applied. On admission to Cushing General Hospital on May 30, 1945, there was inability to extend the toes and ankle or to evert the foot, and there was anesthesia of the peroneal nerve distribution. X-ray studies soon thereafter showed that the tantalum cuffs were crinkled. On June 2, 1945, in neurosurgical conference, it was suggested that the peroneal and tibial nerves be reexplored, that the cuffs be removed, and that the patient be given a foot-drop brace. Accordingly, on June 22, 1945, reexploration was carried out. It was found that cuffs had been placed on the peroneal and tibial nerves in the popliteal space. These cuffs were badly fragmented and scar tissue had penetrated between the layers and crevices. The suture line of the peroneal nerve was smooth and looked good. Electrical stimulation produced good sensory but no motor response below this suture line. The posterior tibial nerve was in good condition and gave both sensory and motor response below the area where the cuff had been placed. Motor function improved steadily, and on November 30, 1945, there was some function in all of the standard peroneal innervated muscles except for the extensor hallucis longus. It was stated that there was no return of sensitivity. The patient was said at that time to be ready for a disability discharge. There was never any evidence of significant tibial nerve involvement.

CENTER EXAMINATION October 18, 1948

The patient complains of occasional tight feeling in the popliteal space, pins and needles feeling on the lateral aspect of the left leg and on the foot, and rapid fatigue. The patient states that he has been unable to continue in his previous occupation because the work was too heavy. He is now employed as a short-order cook in a restaurant and is able to handle this work satisfactorily.

The distance of injury is 17 in. [25] *Sensory examination* reveals that the peroneal autonomous zone does not respond to 40 gm. of pain, and it does respond to 16 gm. of touch. The area of analgesia is extensive on the lateral aspect of the lower leg.

Motor examination shows that the tibialis anticus functions at 60 percent, the peroneus longus at 100 percent, the extensor digitorum at 75 percent, and the extensor hallucis longus at 50 percent. The peroneus longus has a chronaxie of 6.0 msec. Chronaxies on the other muscles were not determined because the rheobase was too high. Tibialis anticus EMG, 80 percent.

Functionally, this patient has a good result. He can walk at least 1 mile. He has not worn a brace since June 1946. This is an excellent result, attributable probably to early suture.

Patient had not reached an end-point in regeneration at discharge 8 months after suture, with 7 in. to grow. The extensor hallucis began to function thereafter and all other muscles became stronger.

---

[25] Measured from the medial malleolus.

Case Report 4214

HISTORY OF INJURY

This patient incurred perforating wounds of left lower third of thigh on December 24, 1944, with subsequent complete peroneal and partial posterior tibial palsy. Just prior to exploration on March 29, 1945, it was noted that tibial function was 20 percent of normal; the gastrocnemius was very weak and inversion was 50 percent of normal. At operation, the peroneal nerve showed a proximal neuroma connected to a distal glioma by a 2 cm. fibrous strand. This nerve was resected (7 cm. gap), and sutured with silk. The posterior tibial nerve showed a neuroma 1½ cm. above point of division into its muscular branches occupying about 60 percent of its diameter. Electrical stimulation showed weak gastrocnemius and soleus contraction, but good long flexor contraction. The neuroma was "liberated" without disturbing the intact fibers, leaving a gap of 3½ cm. which was sutured with silk. Electrical stimulation immediately after the removal of the neuroma gave better results than previously. The last progress note, November 14, 14, 1945, stated that "he has better tibial function than he had preoperatively; there is fairly good dorsiflexion and slight extension of all toes except the large one; anesthesia remained in the peroneal distribution and in part of the sural; sensation on the plantar surface was quite adequate." He was discharged December 5, 1945.

INTERVAL HISTORY

No treatment since discharge. Dorsiflexion and eversion of foot and return of feeling to lateral aspect of foot improved about December 1946. Ankle joint "a good deal" more limber. Complains of occasional spontaneous pain, paresthesia at site of injury on percussion, coldness at night in foot, and rapid fatigue. Receives 60 percent disability compensation, but feels he is being undercompensated for injury. Premilitary occupation: elevator operator, to which occupation he could return and apparently wishes to return, but does not attempt to recover his job. Also would like to raise hogs, has had some education in raising hogs, but does not wish to go to a hog-raising area. Complains all employers feel he is "too slow" for the job, such as short-order cook.

CENTER EXAMINATION April 20, 1949

Patient was 19 years of age at time of injury, and right handed. Suture line 15 in. proximal to medial malleolus. No abnormal vasomotor responses.

Motor examination. Clinically patient has an excellent foot. He needs no brace. He can walk about 1½ miles without pain, but does have some fatigue. Patient has merest suggestion of a steppage gait. He can stand on his toes and squat very well. Examination of peroneal nerve reveals 70 percent muscle strength; the tibial nerve shows the same average return. Chronaxie examination of tibialis anticus is 1½ times normal, and of peroneus longus is 3 times normal. Electromyographic examination of tibialis anticus with coaxial needles on voluntary action revealed good spiking.

Sensory examination. Analgesia over the lateral aspect of the lower leg and the lateral aspect of the dorsum of the foot, including dorsum of 4th and 5th digits. Feels only 16 gm. touch in this area. In the autonomous area of the peroneal, he feels 2 gm. of pain and 1 gm. touch. In the autonomous area of the tibial nerve, he responds to 6 gm. of pain and 5 gm. of touch. Deep pressure is somewhat diminished but well localized. Two-point discrimination is 5 in. over analgesic area of lower leg. Position and vibration sense unimpaired.

OVERALL EVALUATION

Functionally, patient has practically a perfect foot. His analgesia is over an area which is not too frequently exposed to injury and, therefore, requires very little attention.

Case Report 8832

HISTORY OF INJURY

On December 1, 1944, this soldier sustained a shell fragment wound of the left thigh. Point of entrance was the left popliteal area in midline, wound of exit on the lateral aspect of the fibula. There was no fracture. Numbness of the dorsum of the foot was present from the beginning, and about 1 week after injury, the patient noticed foot-drop. Occasionally, he had feelings of needles and pins in his left leg. There was no severe pain in the foot. On March 1, 1945, on admission to Cushing General Hospital, examination revealed complete motor and sensory paralysis of the left peroneal nerve. There was no atrophy or sympathetic involvement. There was anesthesia of the left foot and ankle anteriorly, and of the left leg below the knee laterally and anteriorly. Posteriorly, there was numbness on the popliteal fossa down to the ankle. On March 7, 1945, at Cushing General Hospital, operation was performed. The peroneal nerve was found to be divided completely at the knee joint. Electrical stimulation proximal to the division produced no motor response. There was a gap of about 4 cm. in the nerve. The divided ends of the nerve were sectioned to normal-appearing nerve bundles. Both cut ends of the divided nerve bled slightly. The gap in the nerve after sectioning was found to be 6 cm. Anastomosis was performed with tantalum wire and there was absolutely no tension. On July 15, 1945, patient could just move the tibialis anticus if the leg were partially flexed. At that time there was some return of sensory function. On December 3, 1945, stimulation of the peroneal nerve at the popliteal space gave strong action in the peroneus longus and a definite contraction in the tibialis anticus. This patient had never been able to use his peroneus longus up to that time, but after he observed the movements in his foot, he was able to initiate strong eversion voluntarily. There was no voluntary function in the tibialis anticus at that time. Sensory function was continuing to improve. On February 4, 1946, there was a definite voluntary contraction of the peroneus longus muscle, and a flicker in the extensor digitorum longus, but the patient could not voluntarily use the tibialis anticus. There was good action in all peroneal muscles on intraneural stimulation. On May 9, 1946, the patient had adequate voluntary function in all peroneal musculature. The patient was discharged in May 1946.

CENTER EXAMINATION October 20, 1948

The patient states that he has no really serious complaints. He does complain somewhat of sharp pain through the leg, of pins and needles sensation on the top of the foot and the toes, numbness in the lateral aspect of the leg and the foot, subjective coldness, hypersensitivity in the popliteal space, and fatigability on long use. The patient is assessed at 50 percent. He has been a student since discharge.

Distance of injury is 20 in.

Sensory examination reveals thresholds to 20 gm. of pain and 5 gm. of touch, in the peroneal autonomous zone. There are large areas in the peroneal zone over which only 16 gm. are felt. Position and pressure senses are normal. There is moderate split sensation.

Motor examination reveals a function of 60 percent in the tibialis anticus, 50 percent in the extensor digitorum longus, 83 percent in the extensor hallucis longus, 80 percent in the peroneus longus. The tibialis anticus has a chronaxie of 2.4 msec. The patient can perform all foot functions. He walks 2 miles, and walks without a limp. Ankle motion is slightly limited, the range being from 100 degrees to 125 degrees. This case represents a good return of function in a peroneal nerve suture in the popliteal space. It is characteristic of peroneal recovery that it took the patient 5 months to learn to lift his foot after reinnervation had occurred.

The 10 cases illustrating poor peroneal recovery are summarized in table 236. The detailed case reports follow for several.

Case Report 4334

HISTORY OF INJURY

On October 7, 1944, this soldier was wounded in action in France by shell fire, receiving multiple fragments in both buttocks and thighs, with fracture of his left femur and traumatic amputation of the left calcaneus. Prior to operation the only function that he showed in his sciatic nerve was strong action in the gastrocnemius muscle. On April 23, 1945, at England General Hospital, operation was performed on the left sciatic nerve. In the popliteal space the left tibial and peroneal nerves were found bound down in dense scar for a distance of about 1 inch; the tibial nerve had only epineural scarring, this was removed, and the nerve was lysed internally; there was a small neuroma in the peroneal, which was resected 3 cm. to normal tubules and sutured with tantalum. There was considerable return of function in the tibial nerve but none in the peroneal, and on May 10, 1946, at England General Hospital, the left peroneal nerve was reexplored. It was found to be compressed at the head of the fibula; electrical stimulation produced slight sensory response, but no motor function, and below the site of compression the nerve appeared soft and pale; it was lysed internally and ballooned well except at the site of compression. This soldier was discharged on May 27, 1946.

INTERVAL HISTORY

The patient had about 1 year of weekly physiotherapy at a VA hospital following discharge; the only improvement that he has noted in the leg is some increased motion at the ankle joint. He complains of pain with use, with changes in weather, and when the leg becomes cold; additionally, the leg is subject to rapid fatigue. While he is able to walk 3 blocks with a brace and go up stairs, he cannot run or climb a ladder. Before the war he was a coal miner, but now he has no job, although he is thinking about getting trained for one. He received 100 percent compensation for all of his injuries.

CENTER EXAMINATION October 12, 1949

Patient is right handed. When he walks without a brace he shows a marked steppage gait and very little pelvic tilt; he has a foot-drop. Distance of the first operation (suture) is 19½ in.; distance of the second operation (lysis) is 15 in. There are no marked trophic changes, the feet are equally warm and moist, and the pulses are full and equal. The calf is diminished ½ in. in circumference. The ankle joint has 30 degrees motion.

In a typical peroneal distribution 40 gm. pain is felt only as pressure; in the same area he is unable to feel 35 gm. touch. Deep pressure produces some local pain in the 1st, 2d, 4th, and 5th toes; position sense is slightly diminished on the large toe, normal on the others; throughout the peroneal area there is 2 to 3 cm. split in sensation. Sensation is normal in the tibial area.

Quantitative muscle evaluation is as follows. Gastrocnemei 100 percent; tibialis posticus 60 percent; tibialis anticus, extensor digitorum longus, extensor hallucis longus, and peronei 0. The intrinsic foot muscles had a rheobase of 130, a chronaxie of 6.0; no rheobase was obtainable for the tibialis anticus or peroneus longus. Intraneural stimulation of the peroneal nerve failed to produce any response whatsoever in the peroneal area.

Functional evaluation. The patient is able to get around moderately well with his leg, and wearing a brace he is able to walk about 3 blocks before he is stopped by fatigue.

POINTS OF SPECIAL INTEREST

The peroneal nerve appears to have undergone two injuries, one being in the midthigh where it was severed, and again at the head of the fibula, where it was compressed.

Table 236.—*Characteristics of Peroneal Nerve Cases With Poor Recovery*

Characteristics of case	Case number									
	1163	1210	2253	3101	3158	3268	[1] 4038	[1] 4060	[1] 4234	5073
Lesion										
Pathology	Complete division.	Partial division.	Partial division.	Complete division.	Neuroma in contin- uity.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.
Site	Thigh, lower ⅓.	Knee	Knee	Leg, upper ⅓.	Knee	Knee	Knee	Knee	Knee	Knee.
Associated lesions and complications.	Fracture, infection, suture line neuroma, resuture.	Plastic re-repair.	Infection	Fracture, plastic repair, separated suture line, resuture.	Separated suture line, resuture	Fracture, suture line mass upon examination.	Infection	Suture line neuroma, resuture	Multiple lesion,[2] fracture.	Fracture, plastic repair, separated suture line.
Definitive suture										
Days after injury	810	140	410	550	450	160	120	530	190	140.
Tension	None	None	?	?	None	None	Moderate	None	None	Moderate.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Done	Not done	Not done	Done.
Suture material	Tantalum	Tantalum	Silk	Silk	Tantalum	Tantalum	Tantalum and silk.	Tantalum	Tantalum	Silk.
Surgical gap, cm	6	4	14	15	9	6	13	10	3	10.
Follow-up examination										
British motor	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.
Pain threshold, gm	No sensation.	40	No sensation.	No sensation.	No sensation.	No sensation.	Deep only	No sensation.	Deep only	No sensation.
British sensory	Absent sensibility.	Deep pain only.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Deep pain only.	Absent sensibility.	Deep pain only.	Absent sensibility.

Skin resistance	Decreased	Decreased	Not tested	Elevated	Elevated	Elevated	Normal	Elevated	Elevated	Elevated.
Overall function, percent	0	70	40	60	70	60	50	50	50	50.
Relative power [3]										
1-Tib. ant	0	0	0	0	0	0	0	0	0	0.
2-Ext. dig. long	0	0	0	0	0	0	0	0	0	0.
3-Ext. hall. long	0	0	0	0	0	0	0	0	0	0.
5-Peron. long	0	0	0	0	0	0	0	0	0	0.

[1] Case reported in text.
[2] Double nerve injury to peroneal. Probably compressed by scar below knee.
[3] Numerical entry gives percentage of normal power.

Case Report 4038

HISTORY OF INJURY

This soldier was wounded in action April 6, 1945, in Germany, by an HE fragment penetrating the right knee, lateral aspect. At debridement next day a foreign body was removed, and the severed peroneal ends were tagged with silk threads. There was considerable tissue loss and the tagged nerve ends were easily seen 10 days later on examination. At McGuire General Hospital on July 10, 1945, he had incision and drainage of multiple abscesses in the right popliteal region. The peroneal nerve ended in much scar and no attempt at suture was done, due to infection. Bulb anastomosis was carried out at this time. On August 9, 1945, at the same hospital, neurorrhaphy was performed on the right peroneal nerve. There was a 3-in. gap, easily made up by flexing the knee. Suture with silk and fine tantalum wire, no cuff. The posterior tibial nerve was intact and merely freed from scar tissue. On January 19, 1946, examination showed anesthesia over the peroneal area, and hypesthesia on the sole of the foot. A note states there was "improvement in anesthesia." The muscles of the posterior tibial group were classed as 50 percent function with none in the peroneal group. Disability discharge on February 13, 1946, with paralysis right peroneal incomplete manifested by foot-drop, and sensory loss on dorsum of foot.

CENTER EXAMINATION May 11, 1948

Sensory examination of the peroneal distribution requires explanation. There is complete loss of touch in all of the peroneal area. Burning and tingling is felt at many points throughout the area in response to 10 gm. pain stimulation, but never felt as a true pinprick. He does not feel 40 gm. pain or 20 gm. touch on the sole of the foot. Deep pressure and position sense are intact. Skin resistance is normal over the entire peroneal area, and presents a mixed pattern on the tibial area. Motor examination shows no function in the peroneal group of muscles, and 40 percent overall in the tibial group. There is no limitation of joint range. Intraneural stimulation of the peroneal nerve gave no response. This observation may not be entirely valid because the patient would not tolerate maximal nerve stimulation although good needle contact was obtained. Chronaxie and tetanus ratio determinations were not possible because the peroneal musculature would not respond to maximal currents.

POINTS OF SPECIAL INTEREST

(1) Failure of regeneration of peroneal nerve made more than likely by abscess formation in popliteal space at time of injury.

(2) Partial injury to posterior tibial nerve, but the muscles are now functioning strongly enough that this would be a suitable case for tendon transplant, and has been recommended to the patient. His physician has been written regarding this question.

(3) No good data as to the original extent of tibial nerve injury, so that one cannot draw conclusions as to the actual amount of tibial nerve regeneration. In July 1945, the tibial group was rated to be absent clinically, not responding to faradic stimulation, but reacting to galvanic stimulation as did the peroneal group. In January 1946, the posterior tibial was recorded as having fair strength clinically. It is interesting that, in spite of the good recovery of all tibial innervated muscles seen at this time, there remains a complete anesthesia over the tibial sensory area on the sole of the foot.

Case Report 4060

HISTORY OF INJURY

October 1, 1944, WIA mortar fragments, Italy. Multiple severe penetrating wounds at left elbow, both legs and thighs, with left peroneal paralysis.

October 9, 1944. Secondary closure, wounds of left calf and left elbow.

January 30, 1945. Neurorrhaphy, left peroneal, excision of neuroma (gap 6 cm.), end-to-end anastomosis (silk).

March 21, 1946. Resuture. Excision of neuroma for 10 cms.; proximal end still unsatisfactory (hyaline appearance). Resutured in spite of this (tantalum wire). No improvement.

August 21, 1946. Disability discharge—no return of function.

The suture line is 18 in. from the internal malleolus. The circumference of the leg 4 in. below the tibial tubercle is 11 in. on the left and 12½ in. on the right. As far as joint function is concerned, the left knee extends to 160 degrees; the right to 175 degrees; the left knee flexes to 50 degrees and the right to 60 degrees.

Examination shows good arterial pulsations in the foot which is warm. There are no gross trophic changes except for marked atrophy of the tibialis anticus and both peronei with a complete foot-drop. The patient wears a kickup splint, and is mortally afraid that we are not as disinterested as we claim to be, and consequently refuses to give the dollar compensation, although he says that he gets 70 percent plus the loss of his foot.

Sensory examination shows a complete peroneal anesthesia with no feeling to 40 grams of pain and 20 grams of touch. Pressure and position sense are present in the toes however. There is a good zone of increased skin resistance corresponding to the touch area of hypesthesia. Clinically, all the peroneal musculature is completely nonfunctioning.

On intraneural stimulation of the peroneal at the knee, there is no reaction. Chronaxie of the tibialis anticus is 2, peroneus longus 10; tetanus ratio of the tibialis anticus is no tetanus with a ratio greater than 2, and the same goes for the peroneus longus.

On the whole, the examinations, with the exception of the intraneural stimulation, were of little value. Functionally, the patient gets along with a kickup splint without too much difficulty.

POINTS OF SPECIAL INTEREST

(1) This patient has had two operations, the second one overcame the gap of 10 cm., and the operator stated that the nerve ends sutured seemed to be hyalinized and lacked good tubule formation.

(2) The patient has no return whatsoever either sensory or motor.

(3) The chronaxie and tetanus ratio are of little value, but the intraneural stimulation made it evident that the man had no function in the muscles innervated by the peroneal nerve.

(4) We feel that the kickup splint is as good a therapeutic prop as anything else.

2. Tibial Nerve

The 10 examples of good tibial recovery are summarized in table 237. The individual case reports on five of these follow.

Case Report 4209

HISTORY OF INJURY

November 16, 1944, while in action in Germany, patient sustained a gunshot wound of the right leg in the posterior calf region—upper ⅓. This was said to result in a right tibial paralysis with anesthesia over the heel and weakness in flexion of the toes. January 22, 1945, at the 83d General Hospital, the tibial nerve was resected to a 5-cm. gap. Tantalum wire and a cuff were applied. He was splinted for 12 days. On August 30, 1945, he was discharged from the Ashford General Hospital with an excellent return of function in both the sensory and motor components according to the chart.

INTERVAL HISTORY

Patient's chief complaint at the present time is fatigue in the affected leg along with a peculiar aching feeling in the foot after prolonged walking. Approximately 12 months after discharge he noted improved ankle and toe motion. At the present time he has some numbness on the outer aspect of the foot and some coolness of the entire foot in cold weather. He feels fatigue after 3 hours of standing or walking 2 to 3 miles. He is able to walk these 2 to 3 miles without any aid whatsoever; however, he finds it more difficult to walk in cold weather. Prior to his injury, he had a job in a gas station. At the present time, he is well situated doing woodwork refinishing. He feels that his 50 percent disability is a fair adjustment.

CENTER EXAMINATION April 8, 1949

The wound is 10⅓ in. from the internal malleolus. The circumference of the lower leg is equal bilaterally. The dorsalis pedis pulse is good and equal bilaterally; the posterior tibial is extremely poor on the right. The right foot is definitely cooler and more moist than the left. There is no impairment of joint function.

Sensory examination shows pressure sensibility to be 75 percent of normal in all the toes. Position sense is less definitely present to a degree of about 60 percent of normal. Clinical evaluation of muscle function shows the gastrocnemius, tibialis posticus, and the long flexor of the toes to be about normal in strength. However, the intrinsic foot muscles show only about 10 percent return. Definitive sensory examination on the sole of the foot shows that the patient is able to feel 30 gm. of pain all over and 35 gm. of touch. There is no question that he would feel more than 40 gm. were it not for the fact that the sole is extremely calloused. It is interesting at this point to note that there is absolutely no hypersensitivity of the sole. Skin resistance shows approximately the same findings in the normal and abnormal foot, with the exception of the lateral aspect of the sole where there is definitely decreased skin resistance in the injured foot. Chronaxie of 4.4 msec. was slightly higher than was expected in the gastrocnemius. However, the figure of 12 msec. is what would have been expected in the case of the intrinsic foot muscles. Electromyography was not performed for technical reasons.

FUNCTIONAL EVALUATION

Except for fatigue which comes on only after standing for several hours or walking for several miles, this foot is as good as the normal one.

POINTS OF SPECIAL INTEREST

This good result illustrates what can be expected in the very low tibial injuries.

Case Report 4133

HISTORY OF INJURY

On December 20, 1944, the patient sustained multiple penetrating wounds of the middle ⅓ of the left arm and of both legs, 2–3 in. proximal to the malleolus. There was resultant complete paralysis of both posterior tibial nerves and partial paralysis of the median and ulnar. On February 25, 1945, neurorrhaphy was performed on both tibial nerves. The left was resected 1½ cm. and the right, 2 cm. Both were sutured with tantalum and tantalum cuffs were placed about the lines of anastomosis. Prior to operation, an incomplete sensory loss was noted on examination; no notation is available on the status of the intrinsic foot muscles at that time. An external neurolysis was performed on the median and ulnar nerves on March 12, 1945; prior to this procedure a slight decrease in muscle strength and a sensory deficit were noted. At examination on April 24, 1945, all muscles were graded as 4 plus, and there was still a slight sensory deficit in the median area.

CENTER EXAMINATION September 30, 1948

Hand. Sensory examination revealed normal thresholds throughout the hand; skin resistance, position sense, deep pressure and pain points were also within normal limits. There was a diminution in two-point perception over the ulnar area, but the median was normal. There was no atrophy

Table 237.—*Characteristics of Tibial Nerve Cases With Good Recovery*

Characteristics of case	Case number									
	2151	2206	3046	3311	3373	[1] 4133	[1] 4206	[1] 4209	[1] 4231	[1] 8717
Lesion										
Pathology	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.	Partial division.	Complete division.	Complete division.	Complete division.
Site	Leg, middle ⅓.	Leg, middle ⅓.	Leg, middle ⅓.	Knee	Leg, lower ⅓.	Leg, lower ⅓.	Ankle	Leg, middle ⅓.	Leg, lower ⅓.	Thigh, lower ⅓.
Associated lesions and complications.	Fracture, infection.	Fracture		Fracture			Fracture, artery.		Fracture, plastic repair, artery.	
Definitive suture										
Days after injury	240	380	90	50	200	60	1	60	230	130.
Tension	None	None	Mild	None	None	None	?	None	None	Moderate.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done.
Suture material	Silk	Tantalum	Tantalum	Tantalum	Silk	Tantalum	Tantalum	Tantalum	Cotton	Tantalum.
Surgical gap, cm	12	9	7	4	5	2	?	5	6	06.
Follow-up examination										
British motor [2]	Synergic and isolated.	Intrinsics, resistance.	Intrinsics, resistance.	Intrinsics, resistance.	Intrinsics, resistance.	Synergic and isolated.	Intrinsics, resistance.	Synergic and isolated.	Synergic and isolated.	Intrinsics, resistance.
Pain threshold, gm	10	<6	10	40	10	6	<6	30	<6	30.
British sensory [3]	Pain and touch, overreaction.	Complete recovery.	Pain and touch, overreaction.	Superficial pain and touch.	Pain and touch, overreaction.	Pain and touch, no overreaction.	Pain and touch, overreaction.	Pain and touch no overreaction.	Pain and touch, overreaction.	Superficial pain and touch.
Skin resistance	Normal	Elevated	Normal	Elevated	Mixed	Not tested	Normal	Decreased	Not tested	Not tested.
Overall function, percent.	80	80	90	80	90	90	80	90	80	90.

Relative power [4]											
1–Gastroc. and sol.	Not affected.	Not affected.	Not affected.	100	Not affected.	Not affected.	Not affected.	Not affected.	Not affected.	30.
3–Fl. dig. long	20	?	55	29	Not affected.	Not affected.	Not affected.	?	Not affected.	25.
4–Fl. hall. long	25	Perceptible	55	29	Not affected.	Not affected.	Not affected.	?	Not affected.	25.
6–Inteross.	Movement not against resistance.	Movement not against resistance.	55	29	0	60	50	25	?	25.

[1] Case reported in text.

[2] The rubric abbreviated here as "Intrinsics, resistance" is: Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance; the rubric abbreviated as "synergic and isolated" is the same, plus capacity to perform some synergic and isolated movements.

[3] The rubric abbreviated here as "pain and touch, overreaction" is: Return of superficial pain and touch sensibility throughout autonomous zone, with overreaction and inability to localize stimulus; that shortened to "Superficial pain and touch" is: Return of some degree of superficial pain and touch sensibility within autonomous zone: "pain and touch, no overreaction" is: Return of superficial cutaneous pain and touch sensibility throughout the autonomous zone, with disappearance of any over-response.

[4] Numerical entry gives percentage of normal power.

and motor power was found to be equal on both hands. Functionally, there was no difficulty in performing any movements with the hand and there was no complaint.

Feet. The patient complains of spontaneous pain, paresthesias, numbness, coldness, hypersensitivity and pain with use. Sensory examination reveals threshold of 6 gm. pain and 2 gm. touch in both feet. Position sense is approximately 80 percent of normal and deep pressure sense is normal. Motor examination results list the left leg as having good function in all muscles but the right showed the intrinsics to be functioning weakly. Functionally, the only limitation is by pain on extended use; the patient can walk several miles, however.

POINTS OF INTEREST

The injuries present no handicap in the patient's job as a bartender. The leg injuries were just proximal to the malleolus and therefore muscle involvement was confined to the foot itself.

Case Report 4231

HISTORY OF INJURY

On January 6, 1945, this officer was wounded in action in France, sustaining a gunshot wound of the left ankle. Debridement same day with ligation of posterior tibial artery. Compound comminuted fracture lower left tibia, and the leg was casted. Posterior tibial nerve injury noted June 10, 1945. August 23, 1945, McCloskey General Hospital, the posterior tibial nerve was resected to a 5½ cm. gap; #120 cotton suture was used. Diameter of distal stump approximately twice that of proximal stump, with no tension. Using a closed pedicle flap, a skin graft was also performed using the right thigh as donor site. September 18, 1945, attached closed pedicle graft cut. December 1945, same hospital, excision of cicatrix from ankle, with splinting. September 26, 1947, retired, and the spring-type brace unsuccessful. Evaluation showed atrophy of intrinsic foot muscles and limitation of joint motion.

INTERVAL HISTORY

Walter Reed General Hospital January 1948 Keeler procedure on last 4 toes (⅔ of proximal phalanx excised) resulting in flail toes. No improvement in mobility or strength but entire sole of foot except heel has become more hypersensitive. Complains of spontaneous pains in foot at times, paresthesias and hypersensitivity over ball of foot, arch, and under toes when stepping over uneven areas such as rocks; numbness in heel and rapid fatigue. Can walk about a mile without pain or undue fatigue. Patient was a Regular Army officer and therefore 100 percent disabled for his former job. He is now doing postgraduate work.

CENTER EXAMINATION May 17, 1949

Patient was 22 years old at time of injury. Suture line approximately 4 in. proximal to medial malleolus. Circumference of thigh 8 in. above tibial, tubercle is 1⅛ in. less than the right, while the circumference of lower leg 4 in. distal to tibial tubercle is ⅜ in. less on the left. He is able to dorsiflex ankle on right to 70 degrees, on left to 90 degrees, able to extend foot on right 140 degrees, on left 125 degrees. There is good passive motion in toes of left foot and they maintain themselves in normal position. Pulses and color normal bilaterally, with no atrophic changes or abnormal vasomotor responses present.

Motor examination. Clinically there is about 50 percent muscle strength present in the intrinsic foot muscles. The patient is able to walk about 1 mile, to stand on toes and heels, to squat and dance. He is able to flex, extend, invert, and evert the ankle well, as well as cup the foot and flex and extend the toes fairly well. Chronaxie examination of intrinsic foot muscles was 20 times normal.

Sensory examination. Hypersensitive to pinprick with 2 gm./mm. and touch with 3 gm./mm. over entire sole of foot except heel. There is anesthesia and analgesia over the heel. He feels "sharp" with 10 gm. and touch with 16 gm./mm. over the plantar aspect of toes, and distal portion of dorsum of 4th and 5th toes. Deep pressure sensation on the little toe caused pain sensation up into the lateral aspect of the foot. Vibration and position sense are intact.

OVERALL EVALUATION

As would be expected from such a low injury, this patient has an excellent functioning foot. His main difficulty is the hyperesthesia on the sole of the foot which probably can be well controlled with the use of a rubber sponge and he has so been advised. He also has been advised to continue the use of the bar in his shoe just proximal to the ball of the foot in order to take the weight off the very hypersensitive ball.

Case Report 4208

HISTORY OF INJURY

Patient WIA, March 30, 1945, Germany. Shell wounds, perforating lateral and medial malleoli right lower leg. "Posterior tibial artery severed and posterior tibial nerve partially severed," noted on evacuation hospital chart. Chip fracture right medial malleolus of tibia and right lateral malleolus of fibula. March 31, 1945, 107 Evacuation Hospital, posterior tibial vein and artery ligated. Ends of tibial nerves approximated with tantalum wire. Boot cast applied. April 7, 1945, closure of wounds. July 19, 1945, plantar flexion limited to 100 degrees; extension to 90 degrees. Mottling and erythema of skin. Only dorsalis pedis artery palpable. Ankle edema. No neuroma. Anesthesia of sole of foot. "Some motor function of all muscles, flexor digitorum longus and flexor hallucis longus being weak." December 3, 1945, Halloran General Hospital, exploration of right posterior tibial nerve. Electrical stimulation distal and proximal to suture gave both sensory and motor response. Small branch of posterior tibial going to heel found severed with neuroma.[38] Neuroma excised and proximal end of nerve placed in subcutaneous tissues. Unable to locate distal end of nerve. March 16, 1946, disability discharge.

INTERVAL HISTORY

No treatment since discharge. Complains of edema of foot on standing and pain in ankle and foot on walking. Hypersensitive on medial aspect sole of foot when walking on uneven ground. Coldness over medial portion of ankle and occasionally in toes. Markedly hypersensitive to touch and "sharp" sensation over area of arch of foot. Pain in whole foot when walking more than 5 blocks. Rapid fatigue. Claims marked improvement in flexion of toes since September 1948 and slight improvement in inversion of foot since March 1948. Claims marked improvement in range of ankle motion. Claims hypersensitivity in arch of foot since discharge. Due to injury, unable to resume prewar job of machine hand at Bethlehem Steel. Now in college preparing for business.

CENTER EXAMINATION April 4, 1949

Patient 24 years old at time of injury and left handed. Suture-line at site of medial malleolus. Circumference of ankle at right 11 in., on left 9½ in. Dorsiflexion of ankle on right 89 degrees, on left 75 degrees; extension on right 155 degrees, on left 170 degrees. No autonomic abnormalities. Posterior tibial pulse on right not palpable. Marked nonpitting ankle edema on right.

Motor examination. 50 percent muscle strength in the intrinsic foot muscles. Chronaxie examination 16 times normal. Functionally, patient without shoes has a slight limp due to inability to put entire weight on right ankle and foot. With shoes, patient's gait is normal. He is able to walk 6 blocks without discomfort.

Sensory examination. Patient able to feel "sharp" with 10 gm. and touch with 16 gm./mm. over the posterior tibial distribution in the sole of the foot. Marked hyperesthesia over the arch of the foot is present extending to within 1 in. of the medial malleolus. Patient hypersensitive to "sharp" with 2 gm. and touch with 3 gm./mm. in this area. Position and vibration sense normal. Deep pressure on toes revealed a nondisagreeable pressure sensation at point of stimulation. Pricking or touching hypersensitive area "feels as if nerve was hit, but disagreeable sensation does not spread." Skin resistance is slightly decreased on the right over both the posterior tibial distribution on the sole of the foot and the long saphenous distribution.

OVERALL EVALUATION

This patient has a practically perfectly functioning foot. His edema probably can be controlled by the use of a thin rubber bandage applied snugly from the ball of the foot to the lower third of the tibia. He was

---

[38] Coded as partial division on review of operation report (Ed.).

so advised. The hyperesthesia due to some irritation of the long saphenous nerve is not sufficiently disagreeable to the patient to warrant further investigation. In view of the fact that this patient's future lies in the business field, he has a functionally satisfactory foot.

Case Report 8717

HISTORY OF INJURY

This patient had a complete injury to the sciatic nerve on the right in March of 1945, and this was sutured overseas May 1945, by overcoming an 8.0 cm. gap for both peroneal and tibial components, the point of suture being 4 in. above the popliteal space. At the time of admission in July 1945, 4 months after suture, there was a Tinel's sign 3 in. below the head of the fibula. By April 1946, 13 months after suture, there was good function in the gastrocnemius and the posterior tibial on the right, as well as beginning function in the anterior tibial, peroneus, and extensor of the toes.

Turning to the left leg, this also showed a wound at the same level about 3 in. above the popliteal space. The patient showed intact peroneal nerve function but a complete tibial nerve paralysis. Operation on this was delayed until July 1945, while the right leg was mobilized following operative fixation of the knee for suture of the nerve. The tibial nerve was found divided below some branches to the gastrocnemius muscle so that the good recovery of that muscle must not be attributed to the suture. The peroneal division was found intact. A gap of 8 cm. was overcome in suturing the tibial nerve in the popliteal space. Our last note on this patient is in March 1946, and at that time he still showed no function in the left tibial nerve except for the flicker in the gastrocnemius which was innervated above the suture line. In the 2 years since discharge, the patient has noticed an increase in his ability to dorsiflex the right foot. He also believes both legs have increased in strength of all muscles. He is able to walk very satisfactorily for a distance of as long as 1½ miles and the only things which he finds difficult are climbing ladders or running. He feels that he has been limited in his earning ability because he cannot be a machine operator and stand on his feet for long periods of time. He therefore changed to a job which allows him to be an inspector and sit a good portion of the day, which he does quite comfortably.

CENTER EXAMINATION October 19, 1948

An examination of the right leg, which has a complete sciatic nerve suture done overseas, shows good function in all of the peroneal group of muscles and all of the tibial group of muscles, except that there is no flexion of the toes and extension of all the toes is slightly weak. Chronaxies and tetanus ratios could be done only on the intrinsic muscles and here the rheobase was 120 and the chronaxie was 12.0 msec., indicating complete denervation which was the clinical impression. There seems to be a fair recovery of sensation throughout and this had to be mapped by slight differences with the pin, it being impossible in this patient to get good thresholds on either side.

Examination of the left leg showed that the peroneal component had intact function as previously and there was some function in all of the tibial musculature except for the posterior tibial. Gastrocnemius was measured at 12 lb. but plantar flexion was greatly aided and substituted for by the peroneus longus muscle. Again electrical study could be done only on the short flexor of the great toe where the rheobase was 100 and the chronaxie was 6.0 msec. Sensation seemed definitely recovered but again could not be very well mapped except to say that the tibial area had slightly diminished sensation as compared to the rest of the leg. From a functional standpoint, the patient walked with no foot-drop of any kind. He limped slightly with the left leg when he was barefoot, but walked with no disability whatsoever when he had both shoes on.

POINTS OF INTEREST

The left tibial nerve had regenerated about as one might expect but the regeneration of the right leg has been singularly satisfactory. This may be attributed both to the low lesion in the popliteal space involving both tibial and peroneal nerves on the right, and it may also be partly the result of extremely early suture which was carried out 8 weeks after injury.

The 10 cases representative of poor tibial recovery are summarized in table 238. Full details on four of these follow.

Case Report 4442

HISTORY OF INJURY

This patient was wounded in action in Germany on February 13, 1945, when struck by high explosive shell. He sustained a penetrating wound of the lower third of the right leg, with compound comminuted fracture of the lower third of the right fibula. His status at the beginning of April 1945 was "inability to flex toes, anesthesia of sole, with early causalgia." On April 11, 1945, a bulb suture operation was performed on the right tibial nerve. Stumps of the nerve were found 4 to 5 cm. separated in the middle and lower third of the right leg. They were sutured side-to-side with silk, apparently under considerable tension, and wrapped in tantalum foil. On September 13, 1945, a neurorrhaphy was done (second-stage bulb suture) on the right tibial nerve. This nerve was resected 4 cm. to normal nerve tissue, and sutured with tantalum. Patient was given a disability discharge on February 18, 1946, at which time there was a Tinel's sign to the medial malleolus but, as yet, no return of function.

CENTER EXAMINATION February 2, 1950

This was a very low tibial nerve injury at the ankle. Suture was of the bulb type in two stages, definitive repair occurring 7 months after injury. There is slight sensory return to the sole of the foot, 40 gm. of pain being appreciated occasionally, with touch running between 50 gm. and 35 gm.

From a motor standpoint the intrinsic foot muscles show no voluntary action but do show a flicker on nerve stimulation. Chronaxie for the adductor hallucis is 9.0 msec.

This patient is in no way disabled except that he cannot run as well as previously, so that he has had to give up playing professional baseball. He probably would be more disabled if his nerve had grown back better. It is hard to see how these extensive procedures help the patient in any way, and it raises the question as to whether an effort should be made to overcome an extensive gap in the posterior tibial nerve.

Case Report 4075

HISTORY OF INJURY

This patient received a perforating wound of the left lower leg with resultant paralysis of the posterior tibial nerve and fracture of the left tibia. The level of injury was such that loss of function was limited to the intrinsic foot musculature and sensory perception in the foot. At neurorrhaphy on September 14, 1945, considerable scar formation was encountered; a defect of 10 cm. was made up by flexing the knee to 80 degrees. Fibrin foam and tantalum foil were utilized to cover the scarred nerve bed. Prior to discharge on February 8, 1946, there was definite evidence of sensory return on the sole of the foot.

CENTER EXAMINATION

There is complete anesthesia in the autonomous zone to 40 gm. of pain and 20 gm. of touch; the remainder of the foot shows a variable threshold. Deep pressure sense is poor in the 4th and 5th digits and position sense is present but diminished in the same area. Clinically, the intrinsic foot muscles seemed to be nonfunctioning nor could they be made to contract upon electrical stimulation. No rheobase or chronaxie was obtained. Skin resistance tests showed an area of increased resistance along the lateral edge of the foot.

The patient can walk without difficulty; except for the hypersensitivity of the sole of the foot he has no real problem.

POINTS OF INTEREST

There was a time lapse of 1 year before suture and a distance of 10 cm. was made up at operation.

Case Report 4008

HISTORY OF INJURY

Patient was injured March 9, 1945, on Luzon. Multiple perforating gunshot wounds resulting in incomplete fracture of the right tibia and fracture of the neck of the right femur. He was admitted to Ashford General Hospital May 30, 1945. On July 31, 1945, a neurorrhaphy of the posterior tibial nerve of the right lower extremity was carried out. The gap closed was approximately 8 cm. An end-to-end anastomosis was carried out with interrupted cotton sutures, with moderate tension. The

Table 238.—*Characteristics of Tibial Nerve Cases With Poor Recovery*

Characteristics of case	Case number									
	2042	2103	2111	2113	2226	3462	[1] 4002	[1] 4008	[1] 4075	[1] 4442
Lesion										
Pathology	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Complete division.
Site	Knee	Leg, middle ⅓.	Knee	Leg, upper ⅓.	Knee	Leg, middle ⅓.	Leg, upper ⅓.	Leg, lower ⅓.	Leg, middle ⅓.	Leg, middle ⅓.
Associated lesions and complications.			Plastic repair.		Peroneal N, artery.	Fracture, infection.		Fracture, plastic repair.	Fracture	Fracture.
Definitive Suture										
Days after injury	70	260	150	100	150	530	120	140	360	210.
Tension	None	None	None	Moderate	Moderate	None	None	Moderate	None	Severe.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Done.
Suture material	Tantalum	Tantalum	Tantalum	Silk	Tantalum	Tantalum	Cotton	Cotton	Tantalum	Tantalum.
Surgical gap, cm	3	7	8	9	12	10	4	9	10	9.
Follow-up examination										
British motor	Proximal only, perceptible.	No contraction	Proximal only, perceptible.	Proximal only, perceptible.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.
Pain threshold, gm	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	Deep only	Deep only	No sensation.	Deep only	40.
British sensory	Absent sensibility.	Deep pain only.	Absent sensibility	Absent sensibility.	Absent sensibility.	Deep pain only.	Absent sensibility.	Absent sensibility.	Deep pain only.	Deep pain only.
Skin resistance	Decreased	Decreased	Elevated	Decreased	Elevated	Normal	Elevated	Normal	Mixed	Not tested.
Overall function, percent	10	60	60	60	30	50	80	80	60	90.

Relative power [2]										
1—Gastroc. & sol.	0	Not affected.	?	Not affected.	0	Not affected.	Not affected.	Not affected.	Not affected.	Not affected.
3—Fl. dig. long.	0	0	?	Not affected.	0	Not affected.	0	Not affected.	Not affected.	Not affected.
4—Fl. hall. long.	0	0	?	Not affected.	0	Not affected.	0	0	Not affected.	Not affected.
6—Inteross.	0	0	0	Movement not against resistance.	0	0	0	0	0	0.

[1] Case reported in text.
[2] Numerical entry gives percentage of normal power.

surgeon made a note that the neurorrhaphy was considered unsatisfactory because it was impossible to resect enough nerve tissue to obtain normal fascicles. He was discharged in November 1945 with no evidence of sensory recovery.

CENTER EXAMINATION March 31, 1948

This man complains of discomfort in the sole of his foot when he is on the foot for more than 2 hours. The foot swells somewhat and occasionally he suffers a transient ulceration on the heel. He used to work in a textile stockroom and now is a gas station attendant with minor limitation. Sensory examination shows no evidence of regeneration. The sole of the foot is anesthetic to 40 gm. pain and 50 gm. touch. Motor examination indicates the only muscles affected are the intrinsics. They have no voluntary innervation and nerve stimulation at the ankle failed to produce any visible contraction. The tendon of the flexor hallucis longus was involved in the original injury, but this is not disabling to the patient. For all practical purposes the motor function is unimpaired.

Functional evaluation. This patient has an entirely useful foot and does not require a brace to walk with an entirely normal gait. Because of his pain on long standing and his susceptibility to edema of the foot and occasional ulceration, his function is rated at 80 percent.

Comment. There is absolutely no evidence of tibial nerve regeneration. If there were regeneration, function would be probably worse than it is now because of pain. This is another case which raises the question as to whether extensive operations to overcome defects in the distal tibial nerve are really indicated.

Case Report 4002

HISTORY OF INJURY

While on active duty in Europe, October 17, 1944, the patient was struck by a mortar-shell fragment, which penetrated his right arm, lower third, causing a transient ulnar nerve paresis. Simultaneously, a wound in the right leg, upper third, resulted in tibial nerve paralysis. By January 1945, the ulnar difficulty recovered to only a slight qualitative change in sensation. On January 20, 1945, it was noted that he had all movements of the foot except spreading of the toes, and that he had some numbness over the tibial sensory distribution. A resection was carried out of a neuroma February 13, 1945, and an end-to-end anastomosis with cotton sutures was made after excision of 4 cm. of a neuroma in continuity. By September 15, 1945, there was return of touch to the foot. The long toe flexors never lost their innervation but the tendons were partially involved in the scar.

CENTER EXAMINATION March 23, 1948

Motor examination. The only function he did not have was flexion of the toes. He had strong inversion to 24 lb. and strong plantar flexion to 42 lb. Intraneural stimulation failed to achieve any flexion of the toes, although the intrinsic foot muscles responded feebly, indicating slight motor recovery through the suture.

Sensory examination. Patient was insensitive to pain to 40 gm. over the sole of the foot. Deep pressure felt via peroneal. No sweating over sole of the foot.

Function is excellent since the patient can walk indefinitely. He notes slight pain at the end of the day. He can't run or dance (80 percent). He is learning to do auto fender work at present, giving up prewar job as laborer.

POINTS OF INTEREST

This man is not handicapped by his poor tibial regeneration. The nerve might just as well have been left alone.

3. Sciatic-Tibial Nerve

The 10 cases illustrating good recovery in the sciatic-tibial are summarized in table 239. Individual case reports follow.

Case Report 4406

HISTORY OF INJURY

This soldier was wounded in action in the Southwest Pacific on January 22, 1944, by a shell explosion with perforating wounds of the middle third of his right thigh and also his left thigh and scrotum. He showed a total sciatic nerve paralysis on the right, but operation was repeatedly delayed because of two attacks of malaria and because of a hurricane in New Jersey. On October 31, 1944, neurorrhaphy was done on the right sciatic nerve. The nerve was found severed over a distance of 2 in. and imbedded in dense scar tissue just external to the sciatic notch; it was mobilized extensively, resected 9 cm. to fairly good tubules in the proximal stump (moderate bleeding, but having a grayish cast) and good tubules in the distal stump; it was sutured with tantalum under slight tension; branches which apparently led to the biceps femoris were included in the suture. Ten days postoperatively the patient had a third attack of malaria, which was suppressed with atabrine. Five months postoperatively there was return of function in the biceps femoris; 9½ months in the soleus; 12 months in the gastrocnemius, with some return of peroneal sensation; 13 months in the peroneus longus, with some tibial sensation; 16 months in the tibialis posticus. At discharge on May 29, 1946, the patient had fairly good function in his thigh muscles, good function on gastrocnemius and tibialis posticus, fair in the peroneus, beginning return of the tibialis anticus, and fair return of sensation in both tibial and peroneal distributions.

INTERVAL HISTORY

The patient has had no treatment since discharge, and has noted no improvement in his leg. He has no complaints at present, experiences no pain whatsoever, and is able to walk 2 miles before becoming fatigued.

Table 239.—*Characteristics of Sciatic-Tibial Cases With Good Recovery*

Characteristics of case	Case number									
	3004	3057	3067	3187	3806	[1] 4329	[1] 4367	[1] 4406	4463	5244
Lesion										
Pathology	Complete division.	Complete division.	Partial division.	Neuroma in continuity.	Complete division.	Complete division.	Partial division.	Complete division.	Neuroma in continuity.	Complete division.
Site	Thigh, upper ⅓.	Thigh, middle ⅓.	Thigh, middle ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.	Thigh, lower ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.	Thigh, lower ⅓.	Thigh, lower ⅓.
Associated lesions and complications.	Sciatic-peroneal N. (suture) fracture.	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (suture) fracture.	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (Lysis).	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (lysis), artery, plastic repair.	Sciatic-peroneal N. (suture).
Definitive suture										
Days after injury	80	110	50	140	200	120	10	280	130	50.
Tension	Moderate	None	None	None	Moderate	None	None	Mild	None	Moderate.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done.
Suture material	Tantalum	Silk	Tantalum	Tantalum	Plasma	Silk	Tantalum	Tantalum	Silk	Silk.
Surgical gap, cm	12	7	7	6	7	6	3	9	5	10.
Follow-up examination										
British motor [2]	Intrinsics, perceptible.	Intrinsics, perceptible.	Intrinsics, perceptible.	Intrinsics, perceptible.	Intrinsics, perceptible.	Synergic and isolated.	Intrinsics, resistance.	Intrinsics, perceptible.	Intrinsics, resistance.	Intrinsics, perceptible.
Pain threshold, gm	40	40	10	6	Hypalgesia	10	Deep only	10	20	6.
British sensory [2]	Pain and touch, overreaction.	Pain and touch, overreaction.	Pain and touch, overreaction.	Pain and touch, overreaction.	Pain and touch, overreaction.	Superficial pain and touch.	Superficial pain and touch.	Pain and touch, no overreaction.	Superficial pain and touch.	Pain and touch, overreaction.

Skin resistance	Elevated	Normal	?	Normal	Elevated	Not tested	Not tested	Not tested	Not tested	Decreased.
Overall function, percent.	70	70	70	80	80	90	80	70	90	50.
Relative power [4]										
Tibial										
1-Gastroc. & sol.	70	50	75	70	100	75	75	50	75	75.
3-Fl. dig. long	Perceptible	0	Perceptible	0	Perceptible	100	50	35	0	Perceptible.
4-Fl. hall. long	do	0	do	0	do	55	25	0	0	Do.
Peroneal [5]										
1-Tib. ant.	do	Perceptible	33	40	Movement not against resistance.	95	85	7	100	20.
2-Ext. dig. long	do	do	20	Against resistance, unmeasured.	do	65	100	6	75	Perceptible.
3-Ext. hall. long	do	Perceptible	20	Movement not against resistance.	do	Movement not against resistance.	100	0	100	Do.
5-Peron. long	do	Movement not against resistance.	10	Against resistance, unmeasured.	20	70	50	4	75	Do.

[1] Case reported in text.

[2] The rubric abbreviated as "synergic and isolated" is "Return of function in both proximal and distal muscles so that all important muscles can act against resistance, and some synergic and isolated movements are possible." The abbreviation "intrinsics, perceptible" means "Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles." The abbreviation "intrinsics, resistance" means "Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance."

[3] The rubric abbreviated here as "pain and touch, overreaction" is "Return of superficial pain and touch sensibility throughout autonomous zone, with overreaction and inability to localize stimulus." That shortened to "Superficial pain and touch" is "Return of some degree of superficial pain and touch sensibility within autonomous zones." "Pain and touch, no overreaction" is "Return of superficial cutaneous pain and touch sensibility throughout the autonomous zone, with disappearance of any overresponse."

[4] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

[5] Muscles of interest in connection with injury to other sciatic branch.

He wears a brace while walking, finds climbing stairs somewhat difficult and requires something to hold onto, and is unable to stand on the injured leg for a protracted length of time. Before the war the patient was a mechanic with a railroad; he has returned to work with a transit company as a clerk, with a decreased earning ability of about 30 percent. His compensation is 90 percent and he is satisfied with this.

CENTER EXAMINATION December 27, 1949

Distance of injury is 29 in. There is no gross atrophy, but the calf is diminished 2 in. in circumference. Both feet are equally warm and dry, and pulses are equal and full. There is slight limitation of motion at the ankle. In both the tibial and peroneal sensory areas the patient is able to feel approximately 10 gm. pain and 3 gm. touch. Deep pressure produces a painful sensation. There is no impairment of position sense.

Quantative muscle evaluation is as follows. Gastrocnemius 50 percent; tibialis posticus trace; flexor digitorum longus 35 percent; flexor hallucis longus 0; tibialis anticus 7 percent; peroneus longus 4 percent; extensor digitorum longus 6 percent; extensor hallucis longus 0. Percutaneous stimulation of the tibial nerve at the knee produced flexion of the foot and slight inversion; percutaneous stimulation of the peroneal nerve at the head of the fibula produced marked eversion and extension of the foot. The tibialis anticus had a rheobase of 140, a chronaxie of 2.0; gastrocnemius had a rheobase of 65, a chronaxie of 2.0. EMG was attempted on the tibialis anticus but there were no photographs made due to technical difficulties; however, there were observed only some very low amplitude waves of varying frequency.

Functional evaluation. The patient is able to walk 2 miles with the use of a brace, and is not limited by pain. Our tests show that he has a slight degree of function in all the major muscles of the lower leg, but the only effectively functioning muscle is the gastrocnemius. It is interesting that he has practically no sensory deficit in the foot.

POINTS OF SPECIAL INTEREST

This was a complete sciatic lesion just external to the sciatic notch. For various reasons repair was postponed 9 months after injury, and at that time required resection of 9 cm. There is a very nice chronological listing of the return of function to the various muscles, and of the sensory return. It is also interesting that a patient with so high a nerve lesion should shown such good function in the gastrocnemius.

Case Report 4367

HISTORY OF INJURY

This soldier was wounded in action in Germany on November 19, 1944, by shell fire, receiving a through-and-through wound of his left posterior thigh in the middle third. He had no function elicitable in the left sciatic nerve, and on November 30, 1944, at the 98th General Hospital, neurorrhaphy was performed on the left tibial nerve and neurolysis on the left peroneal. The lateral aspect of the tibial nerve was found to be macerated and almost completely severed; 3 cm. of this were resected and the nerve was sutured with tantalum and wrapped in a tantalum cuff; the peroneal nerve appeared bruised, and it was lysed and wrapped in a tantalum cuff; sulfanilamide was sprinkled in the wound. One month postoperatively there was noted to be return of function in all the peroneal distribution. Nine months postoperatively function was noted in the gastrocnemius. At discharge on December 7, 1945, his muscle rating was as follows. All peroneal muscles 100 percent; gastrocnemius 100 percent; tibialis posticus 50 percent; flexor hallucis longus 25 percent; and flexor digitorum longus 0. There was hypesthesia but perception of pain over the sole of the foot.

INTERVAL HISTORY

The patient has had no treatment since discharge, but he has had increased strength in dorsiflexion of his foot and toes, and a return of sensation to the sole of the foot. His primary complaint is of tenderness and occasional cramps in the leg, but he suffers no real pain in the leg whatsoever, although he does have rapid fatigue and numbness of digits 3, 4, and 5. Before the war he was a student; he now refills tanks on buses, and feels that he would be able to earn more if he were not injured. His compensation is 40 percent, and he is satisfied with this.

CENTER EXAMINATION November 9, 1949

Distance of the injury is 24½ in. There is no grossly apparent atrophy, and the calf is not diminished in circumference. Both feet are cool and dry, but pulses are present and equal. There is very slight limitation of the extent of ankle dorsiflexion.

In the calloused areas of the sole the patient is unable to feel 40 gm. pain, but he does feel 20 gm. pain at the arch; in the peroneal distribution he is able to feel 6 gm. pain. In the tibial distribution he is able to feel 16 gm. touch, and in the peroneal distribution 5 gm. touch. Deep pressure is approximately normal in the 1st and 2d toes, but produces a painful sensation in the 3d, 4th, and 5th toes. Position sense is unimpaired in the 1st and 2d toes, absent in the 3d, 4th, and 5th. There is no split sensation.

Quantitative muscle evaluation is as follows. Tibialis anticus 85 percent of normal, peroneus longus 50 percent, extensor digitorum longus 100 percent, extensor hallucis longus 100 percent, gastrocnemius 75 percent, flexor digitorum longus 50 percent, flexor hallucis longus 25 percent, tibialis posticus 75 percent.

Functional evaluation. This patient states that he is able to walk approximately 1 mile without trouble, and then is forced to stop because of fatigue; he is able to climb stairs but not a ladder. All in all, he has a rather good return of function in his leg.

POINTS OF SPECIAL INTEREST

This is an unusually early suture (11 days) of a fairly high sciatic nerve injury (24½ in.). The tibial nerve was sutured; the peroneal was only lysed. The patient shows an unusually good return of function in both nerve distributions.

Case Report 4329

HISTORY OF INJURY

This soldier was wounded in action in France by a shell explosion on September 18, 1944, receiving a penetrating wound of the left lateral popliteal area. During debridement 7 hours later the peroneal and tibial nerves were noted to be lacerated. Because the patient continued to show a total motor and sensory paralysis of both his peroneal and tibial nerves, neurorrhaphy was performed on the left sciatic nerve at Percy Jones General Hospital on January 15, 1945. The sciatic nerve was found buried in dense scar tissue and severed, and gave no electrical response. It was resected leaving a 6 cm. gap, with the nerves combined into a single stump proximally, but with separate peroneal and tibial stumps distally; these were sutured with black silk. The pathological report is of interest in that it notes that the sections from the tibial nerve showed "atrophy and fibrosis of the epineurium and perineurium, but with normal appearing fibers traversing it" Three months postoperatively the patient showed 50 percent function in his gastrocnemius, with the peroneal Tinel sign in the lower third of the lower leg, and the tibial Tinel to the middle third of the calf. There was a good function in the tibialis anticus and a flicker in the peroneus at 4 months. Six months postoperatively the patient showed 75 percent function in the gastrocnemius, tibialis posticus 50 percent, tibialis anticus 50 percent, peroneus longus 25 percent, and a flicker in the extensor digitorum longus. At 7 months there was a return of pinprick sensation in the peroneal area. At 9 months, when the patient was discharged on December 19, 1945, there was 50 percent to 75 percent function in all the leg muscles except an absence of function in the flexors of the toes, and there was returning sensation in both components.

INTERVAL HISTORY

Since discharge the only treatment the patient has been receiving is physiotherapy at a VA hospital. The only improvement he has noted is increased strength and flexibility at the ankle and some further return of sensation. His primary complaints are weakness in the leg, pain with use, spontaneous pain, and he is also bothered by hypersensitivity of the sole. Before the war he worked as a machine operator; he is now a clerk and his earning ability is approximately the same. His compensation is 50 percent and he feels that this is not quite adequate.

CENTER EXAMINATION October 7, 1949

Distance of the injury is 18½ in. There is no marked atrophy, except that the left thigh is diminished 1½ in. in circumference, and the left calf is diminished ¼ in. in circumference. Pulses are equal and full bilaterally, and both feet are warm and dry. There is only slight limitation of motion at the ankle. The patient states he is able to walk approximately a half mile, but he is unable to stand for more than about 15 minutes. He is able to roller skate about 5 minutes at one time.

In a typical peroneal area the patient is able to distinguish 25 gm. touch and 30 gm. pain, but he is able to perceive lesser stimuli as paresthesiae. In the tibial area on the sole of the foot the patient is hypersensitive to 10 gm. pain and 25 gm touch. The patient is slightly hypersensitive to deep pressure; position sense is somewhat impaired, particularly in the 2d and 5th digits.

Quantitative muscle evaluation is as follows. Gastrocnemius 75 percent of normal; tibialis posticus 100 percent; flexor digitorum longus 100 percent; flexor hallucis longus 55 percent; tibialis anticus 95 percent; peroneus longus 70 percent; extensor digitorum longus 65 percent; extensor hallucis longus 0.

Functional evaluation. This patient is apparently able to walk without a foot-drop brace a distance of approximately one-half mile, being limited by fatigue. His other difficulty occurs in the hypersensitivity of the sole of his foot, but this apparently does not affect him much when he is wearing shoes as he is able to roller skate.

POINTS OF SPECIAL INTEREST

This was a combined peroneal and tibial injury at the level of the knee, with a 6-cm. gap, and there being a single sciatic stump proximally, but a separate peroneal and tibial stump distally. The nerve was repaired 4 months after injury. The pathological note regarding the tibial nerve sections is of interest. The patient has a well-documented history of the return of motor function which, as noted above, was exceedingly rapid and surprisingly full.

Ten examples of poor sciatic-tibial recovery are summarized in table 240. The individual case reports follow.

Case Report 4198

HISTORY OF INJURY

June 5, 1944, this patient sustained a perforating wound of right thigh while in action in Rome. The sciatic nerve was recognized as being injured. June 17, secondary closure was carried out. It was not until August 22 at Walter Reed General Hospital that both components of the sciatic were resected. There was a 7 cm. gap. Tantalum wire with foil was used. No tension. Leg was flexed to 90 degrees and was placed in a cast for 6 weeks. Patient had 5 lumbar sympathetic blocks because there was swelling of the right leg and foot. There was no appreciable improvement in his condition. These were carried out in June and July of 1946. On October 24, 1946, at Halloran General Hospital, the tantalum cuff was removed. The suture site was excellent. Stimulation distal to

Table 240.—*Characteristics of Sciatic-Tibial Cases With Poor Recovery*

Characteristics of case	Case number									
	2344	3063	3084	3896	[1] 4153	[1] 4198	[1] 4301	4520	[1] 8767	8779
Lesion										
Pathology	Complete division.	Complete division.	Partial division.	Complete division.	Partial division.	Complete division.	Complete division.	Complete division.	Partial division.	Complete division.
Site	Thigh, upper ⅓.	Thigh, upper ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.	Thigh, lower ⅓.	Thigh, upper ⅓.	Thigh, upper ⅓.	Thigh, upper ⅓.	Thigh, upper ⅓.	Thigh, upper ⅓.
Associated lesions and complications.	Sciatic-peroneal N. (suture), fracture.	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (suture), separated suture-line, resuture, plastic repair.	Sciatic-peroneal N. (suture).	Sciatic-peroneal N. (suture), fracture.	Sciatic-peroneal N. (suture), fracture.	Sciatic-peroneal N. (suture), fracture.	Sciatic-peroneal N. contusion, recovery spontaneous.
Definitive suture										
Days after injury	200	120	60	90	250	80	190	640	290	130.
Tension	Moderate	None	None	None	None	None	None	Severe	None	None.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Done	Not done	Not done.
Suture material	Silk	Tantalum	Tantalum	Plasma	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Unknown.
Surgical gap, cm	12	9	3	6	5	7	10	11	7	5.
Follow-up examination										
British motor	Proximal only, perceptible.	Proximal only, perceptible.	No contraction.	No contraction.	No contraction.	Proximal only, perceptible.	No contraction.	No contraction.	Proximal only, perceptible.	No contraction.
Pain threshold, gm	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	No sensation.	Deep only.
British sensory	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.

Skin resistance	Elevated	Elevated	Elevated	Elevated	Decreased	Not tested	Elevated	Not tested	Not tested.	Not tested.
Overall function, percent.	80	60	60	?	50	0	40	60	50	50.
Relative power [2] Tibial										
1—Gastroc. & sol.	Perceptible	40	0	0	0	10	Perceptible	0	20	0.
3—Fl. dig. long.	0	0	0	0	0	0	0	0	0	0.
4—Fl. hall. long.	0	0	0	0	0	Not tested	0	0	0	0.
Peroneal [3]										
1—Tib. ant.	0	Movement not against resistance.	0	Not tested	0	0	0	0	0	100.
2—Ext. dig. long.	0	Movement not against resistance.	0	Not tested	0	0	0	0	0	100.
3—Ext. hall. long.	0	Movement not against resistance.	0	Not tested	0	Not tested	0	0	0	100.
5—Peron. long.	0	Perceptible	0	Not tested	Perceptible	0	0	0	0	100.

[1] Case reported in text.

[2] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

[3] Muscles of interest in connection with injury to other branch of sciatic.

the suture resulted in good motor and sensory response. November 1946, he was discharged and a note was made that there was some motor and sensory return of the tibial with no peroneal return. The patient had a chronic ulcer on his foot which prolonged his hospitalization.

INTERVAL HISTORY

Chief complaint of the patient is his great difficulty in walking. There has been no change in his muscle or sensory status since discharge. At the present time, he has definite difficulty with coldness of his foot, and with changes in weather hypersensitivity is marked in the sole of the foot and the toes. He also has ulcerations in the region of the heel and some pain and rapid fatigue with use. He walks approximately 1 block with a brace. He finds it impossible to perform extended walking or standing for any length of time. The only treatment he has had since discharge has been for trophic ulcers at a VA hospital. He receives 100 percent compensation which of course he feels is adequate. Prior to his injury he was a route man for a laundry but now is unable to work.

CENTER EXAMINATION March 15, 1949

Reveals a patient who for all practical purposes has no use of his right leg whatsoever. It is markedly thin and atrophic throughout compared to the left, and on clinical examination he showed no function at all in the peroneal musculature and no function in any of the tibial muscles except about 10 percent strength in the gastrocnemius. Position and pressure sense in the toes are entirely absent, and although pulses are equal and full bilaterally, there are numerous old pigmented areas of previous ulcerations on the sole of the foot, and the foot is definitely cooler and drier than on the left side. There is no real joint dysfunction, but there is marked shortening of the Achilles tendon on the involved side so that dorsiflexion is limited to 134 degrees. The ankle is definitely swollen on the involved side as well. It was noted that there was marked fibrosis of the muscles generally.

Sensory examination revealed that he was unable to feel 40 gm. of pain and 35 gm. of touch anywhere below the knee. Special electrical examinations were of interest because intraneural stimulation of the peroneal at the knee showed a moderately good response in the tibialis anticus and the peronei and the extensor of the toes. Stimulation of the tibial at the ankle, however, failed to reveal any function in the intrinsic foot muscles. Chronaxie measurements of the tibialis anticus could not be made because the rheobase was 275. The rheobase was 90 in the gastrocnemius and the chronaxie was 2.0 msec; in the intrinsic foot muscles, once again the rheobase was 275 plus.

The patient is barely able to support himself on his withered and atrophied foot without his brace. He is unable to walk barefooted and practically falls on his face. For all practical purposes, at the present time he has a useless extremity. The muscle fibrosis is so marked that even though there is good or fairly good response to the peroneal nerve on stimulation, it is unlikely that he can ever get a really good functioning extremity unless he puts in an exceptional amount of work and effort.

POINTS OF SPECIAL INTEREST

This is a high sciatic lesion which was well treated and which resulted in better function neurologically than is present clinically.

Case Report 8767

HISTORY OF INJURY

On December 9, 1944, this soldier sustained shell-fragment wounds, perforating, of the upper third of the left thigh. There was immediate sciatic paralysis, and there was a fracture of the upper third of the femoral shaft. On admission to Cushing General Hospital, August 20, 1945, there had been no improvement in the left sciatic nerve; there was complete sensory and motor paralysis of the left sciatic nerve in the upper third of the left thigh; there was a positive Tinel's sign in the upper third of the left leg, along both peroneal and tibial nerves. On September 24, 1945, needling of both nerves at the popliteal space showed evidence of some intact sensory fibers in each nerve, but no motor response. On September 26, 1945, the left sciatic nerve was sutured. The nerve was dissected free from the gluteal fold down to the upper portion of the popliteal space; there was moderate scarring in the midthigh. There were a few bundles going through the lesion, carrying sensation to the sole of the foot and to the lateral side of the foot on stimulation. This functioning portion represented less than one-fourth of the nerve. The involved portion was resected to a 7 cm. gap and normal bundles. End-to-end suture was performed, using tantalum wire; there was no tension on the suture line. On May 4, 1946, there was a Tinel's sign for both nerves in the lower third of the calf. Gastrocnemius function began in July (10 in. in 10 months) and patient was given a disability discharge August 1946.

CENTER EXAMINATION October 21, 1948

The patient complains chiefly of difficulty in walking, and of occasional drainage from the wound. He complains also of numbness of the lower leg and foot, pain with use, loss of motor power and rapid fatigue. The patient has noticed an increase in strength of plantar flexion, but no other motor recovery or return of sensation. His disability is assessed at 100 percent and he feels that this is fair because he can not resume his machinist's duties, due to inability to stand or use the leg for any length of time. Patient is now a college student.

Sensory examination reveals no response to 40 gm. pain and 75 gm. touch in either nerve's autonomous zone.

Motor examination reveals 20 percent of normal strength in the gastrocnemius and no clinical function in any of the other standard posterior tibial and common peroneal muscles. There is a 3-plus contraction in the biceps. It was not possible to determine chronaxies by direct muscle stimulation. Stimulation of the peroneal at the knee gave a barely visible contraction in the peroneus longus muscle.

The patient can walk one-fourth mile (using a brace) at the most. He is unable to walk to any extent without a brace and walks with a marked limp even with a brace. This represents an almost complete failure of sciatic nerve suture in the upper third of the thigh about 9½ months after injury—average result for this level with this delay. Delay was due to fracture plus need for securing knee flexion after fracture immobilization. The functional disability (pain on walking) is more the result of the fracture than of the nerve injury.

Case Report 4153

HISTORY OF INJURY

This soldier received a gunshot wound March 12, 1944, perforating through the soft tissue posterior to the bone in the lower one-third right thigh, 4 in. above knee, (partly—Ed.) severing the sciatic nerve and some tendons. Wound debrided 3 hours later when nerve repaired with 1 black silk suture in nerve and 4 in the sheath and leg splinted in partial flexion. A skin graft to wound of exit March 25, 1944. Neurorrhaphy performed May 24, 1944, at Walter Reed General Hospital. Previous anastomosis found pulled apart with black silk buried in middle of neuroma. Both nerves resected to good tubules, gap 5 cm. each with distal stumps larger than proximal. Sutured with .003 tantalum without sling stitch and tibial nerve only wrapped in tantalum. After no improvement postoperatively, neurorrhaphy again performed November 16, 1944. Suture found pulled apart in both nerves, gap 2.2 cm. A dirty brown fluid found in the tantalum cuff. Both nerves resected 5.3 cm. Tubules still edematous but a larger gap was not permitted. Peroneal stump again larger distally than proximally. Tibial sutured with interrupted .003 tantalum and peroneal with three interrupted sutures and a continuous running suture because of the difference in size of the two stumps. Individual cuffs were put on. January 1945, patient developed fibrinous pleurisy and partial occlusion of right femoral artery, probably from scar tissue, which improved on medical treatment. October 26, 1945, cuffs removed at England General Hospital. Anastomosis larger than rest of nerve but smooth, and tubules appeared large and fragile. Stimulation showed some function in both peroneal components. External lysis only performed. At discharge on June 13, 1946, pinch perceived throughout except on sole; no pinprick. Gastrocnemius 40 percent; tibialis posticus 25 percent; peronei 25 percent. Tibialis anticus 0; flexor digitorum longus and flexor hallucis longus 0. Tinel's sign in lower leg for both nerves.

INTERVAL HISTORY

Was a poultryman before the war and now that he is going to commercial college, he feels his earning ability will not be limited even though his right leg is useless. Receives 87 percent compensation. Main complaints are pain in the sole, and callous, and scar, some paresthesias, hypersensitivity, numbness, coldness, pain with use, and rapid fatigue. Has recovered no more sensation or motor power and has even lost his gastrocnemius function present for about 6 months after discharge. With brace, walks about 5–6 blocks before fatigue. Without brace, walks a block. Without brace or shoes, he cannot walk at all.

CENTER EXAMINATION November 24, 1948

Right leg shows severe atrophy below knee. Both feet are warm. Dorsalis pedis equal bilaterally but posterior tibial decreased on right. Distance of injury 21 in. Absent position and pressure sense and complete anesthesia and analgesia throughout peroneal and tibial area. Skin resistance decreased in tibial area.

Motor function. Biceps femoris 3 plus; tibialis anticus 0, chronaxie 10 msec., contraction slow; peronei trace, chronaxie 20 msec., contraction slow; extensor digitorum longus 0; extensor hallucis longus 0; gastrocnemius 0, chronaxie, 2.0 msec.; tibialis posticus 0, flexor digitorum profundus 0; flexor hallucis longus 0; intrinsic foot muscles 0, chronaxie 8.0 msec. Percutaneous stimulation of nerves at knee gives a 3-plus response in gastrocnemius and 1-plus response in tibialis posticus, none in peroneal muscles.

POINTS OF SPECIAL INTEREST

Illustrates clearly the great importance of good mobilization of the nerves, freedom from excess scarring and positive splinting in flexion to secure good union after suture in this location.

Case Report 4301

HISTORY OF INJURY

On March 8, 1945, in Germany, this soldier was wounded in action, a rifle bullet perforating the middle third of his right thigh with fracture of the femur. In August of 1945 he received several lumbar blocks for swelling and cyanosis of the foot (at this time the posterior tibial pulse was good, the dorsalis pedis absent). There was no function in either component of the sciatic nerve, and on September 21, 1945, at England General Hospital, neurorrhaphy was performed on the right sciatic nerve. The nerve seemed to end in a massive scar at the level of the gluteal fold. The nerve was resected 9 cm. to normal tubules and, following extensive mobilization, was sutured with tantalum. The blueness, coldness, and pain continued in this soldier's foot, and in October 1946 lumbar sympathetic block was tried prognostically, producing nothing except a fleeting warmth; however, on January 7, 1947, at Walter Reed General Hospital, a right lumbodorsal sympathectomy was performed, removing the sympathetic chain from above D–11 to below L–2. At discharge on April 27, 1947, there had been no record made of function in the leg or of the outcome of the sympathectomy.

INTERVAL HISTORY

The patient has had no treatment since discharge and has noted no improvement in the foot. He complains of spontaneous pain, paresthesiae, numbness, pain in cold weather, hypersensitivity, pain and rapid fatigue with use, and ulcerations over the Achilles tendon. He cannot walk without a foot-drop brace, and with it he is limited by pain to 3 or 4 blocks. He had a sixth-grade education, then received training in welding, and before the war worked both as a welder and as a crane operator; he has not worked since the war. He receives 100 percent compensation.

CENTER EXAMINATION September 15, 1949

The patient is right handed. There is a soft tissue defect on the posterior aspect of the right thigh with considerable diminution of muscle substance on the posterior thigh and of the entire lower leg. Distance of the injury is 29 in. The thigh is diminished 3¾ in. in circumference, the calf 1½ in. There are moderate trophic changes of the skin of the foot. Dorsalis pedis pulses are equal and full, but the right posterior tibial pulse is not palpable; on oscillometry, the right leg shows an excursion of 1.5 mms., the left 6.0 mm. When he walks barefooted his gait is steppish, with a pelvic tilt and a foot-drop. After exertion there are fibrillations and clonic-like reactions.

The entire foot, the lateral and posterior aspects of the leg, and the lateral aspect of the lower two-thirds of the thigh are insensitive to 40 gm. pain, 35 gm. touch. Deep pressure and position sense are 0. Skin resistance on the leg is markedly increased in an area well demarcated and corresponding to the sensory area.

There is a trace of function in the gastrocnemius, but unmeasurable; the biceps femoris has a moderate amount of strength; all other peroneal and tibial muscles show no clinical function. The peroneus longus has a rheobase of 120, a chronaxie of 8.0 msec. The gastrocnemius has a rheobase of 140, a chronaxie of 10.0, prompt; the tibial intrinsics have a rheobase of 180, a chronaxie of 16.0; the tibialis anticus has no rheobase obtainable at 275 volts. Electromyography was done on the tibialis anticus, but no recording was made because there were no definite voluntary action currents. On stimulation there were marked polyphasic spikes, and on supramaximal stimulation the tibialis anticus had maximum spikes of 2.0 inches, compared with a normal of 6.0.

Functional evaluation. Without a foot-drop brace this leg is practically useless; even with the brace he is limited to 3 to 4 blocks walking by pain and fatigue.

POINTS OF SPECIAL INTEREST

This was a high injury (gluteal fold), a long gap of 10 cm., and operation a little more than 6 months after injury; there has been practically no return in the leg. Sympathectomy had been done to improve circulation in this leg with no clear-cut result.

4. Sciatic-Peroneal Nerve

Ten examples of good sciatic-peroneal recovery are abstracted in table 241. Detailed case reports follow.

Case Report 4068

HISTORY OF INJURY

On August 1, 1944, patient was struck by an 88-mm. shell fragment in left thigh at junction of the lower and middle thirds. He suffered a chip fracture of the femur, a complete peroneal palsy, and an incomplete tibial palsy. He had paralysis of tibial anticus, long toe extensors, peronei, and "hypesthesia" over dorsum of foot and outer aspect of leg. Weak plantar flexion was present. Operation was performed October 20, 1944. Peroneal nerve did not respond to galvanic or faradic stimulation. Stimulation of posterior tibial nerve gave a slight contraction of tibialis posticus muscle. A neuroma in continuity involving both portions of the nerve was found and was resected to a gap of 4 cm. to good tubules. Tantalum wire and cuff were used for suture without tension. On discharge February 2, 1946, all movements were possible except flexion and extension of the toes; the anesthetic zone was very small.

CENTER EXAMINATIONS August 3, 1948, and again on March 18, 1949

The patient complains only of numbness in the foot and hypersensitivity of the sole. He is able to perform all movements to some extent; toe motion is limited. He does not need a brace and can walk barefooted with scarcely any limp. The toe of the shoe on the involved side shows but slightly more wear than the normal. He has the same job as he had prewar, and is not handicapped.

Sensory examination reveals perception of 2 gm. pain and touch throughout except for calloused areas. Pressure sense is good throughout, position sense fair to excellent.

All muscles function against resistance. Toe flexion and extension, however, are weak. Tibialis anticus had a chronaxie of 0.4 msec., peroneus longus 1 msec., both fast. Intrinsics had slow response at 0.8 msec. Myography revealed a 60 percent spike on voluntary motion of injured side in tibialis anticus.

There was insignificant change in the second examination as compared with the first. For that reason prognosis for further improvement must be guarded. However, this is one of the best sciatic sutures we have seen and we have nothing to offer the patient.

Case Report 4157

HISTORY OF INJURY

November 3, 1944, while in action in Germany, the patient stepped on a land mine sustaining multiple wounds to both feet and legs as well as the thighs. Both the tibia and fibula were fractured in the left leg, and the fibula was fractured in the right. The right ankle was fractured as

Table 241.—*Characteristics of Sciatic-Peroneal Cases With Good Recovery*

Characteristics of case	Case number									
	1232	1253	2179	3204	3257	3455	3478	[1] 4068	[1] 4157	5369
Lesion										
Pathology	Neuroma in continuity.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.	Complete division.	Complete division.	Neuroma in continuity.	Complete division.	Complete division.
Site	Thigh, middle ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.	Thigh, upper ⅓.	Thigh, middle ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.	Thigh, middle ⅓.	Thigh, lower ⅓.	Thigh, upper ⅓.
Associated lesions and complications.	Sc.-tibial N. (suture), fracture.	Sc.-tibial N. (suture).	Sc.-tibial N. (lysis).	Sc.-tibial N. (suture).	Sc.-tibial N. (suture), fracture, infection.	Sc.-tibial N. (suture).	Sc.-tibial N. (suture), infection.	Sc.-tibial N. (suture), fracture.	Sc.-tibial N. (suture), fracture.	Sc.-tibial N. (lysis), neuroma in continuity.
Definitive suture										
Days after injury	110	50	160	50	180	110	210	80	240	70.
Tension	None	None	None	None	None	Slight	None	None	None	None.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Done	Not done	Not done	Not done.
Suture material	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum	Tantalum.
Surgical gap, cm	5	6	7	7	9	11	>5	4	5	?
Follow-up examination										
British motor [2]	Intrinsics, resistance.	Synergic and isolated.	Intrinsics, resistance.	Intrinsics, resistance.	Intrinsics, resistance.	Intrinsics, perceptible.	Intrinsics, resistance.	Synergic and isolated.	Intrinsics, perceptible.	Intrinsics, resistance.
Pain threshold, gm	6	<6	<6	6	40	40	6	<6	10	40.
British sensory [2]	Pain and touch, no overreaction.	Pain and touch, no overreaction.	Complete recovery.	Pain and touch, overreaction.	Pain and touch, overreaction.	Pain and touch, overreaction.	Pain and touch, overreaction.	Pain and touch, no overreaction.	Pain and touch, no overreaction.	Pain and touch, overreaction.
Skin resistance	Normal	Normal	Normal	Elevated	Decreased	Normal	Normal	Normal	Not tested	Decreased.
Overall function, percent	80	90	80	80	80	80	70	90	70	60.

Relative power [4]										
Peroneal										
1-Tib. ant.	Against resistance, unmeasured.	18	70	21	20	18	34	67	60	20.
2-Ext. dig. long	Against resistance, unmeasured.	34	0	25	Movement not against resistance.	Movement not against resistance.	7	10	Perceptible.	20.
3-Ext. hall. long	Against resistance, unmeasured.	34	50	25	Movement not against resistance.	Movement not against resistance.	Movement not against resistance.	67	Perceptible.	10.
5-Peron. long	Against resistance, unmeasured.	13	50	30	24	29	50	70	10	20.
Tibial [5]										
1-Gastroc. & sol.	Against resistance, unmeasured.	Against resistance, unmeasured.	95	100	100	50	67	88	65	80.
3-Fl. dig. long	0	21	25	40	0	Not tested	0	10	Perceptible.	60.
4-Fl. hall. long	0	21	50	40	0	Not tested	0	10	Perceptible.	60.

[1] Cases reported in text.

[2] The abbreviation "Intrinsics, resistance" means: "Return of function in both proximal and distal muscles of such an extent that all important muscles are of sufficient power to act against resistance." The abbreviation "Synergic and isolated" means the same, plus capacity to perform some synergic and isolated movements. The abbreviation "Intrinsics, perceptible" means "Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles."

[3] The rubric abbreviated here as "Pain and touch, overreaction" is "Return of superficial pain and touch sensibility throughout autonomous zone, with overreaction and inability to localize stimulus." That shortened to "Pain and touch, no overreaction" is the same except that any overresponse has disappeared.

[4] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

[5] Muscles of interest in connection with injury to other branch of sciatic.

well. Debridement was carried out and cast applied. Injury to the nerves was not noticed at this time.

On July 6, 1945, at McCloskey General Hospital, the sciatic nerve was sutured. The gap was 5 cm. and no cuff was applied. A cast was applied with the knee flexed to 90 degrees.

On February 8, 1946, the patient was discharged and a notation was made that there was some return of sensation and muscle function.

CENTER EXAMINATION December 6, 1948

The suture line is 11½ in. from the medial malleolus. The suture-line is palpable with a fusiform swelling but no radiating pain can be released on pressure. The circumference of the leg, 6 in. below the tibial tubercle, is 9 in. on the left and 12 in. on the right. It is of interest that the left leg is 1 in. shorter than the right, and that there is severe atrophy of the calf. The left foot is definitely cooler although there are no gross ulcerations or trophic changes present in the skin. The pulses are somewhat diminished on the left side but still quite full. The knee joint is perfectly free and mobile as are the toes. The ankle, however, is somewhat stiff and can be only dorsiflexed to 105 degrees as compared to 90 degrees on the normal side.

This is simply a function of the minimal work that the patient has put into limbering this joint.

On performance tests, he claims that he can walk with or without his brace for about the same distance, a mile. However, without his brace he is very fatigued and complains of a great deal of pain in the foot at the end of this distance. He is unable to walk barefooted because of pain. At the present time his brace is broken and he is making an attempt to get it fixed.

Pressure sensation is present in all the toes but is not normal pressure sense, but is rather a painful tingling which shoots backward up the leg. Position sense is about 50 percent of normal in all the toes.

Clinical examination of muscle function shows an excellent biceps femoris; the peroneus longus can just be made out, tibialis anticus is 2-plus, the extensor digitorum longus and the extensor hallucis longus show a trace. The gastrocnemius is strong, the tibialis posticus and the flexor digitorum profundus show only a trace, as does the flexor hallucis longus. The intrinsic foot muscles are definitely present, but weak.

Chronaxie examination of the tibialis anticus shows a rheobase of 120 and a chronaxie of 1.2 msec., which is excellent. The extensor digitorum longus shows 75 rheobase and a 4.8 msec. chronaxie. The intrinsic foot muscles show a 90 rheobase and a 12 msec. chronaxie. This more or less confirms the clinical impression of the amount of regeneration present in these muscles. Stimulation of the nerve was said not to be necessary because of the patient's good clinical result.

Sensory examination showed a good return of sensation over the entire foot. There was some slight hypersensitivity of the sole to nocuous stimuli.

Functionally, we felt that this patient, despite the shortening of the leg and the marked atrophy of the calf, had an unusually good result, considering that this was a complete sciatic suture. He has good dorsiflexion at the ankle, and provided he loosens up the joint, will have even better function. He should wear a thick sponge rubber insert sole and a somewhat larger shoe. However, the patient did not seem interested in our sending a letter to him to that effect, and possibly he will go over to the VA to see whether or not they can arrange for the new shoes.

Ten cases illustrating poor recovery in the sciatic-peroneal are summarized in table 242. Detailed case reports follow.

Case Report 4042

HISTORY OF INJURY

This soldier was wounded in the buttocks September 16, 1944, suffering a complete right sciatic nerve paralysis. Neurorrhaphy was performed December 13, 1944. The nerve was found to be involved in a large neuroma just below the sciatic notch; after resection there was a 12 cm. defect. It was necessary to sacrifice some of the branches to the hamstrings. End-to-end suture with tantalum wire was performed without undue tension and the ends wrapped in tantalum foil. Before discharge in May 1946, he was noted to have feeble plantar flexion, no return of sensation, and a Tinel's sign in peroneal nerve to within 3 inches of ankle.

INTERVAL HISTORY

This patient worked in a distillery prior to his service, and is presently employed as a file clerk at lower salary. His compensation is 70 percent. He complains of spontaneous pain in the ankle and toes, paresthesias, complete sensory loss in the affected area, painful response to extreme cold, severe ulcerations on the sole of the foot, pain with use, and marked fatigability at end of day's work. He wears a brace and can walk 1 mile before he is required to rest. Despite these complaints he is apparently not markedly handicapped in his present position.

CENTER EXAMINATION May 14, 1948

On the sensory side, there was a complete analgesia and anesthesia throughout the peroneal and tibial distributions. Skin resistance was sharply increased over this same area. Position sense seemed normal for both the ankle and large toe, absent in the other toes. On voluntary motor examination, only the gastrocnemius functioned (70 percent). There was stiffness in the ankle and toe joints. Percutaneous stimulation of the peroneal nerve at the knee gave only perceptible contractions in tibial anticus, peronei and toe extensors. There was no response to posterior tibial stimulation at the knee and ankle. Neither chronaxie nor tetanus ratio could be determined because of the high rheobase of all musculature. Functionally, the patient walks without a limp with his brace. He shows a complete foot-drop when he attempts to walk without the brace.

Table 242.—*Characteristics of Sciatic-Peroneal Cases With Poor Recovery*

Characteristics of case	Case number									
	1015	2036	2110	2127	2139	2204	[1] 4027	[1] 4042	[1] 4243	5247
Lesion										
Pathology	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.	Complete division.
Site	Thigh, upper ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.	Thigh, upper ⅓.	Thigh, middle ⅓.	Thigh, middle ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.	Thigh, middle ⅓.	Thigh, upper ⅓.
Associated lesions and complications.	Sciatic-tibial (suture), fracture, infection	Sciatic-tibial (suture), separated suture-line	Sciatic-tibial (suture), fracture, separated suture-line	Sciatic-tibial (suture), fracture	Sciatic-tibial (graft), separated suture-line, (per. used as tib. graft).	Sciatic-tibial (suture), separated suture-line, re-sutured	Sciatic-tibial (lysis)	Sciatic-tibial (suture)	Sciatic-tibial (partial suture)	Sciatic-tibial (suture), fracture.
Definitive suture										
Days after injury	230	100	200	170	60	390	650	80	80	30.
Tension	None	None	None	None	None	None	Slight	Slight	None	None.
Bulb suture	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done	Not done.
Suture material	Tantalum	Tantalum	Plasma	Silk	Tantalum	Silk	Tantalum	Tantalum	Tantalum	Silk.
Surgical gap, cm	4	5	11	5	8	10	9	12	5	>5.
Follow-up examination										
British motor	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.	No contraction.
Pain threshold, gm	?	No sensation.	No sensation.	No sensation.	No sensation.	?	No sensation.	No sensation.	No sensation.	No sensation.
British sensory	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.	Absent sensibility.

Skin resistance	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated	Elevated	Decreased	Elevated.
Overall function, percent	30	20	30	40	30	30	70	70	80	20.
Relative power [2]										
Peroneal										
1–Tib. ant	0	0	0	0	0	0	0	0	0	0.
2–Ext. dig. long	0	0	0	0	0	0	0	0	0	0.
3–Ext. hall. long	0	0	0	0	0	0	0	0	0	0.
5–Peron. long	0	0	0	0	0	0	0	0	0	0.
Tibial [3]										
1–Gastroc. & sol	0	0	Movement not against resistance.	Movement not against resistance.	Against resistance, unmeasured.	Against resistance, unmeasured.	?	70	75	0.
3–Fl. dig. long	0	0	0	Perceptible	0	0	?	0	0	0.
4–Fl. hall. long	0	0	0	Perceptible	0	0	?	0	0	0.

[1] Case presented in text.

[2] Numerical entry gives percentage of normal power; "against resistance" means that relative power was not actually measured.

[3] Muscles of interest in connection with injury to other branch of sciatic.

POINTS OF SPECIAL INTEREST

(1) Unsatisfactory recovery from a high sciatic lesion. The nerve was sutured in the region of the sciatic notch after overcoming a gap of 12 cm. This procedure was carried out 3 months after injury under apparently ideal situations.

(2) The patchy nature of the recovery. Although the gastrocnemius has received a good innervation, all of the remaining posterior tibial muscles are without innervation. The peroneal muscles have regained slight innervation but this is insufficient to be of any practical use to the patient. A complete anesthesia with trophic disturbances persists.

(3) From the standpoint of treatment, only an ankle fusion would be feasible and this is not desirable as it would result in the loss of the stepping off function which is provided by the well-functioning gastrocnemius.

Case Report 4027

HISTORY OF INJURY

This soldier suffered a penetrating wound from a shell fragment in the upper third of the right thigh on April 23, 1943, in Tunisia. By the next day, it was apparent that there was a severe cellulitis present in the wounded area; this healed fairly well in 2 weeks. He was noted to have paralysis of the sciatic nerve, right, common peroneal portion, with inability to dorsiflex foot and anesthesia over the dorsum of foot. On August 26, 1943, the nerve was explored. There were dense adhesions, but the "peroneal" (actually the tibial—Ed.) nerve was found to be in fairly good continuity with a small injury to the nerve itself. A neuroma in continuity was removed along with a small amount of scar tissue in the nerve. Neurorrhaphy was deemed unnecessary because of the limited involvement; therefore, internal neurolysis was performed, the nerve was wrapped in tantalum foil and the wound closed. Postoperatively an advancing Tinel's was noted down to the ankle, but despite this the only return was a slight amount of sensation. Accordingly, he was reoperated upon February 8, 1945. Electrical stimulation showed hamstrings and tibial nerves functioning normally but no peroneal function. It was discovered that the tibial nerve had been lysed and cuffed in the previous operation. The peroneal segment was bound in dense scar tissue; it was sectioned to good tubules proximally, but the distal end appeared degenerated even after a defect of 8½ cm. was fashioned. The nerve was sutured with tantalum; no cuff used. At discharge on January 25, 1946, there were "fairly definite peroneal muscle contractions" and patient could evert his foot. There was no tibialis anticus function or toe extensor function.

CENTER EXAMINATION April 19, 1948

The patient complains chiefly of numbness in the peroneal area and adverse reaction to cold. He must wear a foot-drop brace continuously, but he is able to walk over a mile and can be on his feet from 1 to 2 hours, before pain forces him to rest. He has had some trouble with his braces, having broken several. He is a gardener as he was prewar; evidently he handles the job without too much difficulty or handicap. He has absolutely no function ascertainable sensory-wise or motor-wise. His peroneal muscles show chronaxies distinctly above the normal range. Tetanus ratio was not possible to determine. There is little to be offered this man in the way of treatment other than a satisfactory brace. He does have a painful callus on the lateral surface of the sole—padding should help. Possibly tendon work would help him if he were interested.

POINTS OF INTEREST

The case is very interesting from several standpoints. First of all, there has been no return of function, doubtless because of the long interval before suture—when sutured, the distal segment of the nerve appeared quite degenerated. Secondly, the original operation in August 1943 was unsuccessful, due to the fact that electrical stimulation was not performed. Because it was not, the chance for definitive repair of the peroneal segment was missed. The tibial component was lysed with the thought that it was the peroneal. Thirdly, following lysis of the *tibial* component, the peroneal component was repeatedly observed to have an advancing Tinel's sign. Either Tinel's didn't mean much here or the observers were overenthusiastic.

Case Report 4243

HISTORY OF INJURY

This soldier was wounded in action in France on January 3, 1945, by a shell explosion, one fragment of which penetrated the medial third of his left thigh, resulting in a paralysis of his left sciatic nerve. He showed an inability to dorsiflex or plantar flex his left foot, although the extensors and flexors of the knee were functioning, and he had a complete sensory loss in the peroneal area with dimished sensation in the tibial area as well. However, the ankle jerk was active, and the knee jerk hyperactive. On March 29, 1945, at Lawson General Hospital, neurorrhaphy was performed on the peroneal component of the left sciatic nerve, and neurolysis on the tibial component. While there was scarring over a distance of 10 to 12 inches in the middle of the thigh, the tibial component was found to be grossly continuous and neurolysis was considered sufficient; there was a 5-cm. gap in the peroneal component, which was resected and sutured with tantalum; sulfanilamide was dusted freely throughout the wound. At discharge on June 20, 1946, there was weakness but no atrophy of the muslces of the lower leg. Two bands of hypesthesia were present, one on the posterior aspect of the thigh, the other on the posterior aspect of the leg. There was some return of function in the tibial component, but none in the peroneal.

INTERVAL HISTORY

In June 1948 the patient was at a VA hospital for physiotherapy for his leg, but he has received no other treatment and has noted no improvement in the leg except some return of sensation to the sole of the foot. He has no complaint of pain in the leg under any circumstances, nor of rapid fatigue; his only complaint is the inability to dorsiflex his foot. Before the war he installed oil burners; now he is a farm laborer, receiving room and board. His compensation is 90 percent for his leg and an additional 10 percent for his shoulder, which he considers fair.

CENTER EXAMINATION June 16, 1949

Distance of the injury is 30 inches. Circumference of the left calf is diminished ½ inch. Dorsiflexion of the ankle is limited to 10 degrees passively. Pulses are equal and full bilaterally, and there is equal warmth and moisture. There is some atrophy of the intrinsic foot muscles and of the peroneal muscles of the leg. The patient does not use the foot-drop brace, and he walks well on flat surfaces as long as he wears his shoes; he is able to walk a mile without difficulty, and has no trouble climbing stairs unless he is carrying weight.

In both the peroneal and tibial distributions the patient is unable to feel 40 gm. pain even as pressure, or 35 gm. touch. Skin resistance is decreased in the peroneal area, with a line of demarcation following the anterior border of the tibia. Deep pressure of the toes is referred to the peroneal cutaneous area of the calf as an ache; there is about 25 percent position sense.

Quantitative muscle evaluation is as follows. Gastrocnemius 75 percent of normal; tibialis posticus 25 percent; flexors of all the toes, intrinsic foot muscles, tibialis anticus, peroneus longus, and extensors of all toes, 0. The gastrocnemius had a rheobase of 165, chronaxie 16.0 (at 280 volts), fast; the intrinsic foot muscles had a rheobase of 175, chronaxie 16.0 (280 volts), slow; tibialis anticus had a rheobase of 150, chronaxie of 16.0 (280 volts), slow; the peroneus longus showed only a flicker at 280 volts. Electromyography was done on the tibialis anticus.

Functional evaluation. Despite the fact that this patient has function only in the gastrocnemius and tibialis posticus, he is able to do without a foot-drop brace and is able to walk at least a mile, and otherwise shows very little handicap as a result of his injury.

POINTS OF SPECIAL INTEREST

This was a fairly high sciatic nerve injury (30 inches); however, the main injury was only to the peroneal component, with some scarring of the tibial component. Ten weeks after injury, neurorrhaphy was performed on the peroneal nerve and neurolysis on the tibial nerve; despite this there was return of function only in the gastrocnemius and tibialis posticus, and no sensory return in either component. In the face of this meager return, the patient has made a very satisfactory adjustment, and suffers very little handicap.

5. Summary

The normal functions of the lower extremity have to do with the maintenance of an erect station and adequate ambulation aided by the appropriate appreciation of touch, pain, and proprioceptive sensory modalities. In the examples of good regeneration in the lower extremity, sensory return was not complicated by incapacitating painful sensation; in the poor cases, there was usually complete lack of sensory return, a relatively minor handicap in the foot as compared to a similar failure of sensory return in the hand. The apparent influence of the factors involved in regeneration in the lower extremity was as follows:

Location of injury

There were 35 cases of complete sciatic nerve injury among 40 sciatic-peroneal and sciatic-tibial injuries, and in only 7 of the good results was the injury at or above the upper third of the thigh. Thirteen of the poor results, on the other hand, were situated at this level. Case 4406, a complete sciatic nerve injury just external to the sciatic notch, showed good and painless sensory return to the foot and motor power return adequate for ambulation, suggesting that high sciatic sutures can be followed by adequate neural regeneration. This analysis only suggests that high lesions do less well than low injuries. Certainly the evidence is not as striking as that found concerning the influence of this factor in the upper extremity.

Time after injury

In cases exhibiting good regeneration the average nerve suture was performed 121 days after injury; in the poor cases, the average definitive suture was done 241 days postinjury. This latter figure probably represents merely the association of a more complicated leg injury since satisfacory regeneration was found in case 2,166, sutured 290 days after injury, and in cases 2,151 and 4,157, both sutured 240 days after injury. By comparison, very poor neural regeneration was obtained in 20 cases that were definitively sutured 30 to 160 days postinjury. Six secondary sutures, performed because an obvious failure was demonstrated after the initial suture, all failed at time intervals from 250 to 810 days postinjury. When suture was done under an 8-month period, no unequivocal influence of delay could be demonstrated in this small series.

Nerve defect and tension

In general, long nerve defects and suture line tension were more often found in instances of poor nerve regeneration, particularly in the more severe and complicated nerve injuries. Some striking exceptions were seen, as noted in case 2,151, where good tibial nerve regeneration was found in the presence of a 12-cm. defect, and in case 3,455 where good sciatic nerve regeneration was found after repair of an 11-cm. nerve defect.

Suture material

No positive influence of the type of suture material could be demonstrated except in the X-ray diagnosis of suture line disruption in the tantalum sutures, which represented a common cause for failure.

Complications

Except for suture-line separations and neuromas, there was no striking difference between the cases of good and poor nerve regeneration with respect to frequency of complications in the lower extremity. In the good cases, there were 23 instances of a second nerve injury in the same extremity, 14 fractures, 3 major soft tissue injuries, 3 wound infections of significance, and 3 vessel ligations low in the extremity. In the poor cases, by comparison, there were 21 concomitant nerve injuries, 17 fractures, 6 major soft tissue wounds, 1 arterial ligation, 5 wound infections, and 11 suture line separations or neuromas. The very high incidence of proved suture line separations in nerve operations in the lower extremities suggests a probable cause for the many instances of poor regeneration for which an adequate reason has not been otherwise demonstrated.

D. CONCLUSION

A careful scrutiny of 140 records of good and bad instances of peripheral nerve regeneration has failed to demonstrate any single factor that favorably influences regeneration and reveals only the general impression that simple uncomplicated injuries do better than their counterparts. It is easy, on the other hand, to show that high injuries, particularly in the upper extremity, do less well than low injuries, that combined nerve-artery injuries in the upper extremity do poorly and that in the lower extremity technical errors or excessive suture-line tension, followed by suture line separation, play a very significant role in the failure of regeneration. Although the average time of suture after injury is appreciably lower in cases of good regeneration than in those of poor regeneration, many injuries sutured at 8 to 9 months after injury showed good sensory and motor return. No really good results were found in sutures performed after the 1-year period and, in particular, late secondary sutures in this series always showed failure of regeneration.

The most helpful aspect of this review of records supports a host of personal observations by military neurosurgeons that adequate motor and sensory return can be obtained in uncomplicated or pure nerve lesions, when the necessary surgical experience is applied to the problem at hand, when the effector mechanism has not been destroyed by undue delay of suture after injury and when the same mechanism is kept in order while reinnervation is proceeding. Unfortunately, the realities of war injury permit all these circumstances to combine in few cases. The potential gain of nerve suture must be viewed objectively and equal if not greater emphasis must be placed upon other means of rehabilitation, especially for those nerve injuries in which suture must inevitably fail.

Chapter XI

NEUROPATHOLOGICAL PREDICTIONS OF RECOVERY

William R. Lyons and *Barnes Woodhall*

A. INTRODUCTION

Collaborative histopathological studies on peripheral nerve injuries were begun by the present authors in 1944 at Walter Reed General Hospital with a number of objectives: (1) to obtain and record the histopathology in a well-studied, representative series of human peripheral nerve injuries treated by suture; (2) to forecast regeneration on the basis of careful histopathological study of the mirror images of the sutured ends and to correlate these forecasts with eventual clinical recovery; (3) to provide the surgeon with a pathologist's advice as an aid in achieving good nerve ends preparatory to suture; and (4) to make a histopathologic study of human nerve degeneration and regeneration and to develop a photographic record of these changes. Surgical decision was implemented by gross and histologic reports on over 600 lesions; the first and fourth objectives were largely attained with the publication of the Atlas of Peripheral Nerve Injuries (46) to which reference may be made for a technical discussion of histologic method; the second objective defines the scope of the present chapter.

Many factors are thought to influence peripheral nerve regeneration; the neuropathologist was asked to make an intensive study of one of them, the surfaces joined by the surgeon in his definitive repair, with the assurance that there would be available for correlation studies not only clinical evaluations of eventual recovery but in addition such other details of the injury and its management as might also have an influence upon end-results. Since the pathological specimens were necessarily obtained at the time of suture, and by that token independently of the clinical assessments of recovery 5 years later, it was not difficult to isolate the neuropathologist from all but the very earliest follow-up data and thus to preserve the integrity of his independent predictions based on the appearance of the nerve ends. Furthermore, since correlation studies could proceed only after follow-up information had been obtained, it was natural to place in the hands of a disinterested third party, the statistician for the follow-up study, the actual task of correlation. In providing the surgeon with assistance at the time of repair, of course, the neuropathologist did obtain information on the nature and extent of the injury and on the details of management, together with a modicum of data on the early postoperative picture, but he made a conscientious effort to avoid being influenced by this information and to base his evaluations solely on the specimens and the slides. It was anticipated that any independent, predictive information which the neuropathological studies might contribute could easily be combined with similar information provided by other variables so as to make the best predictions possible as well as to determine the relative contributions of the various predictive variables.

At the time the sampling plan for the follow-up study was crystallized, it may be recalled from chapter I, a special effort was made to allocate to the follow-up centers an appreciable number of men on whom histologic studies had been made. The entire roster (AFIP Accession No. 110,822) was used in this process, and at the conclusion of the study it was found that, of the 2,554 men used in the main statistical analysis, 356 had been allocated from the roster with histologic studies. Of the 356 men, 253, or 71 percent, were examined. In some of the latter group histologic studies were incomplete, the lesions were treated by neurolysis, partial suture, or graft, or a second suture had been necessary for which no histologic material was available. After all such cases were deleted there remained for study 181 complete sutures on the 7 major nerves, and these furnish the material for the present chapter. Table 243 contains for reference a listing of each case giving most, but by no means all, of the individual characteristics analyzed here. The 26 among them which are discussed in the Atlas (46) are cross-referenced to the latter by page.

Table 243.—*Listing of 181 Individual Nerve Injuries on Which Correlation Studies Were Based* [1]

Case No.[2]	Injury		Injury to operation, tens of days	Surgical gap, cm.	Sensory recovery			Skin resistance	Motor recovery			Practical function	Pathologic forecast
	Type	Site			Thresholds, in gms.		British summary		Muscle movements		British summary		
					Pain	Touch			Proximal	Distal			
MEDIAN													
1108	CD	6	22	06	0	0	0	N	0, 0, 0	5, V	4	50	41
1140	NC	8	11	05	20	5	5	TA	0, 0, 0	5, 0	4	70	54
1187	NC	1	13	03	20	16	5	N	5, 5, 5	5, 5	3	60	66
1228	CD	6	15	06	30	16	5	V	5, 5, X	5	5	70	77
1279*	CD	5	13	07	D	0	0	N	1, 0, 0	5, V	4	50	66
3023	NC	1	12	06	H	H	5	AZ	4, 5, X	1, X	2	50	54
3059	NC	4	12	03	<6	3	6	V	1, 1, 3	5, 5	4	50	77
3075	NC	2	6	03	H	H	4	N	5, 5, X	2, 5	4	60	81
3079	CD	5	23	06	H	H	V	V	5, 5, X	5, 5	4	V	63
3105	CD	1	24	09	<6	5	4	V	4, 4, 5	1, 2	2	20	15
3128	CD	6	19	07	H	H	4	AZ	0, 0, X	5, 5	4	70	46
3142	NC	3	14	06	H	0	1	N	5, 5, X	4, 5	3	60	68
3150	NC	8	17	04	40	5	4	AZ	0, 0, 0	4, 4	3	60	47
3231	NC	1	13	05	D	0	1	AZ	3, 5, X	5, 5	4	50	64
3233*	NC	2	6	04	10	0	2	AZ	5, 5, 5	5, 5	3	50	88
3242	CD	3	15	05	6	5	4	AZ	5, 5, X	1, 1	2	40	54
3245	NC	6	7	04	40	35	3	AZ	0, 0, 0	5, 5	3	60	34
3255	CD	5	10	05	40	0	1	N	0, 0, 0	5, X	4	50	72

See footnotes at end of table.

Table 243.—*Listing of 181 Individual Nerve Injuries on Which Correlation Studies Were Based* [1]—Continued

Case No.[3]	Injury		Injury to operation, tens of days	Surgical gap, cm.	Sensory recovery			Skin resistance	Motor recovery			Practical function	Pathologic forecast
	Type	Site			Thresholds, in gms.		British summary		Muscle movements		British summary		
					Pain	Touch			Proximal	Distal			
MEDIAN—Continued													
3265	NC	6	12	03	20	5	3	D	0, 0, 0	5, 0	3	V	68
3266	CD	5	10	05	40	0	2	N	0, V, V	5, 5	3	50	47
3270	CD	2	7	08	30	16	3	AZ	5, 5, 5	5, 5	4	30	72
3280	NC	7	12	03	20	5	5	AZ	5, 5, 5	5, 5	4	70	63
3288*	CD	4	1	04	6	16	4	N	5, 5, X	5, 5	4	60	83
3445	NC	1	11	04	40	16	3	AZ	3, 4, 5	3, 3	3	60	67
4216	NC	6	18	03	D	0	1	AZ	5, 5, 0	5	6	50	71
4253	CD	5	79	08	D	16	5	D	0, 0, 0	5	5	60	8
4305*	CD	8	0	03	<6	16	3	N	5, 5, 5	5	4	60	54
4308	CD	1	7	08	10	5	4	AZ	5, 5, 5	2, 2	3	10	55
4469	NC	1	11	04	20	16	5	AZ	2, 4, 5	2	3	70	63
RADIAL													
1011	NC	1	13	03	V	V	V	V	5, 5, 5, 5, 5	5, X, X	4	90	72
1048	CD	2	17	07	D	<3	5	V	1, 5, 5, 5, 5	1, 5, 5	V	80	24
1120	NC	3	6	05	H	H	3	D	4, 4, 5, 0, 0	3, 4, X	2	70	81
1226	CD	2	10	05	<6	3	6	N	2, 5, 5, 5, 0	5, 5, 5	5	100	40

3018	CD	2	13	07	10	5	5	D	5, 5, 5, 5, 0	5, 5, 5	4	80	50
3087	CD	2	10	06	H	H	4	N	5, 5, 5, 5, 0	4, 5, X	4	80	32
3096	NC	3	14	02	H	0	1	N	3, 5, 5, 0, 0	5, X, X	3	80	45
3122	NC	2	13	04	30	16	5	V	2, 5, 5, 5, 0	5, X, X	4	80	68
3161	NC	2	6	03	H	5	6	D	5, 5, 5, 5, 0	5, 5, 5	4	90	90
3168	CD	2	22	08	40	25	6	N	1, 5, 5, 5, 0	5, 5, 5	V	80	9
3199	CD	1	13	04	V	V	V	N	1, 1, 1, 1, 0	1, 1, 1	0	50	46
3232	CD	2	17	10	6	16	5	N	2, 2, 3, 3, 0	X, X, X	1	70	40
3250	CD	7	8	05	40	0	2	D	4, 4, 5, 5, 0	4, 4, 4	3	80	41
3258	NC	2	12	04	<6	25	2	N	4, 5, 5, 5, 0	4, 4, X	3	80	76
3262	NC	1	10	03	<6	16	5	N	5, 5, 5, 5, 0	5, X, X	4	80	72
3331	CD	7	12	04	40	16	6	M	5, 5, 5, V, 0	5, 5, 5	5	70	63
3383	CD	2	21	04	6	<3	6	N	4, 5, 5, 5, 0	1, 1, 1	2	70	35
3399	PD	2	13	03	30	16	4	D	4, 5, 5, 5, 0	4, 4, 4	3	70	81
3405	CD	3	12	04	6	25	2	D	2, 4, 5, 5, 0	4, 4, 4	3	60	44
3458	CD	1	10	04	30	5	5	TA	2, 2, 5, 5, 5	2, 3, 3	3	30	43
3476*	CD	3	16	07	40	5	4	D	3, 4, 5, 0, 0	3, 3, 4	3	80	64
4092	CD	2	31	04	V	16	3	V	5, 5, 5, 5, 0	5, 5, X	5	80	8
5183	CD	2	13	06	6	3	6	N	5, 5, 5, 5, 0	5, X, X	4	60	65

ULNAR

1071	CD	3	29	08	<6	<3	5	AZ	5, 5	2, 3, X	3	20	50
1119	CD	4	10	08	<6	<3	3	TA	0, 0	5, 5, X	5	70	72
1123	CD	2	19	06	D	16	3	TA	5, 5	5, 5, X	4	70	65
1134	CD	8	13	06	[8] V	[8] V	[8] V	D	0, 0	X, X, X	V	60	65
1177	NC	5	12	08	40	16	5	N	0, 0	5, 5, 5	3	80	63
1183	CD	2	16	07	10	3	5	TA	2, 2	4, 4, X	3	90	62
1187	NC	1	13	03	40	16	3	N	5, 5	5, 5, X	3	60	72
1214*	NC	5	16	06	20	16	3	N	0, 0	5, 5, X	4	80	71

See footnotes at end of table.

Table 243.—*Listing of 181 Individual Nerve Injuries on Which Correlation Studies Were Based* [1]—Continued

Case No.[2]	Injury		Injury to operation, tens of days	Surgical gap, cm.	Sensory recovery			Skin resistance	Motor recovery			Practical function	Pathologic forecast
	Type	Site			Thresholds, in gms.		British summary		Muscle movements		British summary		
					Pain	Touch			Proximal	Distal			
ULNAR—Continued													
1235.........	NC	4	11	04	20	16	5	N	5, 0	5, 5, 5	4	90	63
1258.........	NC	4	11	08	6	16	5	TA	4, 5	4, 5, 5	4	70	63
1260*........	CD	4	8	06	10	5	5	TA	5, 5	5, 5, 5	5	90	72
1266.........	NC	3	11	04	<6	16	5	N	5, 5	3, 4, 4	4	80	81
3023.........	NC	1	12	04	H	H	4	AZ	4, 5	1, 1, X	2	50	48
3105.........	CD	1	24	07	<6	5	4	V	4, 5	3, 4, 4	3	20	43
3130.........	CD	1	20	10	H	H	4	V	1, 2	1, 1, 1	1	10	47
3134.........	CD	1	7	05	H	H	5	N	5, 5	3, 4, X	3	60	74
3152.........	NC	4	22	05	H	50	1	AZ	5, 5	5, 5, 5	4	90	65
3188.........	NC	3	25	06	10	16	4	M	5, 5	3, 3, 3	3	80	51
3210.........	CD	6	23	04	6	5	5	AZ	0, 0	5, 5, X	4	80	60
3212.........	NC	8	20	05	30	16	3	AZ	0, 0	1, 4, X	3	70	54
3231.........	CD	1	13	10	D	0	1	AZ	3, 5	4, 5, X	4	50	52
3242.........	CD	3	15	08	<6	5	5	AZ	5, 5	1, 2, X	3	40	36
3249.........	CD	6	15	07	6	0	2	AZ	0, 0	1, 3, X	3	70	43
3250.........	NC	7	8	05	40	0	2	AZ	1, 5	3, 3, 4	3	80	70
3269*........	CD	5	18	07	10	16	4	M	0, 0	4, 5, 5	4	70	26
3270.........	CD	2	7	09	30	16	5	AZ	4, 5	3, 3, 4	3	30	63
3279.........	NC	7	19	05	20	0	2	AZ	5, 3	4, 5, X	3	70	56
3314.........	NC	7	17	05	6	16	5	M	5, 5	5, 5, 5	3	90	72

408980—57——34

3315..........	CD	4	12	05	D	5	1	AZ	0, 0	2, 2, 5	3	80	60
3316..........	CD	6	16	07	10	16	3	AZ	3, 0	3, 3, 3	3	60	54
3343..........	CD	1	9	06	6	5	4	M	5, 5	3, 3, 4	3	70	58
3351..........	CD	8	10	07	30	0	2	AZ	0, 0	3, 3, 4	3	70	10
3352*.........	CD	8	2	03	40	16	3	AZ	0, 0	4, 4, 4	3	80	29
3358..........	NC	2	15	05	40	16	5	M	5, 5	4, 4, 5	3	80	48
3375*.........	CD	3	16	03	D	16	5	D	4, 5	4, 4, 5	3	70	60
3392..........	CD	2	6	06	D	25	3	AZ	4, 5	4, 4, 5	3	80	20
3394..........	CD	6	13	05	6	3	4	AZ	0, 0	4, 5, 5	4	50	45
3427*.........	CD	5	10	10	10	16	4	D	5, 0	5, 5, 5	5	90	60
3436..........	CD	7	22	08	40	5	4	M	5, 5	5, 5, 5	4	80	32
3449..........	NC	5	16	06	40	25	1	TA	5, 5	4, 5, X	3	50	64
3458..........	CD	1	9	04	D	5	1	TA	4, 4	1, 2, 2	3	30	72
3475..........	CD	6	23	04	20	16	4	M	0, 0	4, 4, 5	3	80	27
4182..........	CD	4	19	08	D	0	1	V	5, 5	2, 5, 5	4	60	30
4277..........	NC	7	12	08	D	25	1	N	5, 5	1, 1, 1	2	70	51
4278..........	CD	7	29	11	D	0	1	AZ	2, 5	1, 2, 5	3	60	27
4294..........	NC	7	7	03	D	0	0	N	5, 5	1, 1, 1	2	60	48
4394..........	CD	4	24	05	6	5	6	N	5, 5	5, 5, X	5	90	50
4423*.........	CD	5	8	06	10	16	6	N	5, 5	5, 5, 5	4	70	54
4472*.........	CD	2	26	09	6	25	2	AZ	5, 5	5, 5, 5	4	30	19
4480..........	NC	3	39	04	[3] V	[3] V	[3] V	V	5, V	1, 5, V	4	0	3

PERONEAL

1032..........	CD	7	10	08	<6	5	6	TA	2, 2, 3, X	....	1	60	54
1093..........	CD	7	23	05	20	25	3	N	1, 3, 3, 5	....	2	80	47
1141..........	CD	2	16	11	<6	16	3	D	1, 1, 1, 1	....	0	70	27
1159..........	CD	7	16	06	40	0	1	V	2, 2, 5, X	....	1	60	44

See footnotes at end of table.

Table 243.—*Listing of 181 Individual Nerve Injuries on Which Correlation Studies Were Based* [1]—Continued

Case No.[2]	Injury		Injury to operation, tens of days	Surgical gap, cm.	Sensory recovery			Skin resistance	Motor recovery			Practical function	Pathologic forecast
	Type	Site			Thresholds, in gms.		British summary		Muscle movements		British summary		
					Pain	Touch			Proximal	Distal			
PERONEAL—Continued													
1193	NC	2	20	07	<6	0	1	D	4, 5, 5, 5	....	3	70	68
1227*	CD	7	10	06	40	16	5	TA	4, 3, 3, 3	....	1	60	60
1263*	NC	7	11	05	<6	3	3	AZ	3, 4, 5, 5	....	4	70	60
1269	CD	3	14	05	<6	16	3	TA	1, 1, 1, 2	....	1	60	51
3007	CD	2	27	09	<6	<3	4	AZ	1, 2, 2, 3	....	1	50	10
3069	CD	2	15	09	H	H	4	N	3, 5, 5, 5	....	2	V	63
3091	NC	1	10	04	H	H	0	AZ	1, 1, 3, 4	....	1	80	44
3094	CD	4	23	05	H	H	4	AZ	1, 1, 1, 1	....	0	80	19
3107	CD	1	52	08	0	0	0	V	2, 1, 1, 1	....	1	60	25
3119*	CD	1	21	04	D	25	1	N	1, 1, 1, 1	....	0	70	47
3149	CD	2	10	11	H	0	1	AZ	1, 1, 1, 1	....	0	80	3
3172	NC	3	30	06	H	5	3	N	1, 4, 4, 5	....	3	60	58
3187	NC	2	14	07	30	35	2	AZ	3, 5, 5, 5	....	4	80	65
3197*	CD	2	33	08	40	25	2	AZ	3, 3, 4, 5	....	2	70	21
3202*	PD	7	11	04	40	0	2	AZ	4, 4, 4, 5	....	2	80	45
3244	CD	3	16	13	20	0	1	N	2, 2, 2, 2	....	1	60	34
3264	NC	7	17	09	20	0	2	AZ	1, 1, 2, 5	....	V	80	4
3267	CD	1	8	07	30	0	2	TA	1, 1, 1, 1	....	0	50	25
3268*	CD	7	16	06	0	0	0	AZ	1, 1, 1, 1	....	0	60	45
3274	CD	1	11	07	40	25	4	AZ	1, 2, 2, 2	....	1	70	45

3277	CD	7	22	08	6	25	5	AZ	1, 2, 3, 5	....	2	80	29
3290	CD	2	15	08	10	35	2	N	1, 1, 2, 2	....	1	70	26
3294	NC	2	23	12	10	0	2	AZ	1, 3, 4, 4	....	2	70	44
3298	CD	2	17	08	D	0	1	AZ	1, 1, 1, 1	....	0	40	49
3307	NC	1	18	07	D	0	1	AZ	1, 1, 1, 1	....	0	70	69
3326	NC	7	11	05	D	0	1	N	4, 5, 5, 5	....	3	70	75
3356	NC	1	15	07	D	0	1	TA	4, 4, 4, 5	....	2	70	66
3420*	NC	1	10	05	D	0	1	TA	2, 2, 3, 3	....	1	70	49
3447*	NC	3	16	07	D	50	1	AZ	3, 4, 4, 5	....	2	80	26
3465	CD	1	8	08	D	25	3	TA	2, 2, 3, 4	....	2	70	52
4113	NC	1	12	03	<6	16	5	N	1, 1, 1, 1	....	0	70	32
4153	PD	3	25	05	0	0	0	V	1, 1, 1, 2	....	1	50	8
4198	CD	1	8	07	0	0	0	V	1, 1, 1, X	....	0	0	34
4277	CD	1	10	04	D	25	1	V	1, 1, 1, 1	....	0	0	14
4279	CD	1	16	10	0	0	0	V	1, 1, 2, 2	....	1	40	35
4284	CD	2	12	06	D	35	1	N	1, 1, 2, 4	....	1	50	51
4285	NC	2	10	01	40	25	2	N	1, 1, 5, 5	....	1	70	49
4306	NC	1	14	05	10	16	4	N	1, 1, 1, 1	....	0	70	51
4466	CD	1	11	07	20	16	4	V	1, 1, 1, 1	....	0	50	30
TIBIAL													
1001	NC	5	12	05	V	V	3	TA	5, 0, 0, 0	X	2	80	70
1032	CD	7	10	07	<6	5	5	TA	1, 1, 5, X	X	2	60	54
1041	CD	6	15	06	10	<3	5	N	0, 0, 0, 0	1	0	80	73
1141	CD	2	16	11	<6	16	3	D	1, 1, 1, 5	1	2	70	51
1180*	CD	4	11	05	40	16	3	D	5, 0, 0, 0	1	1	80	81
1193	NC	2	20	07	40	0	1	D	2, 2, 5, 5	1	2	70	68
1227	CD	7	10	06	D	0	1	TA	1, 1, 5, 5	1	2	60	60
1255	NC	6	17	05	<6	<3	3	D	4, X, X, 0	1	2	80	36

See footnotes at end of table.

Table 243.—*Listing of 181 Individual Nerve Injuries on Which Correlation Studies Were Based* [1]—Continued

Case No.[3]	Injury: Type	Injury: Site	Injury to operation, tens of days	Surgical gap, cm.	Sensory recovery: Thresholds, in gms.: Pain	Sensory recovery: Thresholds, in gms.: Touch	Sensory recovery: British summary	Skin resistance	Motor recovery: Muscle movements: Proximal	Motor recovery: Muscle movements: Distal	Motor recovery: British summary	Practical function	Pathologic forecast
TIBIAL—Continued													
1269	CD	3	14	06	<6	16	4	TA	1, 1, 2, 5	1	2	60	51
3004	CD	1	8	12	40	16	4	AZ	2, 2, 3, 5	2	3	70	49
3006	NC	5	18	06	H	H	4	N	3, 4, 5, 5	1	2	60	48
3020	CD	6	15	11	H	H	4	AZ	0, 0, 0, 0	1	2	40	14
3039	NC	5	64	06	H	H	4	N	0, 0, 0, 0	1	2	80	68
3046*	CD	5	9	07	10	16	4	N	5, 5, 0, 0	5	4	90	68
3069	CD	2	15	09	0	0	0	AZ	3, 3, 5, 5	1	2	V	63
3107	CD	1	52	08	0	0	0	V	1, 1, 1, 5	1	1	60	25
3119	CD	1	21	04	D	16	1	N	1, 1, 1, 5	1	2	70	47
3147	NC	2	10	04	V	16	1	AZ	1, 1, 5, 5	1	4	80	64
3187	NC	2	14	06	6	16	4	N	1, 1, 5, 5	1	3	80	45
3197*	CD	2	33	08	40	25	2	AZ	1, 1, 4, 5	1	2	70	21
3237	PD	1	47	08	D	0	1	AZ	1, 1, 2, 4	1	2	60	36
3244	CD	3	16	13	<6	16	3	N	2, 2, 2, 5	2	2	60	34
3281*	CD	5	15	09	6	35	2	AZ	3, 3, 5, 5	3	3	70	65
3290	CD	2	15	08	<6	16	4	N	1, 1, 1, 5	1	1	70	38
3294	CD	2	23	12	40	0	2	AZ	3, 3, 3, 5	3	3	70	23
3299	CD	5	16	09	D	35	1	N	2, 4, 5, 0	2	2	80	28
3342	CD	6	15	06	D	50	1	N	0, 0, 0, 0	5	4	90	44
3420	NC	1	10	05	D	0	1	TA	1, 1, 1, 5	1	2	70	49
3439	CD	5	16	07	40	16	4	AZ	0, 0, 0, 0	4	3	80	31

3477	CD	5	23	04	10	5	4	N	1, 2, 0, 0	4	3	80	32
4153*	PD	3	25	05	0	0	0	D	1, 1, 1, 1	1	0	50	08
4198	CD	1	8	07	0	0	0	V	1, 1, 5, X	X	1	0	34
4279	CD	1	16	10	0	0	0	V	1, 1, 1, 5	1	2	40	35
4284	CD	2	12	08	40	16	4	AZ	1, 1, 2, 5	1	2	50	51
4476	CD	2	11	08	0	0	0	V	0, 0, 0, 0	X	2	80	52
5357	CD	5	33	09	30	3	6	N	5, 5, 5, 5	2	3	80	11

[1] To conserve space many items have been coded; see code equivalents following table.

[2] Of the 150 cases exhibited in the *Atlas of Peripheral Nerve Injuries*, the 26 marked with an asterisk (*) have complete follow-up studies, and their page references in the *Atlas* follow:

[3] Amputation, test not done.

	Case No.	Page		Case No.	Page
Median	1279	49	Ulnar	1214	265
	3233	177		1260	99
	3288	241		3269	247
	4305	109		3352	49
				3375	267
Radial	3476	45		3427	185
				4423	183
Peroneal	1227	33		4472	41
	1263	247			
	3119	271	Tibial	1180	129
	3197	41		3046	33
	3202	131		3197	41
	3268	101		3281	37
	3420	165		4153	107
	3447	191			

Code Equivalents for Table 243

Type of Injury to Nerve

CD Complete nerve division
PD Partial nerve division
NC Neuroma in continuity

Site of Injury to Nerve

1 Upper third of arm or thigh
2 Middle third of arm or thigh
3 Lower third of arm or thigh
4 Upper third of forearm or leg
5 Middle third of forearm or leg
6 Lower third of forearm or leg
7 Elbow or knee
8 Wrist or ankle
9 Hand or foot

Injury to Operation, Tens of Days

Days elapsing between injury and definitive suture were coded in 10-day intervals, so that 0 means 0 to 9 days, 1 means 10 to 19, 22 means 220 to 229, etc.

Surgical Gap. cm.

The surgical defect at the definitive suture was coded to the nearest cm., so that 01 means an interval from 0.5 to 1.4 cm., etc.

Sensory Recovery

Pain Threshold in Grams

Numerical values—threshold as measured; only values of 40, 30, 20, 10, 6, and <6 gm. were employed.

O No sensation
D Deep pressure only
H Hypesthesia, unmeasured
V Unknown

Touch Threshold in Grams

Numerical values—threshold as measured; only values of 50, 35, 25, 16, 3, and <3 gm. were employed.

O No sensation or threshold <50 gm.
H Hypalgesia, unmeasured
V Unknown

British Summary

0 Absence of sensibility in autonomous zone (AZ)
1 Recovery of deep cutaneous pain in the AZ
2 Recovery of superficial pain sensibility
3 Return of superficial cutaneous pain and touch throughout the AZ
4 Return of superficial pain and touch throughout AZ plus overreaction and inability to localize
5 Same as category 4 without overresponse
6 5 plus some two-point discrimination
7 Complete recovery
V Unknown, not tested

For a discussion of this code see chapter V, pp. 254–259.

Skin Resistance (SR)

TA Elevated SR in total area
AZ Elevated SR in autonomous area
D Decreased SR
N Normal SR
M Mixed SR patterns
V SR not tested, or otherwise unknown

Motor Recovery

Muscle Movements

Separately for the proximal and distal muscles as defined in table 48, chapter III, all the muscles in the standard set are coded as to response to voluntary stimulation, as follows:

0 Not affected
1 No contraction
2 Perceptible movement only
3 Movement but not against gravity
4 Movement against gravity, but not against resistance
5 Movement against resistance
X Affected, not tested
V Unknown if affected

However many muscles there may be in the standard set (for proximal or distal), the entry consists of a listing of the codes for each. The order of the listing is not anatomic but rather is that of the code. Thus an entry "1, 1, 1" means that all three standard muscles were affected and in none of them was contraction observed. An entry "0, 1, X" would mean that one of three standard muscles was not affected, another was affected but did not respond at all, and a third was affected but not tested.

It will be noted in table 48, chapter III, that the abductor pollicis brevis was not a standard median muscle in the original protocol, but that use has been made of it in many cases. When the table gives two distal muscles the abductor pollicis brevis is included. When only one is given it is the opponens.

British Summary

0 No contraction
1 Return of perceptible contraction in proximal muscles
2 Proximal muscles acting against gravity, no return of power in intrinsic muscles
3 Proximal muscles acting against gravity, perceptible contraction in intrinsic muscles
4 Return of function in both proximal and distal muscles so that all important muscles can act against resistance
5 Same as category 4-plus synergic and isolated movements
6 Complete recovery
V Unknown

For a discussion of this code, see chapter III, pp. 74–76.

Practical Function

Percentage of useful or effective recovery not only because of nerve and muscle recovery but also because of prosthetic devices, orthopedic procedures, etc. See chapter VIII for criteria.

Pathologic Forecast

See text, this chapter. It is the summary index only which is shown here.

B. METHODOLOGY

The chief methodological problem concerns the choice of the characteristics considered to be descriptive of the lesion or, more specifically, of the surfaces joined by the surgeon. To the extent that the choice employed here is arbitrary, others might conceivably prove more fruitful. Both the distal and the proximal surfaces were evaluated, and four separate assessments were made for each in the form of expected percentage losses in recovery. The losses were estimated from the degree of fibrous or neuromatous change evident in the (1) epineural, (2) interfascicular, (3) perineural, and (4) intrafascicular regions. There were thus 8 separate assessments, 4 for each nerve stump. The neuropathologist interpreted his task to be that of predicting regeneration across the gap and no farther; he paid no attention to other factors which must surely affect end results, e. g., the distance (or time) over which regenerating fibers must grow to reach their end-organs. To have incorporated into a single index estimates of the influence of additional variables would have made his ratings even more subjective than they necessarily were, and seemed unnecessary as long as there was every expectation that the effects of other variables could be controlled statistically. The decision was made to base the neuropathological ratings upon fibrosis generally rather than to make separate forecasts for the fine fibres (pain and autonomic) and the larger ones (pressure, touch, and motor). In reviewing the slides it often seemed that the fine fibres should get through without much trouble, whereas if the larger ones were capable of getting through they might not myelinate normally. The estimated losses, however, are not specific to one variety of fibre or another, but represent degrees of fibrous or neuromatous change, and may not apply with equal force to all varieties of fibers.

Three more summary assessments were then derived from these on the following assumptions:

1. That the four separate estimates for each nerve segment were independent and additive; and
2. That the condition of each nerve end was independent of that of the other, and nerve regeneration best viewed as a product of the residual chances of recovery obtained for each.

Accordingly, the sum of the losses for each nerve stump was taken as a summary of the deleterious influences inherent in the condition of that particular nerve end. For each nerve end the complement of the losses was then obtained, i. e., the residual expectation of regeneration. Thus, if a poor distal end was assessed with deductions of 5, 10, 10, and 40 percent, or 65 percent in the aggregate, its expectation of regeneration was taken at 35 percent or .35. The separate expectations of the 2 nerve ends were then combined by multiplication; a distal nerve end rated at .35 and a proximal rated as .80 thus yielded an overall expectation of .28 (or 28 percent) for the recovery of the nerve.

Especially arbitrary are the 3 summary assessments derived from the basic 8 enumerated above. The assumptions upon which they proceed are not necessarily the best; the individual losses might not be additive, or, if additive, might better be weighted in some other fashion. The method of combining the assessments on the two nerve ends is obviously but one of several possible methods. If fibrotic areas are seen in both nerve ends and are so placed as to overlap considerably when joined together, the multiplication procedure may exaggerate the effect upon regeneration. In general, however, since several cm. of nerve length were resected or obliterated by injury, the assumption that the nerve ends actually joined are independent of one another seems reasonable. Before the statistical analysis was begun, therefore, it was agreed that these 3 summary ratings might not provide the best combinations of the 8 unitary assessments and that, should any of the correlations prove at all promising, statistical methods would be employed to develop an optimum pattern for combining the 8 values. As it turned out, however, the correlations were not sufficiently encouraging to warrant the effort which such an analysis might have required.

The process of classification is best explained on the basis of concrete examples, of which two sets are presented. The first, consisting of 9 illustrated cases, is drawn from those with follow-up information studied here but is probably also typical of the entire series of over 600 nerves. The second, consisting of 8 cases (including 1 in the first set of 9), was chosen to explain why so much emphasis has been placed on the appearance of the intrafascicular regions.

The nine representative cases follow.

Case 1193. A neuroma in continuity of the sciatic nerve in the middle-third of the thigh. The segment shown in plate 1 was removed and the nerve sutured 6½ months after injury.

Pathology. Proximal (plate 2) and distal segments (plate 3) were rated as in table 244. Deductions were made for slight fibrosis throughout the proximal stump, and for moderate fibrosis of the perineural and intrafascicular areas of the distal stump. The 10 and 25 percent estimated losses for the 2 nerve ends were combined into a summary estimate of recovery of 68 percent.[27]

Table 244.—*Neuropathological Ratings, Case 1193*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epineural	Interfascicular	Perineural	Intrafascicular	Total segment
Proximal	2	5	3	0	10
Distal	0	0	10	15	25
Summary Index	....	....	....	....	68

[27] The complements of 10 and 25 percent, i. e., 90 and 75 percent, were multiplied to give the summary estimate of 68 percent.

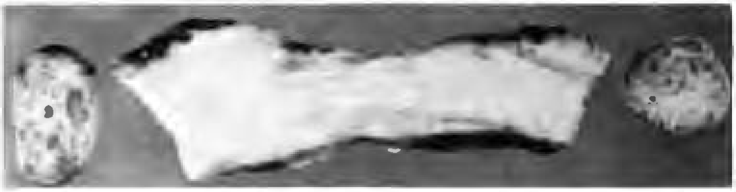


Plate 1. *Case 1193*

Plate 2. *Case 1193*

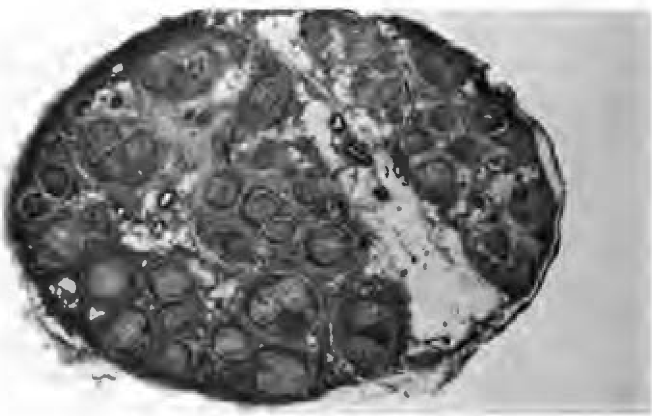


Plate 3. *Case 1193*

Result. Pain thresholds 40 gm. in p. tibial and <6 gm. in c. peroneal; touch nil; autonomic good in both; motor good in peroneal, and fair in p. tibial proximal muscles, nil in intrinsic muscles. Complaints: some loss of gross muscle power, easy fatigability, excessive sweating, split sensation.
Comment. The nerve cross sections were good and the recovery was good for a midthigh sciatic lesion. The explanation for some of the failure (e. g., touch) in this nerve may best be sought in the mismatched fascicular patterns. The sciatic nerve at this level may have as many as 80 fascicles, and

when a long segment is removed the fascicular patterns of the ends finally sutured are usually entirely dissimilar. To illustrate this point as Sunderland (78) has done, the fascicles of the distal section have been superimposed as rings on the proximal section. Even where a proximal fascicle or a fraction of one might happen to fall within any or all of the area of a distal one, it would be purely fortuitous that they should be the appropriate mates. Time fibrosis within the tubules of such a long distal segment might also help to explain why large fibers subserving touch and skeletal motor functions did not return adequately. One would also expect atrophy of the distal muscles.

Case 3046. A complete severance of the posterior tibial nerve in the middle-third of the leg. The segments shown in plate 4 were resected and the nerve sutured 3 months after injury.

Pathology. Proximal (plate 5) and distal (plate 6) cross sections were rated as in table 245. The small deductions for slight fibrosis in the epineural, interfascicular, and intrafascicular regions of both ends left a final rating of 68 percent.

Result. Threshold for pain, 6 gm.; for touch, 16 gm.; autonomic good. Motor: 1 proximal and 2 distal muscles were tested and all contracted against resistance. Complaints: paresthesia, pain on use or pressure, bizarre sensory pattern (split sensation), adverse reaction to heat and cold.

Plate 4. *Case 3046*

Plate 5. *Case 3046*

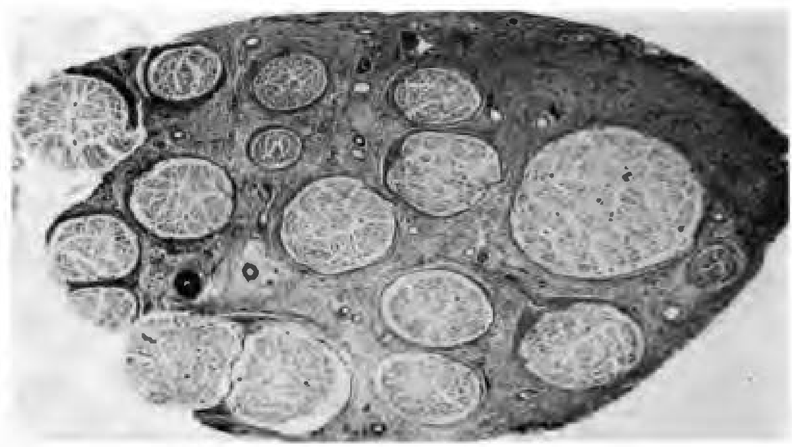


Plate 6. *Case 3046*

Comment. This case illustrates the aim of the surgical pathology team: to insure good nerve regeneration by resecting to the best possible cross sections proximally and distally. This was one of the more favorable cases in that only about 25 mm. had to be excised from each stump in order to eliminate most of the neuromatous and fibrotic tissue. On review, the pathology rating of 68 percent seemed somewhat severe and the correspondence between the nerve ends and functional return was good.

Table 245.—*Neuropathological Ratings, Case 3046*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	5	10	0	5	20
Distal	5	5	0	5	15
Summary index					68

Imperfect matching of sensory fascicles rather than the slight fibrosis seemed the better explanation for pain and touch returns being subnormal. However, as may be seen in plates 5 and 6 the proximal and distal fascicular appositions were probably better than usual. Plate 5 shows the proximal cross section with the distal stump fascicles superimposed as inked-in rings. Epineural stitching would probably have brought about better conformity of these ends; and therefore might have permitted better fascicular apposition than shown here. Only four of the proximal fascicles do not overlie some part of one or more of the distal rings. Two of the latter are not covered by some part of a proximal fascicle; but in these cases there are perineural contacts.

Case 3307. A double neuroma in continuity of the peroneal component of the sciatic nerve in the upper-third of the thigh. The 7 cm. specimen (plate 7) was resected and the nerve sutured 6 months after injury. An intraneural tantalum sling stitch was used.

Pathology. Proximal (plate 8) and distal (plate 9) ends were rated as in table 246. The small deductions were made from both ends because of the mild degree of epineural and intrafascicular fibrosis shown in these plates, and the endoneural fibrosis (not visible at this magnification) that had developed in the 6-month interval. The final rating was 69 percent.

Table 246. *Neuropathological Ratings, Case 3307*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	5	5	0	0	10
Distal	5	5	3	10	23
Summary index	....	....	....	....	69

Result. Pain was elicited on deep pressure only; touch was nil; autonomic was poor in autonomous zone but normal in overlap areas; motor was nil in four muscles tested. Complaints: gross sensory and motor loss.

Comment. Reasons for a nerve faring badly in spite of favorable histology in its sutured stumps have been dealt with extensively in other chapters. Some of these are: badly placed sutures or wrappers; a pathologic "bed"; high lesions resulting in postoperative "time" fibrosis in the distal tubules; stretch fibrosis because of the necessity of resecting too extensively; associated bone, vascular, or other nerve lesions; mismatched proximal and distal fascicular patterns such as illustrated in plate 8 in which the inked-in rings represent the distal fascicles in one possible pattern of apposition with the underlying proximal fascicles. In this case the double neuroma necessitated a long resection; and the surgeon felt that a sling suture was necessary because of tension. This precaution against separation at the suture line—notoriously frequent in this nerve—must have seemed the lesser of two evils, the other being the likely stretch fibrosis known to occur in such

Plate 7. *Case 3307*

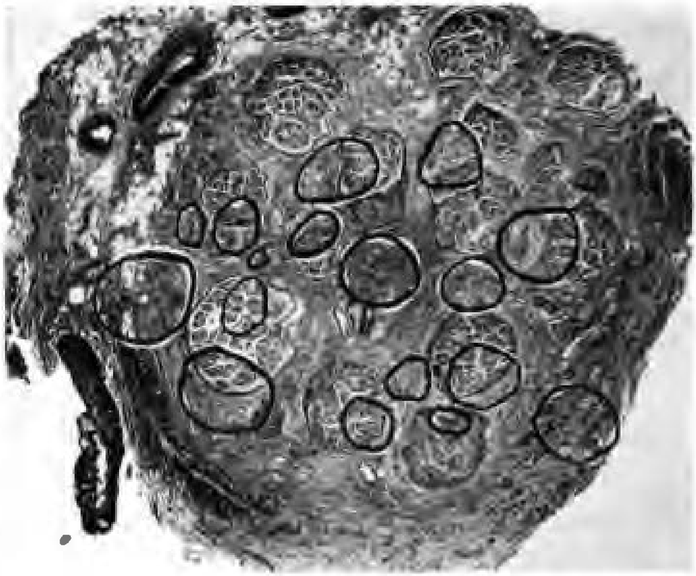


Plate 8. *Case 3307*

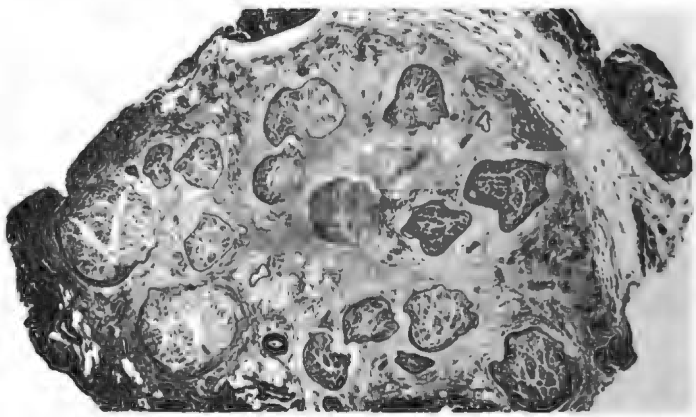


Plate 9. *Case 3307*

cases when the knee was eventually extended. Although this nerve was not considered to have separated, the functional return was consistent with that of a disrupted nerve or one that had undergone stretch fibrosis. Pain was elicited with deep pressure in the autonomous zone; but this may have been due to an overlapping nerve in the sclerotomal regions.

Case 3197. A completely severed sciatic nerve in the middle-third of the thigh. Segments shown in plate 10 were resected and nerve was sutured 10½ months after injury.

Pathology. The specific ratings were as in table 247. The summary rating was poor (21 percent) not only because of the neuromatous proximal stump, but because of the shrunken fibrotic distal fascicles (plates 10, 11, and 12). It is clearly shown in these plates that the cross-sectional fascicular and tubular areas are reduced to a small fraction of the normal with replacement by fibrous and adipose tissue.

Result. Pain threshold 40 gm. and touch 25 gm. for both nerve components; autonomic was poor. Six of the 8 tested proximal muscles showed varying

Table 247.—*Neuropathological Ratings, Case 3197*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epineural	Interfascicular	Perineural	Intrafascicular	Total segment
Proximal	5	15	5	15	40
Distal	0	5	10	50	65
Summary index					21

Plate 10. *Case 3197*

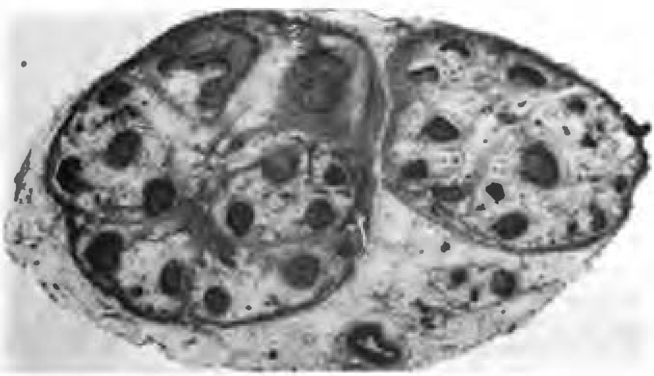


Plate 11. *Case 3197*

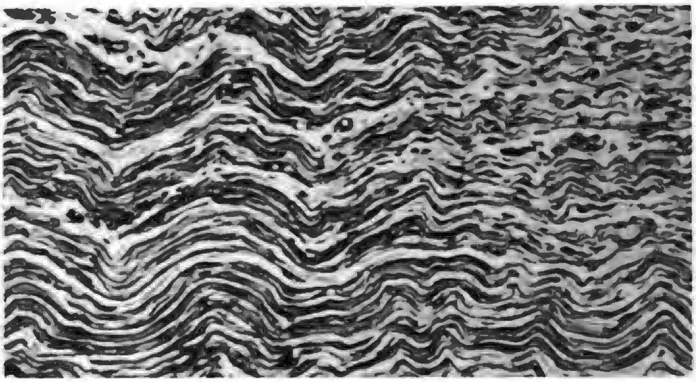


Plate 12. *Case 3197*

degrees of functional return but with only 1 muscle for each nerve contracting against resistance; complete paralysis of the intrinsic muscles. Complaints: paresthesia, gross sensory loss, pain on use or pressure, some loss of gross muscle power, adverse reaction to heat and cold, loss of sweating, split sensation.

Comment. Upon reviewing this case in face of the follow-up evidence, the distal tubules were still considered to be very fibrotic and unfavorable for good expansion of thick, myelinated axons. At the time of the original microscopic examination it seemed reasonable to predict that amyelinated axons might progress along the lines of Schwann cells shown in the shrunken tubules (plate 12) and that if full myelination were not a prerequisite to function, such axons might indeed subserve their normal function. One usually expected that pain and autonomic fibers might regrow and function under spatial circumstances thought to be inadequate for voluntary effectors, touch, pressure, and muscle sense receptors. There remains the possibility that regeneration and maturation might have taken place in the extensive interfascicular regions, which, in this nerve, consisted of well-vascularized adipose and loose areolar tissue. Nerve fibers do proliferate in extra fascicular areas; but whether these regions provided the growth facilities in the nerve in question or merely permitted expansion of the contracted reinnervated tubules remains unknown.

Case 4472. A completely severed ulnar nerve in the middle-third of the arm. Nerve ends were coapted at the time of injury. Definitive suture was performed after resection of specimen shown in plate 13 8½ months later.

Pathology. Small deductions were made because of slight fibrosis in epineural and interfascicular regions in both proximal (plate 14) and distal (plate 15) sections, and slight perineural fibrosis in the distal fascicles; the specific deductions were as in table 248. The large deduction was made from the distal section because of the endoneural fibrosing process that had almost obliterated the neurilemmal tubules. The summary rating was 19 percent.

Plate 13. *Case 4472*

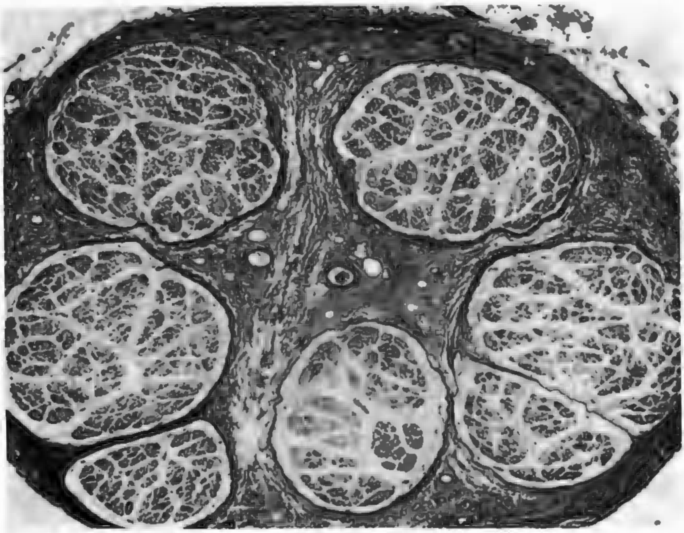


Plate 14. *Case 4472*

Plate 15. *Case 4472*

Table 248.—*Neuropathological Ratings, Case 4472*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	2	3	0	0	5
Distal	5	10	5	60	80
Summary index	....	....	....	....	19

Result. Pain threshold 6 gm., and touch 25 gm.; autonomic was poor in the autonomous zone and normal in the overlap areas; of the 2 proximal and 3 distal muscles tested, all contracted against resistance. Complaints: spontaneous pain, pain on use of hand, feeling of coldness, adverse reaction to heat and cold, gross sensory loss, some loss of fine muscular coordination, easy fatigability, incomplete opposition.

Comment. This case proved interesting because the nerve ends were rated as fair at surgery, but, after microscopic examination, the degree of intrafascicular "time" fibrosis influenced the judgment of the pathologist to such an extent that one of the lowest ratings in the series was finally given to this nerve. This is another of several examples encountered in this survey indicating that voluntary motor fibers may regenerate along fibrotic fascicles and reactivate the denervated muscles. That normalcy was not attained in this patient may be deduced from the number of complaints listed above.

Case 3269. An ulnar nerve completely severed in the middle-third of the forearm; bulb-sutured 3½ months after injury, and definitively sutured 2½ months later after resection of the suture-zone neuroma (plate 16).

Pathology. Proximal (plate 17) and distal (plate 18) segments were rated as in table 249. The distal end was one of the worst seen in this series due in part to a stretch fibrosis apparently induced by the bulb suture. The summary rating was 26 percent.

Result. Pain threshold 10 gm. and touch 16 gm.; autonomic return was equivocal, a mixed skin resistance pattern having been coded; proximal muscles not involved but 2 of the 3 distal muscles tested contracted against resistance, the other against gravity. Complaints: paresthesia, gross sensory loss, some loss of fine muscular coordination, split sensation, brace used.

Plate 16. *Case 3269*

Plate 17. *Case 3269*

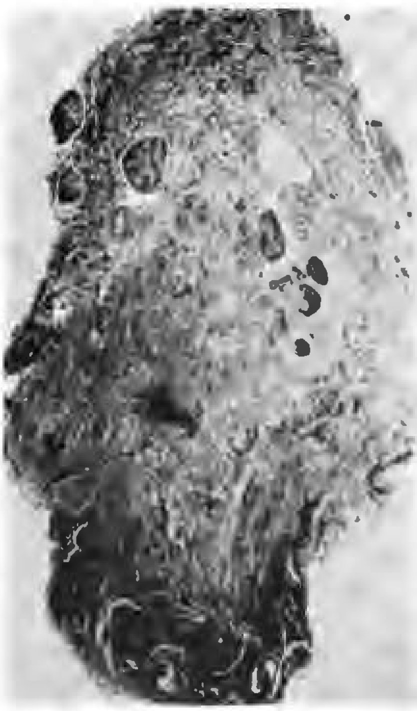


Plate 18. *Case 3269*

Table 249.—*Neuropathological Ratings, Case 3269*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	5	5	3	0	13
Distal	10	25	0	35	70
Summary index					26

Comment. The result might be rated as fair, and even this seemed incredible, in view of the distal cross section. The pathologist recorded the presence of about 10 shrunken distal fascicles among fibrotic surroundings, and also noted that amyelinated axons had grown into some of them following the bulb suture. In order to qualify the record of this unexpected functional recovery, some of the adverse phenomena coded under complaints (see above) must receive due consideration.

Case 5357. A severed posterior tibial nerve, the stumps of which had remained in fibrous continuity. Severance point was in the middle-third of the leg. Resection of 2 segments, together measuring 6 cm. (plate 19) was done, and neurorrhaphy performed 11 months after injury.

Pathology. The proximal (plate 20) and distal (plate 21) cross sections appeared grossly good, but on microscopic examination the distal fascicles

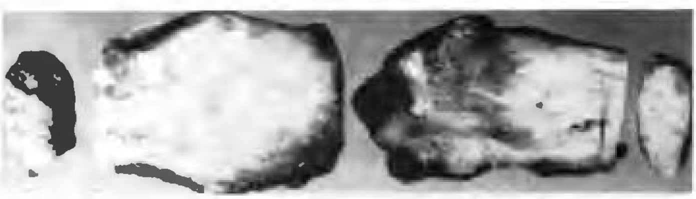


Plate 19. *Case 5357*

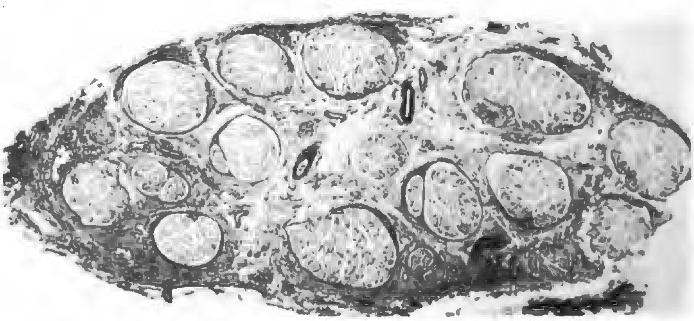


Plate 20. *Case 5357*

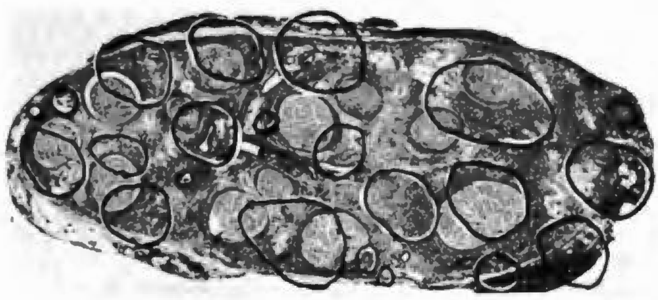


Plate 21. *Case 5357*

showed extremely shrunken tubules, and endoneural fibrosis to a degree comparable to that shown in plate 37. The specific ratings appear in table 250. The summary rating of 11 percent was one of the lowest in the series.

Table 250.—*Neuropathological Ratings, Case 5357*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	0	5	2	0	7
Distal	3	10	5	70	88
Summary index					11

Results. Pain threshold 30 gm.; touch 3 gm.; autonomic was normal; of 5 muscles tested, 4 (proximal) contracted against resistance, and 1 (distal) contracted, but not against gravity. Complaints: paresthesia, gross sensory deficit, loss of fine muscular coordination, easy fatigability, stiff joint, adverse reaction to heat and cold.

Comment. In plate 21 the inked-in circles represent the proximal fascicles in a way that may be said to approximate their relation to the distal fascicles at suture. Of 20 large and small proximal fascicles, 5 show no contact whatsoever with distal fascicles. Even with overlap there can be no assurance that the proximal fascicle overlies its distal mate. On the other hand, propinquity of proximal and distal mates may permit regenerating axons to reach their normal endings since, at the point of surgical severance, there is always a tendency for single axons to send out many branches, sometimes as many as 50, along paths of least resistance. This case is presented for another reason. Although the recovery was greatly in excess of what was expected from microscopic examination, it is necessary to discount the credit for proximal muscle recovery. The lesion was in midleg and not all the branches to the proximal muscles would, therefore, be involved. In fact, the operative note specifically recorded contraction of gastrocnemius and soleus upon stimulation, muscles credited with 80 percent power.

Case 1214. A severed ulnar nerve, middle-third of forearm; temporary suture at time of injury and 5½ months later the specimen shown in plate 22 was resected and neurorrhaphy performed.
Pathology. The proximal (plate 23) and distal (plate 24) sections were rated as in table 251. The summary rating was 71 percent.
Result. Pain threshold 20 gm. and touch 16 gm.; autonomic was normal; of 3 distal muscles affected, 2 were tested and both contracted against resistance. Complaints: spontaneous pain, paresthesia, feeling of coldness, pain on use or pressure, some loss of gross muscle power, fatigability on long use. At the time of nerve injury the ulna and radius had been fractured, and there was a residual orthopedic deformity.
Comment. This is an example of a case with better than usual nerve ends showing good although not perfect functional recovery. There was good practical function with an overall rating of 80 percent. Dynamometry on the 2 distal muscles showed 80 percent of normal. Failure of pain and touch fibers to return more abundantly to the autonomous zone may find

Plate 22. *Case 1214*

Plate 23. *Case 1214*

Plate 24. *Case 1214*

an explanation in a possible mismatching of proximal and distal fascicles, as illustrated in plate 24. Here the proximal fascicles represented by the black circles are superimposed upon the distal cross section in one form of appositional pattern that may have resulted at suture. A few of the fascicles of each stump do not have corresponding mates, and even where there is some measure of matching, there is no way of knowing whether the suture brought the appropriate fascicles together.

Table 251.—*Neuropathological Ratings, Case 1214*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epineural	Interfascicular	Perineural	Intrafascicular	Total segment
Proximal	0	3	2	0	5
Distal	5	5	5	10	25
Summary index	....	....	....	....	71

Case 3250. A neuroma in continuity of the ulnar nerve, and a complete severance of the radial nerve at the elbow. The specimens shown in plate 25 were removed and sutures performed 80 days after injury.

Pathology. The ulnar ends (plate 25 upper), proximal (plate 26), and distal (plate 27) were rated as in table 252. The summary was 70 percent. The radial nerve (plate 25 lower), proximal (plate 28), and distal (plate 29) received the deductions shown in table 253. The summary was 41 percent. The proximal nerve stump was split into two parts for suturing, the smaller being somewhat less fibrotic and neuromatous than the extremely poor larger division.

Table 252.—*Neuropathological Ratings, Case 3250 (Ulnar)*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epineural	Interfascicular	Perineural	Intrafascicular	Total segment
Proximal	5	5	3	0	13
Distal	3	2	5	10	20
Summary index	....	....	....	....	70

Table 253.—*Neuropathological Ratings, Case 3250 (Radial)*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epineural	Interfascicular	Perineural	Intrafascicular	Total segment
Proximal	10	40	5	0	55
Distal	0	0	5	5	10
Summary index	....	....	....	....	41

Plate 25. *Case 3250*

Result. Ulnar. Pain threshold 40 gm.; touch nil; autonomic was poor in the autonomous but normal in the overlap area; motor was fair, 4 of 5 tested proximal and distal muscles showing varying degrees of return, including 1 that contracted against resistance.

Plate 26. *Case 3250*

Radial. Pain threshold 40 gm.; touch nil; autonomic was normal; motor was good, all of the 6 tested proximal and distal muscles contracting against gravity and 2 against further resistance. Complaints: paresthesia, some loss of fine muscular coordination, fatigability on long use, adverse reaction to heat and cold. Same for ulnar nerve.
Comment. This case is presented because it afforded an opportunity to compare 2 nerves, 1 with a good rating and the other with a low rating, in the same patient. Although it is impossible to summate the functional returns for correlation with the pathology rating, it would seem safe to conclude that the result with the radial nerve, which had the poor ends,

was as good if not better than that with the highly rated ulnar nerve. Although the ulnar nerve sections were good, the fascicular patterns varied considerably at the two ends of the resected neuroma, as shown in the illustrations. Apparently proximal fascicles that carried sensory and autonomic fibers supplying the autonomous zones were not in apposition with their distal mates. It is not difficult to understand how the neuromatous radial proximal stump, largely motor at this level, sent some fibers down some of the rather widely separated distal fascicles to give the patient a fairly good return of wrist and finger extension, without good coordination of fine movements.

Plate 27. *Case 3250*

Eight cases, illustrated in plates 30–37, have been chosen to exhibit variation in distal tubular diameters and to suggest their relation to the interval from injury to suture. All plates are cross sections of a representative distal fascicle stained with protargol-analine blue, enlarged 600 times.

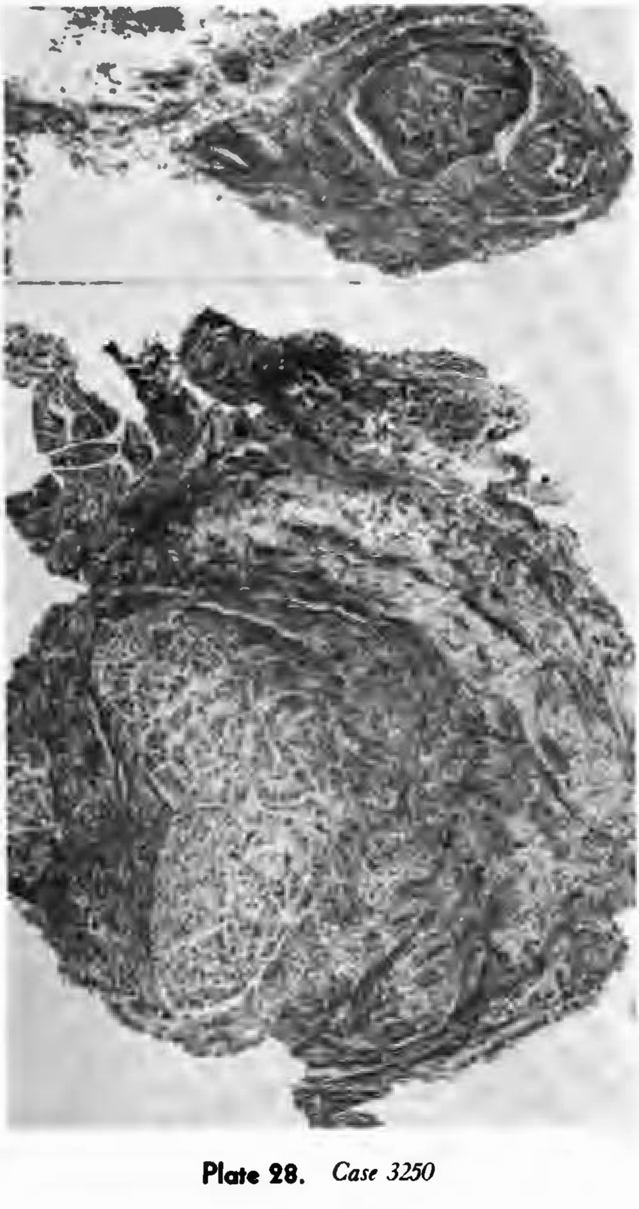


Plate 28. *Case 3250*

Plate 29. *Case 3250*

Case 3288 (*plate 30*). Complete severance, median n. upper-third of forearm; 13 days after injury. Neurilemmal tubules were widely "patent" and still contained degenerating axonal and sheath material and macrophages. The specific assessments are as in table 254. The summary rating was 83 percent. *Recovery:* pain threshold 6 gm.; touch 16 gm.; autonomic was poor in total area; 4 of 4 muscles tested showed good contraction.

Table 254.—*Neuropathological Ratings, Case 3288*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	3	2	0	0	5
Distal	3	5	0	5	13
Summary index					83

Plate 30. *Case 3288*

Case 3233 (*Plate 31*). Neuroma in continuity, median n. mid-third of arm; 2 months after injury. Tubules were maximally distended, and a few amyelinated axons shown as minute black dots had grown through the neuroma and along the tubules. The specific assessments are as in table 255. The summary rating was 88 percent, the second highest in the entire series.

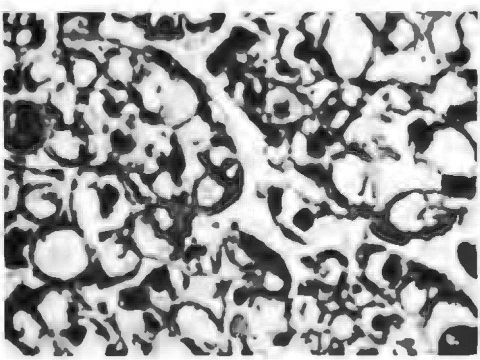


Plate 31. *Case 3233*

Table 255.—*Neuropathological Ratings, Case 3233*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	5	2	0	0	7
Distal	0	5	0	0	5
Summary index					88

Recovery: pain threshold 10 gm.; touch nil; autonomic was poor in autonomous zone only; all five affected muscles showed good contraction.

Case 3420 (*Plate 32*). Neuroma in continuity, sciatic n. upper-third of thigh; 3⅓ months after injury. Most of the tubules showed considerable shrinkage, this being typical of all areas of all fascicles. The individual deductions are as in table 256. The 25 percent deduction was made for shrinkage although the endoneurium was not dense, but rather a fine reticulum. Amyelinated axons had grown within and between the tubules. The summary rating was 49 percent. *Recovery:* pain felt on deep pressure only; touch nil; autonomic was poor in total area; of 7 muscles tested, 1 showed good contraction, 4 were weak, and 2 remained paralyzed.

Table 256.—*Neuropathological Ratings, Case 3420*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	5	10	3	0	18
Distal	5	5	5	25	40
Summary index					49

Case 1177 (*Plate 33*). Neuroma in continuity, ulnar n. at elbow; 4 months after injury. Most of the tubules in all fascicles showed considerable shrinkage—a few remained patent as shown. Fine axons had grown along the inside and outside of the tubules. About 10 of these may be seen around the periphery of the large tubules in the upper right corner. The deductions appear in table 257. The summary rating was 63 percent. *Recovery:* pain threshold 40 gm.; touch 16 gm.; autonomic was normal; all 3 of the 3 tested muscles contracted well.

Table 257.—*Neuropathological Ratings, Case 1177*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	3	5	2	0	10
Distal	3	5	2	20	30
Summary index					63

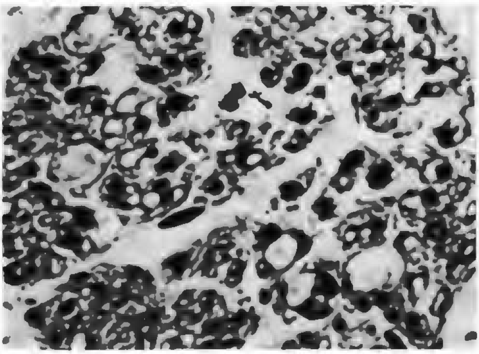


Plate 32. *Case 3420*

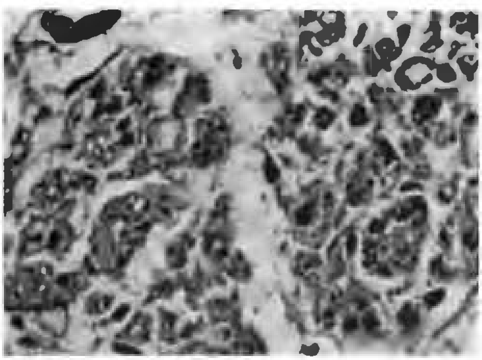


Plate 33. *Case 1177*

Case 3405 (*Plate 34*). Complete severance, radial n. lower-third of arm; 4 months after injury. Most of the tubules showed diameters that were reduced in comparison with the 2-month case, but were about equal to those of case 3420 (3½ months). Even in this severed nerve a scattering of fine axons had found their way into the distal stump, a frequent finding. A deduction of 20 percent was made because of tubular shrinkage and beginning endoneural collagenization; other deductions are as shown in table 258. The summary rating was 44 percent. *Recovery:* pain threshold 6 gm.; touch 25 gm.; autonomic was poor in the autonomous zone only; of the 7 muscles tested 2 contracted well and 5 poorly.

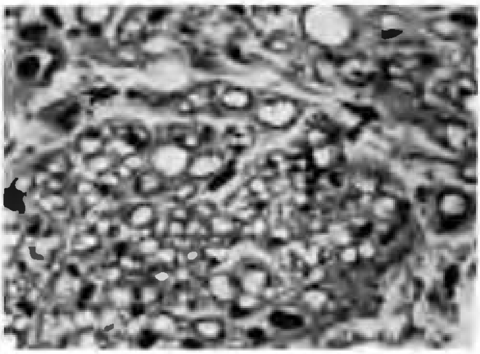


Plate 34. *Case 3405*

Case 3342 (*Plate 35*). Neuroma in fibrous continuity, posterior tibial n. lower-third of leg; 5 months after injury. Most of the tubules in all of the distal fascicles appeared shrunken, although the endoneural fibrosis was

Table 258.—*Neuropathological Ratings, Case 3405*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epineural	Interfascicular	Perineural	Intrafascicular	Total segment
Proximal	5	5	10	0	20
Distal	10	10	5	20	45
Summary index					44

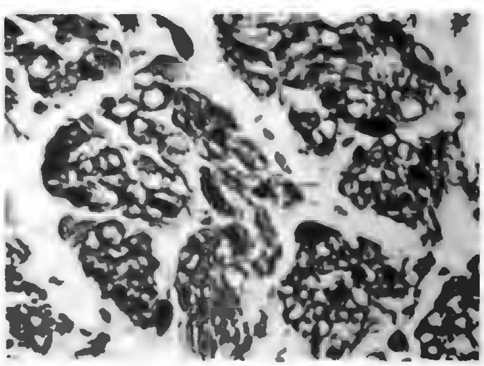


Plate 35. *Case 3342*

not severe. A few amyelinated axons had penetrated the fibrous connection at the severance point and reached these distal tubules. Deductions were as shown in table 259. The summary rating was 44 percent. *Recovery:* pain felt on deep pressure only; touch threshold 50 gm.; autonomic was normal; the one muscle tested showed good contraction.

Table 259.—*Neuropathological Ratings, Case 3342*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	5	5	5	5	20
Distal	5	5	5	30	45
Summary index					44

Case 3268 (*Plate 36*). Complete severance, c. peroneal n. at the knee; 5½ months after injury. All tubules showed shrinkage to fairly uniform diameters, approximating 10–15 micra. In the plate, they appear as closely packed ringlets of reticulum. The deductions were as shown in table 260. The summary rating was 45 percent. *Recovery:* no pain sensation felt; touch nil; autonomic was poor in the autonomous zone only; none of the four tested muscles contracted.

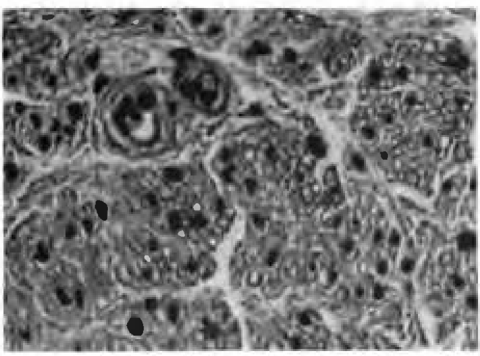


Plate 36. *Case 3268*

Case 3197 (*Plate 37*). Sciatic nerve injury previously discussed on page 518. Neurilemmal tubules could be seen with difficulty because of shrinkage and fibrotic endoneurium. Deduction was 50 percent for the distal intrafascicular area, and this plus further penalties for fibrosis in the other areas left a 21 percent rating.

Table 260.—*Neuropathological Ratings, Case 3268*

Nerve segment	Estimated percentage loss, by region evaluated				
	Epi-neural	Inter-fascicular	Peri-neural	Intra-fascicular	Total segment
Proximal	5	5	0	0	10
Distal	5	5	10	30	50
Summary index					45

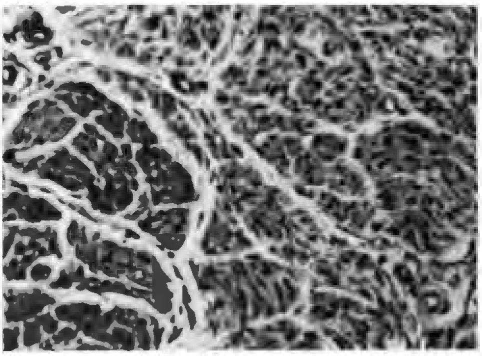


Plate 37. *Case 3197*

The foregoing cases suggest that a surgeon may electively resect to ends presumably devoid of deleterious pathological changes, and nevertheless obtain a functional result far from perfect. The mismatching of one or two small fascicles may have prevented such cases as 3288 and 3233, for which the pathological picture is so favorable, from showing good sensory and autonomic recovery even though the muscle recovery was good. Such results are not predictable on the basis of pathologic study. At the opposite extreme are individuals like patient 3197 whose distal tubules presented so shrunken an appearance that the pathologist concluded the chance of regeneration was quite poor (21 percent), and probably confined to the small fibers. The observed result might indeed be classified as poor, but it would hardly be expected that a high sciatic lesion of severance, sutured 10½ months after injury, with resection to fascicles already fibrotic and supposedly destined to become even more so, should show even the indicated degree of functional recovery. It would seem that axons need not be thick and well-myelinated to transmit tactile impulses and to activate skeletal muscles, or that such axons did indeed maturate fully in spite of the spacial limitations detected in the distal sections.

The sample cases also suggest the strong association between degree of fibrotic change and time from injury to suture, which is discussed in a subsequent section.

The pathologist's forecasts were not made for each modality but represent overall judgments as to the chance of regeneration generally, whereas regeneration was assessed in terms of specific modalities. To the extent that recovery was generalized, as in the functional ratings, it stems from clinical concepts of useful function rather than from quantitative estimates of the number of axons reaching their appropriate end-organs. This discrepancy between the points of view from which the pathological and the clinical evaluations were made has not been thought, however, to interfere with their correlation in any way. Fibrotic and neuromatous changes are viewed as impeding the regeneration of each type of axon, and if there be differences in their effects upon the various types of axons these differences are viewed as essentially quantitative in nature. Thus an overall recovery forecast of 50 percent may mean one thing for pain fibers and quite another for touch, but in each instance should be associated with better recovery than a forecast of, say, 10 percent. Accordingly, so long as any pathological assessment or combination of assessments is studied in relation to a single modality, any effect should be a scalable one, whereas this may not be true if recovery is represented by a composite such as the British summary of sensory regeneration or the overall functional assessments.

The content of the follow-up examination has been described and evaluated in previous chapters. In preparing the present chapter the writers had access to all the follow-up information coded by the several centers, but at a time well in advance of the preparation of final manuscripts on these chapters and, by that token, before the quality and full meaning of the data had been completely appraised. However, on the basis of what was known at the time and the specifications which the neuropathologist made for the statistical studies, the following selection was made from among the various elements of the follow-up examination:

Pain threshold.
Touch threshold.
Skin resistance.
British summary of motor recovery.
Number of affected proximal muscles contracting voluntarily.
Number of distal muscles contracting voluntarily.
Overall functional evaluation.
Strength of selected individual muscles.

As an initial step in the exploration of the prognostic significance of the neuropathologic forecasts, individual and summary assessments were separately correlated with particular modalities of follow-up status to ascertain whether, regardless of the influence of other variables, the condition of the nerve ends seems to have an important bearing upon eventual recovery. These early tables were also useful in that they showed the summary forecast to be an adequate basis for all later work. Subsequently, better controlled studies were made by removing the influences of other variables, e. g., time, length of surgical gap, etc., which in earlier analyses, especially that on motor recovery, had been thought to affect regeneration. The effects of such variables were removed by correlating pathological assessments and follow-up status within subsets of the sample so chosen as to be homogeneous with respect to such control variables. The amount of material is so small that only one control variable could be used at a time, as a rule, so long as only these simpler statistical devices were employed. Although preparation had been made for more elaborate correlation studies, employing several predictive variables and several control variables simultaneously, the early results were considered not to justify an elaborate, multivariate analysis. The following eight variables were used as controls:

Site of lesion.
Presence of associated arterial lesion.
Number of operations.
Days from injury to definitive operation.
Special operative features.
Type of cuff.
Use of stay suture.
Length of surgical defect.

Although correlation studies were done on the basis of individual nerves as much as possible, because the cases were so few it was necessary at many points to combine two or more nerves, especially in the lower extremity. The sample of 181 lesions finally used in the statistical studies is distributed as follows among the seven major nerves:

Median	29 cases
Ulnar	50 cases
Radial	23 cases
Peroneal	13 cases
Tibial	17 cases
Sciatic-peroneal	30 cases
Sciatic-tibial	19 cases

For purposes of tabulation the nerves were usually grouped as follows:

Upper Extremity	
Median	29 cases
Ulnar	50 cases
Total, including radial	102 cases
Lower Extremity	
Peroneal plus sciatic-peroneal	43 cases
Tibial plus sciatic-tibial	36 cases
Total lower extremity	79 cases

Whenever a group of two or more nerves did not differ greatly as to level of recovery in a given modality, they were pooled for the particular correlation study contemplated. The various inflicting forces acted indiscriminately upon all nerves, and the same readily recognized types of damage were created in all.

Finally, the problem of correlation was approached in most general terms, with no particular emphasis upon the prediction of either especially good or especially poor results at follow-up. In some instances, e. g., skin resistance, the follow-up information provides no more than a dichotomy, while in other instances functional return is scaled in some detail. In the latter the analysis has been oriented by the amount of information available and the nature of the distributions themselves and not by any emphasis on one or the other end of the recovery scale.

C. GROSS VARIATION IN PATHOLOGICAL PREDICTIONS OF REGENERATION

The pathological assessments for all nerves combined are shown in figure 23 for each variety of assessment, and the summary assessments in figure 24. The great majority of the individual estimates of percentage loss is below 10 percent for each assessment except for that on the intrafascicular region of the distal segment, for which 90 percent lie above this point. As would be expected from the top panels of figure 23, the aggregate estimate of loss for the proximal segment is usually below 20 percent. For the distal segment, on the other hand, the aggregate loss is usually above 20 percent, and the evaluation of both segments reflects very largely any estimated losses attributed to the appearance of the distal segment. The individual cases summarized above exemplify the way in which the specific assessments are combined to produce the summary assessments, and further illustrate how critical is the estimated loss in recovery attributable to the intrafascicular region of the distal segment: it is the chief ingredient of the overall summary based on the appearance of both ends.

Variation among nerves is greater than one would expect from purely random variation. Table 261 contains the mean values of the summary estimate of regeneration. Several comparisons were made, with the following results:

All nerves	$<.01$	
Upper v. lower	$<.01$	
Median v. ulnar v. radial	$>.05$	
Sciatic-peroneal v. sciatic-tibial	$>.05$	
Peroneal v. tibial	$>.05$	
Sciatic-peroneal v. peroneal	$>.05$	combined $P>.05$
Sciatic-tibial v. tibial	$>.05$	

The differences are in line with any expectation based on functional recovery: they are less extensive than might be anticipated from observed variation in motor recovery. One would expect war wounds affecting peripheral nerves to be quite variable from lesion to lesion, but not, in the aggregate, from nerve to nerve, and it is of some interest that the pathological assessments serve to distinguish the individual nerves at all. In chapter II it was noted that the nerves differ somewhat as to characteristic interval from injury to definitive suture, ulnar and radial lesions being operated upon earlier than the others, and median, peroneal, and tibial later. Plainly the pattern of variation among nerves is not the same in

Figure 23. *Percentage Distributions of All Lesions by Specific Pathologic Ratings*

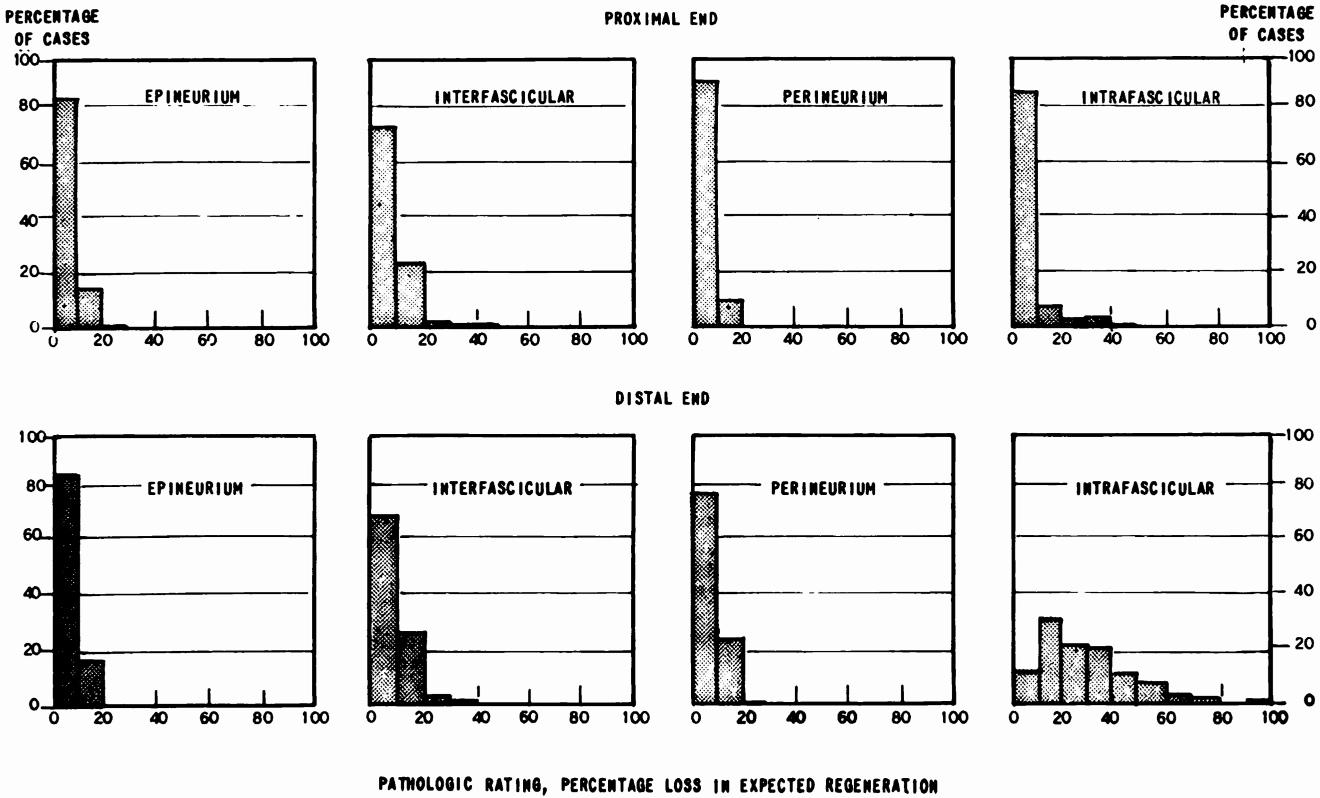
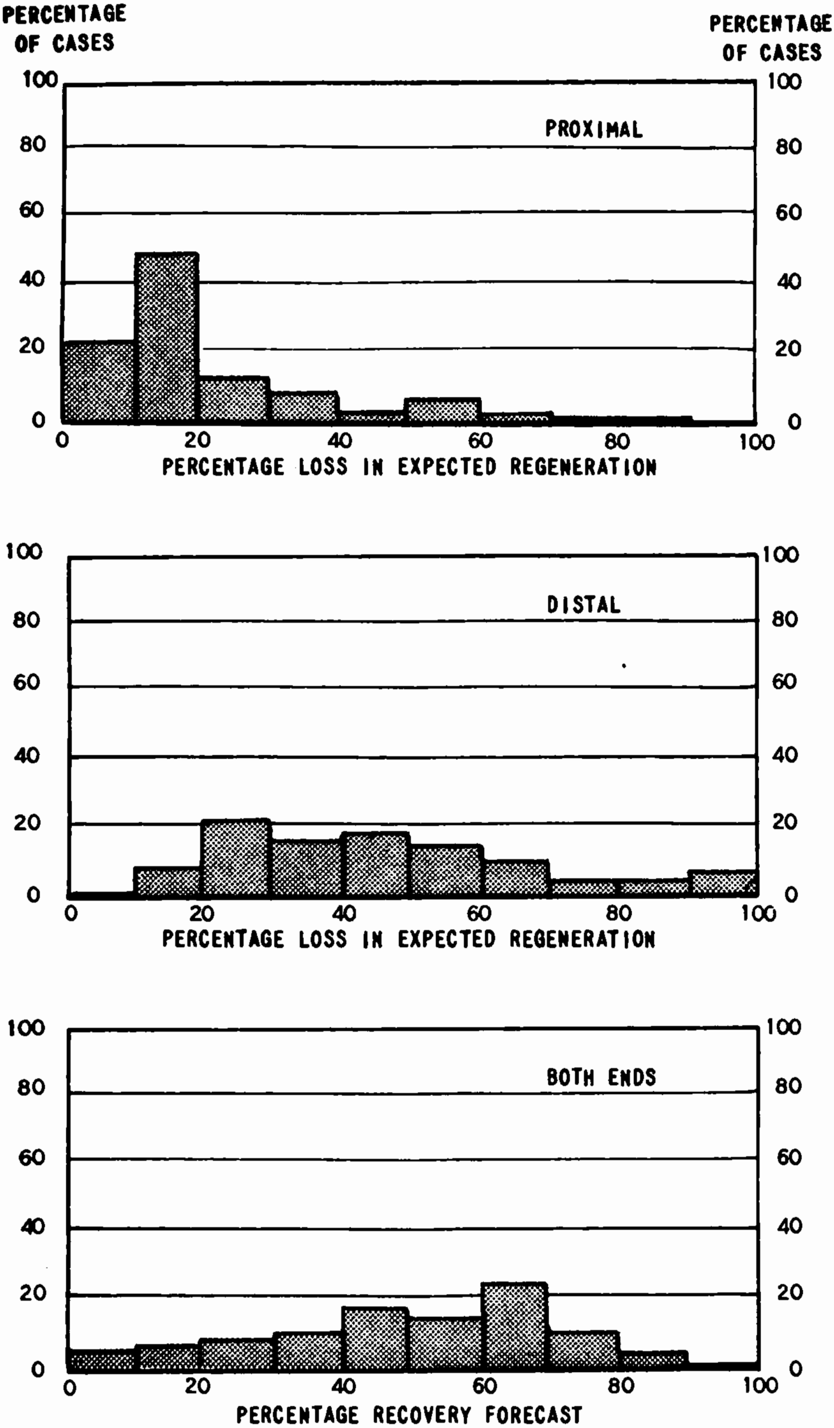


Figure 24. *Percentage Distributions of All Lesions by Summary Pathologic Ratings*



the pathologist's ratings as it is in the distributions on interval from injury to definitive suture.

Table 261.—*Mean Summary Forecast of Percentage Chance of Regeneration, by Nerve*

Nerve	Number of lesions	Mean forecast
Median	29	59.24
Radial	23	51.70
Ulnar	50	51.60
Peroneal	13	43.54
Sciatic-peroneal	30	39.57
Tibial	17	49.12
Sciatic-tibial	19	41.68
Total	181	48.99

Since fibrotic and neuromatous changes are initiated by injury, and take place gradually thereafter, their extent at the time of repair should be somewhat correlated with the length of the interval from injury to suture. One would expect, therefore, that the neuropathologist's estimates of the effect of such changes upon regeneration would be similarly correlated with the preoperative interval. Since the neuropathologist read fibrosis as he saw it, without reference to the time interval, it is instructive to study his assessments in relation to time, as may be done from table 262, which represents the overall pattern of variation for all nerves combined. The fact of association between time and pathological rating is quite reliable in the statistical sense, but in degree unimpressive. However, the values for cases grouped by nerve fall in among these mean values somewhat in relation to time and there remains some possibility that the association reflects merely some variation among nerves. The material was retabulated, therefore, to show the correlation between the two variables in detail, and by nerve. The correlation diagrams suggested that linear correlation coefficients were appropriate. For all nerves combined the coefficient is $-.40$ on 181 cases and the equation of best fit

$$Y=62.52-.081X$$

where Y is the forecast and X time from injury to surgery in days. A difference of 100 days in the interval, that is, would change the forecast by 8.1 units. Inspection of the correlation diagrams for the individual nerves suggested that approximately the same relationship holds for each nerve. Accordingly, calculations were carried out for only the ulnar which has the only large group of cases. The correlation coefficient for the 50 ulnar injuries was found to be $-.41$, and the best-fitting straight line

$$Y=78.35-.105X$$

In short, the observed association does not merely reflect some variation among nerves but is characteristic of individual nerves.

Table 262.—*Summary Forecast of Regeneration by Days From Injury to Definitive Suture, All Nerves Combined*

Forecast (percent)	Days from injury to suture			
	0–109	110–169	170 or more	Total
03–07	1	0	2	3
08–12	1	0	7	8
13–17	1	1	1	3
18–22	1	0	4	5
23–27	1	3	7	11
28–32	2	4	4	10
33–37	3	5	3	11
38–42	2	1	2	5
43–47	3	11	8	22
48–52	6	12	5	23
53–57	5	4	2	11
58–62	4	4	2	10
63–67	2	19	3	24
68–72	8	7	6	21
73–77	1	5	0	6
78–82	2	3	0	5
83–87	1	0	0	1
88–92	2	0	0	2
Total	46	79	56	181
Mean forecast	53.5	54.7	37.7	49.1

Correlation ratio: —.39; P<.01

Time also plays a role after suture, for the axons require time to grow down the empty distal tubules and to forestall any further intrafascicular or tubular fibrosis. If preoperative time is of significance in influencing distal tubular fibrosis, equal consideration should be given to the postoperative period in which tubules are empty and presumably shrinking. It might be expected that preoperative changes would be reflected in the neuropathologist's assessments, but the only measure of postoperative change is provided by the height of the lesion or, more precisely, the distance from lesion to end-organ. High lesions operated upon long after injury will, on this analysis, fare badly. Further, one would not expect the neuropathologist's assessments to vary by site, and indeed this is the case, as may be seen in table 263. The high-low differences evident there are obviously within the range of chance variation, although formal tests have not been done.

Since height of lesion is associated with degree of clinical recovery, but does not affect the neuropathologic forecast, one would expect that a control on site would be especially important in correlation tables on recovery versus forecast.

Table 263.—*Mean Summary Forecast of Regeneration and Gross Site of Lesion, by Nerve*

Nerve	High [1]		Low [1]	
	Number of lesions	Mean forecast	Number of lesions	Mean forecast
Upper extremity				
Median	12	62.25	17	57.12
Ulnar	19	53.74	29	51.41
Radial	18	53.27	2	52.07
Total	49	55.65	48	53.46
Lower extremity				
Peroneal and sciatic-peroneal	32	39.72	11	43.82
Tibial and sciatic-tibial	19	41.05	15	47.53
Total	51	40.22	26	45.96

[1] As used in earlier chapters; in the upper extremity high lesions are those on the arm or at the elbow, and in the lower extremity on the thigh or at the knee.

Length of surgical gap is another fundamental characteristic of the nerve lesion as finally sutured. It was shown above (p. 154) that length of gap and interval from injury to suture are reliably correlated, presumably because the surgeon finds more fibrosis after a long interval and tends to resect farther. On this basis, one would expect some association between gap and pathologic forecast. Of course it must also be borne in mind that the length of nerve resected by the surgeon in attempting to remove pathologic tissue represents an interaction of opposing influences, since his purpose is to achieve good ends provided the gap thus created can still be closed by suture. In general, and within limits, the farther back the surgeon resects the better will be the ends he finally brings together, but the farther back he finds it necessary to resect the more fibrosis there was in the first place. In table 264 appears a summary of the association between length of surgical gap and the summary forecast; the association is much like that between time and pathologic forecast. Some refinement would be introduced by separate analyses by nerve, since the various nerves are by no means uniform as to length of gap, but for none of the individual nerves is the association between forecast and length of gap a very intimate one.

Finally, as noted in the motor chapter (p. 170) there is a strong correlation between the operator's gross evaluation of nerve ends prior to anastomosis and the neuropathologic forecast of expected regeneration.

Table 264.—*Summary Forecast of Regeneration, by Length of Surgical Gap at Definitive Suture, All Nerves Combined*

Forecast (percent)	Surgical gap, in cm.			
	0–4.4	4.5–6.4	6.5 or more	Total
03–07	1	0	2	3
08–12	1	2	5	8
13–17	1	0	1	2
18–22	0	2	3	5
23–27	1	0	10	11
28–32	3	1	6	10
33–37	2	1	8	11
38–42	0	3	2	5
43–47	9	7	5	21
48–52	3	10	10	23
53–57	1	6	4	11
58–62	2	6	2	10
63–67	7	7	10	24
68–72	5	8	6	19
73–77	1	4	0	5
78–82	3	2	0	5
83–87	1	0	0	1
88–92	2	0	0	2
Total	43	59	74	176
Mean forecast	54.2	54.7	41.4	49.0

Correlation ratio: —.33; P<.01

D. CORRELATION BETWEEN NEUROPATHOLOGICAL FORECASTS OF REGENERATION AND CLINICAL ASSESSMENTS OF EVENTUAL RECOVERY

As might be anticipated from the distributions in figures 23 and 24, when preliminary tables were prepared to explore the individual and summary assessments prepared by the neuropathologist, it was found that three assessments gave essentially the same information: intrafascicular region of distal segment, entire distal segment, and both segments combined. However, since the variation associated with the summary forecast seemed slightly greater than with the other two, it was chosen to represent the neuropathologic evaluations in the correlation studies which follow. Each modality of the clinical follow-up examination is discussed in a separate section, first without regard to other such variables and then with regard to such variables as seemed, in the earlier chapters, to influence eventual recovery.

1. Pain Threshold

In the chapter on sensory regeneration it was shown that the determinations of pain thresholds varied less among the several centers than any other test of sensory recovery, and it was concluded that the clinical evaluation of pain threshold is the most reliable of the sensory indices. Table 265 provides the basic information on the relation between pain threshold and summary forecast of expected regeneration. Although the grouping of sciatic-peroneal with peroneal and sciatic-tibial with tibial may obscure slightly the association between the regeneration forecast and final level of pain sensibility, it would appear from table 265 that any association is at best quite weak.

From the analysis of possible determinants of pain recovery presented in chapter V, in which so few variables appeared to have a significant influence upon pain threshold at follow-up, and none to have a really important influence, it would not be expected that the introduction of any third variable as a control would materially improve the association revealed in table 265, and such proved to be the case. Table 266 summarizes the results obtained with several which seemed, on inspection, to improve the association slightly; such improvement may be within the bounds of chance. The 4 control variables employed in table 266 merely provide different ways of regrouping the material, and some of the control variables themselves are closely associated. For example, in the upper extremity low lesions tend to be those without associated arterial injury.

Table 267 has been prepared to show just how close the relationship is between forecast and pain threshold under favorable circumstances. From table 266 were chosen those controlled comparisons in which the association seemed closest, i. e.

Median—without associated arterial injury
Ulnar—below elbow
All four lower extremity nerves combined—cuff used

For each of these table 267 shows in somewhat more detail the association between forecast and pain threshold. Although the selection of the tables has been such as to favor the relationship, even on these terms it does not appear to furnish the basis for reliable clinical predictions. No numerical measure of the relationship seems useful.

2. Touch Threshold

Study of the touch threshold was carried out in the same fashion as that for pain. Table 268 provides a summary of the initial analysis done without reference to any control variables. For none of the nerves except the ulnar is there any evidence of association, but for the ulnar the evidence seems

Table 265.—*Mean Summary Forecast of Regeneration and Pain Threshold at Follow-up, by Nerve*

Pain threshold	Upper extremity						Lower extremity					
	Median		Ulnar		Total [1]		Peroneal [2]		Tibial [2]		Total	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
No sensation	1	41.00	0	....	1	41.00	5	29.40	6	36.17	11	33.09
Deep-pressure only	4	52.25	10	48.50	15	47.87	10	49.80	6	44.00	16	47.63
Superficial pain to 40 gm	5	53.40	7	54.00	16	51.38	6	44.00	7	46.29	13	45.23
Superficial pain to 30 gm	2	74.50	3	42.33	8	58.50	2	45.00	1	11.00	3	33.67
Superficial pain to 20 gm	5	62.80	4	54.25	9	59.00	4	28.75	0	....	4	28.75
Superficial pain to 10 gm	2	71.50	7	54.14	10	57.20	3	40.33	3	57.67	6	49.00
Superficial pain to 6 gm	2	68.50	8	51.25	14	52.21	1	29.00	2	55.00	3	46.33
Superficial pain $<$6 gm	3	48.67	5	56.40	11	56.00	7	43.14	6	44.00	13	43.54
Hypesthesia, unmeasured	5	62.40	4	58.50	13	61.08	5	37.40	3	43.33	8	39.63
Total	29	59.24	48	52.33	97	54.57	43	40.77	34	43.91	77	42.16

[1] Including radial.

[2] Including corresponding sciatic component.

Table 266.—*Mean Summary Forecast of Regeneration and Pain Threshold at Follow-up, by Nerve and by Certain Control Variables*

Pain threshold	Upper extremity						Lower extremity					
	Median		Ulnar		Total [1]		Peroneal [2]		Tibial [2]		Total	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Lesions at or below the elbow or knee												
Absent	1	41	0	....	1	41	1	45	0	....	1	45
Deep pain only	3	48	5	43	8	45	1	75	3	44	4	52
20–40 gm.[3]	10	57	12	50	24	53	3	37	6	42	12	39
<20 gm	3	71	12	56	15	59	3	48	6	55	9	52
Total	17	57	29	51	48	53	11	44	15	48	26	46
Lesions without associated arterial injury												
Absent	1	41	0	....	1	41	5	29	6	36	11	33
Deep pain only	4	52	8	48	13	48	10	50	6	44	16	48
20–40 gm.[3]	11	59	13	55	34	57	17	39	11	42	28	40
<20 gm	4	70	17	54	29	56	11	41	10	52	21	46
Total	20	59	38	53	77	55	43	41	33	44	76	42

Lesions sutured prior to day 110

Absent	0	....	0	....	0	....	1	34	1	34	2	34
Deep pain only	0	....	3	47	3	47	3	38	2	55	5	45
20–40 gm.[3]	5	61	5	49	15	56	5	36	1	49	6	38
<20 gm	4	70	5	63	11	64	1	54	2	61	3	59
Total	9	65	13	54	29	58	10	38	6	52	16	44

Tantalum cuff used

Absent	1	41	0	....	1	41	5	29	6	36	11	33
Deep pain only	4	52	7	45	12	45	5	38	2	39	7	38
20–40 gm.[3]	12	64	12	56	32	60	8	46	10	41	18	43
<20 gm	5	64	10	49	20	55	8	42	10	51	18	47
Total	22	60	29	51	65	55	26	40	28	43	54	42

[1] Including radial.
[2] Including sciatic counterpart.
[3] Including "hypesthesia, unmeasured."

fair (P<.05). When the eight control variables were introduced into the analysis again only the ulnar seemed to display the association, which recurred with each subdivision of the material. Few of the control variables appeared to offer any prospect of improvement in the association, however, and table 269 is confined to these. Further details of the association are shown in table 270 for two controls which do as much as any for the association between forecast and touch recovery. Again, as in the case of pain sensitivity, however, any association is too weak to have clinical value.

3. Skin Resistance (SR)

Follow-up examiners classified their SR results according to the following scheme:

Elevated in autonomous area.
Elevated in total area.
Decreased.
Normal.
Mixed patterns.

The autonomous zones for autonomic fibers are less certainly known than the sensory, and there was some doubt as to the best handling of the SR data for the purposes of the present chapter, especially since cases with elevated SR in the autonomous zone had generally been given a lower forecast than cases with elevated SR in the total area of autonomic innervation. However, the decision was made to dichotomize the observations, regardless of the autonomous zone, into elevated SR versus other SR, with the omission of cases with "mixed patterns." As may be seen from table 271, which gives the mean values of the forecasts corresponding to this dichotomy any evidence of association between the summary forecast and SR is confined to the ulnar and peroneal (including sciatic-peroneal) nerves.

When the control variables were introduced into the analysis little or no improvement resulted. Table 272 gives the results obtained when the selection of cases was confined to those with a single operation, for this factor seemed to do as much as any control variable for the association between the forecast and SR. In the ulnar and the peroneal the discrepancies remain greatest, but still not large in the light of the practical requirements for useful forecasting. Table 273 shows the relationship in somewhat more detail for these two nerves; although the absence of cases with normal SR among those with low percentage forecasts is provocative, the amount of information is so small that no statistical significance can be attributed to the discrepancy. However, the gross comparisons exhibited in table 272, taken in the aggregate, do support the view that autonomic recovery bears some relation to the neuropathologist's forecast. As was observed for pain and touch, any association is weak.

Table 267.—*Summary Forecast of Regeneration and Pain Threshold at Follow-up, by Nerve, With Certain Restrictions*

Pain threshold	Summary forecast, percent										
	0–12	13–22	23–32	33–42	43–52	53–62	63–72	73–82	83–92	93–	Total
Median without associated arterial injury											
No sensation	......	......	......	1	......	......	......	......	......	......	1
Deep-pressure pain only	1	......	......	......	......	......	3	......	......	......	4
Superficial pain, 20–40 gm	......	......	......	1	3	1	4	2	......	......	11
Superficial pain, <20 gm	......	......	......	......	......	2	......	......	2	......	4
Total	1	......	......	2	3	3	7	2	2	......	20
Ulnar at or below elbow											
No sensation	......	......	......	......	......	......	......	......	......	......	......
Deep-pressure pain only	......	......	2	......	2	1	......	......	......	......	5
Superficial pain, 20–40 gm	1	......	3	......	......	2	6	......	......	......	12
Superficial pain, <20 gm	......	......	1	......	3	4	4	......	......	......	12
Total	1	......	6	......	5	7	10	......	......	......	29
All nerves of lower extremity, cuff used											
No sensation	2	......	2	4	2	......	1	......	......	......	11
Deep-pressure pain only	......	1	2	......	4	......	......	......	......	......	7
Superficial pain, 20–40 gm	1	3	2	1	6	......	4	1	......	......	18
Superficial pain, <20 gm	1	......	3	2	6	2	3	1	......	......	18
Total	4	4	9	7	18	2	8	2	......	......	54

Table 268.—*Mean Summary Forecast of Regeneration and Touch Threshold at Follow-up, by Nerve*

Touch threshold	Upper extremity						Lower extremity					
	Median		Ulnar		Total[1]		Peroneal[2]		Tibial[2]		Total	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
No sensation, >50 gm	8	64.63	8	42.00	18	52.17	18	40.11	11	41.18	29	40.52
Deep-pressure, 50 gm	0	....	1	65.00	1	65.00	1	26.00	1	44.00	2	35.00
Deep-pressure, 35 gm	1	34.00	0	....	1	34.00	3	47.33	2	46.50	5	47.00
Deep-pressure, 25 gm	0	....	4	38.50	7	40.43	8	38.00	1	21.00	9	36.11
Superficial pressure, 16 gm	8	61.25	19	56.63	33	57.52	6	41.83	12	50.83	18	47.83
Superficial pressure, 5 gm	7	50.86	9	53.67	20	54.30	2	56.00	2	43.00	4	49.50
Superficial pressure, 3 gm	1	77.00	2	53.50	5	57.80	1	60.00	1	11.00	2	35.50
Superficial pressure, <3 gm	0	....	2	61.00	4	45.25	1	10.00	2	54.50	3	39.67
Hypalgesia, unmeasured	4	61.00	3	56.33	9	58.44	3	42.00	3	43.33	6	42.67
Total	29	59.24	48	52.33	98	54.09	43	40.77	35	44.49	78	42.44

[1] Including radial.
[2] Including corresponding sciatic component.

Table 269.—*Mean Summary Forecast of Regeneration and Touch Threshold at Follow-up, Ulnar Nerve Sutures With Specified Characteristics*

Characteristic	Touch threshold							
	Absent, or >50 gm.		16 to 50 gm. or hypalgesia, unmeasured		<16 gm.		Total	
	Number	Mean	Number	Mean	Number	Mean	Number	Mean
At or below elbow	7	41	15	54	7	56	29	51
Special features	8	42	23	54	11	55	42	52
No stay suture	8	42	27	54	11	54	46	52
Gap ≥7 cm	5	32	9	50	6	49	20	45

Table 270.—*Summary Forecast of Regeneration and Touch Threshold at Follow-up, Low Ulnar Sutures, and Ulnar Sutures With Long Gaps*

Touch threshold	Summary forecast, percent										
	0–12	13–22	23–32	33–42	43–52	53–62	63–72	73–82	83–92	92–	Total
Lesions at or below elbow											
Absent, or >50 gm	1	......	2	......	2	1	1	......	......	......	7
16 to 50 gm. or hypalgesia, unmeasured	......	......	3	......	1	4	7	......	......	......	15
<16 gm	......	......	1	......	2	2	2	......	......	......	7
Total	1	......	6	......	5	7	10	......	......	......	29
Lesions with extensive mobilization or transposition											
Absent, or >50 gm	1	......	2	......	3	1	1	......	......	......	8
16 to 50 gm. or hypalgesia, unmeasured	......	2	2	......	4	4	9	2	......	......	23
<16 gm	......	......	......	1	4	4	2	......	......	......	11
Total	1	2	4	1	11	9	12	2	......	......	42

Table 271.—*Mean Summary Forecast of Regeneration and Skin Resistance at Follow-up, by Nerve*

Skin resistance	Upper extremity						Lower extremity					
	Median		Ulnar		Total [1]		Peroneal [2]		Tibial [2]		Total	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Elevated [3]	14	59.4	26	51.2	41	53.8	23	40.7	15	46.7	38	43.1
Normal or decreased	11	59.5	13	62.5	41	58.0	13	48.3	17	45.9	30	46.9
Total	25	59.4	39	54.9	82	55.9	36	43.4	32	46.3	68	44.8

[1] Including radial.
[2] Including corresponding sciatic component.
[3] In either autonomous or total area.

Table 272.—*Mean Summary Forecast of Regeneration and Skin Resistance, All Nerves Operated Upon Only Once*

Skin resistance	Upper extremity						Lower extremity					
	Median		Ulnar		Total [1]		Peroneal [2]		Tibial [2]		Total	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
Elevated [3]	9	56. 1	21	49. 6	31	51. 3	17	40. 2	12	49. 4	29	44. 0
Normal or decreased	9	63. 8	12	62. 7	37	60. 2	10	49. 6	13	50. 7	23	50. 2
Total	18	59. 9	33	54. 3	68	56. 1	27	43. 7	25	50. 1	52	46. 8

[1] Including radial.
[2] Including corresponding sciatic component.
[3] In either autonomous or total area.

Table 273.—*Summary Forecast of Regeneration and Skin Resistance, Ulnar and Peroneal Nerves Operated on Only Once*

Forecast (percent)	Ulnar: Elevated skin resistance	Ulnar: Normal, decreased skin resistance	Ulnar: Total	Peroneal [1]: Elevated skin resistance	Peroneal [1]: Normal, decreased skin resistance	Peroneal [1]: Total
0–12	1	0	1	3	0	3
13–22	2	0	2	2	0	2
23–32	2	0	2	1	3	4
33–42	1	0	1	0	0	0
43–52	4	3	7	6	3	9
53–62	3	2	5	2	1	3
63–72	8	5	13	3	2	5
73–82	0	2	2	0	1	1
93–	0	0	0	0	0	0
Total	21	12	33	17	10	27

[1] Including sciatic component.

4. Motor Recovery

It will be recalled from chapter III that motor recovery may be approached via several indices, the most summary being the modified British classification which is subject to some center variation. Although the most reliable motor observation is the measured strength of individual muscles, the more summary indices were explored first, and only after it became apparent that any relationship between the forecast and motor recovery was probably weak were tabulations extended to a few representative muscles as a final check. Table 274 provides a summary of the relationship between the neuropathologist's forecasts and the British classification. At best the evidence there seems suggestive in the statistical sense; only for the peroneal is the discrepancy of any real magnitude. The tabulations were then extended by introducing the eight control variables. Most of these resulted in some strengthening of the evidence of association between forecast and motor recovery in the upper extremity, but were without effect in the lower extremity. The evidence of association seen in table 274 for the peroneal is reflected in each of the 8 separate tables and to about the same extent, whereas none of the control variables provides more evidence of association in the tibial than table 274 shows for this nerve. The control variables which seem best able to support the association between forecast and motor recovery are site (for ulnar lesions) and number of operations (for median lesions), and table 275 presents the tabulated detail. Parallel data for peroneal lesions are given in table 276 for all lesions studied, since

Table 274.—*Mean Summary Forecast of Regeneration and British Classification of Motor Recovery, by Nerve*

British summary	Upper extremity						Lower extremity					
	Median		Ulnar		Total[1]		Peroneal[2]		Tibial[2]		Total	
	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean	No.	Mean
No contraction	0	....	0	....	1	46.00	13	34.23	2	40.50	15	35.07
Return of perceptible contraction in the proximal muscles	0	....	1	47.00	2	43.50	15	39.00	4	44.50	19	40.16
Proximal muscles acting against gravity	13	55.85	29	51.21	51	53.35	12	49.50	27	44.15	39	45.79
Return of function in proximal and distal muscles	16	62.00	19	51.74	45	56.33	2	62.50	3	58.67	5	60.20
Total	29	59.24	49	51.33	99	54.43	42	41.64	36	45.19	78	43.28

[1] Including radial.

[2] Including corresponding sciatic component.

none of the control variables improved the evidence of association between forecast and recovery. Taken all together the evidence points to a definite but somewhat weak association between the neuropathologist's forecast and motor recovery.

Motor recovery in the lower extremity was also explored on the basis of number of affected muscles able to contract voluntarily at the time of follow-up, with substantially the same results as were obtained with the British summary of motor recovery. The muscles studied in this way, and their classification as proximal or distal, are discussed on pages 106–113. Table 277 provides the mean values of the neuropathologist's forecasts for cases classified as to number of affected muscles able to contract voluntarily at follow-up. Again the evidence of association is at least suggestive for peroneal injuries, but within the range of chance variation for the tibial.

Table 275.—*Summary Forecast of Regeneration and British Classification*[1] *of Motor Recovery, for Median and Ulnar Lesions With Specified Controls*

Forecast of regeneration	Median, operated upon only once		Ulnar at or below elbow	
	A[1]	B[1]	A[1]	B[1]
0–12	0	0	1	0
13–22	1	0	0	0
23–32	0	0	3	3
33–42	1	1	0	0
43–52	2	0	3	2
53–62	2	2	4	3
63–72	4	5	4	6
73–82	0	3	0	0
83–92	0	1	0	0
Total	10	12	15	14
Mean rating	51.6	66.2	48.5	54.5

[1] In every case calculated here proximal muscles were acting against gravity, so that two classes were defined on the basis of the modified British scale:

A—Proximal muscles acting against gravity or against resistance, intrinsic muscles showing at most perceptible contractions.

B—Both proximal and distal muscles contracting against resistance.

These correspond to the following rubrics given in detail on page 115.

A—Groups 2 and 3.

B—Groups 4, 5, and 6.

Table 276.—*Summary Forecast of Regeneration and British Classification of Motor Recovery, for All Peroneal and Sciatic-Peroneal Sutures*

Forecast of regeneration	British summary of motor regeneration [1]				
	No contraction	Perceptible contraction in proximal muscles, none in intrinsics	A	B	Total
0–12	1	2	0	0	3
13–22	2	0	1	0	3
23–32	4	2	2	0	8
33–42	1	2	0	0	3
43–52	4	7	4	0	15
53–62	0	2	1	1	4
63–72	1	0	3	1	5
73–82	0	0	1	0	1
83–92	0	0	0	0	0
Total	13	15	12	2	42
Mean rating	34.2	39.3	49.6	62.5	41.8

[1] Rubrics A and B have the meanings specified in table 275.

Table 277.—*Mean Summary Forecast of Regeneration and Number of Affected Muscles [1] Contracting Voluntarily at Follow-up, Peroneal and Tibial Injuries*

Number of muscles contracting	Peroneal and sciatic-peroneal		Tibial and sciatic-tibial	
	Number of nerves	Mean forecast (percent)	Number of nerves	Mean forecast (percent)
	A. Four proximal muscles affected			
0–3	27	34.7	14	41.5
4	13	52.6	8	45.1
Total	40	40.5	22	42.8
	B. One distal muscle affected			
0	....	....	22	46.9
1	....	....	10	38.5
Total	....	....	32	44.3

[1] In standard list of muscles (p. 73).

In planning the statistical correlations of pathological assessments and motor recovery it was thought unnecessary to provide for analyses based on individual muscles, and the design of the punchcards proceeded accordingly. However, one of the motor fields contains the average power of distal muscles in the standard set, and two nerves are represented by single muscles, the median by the abductor pollicis brevis and the tibial by the interossei. In view of this specificity it was decided to study the average power of distal muscles [28] in relation to the summary pathological rating. In the lower extremity there is too little variation in the power of movement against resistance for this approach to have any value, but for the upper extremity the results of the correlation study are as follows:

Nerve	No. of lesions	Correlation coefficient [1]	P
Median	24	+.27	>.05
Radial	16	+.12	>.05
Ulnar	48	+.22	>.05
All three combined	88	+.22	.05

[1] Product-moment coefficient.

All three independent coefficients are small and positive, with none outside the chance range; in the aggregate they have a probability of .05 under the hypothesis of independence. There is, then, only borderline evidence of association between the summary forecast and actual power at follow-up.

5. Overall Functional Evaluation

As described in the following chapter, functional performance was evaluated with the aid of an 11-point scale (0, 10, . . . 100 percent) developed by Dr. Lewey, and as the most summary evaluation of recovery it seemed attractive to compare the neuropathologist's forecasts with these functional ratings. The material was tabulated separately for the upper and lower extremities and table 278 gives the mean summary forecast for each point on the scale of useful function. For neither upper nor lower extremity lesions is there statistical evidence of association.

6. Composite Index of Nerve Regeneration

Except for Dr. Lewey's functional rating, the foregoing analysis deals with single modalities of recovery, and it was thought desirable to test the pathologist's summary rating against a composite index of regeneration less dependent upon the performance of useful functions. Pain, touch, SR, and motor recovery were chosen as the bases for this index, and a

[28] The distal muscles are specified on p. 73.

simple dichotomy defined for each nerve and for each modality so that all nerves might be combined.

Pain:

Median and peroneal: threshold of 30 gm. or more v. <30 gm.
Ulnar and tibial: threshold of 40 gm. or more v. <40 gm.
Radial: threshold of 20 gm. or more v. <20 gm.
Sciatic components: at most deep pressure v. threshold of 40 gm. or less.

Touch:

Median, ulnar, radial: threshold of 16 gm. or more v. <16 gm.
Peroneal and tibial: threshold of 25 gm. or more v. <25 gm.
Sciatic components: threshold >50 gm. v. 50 gm. or less.

SR: All nerves: elevated in autonomous or total area v. normal or decreased SR.

British Motor:

All nerves except sciatic-tibial: no more than perceptible contraction in intrinsics v. intrinsics moving against resistance.
Sciatic-tibial: no return in intrinsics v. any return in intrinsics.

Table 278.—*Mean Summary Forecast of Regeneration and Overall Functional Evaluation at Follow-up*

Scale of function	Upper extremity		Lower extremity	
	Number of cases	Mean forecast	Number of cases	Mean forecast
0	1	5	3	28
10	2	50	0	....
20	3	37	0	....
30	5	54	0	....
40	2	45	4	34
50	14	59	7	26
60	18	55	15	46
70	22	55	25	48
80	23	48	21	42
90	9	67	2	58
100	1	40	0	....
Total	100	54	77	42

If each such dichotomy is represented as 0 or 1, depending on whether recovery is poorer (0) or better (1), then the lesions on each nerve or group of nerves will fall into 16 subgroups ranging from 0000 (poorer in all 4 modalities) to 1111 (better in all 4). The dichotomies were designed to facilitate the combination of the several nerves, and for purposes of analysis the 16 subgroups were combined on the basis of the number of 1's, ranging from none to 4. From the tabulated result which appears in table 279 the only possible conclusion is that the predictive value of the summary forecast is not improved by combining the four modalities in this fashion; the variation among the means presented there is well within the range of chance.

E. SUMMARY

Over 600 cases of peripheral nerve suture were studied during World War II by an histologist working with a group of neurosurgeons with a view to evaluating the microscopic quality of sutured ends. The records of the findings have been deposited in the form of reports, photomicrographs, microscopic sections, etc., in the Armed Forces Institute of Pathology. An effort has been made to forecast peripheral nerve regeneration on the basis of this material, and these predictions have been correlated with the results of follow-up examinations made in the five clinical centers as part of the larger follow-up study. The mechanics of correlation have been in the hands of the statistician for the follow-up study.

Table 279.—*Mean Summary Forecast of Regeneration and Composite Index of Regeneration*

Number of modalities with regeneration rated favorably	Number of lesions	Mean rating
0	18	48.33
1	33	51.67
2	37	49.59
3	31	52.90
4	6	53.33
Total	125	50.96

Follow-up status was represented by the pain and touch thresholds, skin resistance, several indices of motor recovery, and overall functional recovery. Not all functions subserved by the periphal nerves were represented, and those that were represented often were only partially covered, as in the restriction of observations on pain and touch to the autonomous zones. Nevertheless, if the follow-up observations be regarded as a sampling on the basis of which recovery might be roughly scaled, the represention of modalities would appear to be adequate for the present purpose.

The neuropathologic assessments were made in terms of changes in four regions of the nerve, seen in cross section: epineural, interfascicular, perineural, and intrafascicular. The neuropathologist evaluated the fibrous or neuromatous changes evident in each individual region and assigned to that region a numerical value representing the relative loss in recovery he expected from these defects. He did not make separate forecasts for fine fibers carrying pain and autonomic impulses and for the larger fibers carrying pressure, touch, and motor impulses. For each segment (distal or proximal) the estimates for all four regions were summed to represent the anticipated influence of all the defects present in that segment. The overall rating was then obtained on the assumption that the defects in the two segments were independent; specifically, the complements of the estimated percentage losses for the two ends were multiplied to provide a numerical estimate of recovery for the nerve as a whole. It was, of course, regeneration across the gap at which the predictions were aimed; other characteristics of the lesion and associated injuries were known and could be integrated with the neuropathologic assessments as required. Any such index is undoubtedly an arbitrary one, and it may seem presumptuous to apply a percentage scale to the pathologic phenomenon of fibrosis in different cross-sectional areas of nerves. However, the most that was hoped for was that in its clinical application the overall summary might permit a rough segregation of cases into those with good, bad, and indifferent nerve ends.

Analysis of the neuropathologist's ratings on the 181 nerve lesions studied here shows that the intrafascicular region of the distal segment is the chief source of variation in the final estimates. The severest penalties were always applied to the nerves with more advanced degrees of distal tubular shrinkage, and it was rare that defects in other regions were considered prejudicial to any appreciable extent. The ratings vary somewhat by nerve, chiefly in that those of the upper extremity were given a better chance of recovery than those of the lower. The ratings were not found to vary by site of lesion, but both the length of gap and time interval from injury to suture were seen to be inversely correlated with the neuropathologist's overall estimates of regeneration.

The correlations have been sought for each modality or other index of recovery, separately by nerve and for all nerves combined, but without developing more than suggestive evidence of association. Various characteristics of the lesion and its handling, e. g., time and length of gap, have also been introduced as control variables, but without adding appreciably to the evidence of association. Summary tables are included as a record of these analyses, together with a master table showing the necessary data for each lesion. On balance the view is taken that a definite association probably does exist, especially for SR and voluntary motor function, but that the relationship is too weak for clinical usefulness.

As already noted, the severest penalties were always applied to the nerves showing the most advanced degrees of distal tubular shrinkage, a phenomenon shown to be pronounced 5 months or longer after nerve severance. There were 30 cases with poor assessment ratings, and in the correlation tables they were equally distributed among good, bad, and indifferent classes of muscle recovery. Since voluntary motor fibers are usually considered to be large in caliber and well myelinated, the good and fair results under adverse histologic circumstances suggest that shrunken neurilemmal tubules may be redistended, or that voluntary contraction of muscle may be accomplished even though the effector fibers may not regain their normal girth or state of myelination.

Case reports, including illustrations, have been presented for a representative group of cases. The photomicrographs of the nerve ends have provided what may be regarded as the most plausible explanation of the poor functional results in cases considered to have had little or no pathologic alterations in the nerve ends at the time of suture. The mismatching of proximal and distal fascicles, an invariable result of the resection and suture of nerve stumps, has been demonstrated, and is considered to be a most important factor in producing imperfect redistribution of nerve fibers and, therefore, subnormal functional recovery.

On the rare chance that the above findings be wrongly interpreted as evidence against careful resection to good tubules preparatory to anastomosis, it must be pointed out that the range of variation in the quality of nerve ends studied here is actually a small one. Had surgeons not uniformly cut back the injured segments to achieve the best ends they could provide within the limitations imposed by the gaps to be bridged, the results reported here, and in the motor chapter where a small effect seemed associated with the quality of the nerve ends, would probably have been very different. On an absolute scale, nerve ends range in quality from those produced by the surgeon's scalpel to the blunt, neuromatous bulbs commonly presented to the surgeon exploring war injuries. Only the better part of this absolute range is adequately represented in the material studied here, and the findings, therefore, pertain only to that part of the range. They must not be taken as any discouragement to painstaking resection preparatory to anastomosis.

Chapter XII

NEUROSURGICAL IMPLICATIONS

Barnes Woodhall, *Frank E. Nulsen*, *James C. White*, and *Loyal Davis*

A. INTRODUCTION

A great mass of pertinent data has been presented in the body of this study of peripheral nerve regeneration. It is now necessary to attempt an interpretation of these data in terms of practical surgical management. A firm realization exists that the concept of treatment by hospital echelon, so clearly seen in World War II, has now become largely obsolete, or at least modified to a great extent by more rapid evacuation of patients. No possible fresh approach to this subject, however, can alter the lessons of the past. These have shown in a most convincing fashion that: (1) no expectant attitude in the treatment of peripheral nerve injury can be maintained unless supported by objective and accurate longitudinal observations; (2) there exists a demonstrable relationship between time of injury and onset of appropriate therapy on the one hand and the extent of nerve regeneration on the other; and (3) men with peripheral nerve injuries can be rehabilitated adequately only through the means of specialized neurosurgical treatment. In the absence of some fundamental contribution to the control of the reaction of connective tissue to injury, which constitutes the essential barrier to peripheral nerve regeneration, the following analysis of management of war injuries to peripheral nerves can be considered as valid as can be fashioned from the observed facts.

B. MANAGEMENT IN FORWARD AREAS

1. Recognition of Peripheral Nerve Involvement

The surgical task in a forward area is not conducive to the recognition and early management of peripheral nerve injury and rightly so. Here the primary surgical design has to do with the preservation of life, and this demand upon the surgeon is often a great one (14). When possible, however, the forward surgeon should look upon himself as the first agent in a potential series of surgical enterprises and, in this function, seek evidence of peripheral nerve injury in all extremity wounds. Simple tests are available for the recognition of nerve involvement for both upper and lower extremity, even if the limb be immobilized in a cast. The testing procedures may be listed as follows for the major peripheral nerves.

Ulnar nerve. Loss of sensitivity to painful stimuli over the distal phalanx of the little or fifth finger.

Median nerve. Loss of sensitivity to painful stimuli over the distal phalanx of the index or second finger.

Radial nerve. Loss of ability to extend the wrist (wrist-drop), inability to extend the thumb and abduct the thumb in the "thumbs up" position. Sensory loss is variable.

Wrist and lower forearm wounds may involve tendons directly and make such testing invalid.

Brachial plexus. Recognized by the position of the wound and the involvement of component nerves of the upper extremity.

Peroneal nerve. Inability to dorsiflex the ankle and the big toe (foot-drop). The sensory loss is inconstant.

Tibial nerve. Loss of plantar flexion of ankle and big toe. Sensory loss over the sole of the foot is constant and may be the only indication of tibial involvement in wounds below the middle third of the calf.

Sciatic nerve. The high location of the wound with either peroneal or tibial or combined nerve involvement.

Characteristic hand postures may be observed immediately after wounding but they are not as well defined as they may be when muscle atrophy and shortening have occurred.

2. Immediate or Emergency Treatment of Peripheral Nerve Wounds

These data have shown that 92 percent of the nerve injuries whose regeneration has been studied were caused by battle wounds. The remainder were due to accidental or civilian type injuries. In battle wounds caused by high velocity missiles, immediate or emergency peripheral nerve surgery is contraindicated, with but a single exception. This exception is found in the rare case of an expanding hematoma, the precursor of a false aneurysm, with progressive peripheral nerve dysfunction caused by pressure. These data have shown conclusively that, even in the best hands, the emergency suture of war wounds of peripheral nerves is followed by a failure to regenerate in over 50 percent of cases.

If the nerve injury is visible without further nerve dissection at the time of wound debridement, its appearance should be described as accurately as possible in terms of complete nerve division, of partial nerve division with an estimate of the cross section involved or of continuity of nerve segments. Even if the examinations noted have indicated the presence of a major nerve segment injury, undue exploration for the lesion at the time of debridement is contraindicated and it is likewise not indicated at the time of secondary wound closure. In cases of complete nerve division, approximation or coaptation sutures may prevent some retraction of divided nerve ends. This is usually not an important issue since so much nerve tissue is customarily lost in war wounds. If such a suture is used, care must be taken not to damage normal nerve trunk and it is mandatory that the word "suture" be not loosely used in the medical record without its qualifying terms. Packs in contact with peripheral nerve tissue may be harmful.

Of primary importance in the initial time period following injury are: (1) identification and recording of the clinical characteristics of the nerve injury; and (2) description of the findings at debridement if the injured nerve is visualized.

3. Early Splinting of Paralyzed Muscles

Continuous splinting should never be carried out as a form of treatment of a peripheral nerve injury. Such splinting or casting is indicated only by fracture or extensive soft tissue wounds near working joint surfaces. When continuously splinted, nerve injuries will show severe joint fixation, particularly of wrist, finger, and thumb articulations. When such casting must be done, the distal half of the hand and fingers should be left free.

Intermittent splinting of peripheral nerve injury is indicated in two specific injuries. The first is the complete wrist-drop of radial nerve paralysis which should be supported by a light cast, splint, or brace which holds only the wrist in dorsiflexion. The patient will feel more comfortable and will use the fingers and thumb for useful function with such support. Support of the proximal phalanges may lead to ankylosis of the metacarpophalangeal joints in partial extension, a severe and often permanent disability. Patients will discard more elaborate braces because of their inability to use the hand for grasping. The end results of regeneration have been good in patients with only the wrist supported. The wrist-drop support should be worn at night but removed intermittently during the day and a full range of wrist movement carried out passively by the patient. The second specific injury requiring intermittent splinting is one involving the sciatic nerve or the peroneal nerve with foot-drop, for which the foot should be splinted in a position of dorsiflexion. The posterior splint should be light so that the patient may be ambulatory with crutches, until such time as he can bear weight and use the ordinary spring brace. The splint must be removed intermittently during the day, both to permit full passive ankle movement and to check for early signs of pressure sores on the heel or sole. Such pressure lesions may develop with posterior tibial nerve involvement alone. Ischemic paralysis of the median nerve with a tight cast, for instance, and peroneal nerve palsy from local cast pressure are common sequelae of poorly designed or unwatched continuous casting.

The corollary to the proper early splinting of nerve injuries is the continuous effort directed toward mobilization of joints by physiotherapy, whether by the physiotherapist or, of greater importance, by the patient himself.

C. EVALUATION AND DEFINITIVE MANAGEMENT

1. Introduction

As already pointed out, evidence gathered from personnel of the auxiliary surgical teams of World War II or the MASH units of the Korean campaign suggests that the forward surgeon cannot be oriented in detail to the problem of peripheral nerve injury. This statement is not to be construed as a measure of their reluctance to be so oriented. It seems clear that, unless survival of an extremity is threatened, the actual demands of neck, chest, and abdominal wounds upon their time and energies are very pressing. Even the simple tests that have been outlined are usually omitted and the demonstration of nerve disruption at the time of debridement is, of course, purely fortuitous. Such inevitable circumstances emphasize sharply the need for the study and exact recording of neurological changes in the wounded extremity when the casualty reaches a fixed installation. Here, for the first time, in the presence of complete clinical paralysis, the surgeon encounters the task of answering the fundamental question, whether this apparent complete nerve paralysis will go on to spontaneous resolution or some degree of return of function better than that which can be gained by suture, or whether an incapacitating paralysis will continue as a result of actual nerve segment disruption. No conservative or expectant attitude can be tolerated toward the return of peripheral nerve function in war injuries, unless maintained by objective evidence studied in terms of time after injury. Only a laborious dissection of the factors that have been presented in preceding chapters can even approximate an answer to this issue.

The statistical evidence concerned with the number of complete anatomical disruptions of nerve tissue as a result of war injury as compared to partial injury or axonal injury with their better prognosis is conflicting. This conflict is in all probability dependent upon the variable pathological forms, perhaps unequally recognized, and upon when after injury the observations were noted.

Perhaps the most succinct statement in this regard has been made by Seddon (68), a statement particularly appealing to surgeons who tend to judge an issue in "black and white" terms, since they must inevitably function in such terms.

"A more difficult question is what to do in the case where a degenerative lesion is present and where the anatomical state of the nerve has not been disclosed during treatment of the wound. Are we justified, as in the case of nerve injuries due to closed fractures, in waiting in the hope that spontaneous recovery will occur?" and "One of the most curious inconsistencies in the whole story of the surgery of peripheral nerve injuries is that it has been generally accepted that primary suture is the ideal form of nerve repair. It has, at the same time, been widely held that in dealing with nerve injuries due to war wounds repair of the nerve is not a matter of urgency, and that in a good proportion of cases an expectant attitude may properly be adopted. If, as we all agree, primary suture is the theoretical ideal, then it follows that in cases requiring secondary suture repair should be undertaken at the earliest convenient time."

Such a policy demands an exploratory operation of every case of complete paralysis due to an open or gunshot wound in which the anatomical status of the nerve segment is not known. What evidence is available in terms of gross tissue injury to indicate that such an exploration is indicated? The Oxford group, in support of this thesis, found complete or virtually complete loss of nerve segment continuity in 50 percent of their cases. Spurling and Woodhall (75) studied operative findings in 2,873 cases of complete paralysis and found nerve segment division in 54 percent of cases; the remainder represented neuromas or nerve contusions in continuity. The observations made were recorded at an average time period of 39 days after wounding. Studying the same matter under somewhat similar circumstances in a specialized center, Foerster (24) found complete nerve division in 44 percent of his cases. "Thus it may be argued," states Seddon, "as the Americans and the writer have done, that with an equal chance of finding a divided nerve the surgeon is justified in subjecting his patient to an operation which may be unnecessary."

There is considerable evidence to the contrary and this evidence needs careful scrutiny since it is well documented. Sunderland (77), studying 339 cases of nerve injury rather carefully segregated in purely Australian hands, found that 68 percent of these cases recovered spontaneously, and the statement is made that this regeneration was better than that to be expected from suture. Sunderland's roster was apparently under recorded contact from the time of wounding and included both partial and complete nerve paralyses and also included some types of accidental wounding. Sunderland states that these findings are supported by Foerster, and by Tinel and Benisty.

Tinel (79) stated "* * * according to our personal statistics, we may estimate at between 60 and 70 percent, approximately, the number of spontaneous regenerations without surgical intervention; at the same time, there are a certain number of these, between 10 and 20 percent, which in our opinion would have gained by such an intervention." Livingston (44) studied 132 patients in World War II at a time period of 3 months postinjury. Their records were uniformly well documented, they had been injured by high velocity missiles, and they had been operated upon by trained personnel as elective procedures. Of these 132 patients, 3 had irreparable injuries, 20 proved to have complete nerve division at operation, and 4 partially divided nerves that required suture. The remainder, roughly 80 percent, appeared at this very early time period at least to be recovering spontaneously. Strange as it may seem, definitive information on the incidence of peripheral nerve injury in World War II is lacking. Men are injured in myriad ways, and injuries to specific structures are also extremely variable. Unfortunately, the extent of injury to a peripheral nerve cannot be determined by gross inspection unless it be divided; nor can one reliably infer the extent of injury from the functional deficit. Sampling is conducted in various ways, ordinarily in more or less close association with therapy, and bias easily enters. To obtain a representative sample of peripheral nerve injuries, one must start with a sample of all WIA involving the extremities. If one samples at any point along the echelons of treatment one will encounter more or less opportunity for distortion. Depending on how the sampling is done, disagreements will inevitably arise. On the basis of accredited sampling, there were 30,000 to 40,000 nerve injuries; at least 17 percent were treated by suture or graft and possibly as many as 26 percent (4).

These varied and good expressions would indicate that the observed degrees of tissue injury are predicated upon the time at which the observations are made after the inflicting trauma, the availability of longitudinal data, and the ability to recognize total or subtotal injury at the time of operation. There must be a substantial percentage of nerve injuries that are incomplete in terms of functional loss if seen shortly after the shock of injury. These present a problem of longitudinal observation that is in turn a weighing of the degree of spontaneous regeneration against what may be obtained, for instance, by resection and suture. Of more immediate concern is the adequate recognition of complete versus incomplete nerve paralysis, without regard to its pathological source, since among these cases will be found some percentage, as noted in the observations above, that may require operative intervention. They may be recognized by the following techniques of study. The same techniques are applicable to the complete, the incomplete, or the regenerating nerve injury.

There appear to be two prerequisites for the proper diagnosis and treatment of peripheral nerve injury. These may be combined in the statement "careful repeated examinations carried out in a standardized fashion." In this way, data collected over any period of time by various observers may be readily and effectively compared. An outline of examination includes history taking, operative observations, pathological records, and tests of motor, sensory, autonomic and electrical properties of nerves and muscles which reduce descriptions to a minimum and convert results into numbers as far as possible. When such examinations must be formulated for practical use, their exposition should be restricted to a single page. Workable examination sheets may be constructed as follows:

Form 1—History. The nerve casualty may now be considered placed at a more permanent installation than the MASH unit or any other forward resuscitation facility. This is the time for recording certain simple and basic data having to do with the date and time of injury and causative agent, the location of the wound, the immediate subjective responses of the patient to trauma, the operative procedures and observations of the forward surgeon, and the subsequent course of the patient prior to this first formal review of the alleged nerve injury.

Form 2—Examination—Motor. Any examination of motor status presupposes a knowledge of the anatomy and function of the muscles in the distribution of each nerve. Specifically, the examiner must know the origin and insertion of the muscle in question, its level of nerve supply, and the isolated, synergistic, and antagonistic functions it is capable of producing. Since an individual always uses a group of muscles to effectuate a functional movement, it is usually difficult to isolate any given muscle. It is also necessary to take into account the possibility that the patient can instinctively but falsely effect any given motor performance by substituted or trick muscle movements. Anomalous innervation, particularly of intrinsic hand muscles, must also be kept in mind. These details of examination and the usual sources of error are won and kept in mind only under the pressure of constant usage. They must be recorded and have been in such texts as these: Haymaker and Woodhall, *Peripheral Nerve Injuries*, Second Edition (33); *British MRC War Memorandum No. 7, Aid to the Investigation of Peripheral Nerve Injuries* (51); and Kendall and Kendall, *Muscles, Testing and Function* (35). Such monographs are not part of the usual scene of even the base wartime installation, particularly in the presence of heavy casualty loads. Form 2, however, may be initiated with a study of certain designated muscles. A standard group of muscles has been tested repeatedly by the study centers. These include representative muscles from proximal and distal groups which by their position or by the particular motion they perform are most reliably tested. The muscles for each nerve are listed and should be written in the examination sheet for the appropriate nerve.

Ulnar Nerve

Flexor carpi ulnaris
Flexor digitorum profundus (fourth and fifth fingers)
Abductor digiti quinti
First dorsal interosseous

Median Nerve

Flexor carpi radialis
Flexor digitorum profundus (index finger)
Flexor pollicis longus
Abductor pollicis brevis
Opponens pollicis

Radial Nerve

Triceps
Brachioradialis
Extensor carpi radialis
Extensor digitorum
Extensor carpi ulnaris
Abductor pollicis longus
Extensor pollicis longus et brevis

Sciatic Nerve

Proximal—Biceps femoris, semimembranosus, semitendinosus
Distal

Tibial Nerve

Gastrocnemius-soleus
Tibialis posticus
Flexor digitorum longus
Flexor hallucis longus
Intrinsic foot muscle (cupping of sole of foot)

Peroneal Nerve

Tibialis anticus
Extensor digitorum longus
Extensor hallucis longus
Peroneus longus

Musculocutaneous Nerve

Biceps brachii

Axillary Nerve

Deltoid

Femoral Nerve

Quadriceps femoris

The choice of muscles made by the group concerned with the follow-up study is given on page 73.

Further discussion of techniques of study is not necessary at this point since these matters have been covered in detail in the preceding data chapters. The purpose in hand will be served better by a survey of the problem of nerve regeneration as it was found in casualties of the Korean campaign.

2. Evaluation of Evidence For or Against Nerve Regeneration as an Indication for Resection and Suture.[20]

It should be clear that a real dilemma may exist in the choice of management of the early nerve lesion. If this lesion will not permit satisfactory regeneration, it is evident, from reference to the correlation between time of suture and end result, that this suture should be undertaken as early as possible. There would seem to be no arbitrary time limit—a suture at 1 month after injury does better than one at 2 months, and far better than one at 6 months where an average reduction of 30 percent in overall motor recovery may be expected. Such a reduction is clearly more critical in nerves which do badly, such as the ulnar or the peroneal, as well as in high lesions of any nerve. But regardless of individual situations, the statistics on the influence of delay can only result in a sense of urgency for every lesion, not only in order to shorten hospitalization by getting necessary treatment under way but also to achieve the best possible end results in a situation which has definite limitations.

The urgency of accomplishing indicated sutures is offset by the certain limitations in regeneration which are imposed when suture is undertaken. Radical management of a nerve lesion should not be undertaken if there is any indication that a neuroma in continuity will permit greater regeneration than could be accomplished by its resection and suture. It must be remembered that roughly 75 percent of nerve lesions associated with initial total paralysis (in the military situation where the usual wounding agent is a high velocity missile) do not require suture and achieve an end result far better than could have been accomplished by suture. Fifty percent of this group showed no evidences of regeneration for such a long period that the nerve lesion was explored and the dissection of a contused nerve segment from surrounding scar tissue was usually referred to as neurolysis. Whether such a neurolysis constitutes a therapeutic measure which actually influences

[20] This section is based on the Valley Forge series studied by Dr. Frank E. Nulsen, Dr. William J. Erdman, II, and Dr. Harry W. Slade.

the course of regeneration or should simply be considered a nerve exploration to establish that resection and suture were not indicated is highly debatable. Nevertheless, it is clear that both those lesions which recover so early that no exploration is undertaken and those which are subjected to lysis for the most part develop more complete regeneration than is seen in the suture group.

On the other hand, an occasional patient subjected to no more definitive treatment than lysis fails to show the level of regeneration expected of suture in this location and an occasional lesion in continuity, subjected to resection, shows histologic evidence of more distal neurotization than suture can achieve. The problem is one of accomplishing all indicated sutures as early as possible but only in those cases where spontaneous regeneration will be limited. Under ideal circumstances, negative explorations should be avoided or kept at a minimum, but this is chiefly a matter of expediency since the negative exploration is an innocuous procedure which does not affect the end result. In other words, if an exploration had only a 10 percent chance of resulting in the early accomplishment of an indicated suture, it would seem justified. Postponement would seem indicated only when a short additional interval of delay might allow for evidences of regeneration that would eliminate an unnecessary operative procedure.

This last consideration would justify delay of most operative procedures until 1 month after injury because of the large proportion of spontaneous recoveries that become defined within this short period of waiting. More than 30 percent of initial total paralyses from high velocity missiles will become resolved as situations not requiring operation as early as 1 month after injury. This is an insufficient time for regeneration of any disrupted neuroma and must be attributed to the functional recovery of intact neurones that have suffered axonopraxis. Such early recovery, either motor or sensory, is especially favorable for, if the nerve trunk contains some axons that did not even degenerate, a major proportion of the degenerated fibers are probably capable of spontaneous regeneration. The kind of disruption that presents a permanent block to axonal regeneration cannot exist in a nerve segment with intact axons. This month's delay for sorting-out purposes would not be indicated if divided nerve ends had actually been visualized at the time of initial injury or if the configuration of the wound was such that the nerve trunk could not possibly have escaped severance. Nor would such delay be indicated in the simple laceration where the neurological deficit can be assumed to be the result of actual severance of axon rather than the possible temporary result of concussion by a missile passing close to the nerve. Whether suture is indicated will usually be settled by the gross appearance of the lesion explored at the end of 1 month, when a clean wound and flexible joints make this feasible. However, when gross anatomical continuity exists even though there is obvious damage to the nerve segment, this is not the time to elect suture. Such neuroma in continuity problems will be found in over 50 percent of those early explorations and only subsequent observation will determine whether spontaneous regeneration is to offer a better result than can be expected from reoperation and suture. An evaluation of evidence for regeneration is therefore an important and necessary task for each nerve lesion until it defines itself as requiring no further operative procedures. In the early case sufficient evidence of regeneration is sought to preclude the necessity for operative exploration. In the neurolysed neuroma in continuity the nature of the lesion is defined, as time passes, as one which will show more or less recovery than can be provided by resection and suture. In the sutured case sufficient evidence for regeneration is compiled to remove any question that a secondary suture might accomplish more. Finally, when a motor deficit can be corrected by tendon transplants or joint fusions and nerve regeneration has also a good expectancy of correcting this motor deficit, the evaluation of regeneration must continue until it is established whether these supplementary procedures are or are not indicated.

The following discussion on evidence for regeneration embodies a concept of examination and evaluation that must be employed at frequent intervals in every nerve injury case until the statement can be made that no further therapeutic measures are required. A knowledge of the final end result in each case is also of importance but has nothing to do with the concept that hospitalization should be continued only until it is clear that, regardless of possible variations in the end result, further definitive procedures will not be employed. The following discussion therefore applies not just to the initial early examination but to all subsequent examinations that are necessary until the individual is finally sorted into the group that can be labeled as requiring no further definitive therapy.

This discussion has been divided into three parts: certain evidence for regeneration, uncertain evidence for regeneration, and certain evidence for failure in regeneration. By satisfactory regeneration is meant regeneration as good as can be accomplished by the average suture of this nerve in this location at a certain time period after injury. Such a degree of regeneration may be far from satisfactory in some situations and it may be defined as a level of function which precludes the necessity for further operative procedure. At this point of the discussion it should be stated that electrophysiological evidence as proof of some regeneration is of no interest unless it carries with it a strong predictive value for satisfactory regeneration.

The rules which are presented for the interpretation of evidence for regeneration cannot be derived from a study of end results but must be based upon serial data obtained from early cases in the interval when decisions regarding surgical management are made. The unavailability of such pertinent data from late follow-up material was realized and a study of 300 patients with early nerve injuries at Valley Forge Army Hospital was therefore undertaken by the Philadelphia Study Center under Army contract in the interval from 1951 to 1954. Further longitudinal data obtained from 500 cases during the active hospitalization period at Cushing General Hospital (1944 to 1946) are occasionally brought to bear as well.

a. Certain Evidence of Regeneration

(*1*) *Voluntary motor function.* When there is movement against resistance which can only be the result of the voluntary contraction of the first muscle receiving its nerve supply through the nerve lesion, satisfactory regeneration is present. This involves the assumption that spotty recovery is a rarity—that the degree of recovery which develops in the most proximal muscle to receive its nerve supply foreshadows the recovery that will obtain in more distal muscles and in sensory supply to skin. Such a correlation uniformly exists in this follow-up study and it obtains again in the Valley Forge series. The extreme distal muscle will not do nearly as well as proximal ones in the high lesions that involve both proximal and distal groups but this is not of present concern since the distal function predictable with this evidence for proximal recovery is certain to be better than could be achieved by resection and suture. The assumption appears to be correct that at the level of nerve damage the axons supplying proximal muscles are so widely dispersed through the entire cross section of the nerve trunk that the recovery of a reasonable proportion of these dispersed axons as reflected in one muscle's contraction is a proper index of the regenerative capacity of the nerve trunk as a whole.

The conclusion that this movement against resistance is truly a reflection of nerve regeneration must be reached with some caution. A clear understanding is necessary of the substitutive or compensatory movements that can be learned progressively by utilizing unaffected muscles. In addition, there is the possibility, particularly in the case of the median and ulnar nerves, for overlapping or anomalous innervation so that even the definitely established contraction of an easily visualized muscle may not be evidence of recovery in the nerve presumed to supply it. Whether a movement should be properly ascribed to innervation by a particular nerve is a question which can sometimes not be settled by clinical observation but can easily be decided, as will be discussed below, by observing the motor responses on electrical stimulation of the nerve in question. The statement has been made that movement against resistance is a certain evidence of satisfactory regeneration, but obviously this degree of muscle strength can occur only after there is at first only a visible contraction in the muscle insufficient to move the part, followed by contraction sufficient to cause movement at the joint which then becomes of sufficient strength to lift the part against gravity and finally against resistance. Accordingly, when only a visible contraction of the muscle is evident at a time early enough to be consistent with progressive improvement in that muscle, there is reason to follow its performance for 4 to 6 weeks in the expectation that contraction against resistance will result. If reference to the expected result of suture in cases like this one indicates that this particular muscle could not possibly go so far as to develop contraction against resistance, satisfactory or end-point regeneration would then be assumed. If, on the other hand, good muscle strength is the usual result of suture in the case at hand, the evidence for regeneration is not certain until the strength level of movement against resistance has been reached. Because definite evidence for improvement is such an important criterion in deciding surgical management, the importance of accurate recording that lists not only muscles which are working but grades their strength cannot be overemphasized. Once there is movement against resistance muscle strength can be measured against a simple spring scale and the progressive increase in pounds of strength recorded is of further help in predicting the end result. However, the practical surgical decision usually depends only upon reaching the functional level of movement against resistance.

(2) *Preservation or recovery of sensation.* It is unusual to see evidence for skin innervation before voluntary contraction in a proximal muscle has signaled satisfactory regeneration, and this never occurs after suture. However, high velocity missiles appear capable of causing a type of nerve contusion which results in temporary motor dysfunction (axonopraxia) without abolishing sensory perception. This situation of sensory perception in the face of total motor paralysis is seen only in early cases and it is an almost certain indication that motor recovery will begin to occur far short of the long periods necessary for regeneration.

The finding of sensory without motor function more than a month after injury calls for more careful examination: either motor recovery actually is present or sensory function is not. Nerve stimulation will produce muscle contraction which the patient has not learned to initiate himself or the sensation perceived is not mediated through the nerve in question. Only sensation in the zone of autonomous supply must be given consideration as previously described. The tips of the index and fifth fingers allow for easy discrimination of autonomous supply in the median and ulnar nerves while the radial nerve has no certain autonomous zone and absence of a clear-cut zone of total sensory loss does not preclude a complete division of the radial nerve. The absence of any area of total loss of peroneal sensation is proof for major continuity but the presence of only a small zone of sensory loss, no matter how limited, can be consistent with interruption. Preservation of sensation in the sole of the foot is proof for a major degree of tibial continuity. The large overlap of saphenous sensation into the instep may be confusing.

Even the lowest grade of sensation in a true autonomous zone, such as the perception of discomfort on forceful pinching of the terminal phalanx of the index finger in the case of the median nerve, strongly suggests the possibility of major continuity. Certain evidence is presented when pinprick to the autonomous zone causes definite pain.

More detailed testing of sensation is of importance in evaluating end result and of interest in following a gradual improvement in sensory recovery during active regeneration. However, from the standpoint of a practical surgical decision, information is sought in the early case concerning the existence of some sensation to the autonomous zone while in the late case the progress of motor recovery usually settles the question of adequate recovery before sensory recovery begins. Only in the case of a distal median nerve lesion may the quantitative degree of sensory recovery enter into surgical judgment.

(*3*) *The preservation of sweating.*—Observations concerning sweating in the autonomous zone of the injured nerve ordinarily parallel sensory findings. Total sensory loss from a peripheral nerve injury is invariably accompanied by total loss of sweating and recovery of sweat function is not discernible even to skin resistance measurements before ordinary testing with a simple pin has revealed that sensation is present. Observations on sweating do have the advantage of being objective and independent of the patient's cooperation. Six patients in the small Valley Forge series have been studied who had convinced their examiners, and possibly themselves, that a major sensory loss existed in hand or foot after a wound of that extremity. The preservation of sweating was certain evidence against a major nerve lesion and was an important step in delineating the problem as one of hysteria or malingering. On two occasions the preservation of sweating in an area of sensory loss established that a root lesion which did not involve autonomic pathways was responsible for the sensory deficit rather than a wound of the extremity which was thought to have damaged a peripheral nerve.

(*4*) *Motor response on nerve stimulation.* This simple electrical test so frequently calls for a revision of the estimate of nerve function deduced from clinical examination that it should be a part of the examination of every case where the adequacy of regeneration is at all in doubt.

The type of current utilized to stimulate the nerve trunk is unimportant so long as it is of adequate intensity to cause maximal nerve stimulation and is still easily tolerated by the patient. For stimulation of the underlying nerve trunk through the intact skin, the usual operating room stimulator or the machine in use in the physical therapy department will be adequate, utilizing simple galvanic shock or bursts of alternating or faradic current applied through a moistened unipolar electrode of 1 cm. in diameter. Points where the various nerve trunks are in a location easily accessible to stimulation from the skin surface are illustrated in current monographs. The nerve trunk must be stimulated proximal to the branches innervating those muscles whose contractions will be a measure of innervation through the lesion. It does not matter, except in the first week after injury, whether the point stimulated is proximal or distal to the lesion since any axons conducting the stimulus to the muscle must be intact from muscle to anterior horn cell. The efficacy of the stimulus can be tested on the opposite normal limb in a symmetrical location. It must be realized that response in a muscle close to the point of stimulation can be the result of direct stimulation of the muscle rather than nerve conduction. When there is no motor response on nerve stimulation, or the intensity must be raised to a point where neighboring nerves and muscles begin to respond, resort must be made to more direct stimulation of the nerve. This is accomplished by inserting two hypodermic needles at 1-cm. distance into the close proximity of the nerve and applying current to these two needle electrodes to secure a confined bipolar stimulation of the nerve trunk. This has been referred to as a bipolar-intraneural stimulation but the needles need not actually impinge upon the nerve trunk although no harm results when they do. The intensity of stimulus required for maximal stimulation of the nerve trunk through needle electrodes in its close proximity is very small and the make-and-break shock delivered by two 1½-volt flashlight batteries is adequate. Intensity can be regulated by a simple rheostat. This simple modified flashlight is a very satisfactory instrument for nerve stimulation or an opthalmoscope with its built-in rheostat can be modified easily to deliver make-and-break shocks graded up to 3 volts. The stimulator used for surface testing is entirely satisfactory if stimulation is begun at a low intensity of current, while the modified flashlight can be used in situations where cumbersome stimulators are not readily available. Surface stimulation is preferred to stimulation through needles when it gives the necessary information but it should not be concluded that a nerve is incapable of response to electrical stimulation until an additional test has been made with bipolar needle electrodes. Positive results with beginning recovery are frequently seen on needle stimulation when no response occurred with the surface electrode. This is particularly true in the case of deep-lying nerves like the radial and tibial. If a Tinel sign is present at the segment of nerve that is stimulated, the same kind of paresthesias referred to the sensory area of supply of the nerve should be experienced with each electric stimulus as an indication of adequate stimulation of the nerve. In this situation a failure in motor response is meaningful as not being the result of inadequate stimulus. When motor response does occur the responding muscles should be noted and the strength of movement of the part graded in the same rough quantitative fashion as is followed for the voluntary motor examination.

Motor response on nerve stimulation has the same significance for regeneration as does voluntary contraction. However, voluntary contraction frequently does not become evident for several weeks after the first response of the muscle to nerve stimulation but the patient will ultimately always learn to initiate a voluntary contraction of the same strength that is demonstrated by artificial nerve stimulation. Accordingly, the same certain evidence for satisfactory regeneration is afforded by muscle contraction on nerve stimulation as is afforded by voluntary muscle testing but at an earlier date and in a way which rules out the possibility that the observed movement is not supplied by the nerve being tested. During the stage of progressive regeneration only a visible contraction in the most proximal muscle is reason to await the development of voluntary contraction against resistance so long as the magnitude of contraction increases with successive examination. In the deep-lying muscle, especially when there is considerable overlying fat or edema, contractibility can be demonstrated by movement of needles inserted in the muscle before movement of the skin or of the part to which the muscle is attached becomes evident. This is a particularly sensitive test of early muscle function.

b. Uncertain Evidence for Regeneration

(1) *Tinel's sign.* When percussion of the nerve trunk distal to the lesion can be performed in such a way that the neuroma itself is not being disturbed and gives rise to paresthesias referred to the area of sensory supply to the nerve trunk, positive proof is present of the continuity of sensory axons from the point percussed through the lesion to the central nervous system. When a Tinel sign is present at all in the distal nerve trunk it will invariably progress distally at a fairly rapid rate to indicate that the sensory axons responsible for this phenomenon are traveling at a rate of 3 or 4 millimeters per day or 3 or 4 inches per month. This behavior of the Tinel sign affords clear evidence that some regeneration is going on but it unfortunately does not give proof that this will be satisfactory regeneration as this has been defined. More than three-quarters of those nerve lesions which require resection and suture have been associated with a properly advanced Tinel sign. This may be correlated to the finding that grossly an anatomical connection between the nerve ends may be scarcely demonstrable while microscopically a handful of unmyelinated fibers in one small area of the distal nerve's cross section appears to have been responsible for the sensitivity of the distal nerve trunk. On the other hand, as will be reemphasized below, the absence of a Tinel sign, when a month has allowed an opportunity for it to progress at least 3 inches below the lesion, is certain evidence of absent regeneration.

(2) *Shrinkage of the area of sensory loss.* It has already been pointed out that sensory return is of importance only when it occurs in the autonomous zone but it is difficult not to be impressed by a shrinkage area of sensory loss as evidence for improvement in nerve function, especially in distal lesions of the median or tibial nerves where the motor functional deficit may be minimal. Unfortunately, the autonomous zone is the most distal, and sometimes it would be profitable to know whether sensation in a more proximal area, previously anesthetic, signifies regeneration or simply overlap supply from undamaged nerves. When the newly recovered sensation is incorrectly localized by the blinded patient excellent evidence is at hand that this is the result of regeneration while proper localization in a previously insensitive area speaks more for overlap. The question can be settled by discovering whether the sensation drops out on anesthetic block of the injured nerve or of the normal neighboring nerves. Ordinarily this evaluation of the diminishing zone of sensory loss is not the crucial point in determining whether there is evidence for satisfactory regeneration.

(3) *Improvement in the usefulness of the extremity.* It is a rare patient who does not use his injured arm and leg better long before nerve regeneration can make any contribution to function. This is the result of compensatory use of uninvolved muscles which occurs to some degree in every well-motivated patient and to marked degree in those whose muscle attachments or shared innervation is such that so-called trick movements develop. Such natural improvement in the absence of specific regeneration emphasizes the point that motor testing must be confined to those visible muscles

and movements which can only be the result of nerve regeneration, checking questionable situations with observation of the responses on nerve stimulation.

(4) *Electromyography.* This is an extremely sensitive method for the unequivocal demonstration of motor innervation as reflected in the demonstration of motor unit potentials on voluntary effort and of action potentials in response to nerve stimulation. The latter method is more objective and should be resorted to when immediate adjacent small muscles can create potentials on voluntary effort which are actually delivered by uninjured nerves.

Because the apparatus involved is expensive and cumbersome and the performance of the test as well as the maintenance of the apparatus require time and considerable technical ability, it is appropriate to see to what extent electromyography adds to the information that is obtained from simple stimulation of nerve with a flashlight battery. One of the major difficulties in evaluating the relative merits of proposed electrodiagnostic tests has been that each enthusiast has reported on the application of only his test. The Valley Forge material provided an excellent opportunity to use the complete battery of electrodiagnostic tests on each patient at the same examination so that the areas of agreement and disagreement could be evaluated.

Evidence for regeneration obtained by EMG testing was in good agreement with the results of nerve stimulation. There was no case in which visible muscle response on nerve stimulation was not associated with recorded action potentials on nerve stimulation. In 39 cases motor units were not seen on voluntary effort when potentials could be produced by stimulating the nerve and visible movement could be seen as well. Median nerve injuries offered a special problem in that voluntary motor units were frequently seen in attempting to record the opponens pollicis only to find nothing on median nerve stimulation and to realize that potentials on voluntary effort must be viewed with skepticism in areas of shared innervation. In no case could voluntary motor units be recorded from within the substance of a large muscle without the demonstration of potentials on nerve stimulation. Accordingly, there was a distinct feeling that action potentials on nerve stimulation constituted a more specific indication of regeneration through that nerve than did the recording of voluntary units from an area assumed to be in that nerve supply. The impression also existed that the contribution of electromyography beyond what was learned on simple nerve stimulation involved first the question "How often does nerve stimulation result in muscle action potential when it causes no visible muscle response?" and the second question "What is the subsequent course of cases who show EMG but not visible muscle response on nerve stimulation?" In the group of 300 patients tested, only 6 showed muscle action potential at a time when visible contraction could not be perceived on nerve stimulation. On 10 occasions actual movement of the muscle was only perceived when needles to be utilized for EMG recording were inserted into the muscle and showed mechanical movement as an indication of definite muscle contraction. Four of these 6 patients had developed visible contraction on nerve stimulation at their next examination which varied from 2 to 4 weeks later. Whether these 4 would have shown these grosser signs of recovery by 2 weeks or even 1 week if retested earlier is an open question. The only other 2 cases which showed EMG evidence of muscle innervation without a grossly visible response on nerve stimulation failed to develop such response or to show increase in EMG potentials in an additional 4-week period. Both cases were operated upon and showed minimal continuity between nerve ends with less than 5 percent of the distal cross section showing myelinated and amyelinated nerve fibers.

Electromyography appeared to afford uncertain evidence for regeneration when muscle function could be demonstrated only by this means and did not progress to sufficient innervation to produce grossly visible contraction on nerve stimulation. If the method were used in conjunction with nerve stimulation it would afford, in an occasional case, the sole evidence for recovery that would delay the performance of an unnecessary exploration. Clearly evidence for innervation by this sensitive test alone is insufficient for the prediction of satisfactory regeneration and should call for only 2 or 3 weeks' postponement of surgery if more valid signs of regeneration do not appear.

(5) *Chronaxie.* The determination of chronaxie by direct muscle stimulation was carried out on the Valley Forge patients whenever total paralysis existed and was continued to the early stages of recovery of voluntary function. By this experience, such testing appeared to be an excellent method for delineating those muscles whose innervation was impaired. The occasional finding of muscles which could not be made to contract on direct stimulation was useful in establishing that, for these muscles, even a return in innervation would not result in satisfactory function because of the paucity of contractile elements that had been largely replaced by atrophy and fibrosis. Chronaxie determinations were not of any help in anticipating regeneration as the high values indicative of denervation usually did not fall significantly before there was definite clinical evidence for motor recovery. In the occasional patient with a wound of the extremity who exhibits a profound motor weakness on an hysterical basis, the findings of normal chronaxie values are of assistance in establishing that there is not even partial denervation of the muscle by the trauma to the extremity. A complete strength-duration curve might have been of more assistance in exhibiting discontinuities of the curve suggestive of beginning innervation at an early stage where such prediction would be helpful but only the chronaxie point on the curve was established routinely.

(6) *Galvanic tetanus ratio.* This test was not used on all Valley Forge patients because in the earlier work at the Philadelphia Study Center occasional men found the test so uncomfortable that they refused to return to Philadelphia for subsequent examinations. However, during the early stages of enthusiasm for this test, it was used routinely at Cushing Hospital

and records were reviewed at Percy Jones Hospital in patients studied before operation was undertaken for resection of neuromas with minimal continuity and suture. It was clearly evident that a satisfactory rise in tetanus ratio above the denervated value of 2.0 was uncertain evidence for satisfactory regeneration. Tetanus ratio changes would appear to be a definite indication for some regeneration through the lesion just as in the case with the progressive Tinel's sign but the test does not differentiate between minimal regeneration and satisfactory regeneration, nor is a failure in rise of tetanus ratio a definite proof for unsatisfactory regeneration.

c. Certain Evidence for Unsatisfactory Regeneration

The decision that a nerve will never regenerate in as satisfactory a manner as could be achieved by resection of the lesion and suture is more difficult to reach than is the decision for satisfactory regeneration when supported by positive signs of recovery. With no evidence for nerve regeneration at 1 month after injury, including the absence of any Tinel's sign below the lesion, nerve exploration should be indicated even though there is still a reasonable chance that a lesion in continuity will be discovered that calls for no radical treatment at this early time. On the other hand, those cases having a gross nerve disruption benefit sufficiently from such early definitive treatment as to justify exploring the entire group. There may not be physiologic evidence to clarify the potentialities for nerve regeneration for 3 to 6 months after injury and prompt exploration is likely to answer the question. Negative exploration at this early date can frequently be prevented by nerve stimulation studies giving positive results in patients who appear to have a total paralysis to clinical testing. In a rare case electromyography will show evidence for regeneration when there is no visible response to nerve stimulation and this is ample reason for waiting up to 1 month to determine whether more certain signs for satisfactory regeneration develop. There would seem to be no reason for being conservative about nerve exploration provided conservative treatment of the nerve is maintained at operation when there is sufficient gross continuity to accommodate regenerating axons. If such is the operative finding, and if either percussion or electrical stimulation of the distal nerve trunk causes paresthesias that establish the presence of axons in continuity through the lesion, resection of the neuroma in continuity is not indicated until sufficient time has passed to clarify from physiologic evidence the potentials for regeneration of this lesion. The problem of the neuroma in continuity whose status cannot be determined by visualization at operation is a frequent one and it is therefore necessary to go to some pains to define certain evidence for unsatisfactory regeneration when this cannot be settled by the gross appearance of the lesion.

Such determination of unsatisfactory regeneration depends upon a knowledge of the time at which reinnervation to a given muscle has gone as far as it can go, plus the assumption that the degree of reinnervation to a proximal muscle or its absence is a reasonable measure of the degree of reinnervation which will subsequently occur to more distal muscles and to skin. The rate of down-growth would appear to vary for different types of regenerating axons. Those axons which are sensitive on percussion in the progressing Tinel's sign would appear to travel as rapidly as 5 mm. per day or roughly 6 inches per month in some instances. A similar growth rate would appear to obtain for axons which reach muscle and produce a change in electrical reactivity as measured by the galvanic tetanus ratio. Whether it is maturation of these same axons which results ultimately in the appearance in the muscle of motor units by electromyography and finally visible contraction, either by nerve stimulation or by voluntary effort, is unknown. At any rate, review of clinical material indicates that visible motor response on nerve stimulation occurs at a time consistent with a fairly uniform growth rate for every nerve, if it is ever going to occur at all. EMG evidence for motor regeneration comes only slightly earlier and is not necessarily followed by this more certain evidence for regeneration. Voluntary motor contraction may begin close to the time when there is a response to nerve stimulation or may not develop until weeks later. Accordingly, when voluntary contraction in a given muscle does not begin at the expected time this case should not be referred as one of unsatisfactory regeneration without making a test of nerve stimulation—good motor reinnervation may be present with an inability of the patient to demonstrate it on voluntary effort.

First evidence of spontaneous regeneration, or of regeneration following suture, may be plotted for any given nerve against the distance from the lesion to the muscle involved (67). Because of varying intervals between examinations an entirely uniform growth rate may not be suggested by these plots but a definite limit to the interval in which innervation will occur, if it is to occur at all, seems clearly defined. In most conservative terms, regeneration will not occur unless a growth rate of at least 1 inch per month is exhibited. In other words, if the first satisfactory test muscle to be innervated below a nerve lesion is x inches from the lesion and does not respond on nerve stimulation after x months, one has certain evidence for unsatisfactory regeneration. Extra time must be allowed when extensive transplantation of a proximal nerve segment makes a level above the suture line the point for beginning down-growth.

Average distance from nerve lesion to muscle is illustrated in the tables developed by Seddon (71). Actually measurements can be made in a given patient without reference to tables or even to anatomical charts. With a galvanic stimulator, the motor point for the muscle in question can be determined in the uninjured extremity and marked on the skin. A symmetrical mark can be made on the uninjured side and the distance from neuroma to this point measured directly.

When motor response does not occur by the calculated deadline, clear evidence is present for unsatisfactory regeneration whether it be after a suture which seemed satisfactory or whether it has occurred when a benign appearing neuroma in continuity has been left in place. Resection of this neuroma in continuity and suture are now indicated unless there is strong reason to believe that little will be accomplished by suture. In high lesions and in situations where there has been an excessive delay since injury, it is worth while to refer to the motor regeneration tables to determine what is to be expected of the operative procedure. In some situations, little in the way of motor recovery can be expected but suture might still be worth while in an effort to establish some sensation, especially in the case of the median and tibial nerves. In addition, two situations should be emphasized where suture is certain to offer little. If there has been so much muscle damage secondary to ischemia or direct trauma, or so much muscle atrophy from prolonged denervation that no contractile elements respond on direct muscle stimulation, such muscles cannot be given function by attempting to improve their nerve supply. Secondly, if the damage to a nerve trunk has occurred by a closed stretch injury with diffuse damage to a long segment of nerve rather than by the usual focal contusion or laceration, no operative procedure on the nerve will improve its function.

D. THE PROBLEM OF THE NEUROMA IN CONTINUITY [30]

1. Introduction

The ideal management of a damaged peripheral nerve would appear to be a simple matter. This would include early surgical exploration of any nerve lesion associated with total paralysis and suture of the nerve when it is found to be disrupted. Such a plan suffices in the usual civilian injury where damage is produced by laceration and nerve paralysis will usually be associated with nerve severance. In the military situation, however, with wounding by high velocity missiles, nerve dysfunction frequently occurs without actual nerve discontinuity, and surgical exposure of such lesions in continuity may give no clue as to the subsequent nerve function to be expected. The surgeon should not resect this lesion when doing nothing, beyond lysis, will result in better recovery than is offered by suture; nor should he settle for lysis when regeneration, to the level offered by suture, will not occur.

Follow-up studies of World War II material do not tell us, in the absence of careful histologic study of resected specimens, the frequency with which suture was carried out when spontaneous regeneration would have given better results. Failure to do suture when spontaneous regeneration would result in poorer function can be ascertained from this material by asking two questions: (a) How many cases ultimately requiring suture were originally treated by lysis? and (b) How many cases, in which lysis was performed, did not achieve an end result in regeneration comparable to the average suture result in this location? It would seem that nerve lesions requiring resection and suture seldom failed to receive such treatment, but that apparently favorable appearing lesions frequently caused a long delay before reexploration and definitive suture were undertaken. At the same

[30] This section is based on the Valley Forge series studied by Dr. Frank E. Nulsen, Dr. William J. Erdman, II, and Dr. Harry W. Slade.

time, data are not available to indicate the frequency of improper resection of favorably regenerating lesions in continuity.

The more recent experience in the study of Korean casualties at Valley Forge Army Hospital from 1951 to 1953 affords more specific information concerning this problem of the neuroma in continuity. Among the cases studied, sutures were performed on 126. In 19 of these latter cases the surgeon found his decision difficult because of a high degree of gross continuity. Nine of these examples (cases 2 through 10) are presented below, beginning with those showing the greatest degree of neurotization in the distal segment by histologic study. Case 1 is presented as a lesion whose unfavorable status, as suggested by gross appearance, was not contradicted by histologic study, but by subsequent physiologic evidence, since resection and suture were impossible. The case method of presentation has been selected to reiterate the following rules of procedure.

1. In the absence of gross discontinuity, it may be impossible to judge the regenerative capacity of a nerve lesion from its appearance and consistency.
2. If resection of a lesion consistent with better recovery than is possible by suture is to be avoided, certain indicated sutures must be deferred until time has provided criteria for unsatisfactory regeneration.
3. Such delays will not be excessive if it is remembered that operation was not necessarily definitive and the waiting period, defined by time of injury and distance from lesion to first muscle, is not exceeded. Even the lesion which appeared favorable at surgery must be resected when the criteria for satisfactory regeneration are not fulfilled on schedule.
4. Early exploration of all nerve lesions associated with major dysfunction is still the best expedient, since the majority of indicated sutures are associated with a finding of gross discontinuity. A policy of awaiting physiologic clarification would have the advantage of avoiding exploration of nerves not requiring suture but would have the far greater disadvantage of delaying the many sutures that can be instituted on the finding of gross discontinuity at early operation.

2. Illustrative Cases

Case 1. This patient sustained a penetrating shell fragment wound just below the right gluteal fold in August 1950. Seven months after injury there was a total motor and sensory paralysis of the sciatic nerve with a suggestion of a Tinel's sign extending to the popliteal space. Nerve stimulation of the sciatic nerve with needle electrodes caused neither visible motor response nor action potentials on recording from the gastrocnemius and the peroneus longus. With the long distance to grow from this high sciatic lesion, this negative physiologic evidence did not necessarily classify the lesion as an unfavorable one but exploration was undertaken on the possibility that a major disruption would be discovered.

At exploration 7 months after injury, the sciatic nerve was found to be involved, over a 14-cm. distance, in dense scarring with 3 separate fusiform enlargements which were stony hard to palpation. (See plate 38.) The surgeon believed the gross appearance of the lesions was so unsatisfactory as to warrant resection and suture on this evidence alone. He settled for a neurolysis only because approximation of the nerve ends for suture would have been impossible if the entire area of involvement had been resected.

Plate 38. *Operative photograph showing three separate fusiform enlargements over a 14-cm. distance on the sciatic nerve (case 1). Hemostat in middle of photograph points to the middle lesion.*

Contrary to the poor prognosis given by the surgeon, plantar flexion of the foot was noted 10 months after injury and dorsiflexion of the foot began at 12 months. Final examination of the patient 17 months after injury revealed 80 percent strength in plantar flexion and 50 percent strength in inversion of the foot. The peroneal muscles were able to evert the foot against gravity but not against resistance while dorsiflexion of the foot could be done against 4 pounds resistance. There were barely perceptible toe flexion and absent toe extension. The patient could walk satisfactorily without a brace, exhibiting no tendency toward foot-drop during ambulation. Forty gm. pain stimulus could be felt throughout the foot and lateral aspect of the leg.

Comment. It was entirely fortuitous that these lesions in continuity, which were consistent with a degree of regeneration far exceeding what could be achieved by the best sciatic suture at the level of the buttock, were not resected. The gross appearance seemed inconsistent with recovery and only the technical impossibility of suture resulted in conservative management. This case example points out that when the gross appearance suggests that reasonable regeneration is conceivably possible, there being no obvious discontinuity, a decision for resection should be delayed until physiologic evidence can clarify the picture. One would here have waited 12 months with 12 inches to grow to the most proximal muscle, the gastrocnemius. Actually the first evidence of recovery in this muscle occurred at 10 months and even with this long interval for first evidence of regeneration, the end result was well above the average seen after sciatic nerve suture.

Case 2. This soldier sustained on April 19, 1951, a shell fragment wound in the left upper arm with involvement of the ulnar nerve at a point 5 inches above the elbow.

At 2 months after injury, a neuroma could be palpated at the site of injury and its manipulation caused tingling in the fourth and fifth fingers. There was no definite Tinel's sign below the lesion. Sensation was disturbed in the ulnar sensory area but the ulnar autonomous zone perceived 10-gm. pain and 4-gm. touch stimuli with good localization. The ulnar forearm muscles (flexor carpi ulnaris and long flexors to fourth and fifth fingers) showed 30 percent strength. Ulnar intrinsic muscles, such as the abductor digiti quinti and first dorsal interosseous, showed visible contraction insufficient to move the fingers. Electrical stimulation of the ulnar nerve produced muscle contraction of the same magnitude. Most important of all, from a functional standpoint, was the patient's ability to open his fingers to their full extent without the disabling fourth and fifth finger clawing that characterizes most ulnar injuries.

At 2½ months the ulnar nerve was explored because of its palpable involvement in a large and moderately painful neuroma. Neurolysis and transplantation of the nerve were planned. Operation revealed a firm neuroma 3 cm. in length and 2½ cm. in diameter (plate 39). Electrical stimulation of the distal nerve trunk produced ulnar paresthesias and excellent motor response in the flexors of the fourth and fifth fingers and the flexor carpi ulnaris. Nevertheless, the gross appearance of the nerve seemed inconsistent with good regeneration so that all of the involved nerve was resected to normal ends. The distal segment was transplanted anteriorly to shorten its course, and the nerve sheaths were approximated with fine tantalum sutures.

Microscopically the center of the lesion in cross section (plate 40) shows an abundance of thickened collagenous material with disruption of some but not all nerve fascicles. However, widely separated myelinated fibers can be distinguished (plate 41). Comparison of proximal and distal cross sections reveals a surprising degree of continuity (plates 42–43). Actually, 50 percent of the myelineated fibers present proximally have passed through the lesion into the distal trunk, as seen in high power (plate 44). These are mature axons and their presence in the distal trunk at 2½ months after injury cannot be the result of regeneration; these are axons so mildly damaged that distal degeneration did not occur. Partial motor and sensory function had become manifest in muscles and skin 20 inches distal to the lesion very early after injury. In addition, a generous supply of amyelinated fibers in all three sections indicates the beginning of a rich regenerative process which would have made an additional contribution to function. The extent of distal neurotization was estimated at 70 percent.

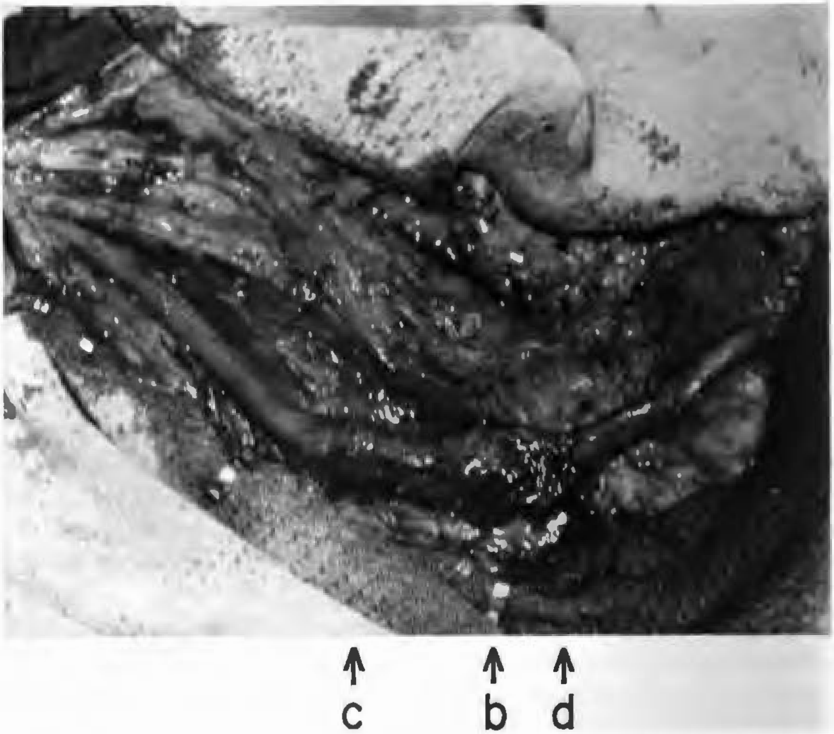


Plate 39. *Operative photograph (case 2) showing the grossly scarred and thickened neuroma in continuity. Lines b, c, and d indicate the regions from which subsequent figures were prepared.*

Following suture this patient ultimately showed the incomplete regeneration which appears to characterize all ulnar sutures performed at a level above the elbow. The forearm muscles began contracting 5 months after operation and reached a strength of 30 percent which is quite adequate for useful grip. But the intrinsic hand muscles, which began recovering on schedule at 9 months, never developed more than 5 percent strength. Sensory recovery was good (10-gm. pain and 4-gm. touch thresholds) but there remained striking mislocalization. Although innervation occurred in all ulnar intrinsic muscles, it was no longer sorted out so as to produce the coordination of interosseous and lumbrical function required for the full opening of the fourth and fifth fingers necessary for grasping large objects, a function which was present preoperatively despite minimal motor innervation.

Comment. These are the expected limitations of ulnar nerve regeneration from a high level. Actually regeneration was far better than average for a suture in this location, yet this patient had a better functioning hand before operation and before spontaneous recovery had reached its peak. The gross appearance of the nerve lesion caused the surgeon to choose the known result of suture to the unknown result of spontaneous regeneration.

403130—57——40

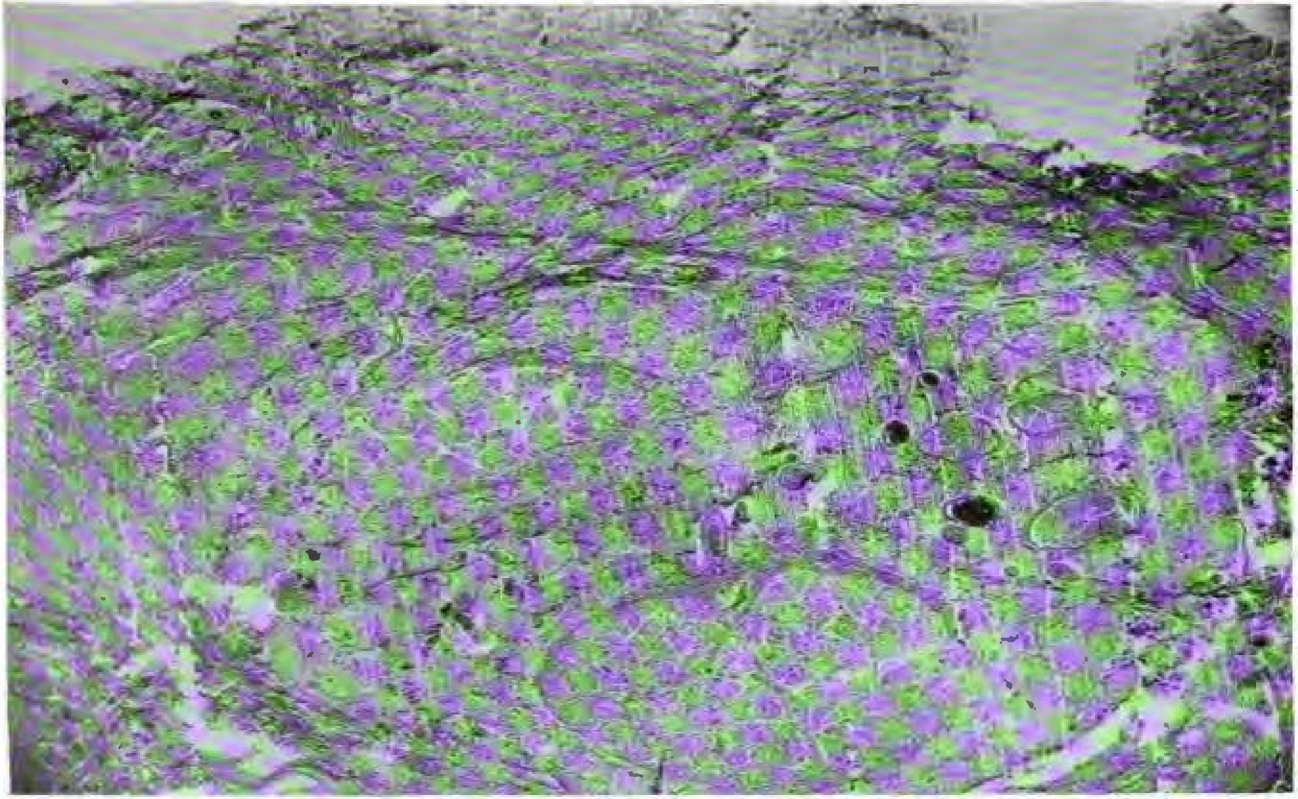


Plate 40. *Cross section through center of lesion (case 2) showing the abundance of thickened collagenous material with disruption of some but not all nerve fascicles. Note the relative intactness of one large and several smaller fascicles (30 x). All are Bodian stains.*

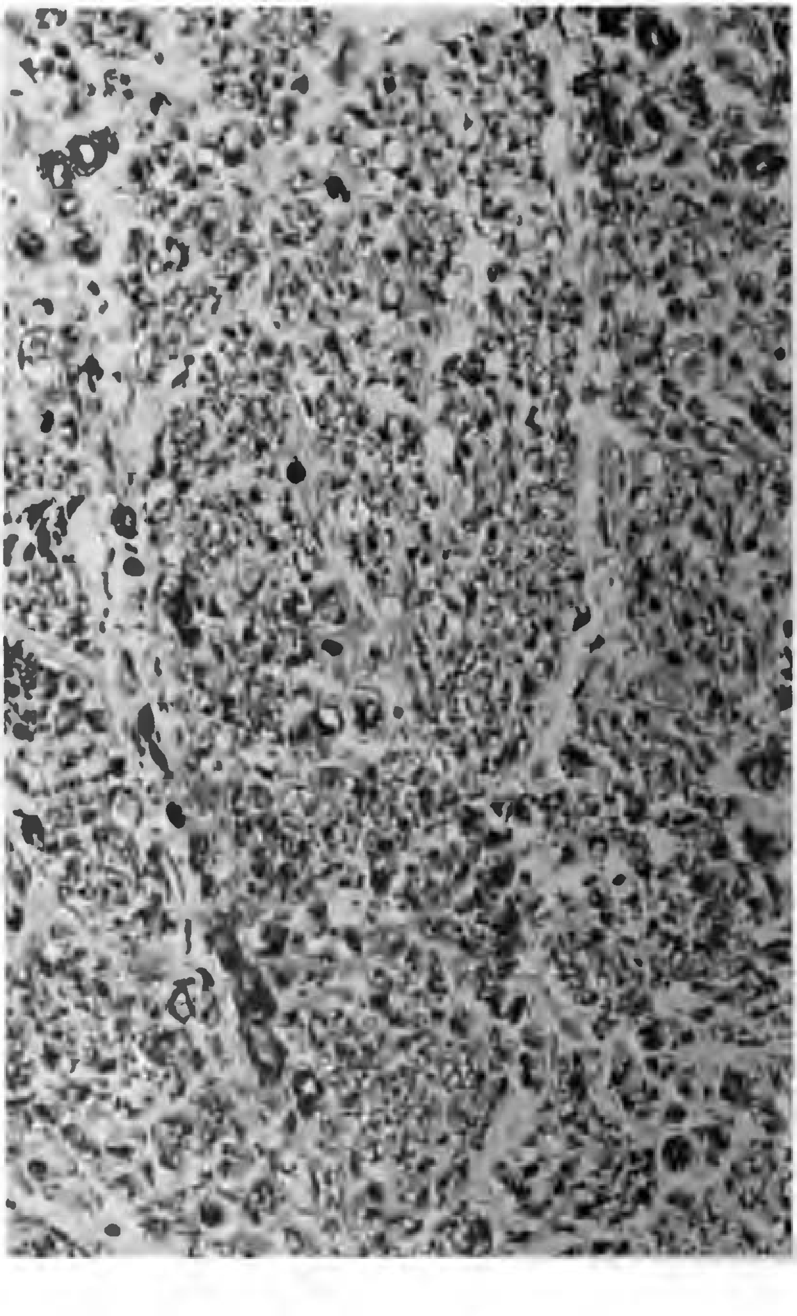


Plate 41. *Higher magnification of center of lesion (case 2) showing many dispersed myelinated nerve fibers (430 x).*

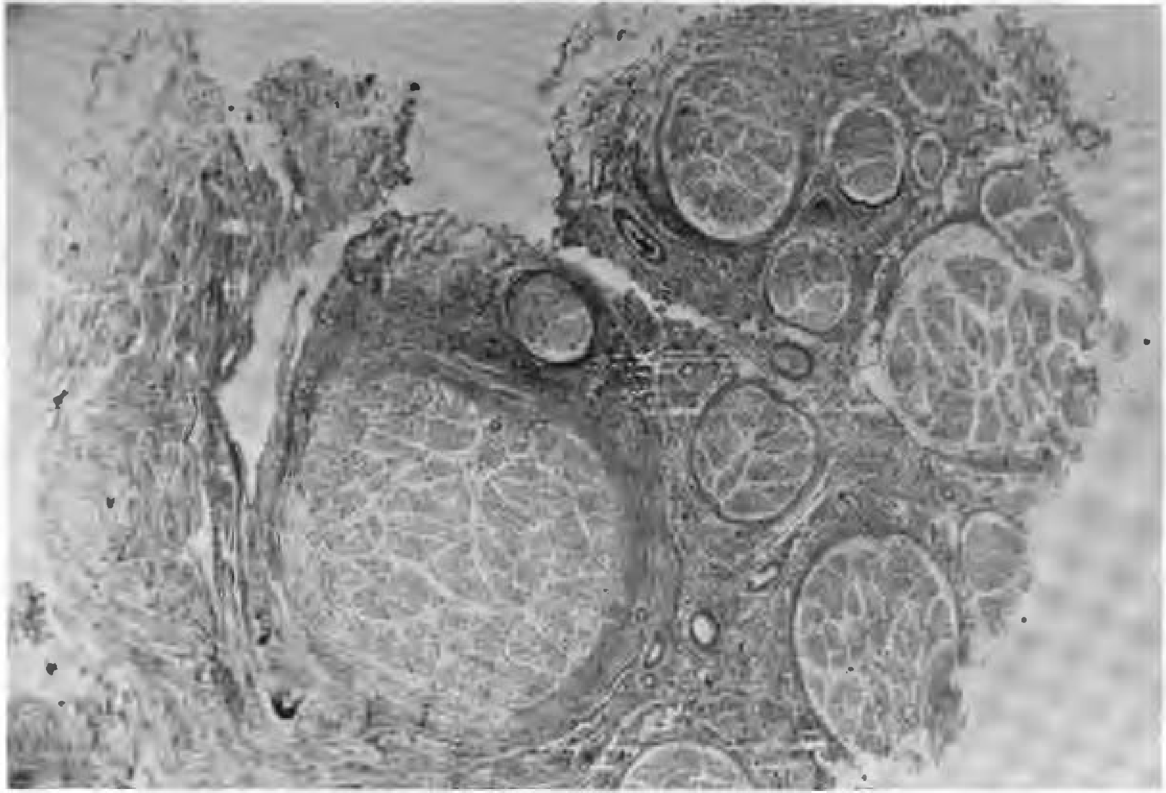


Plate 42. *Cross section through proximal end of lesion (case 2) showing some degree of collagenous thickening but preserved fascicles (30 x).*

Plate 43. *Cross section through distal end of lesion (case 2) showing moderate degree of collagenous interfascicular thickening with preservation of gross continuity of the majority of the fascicles (30 x).*

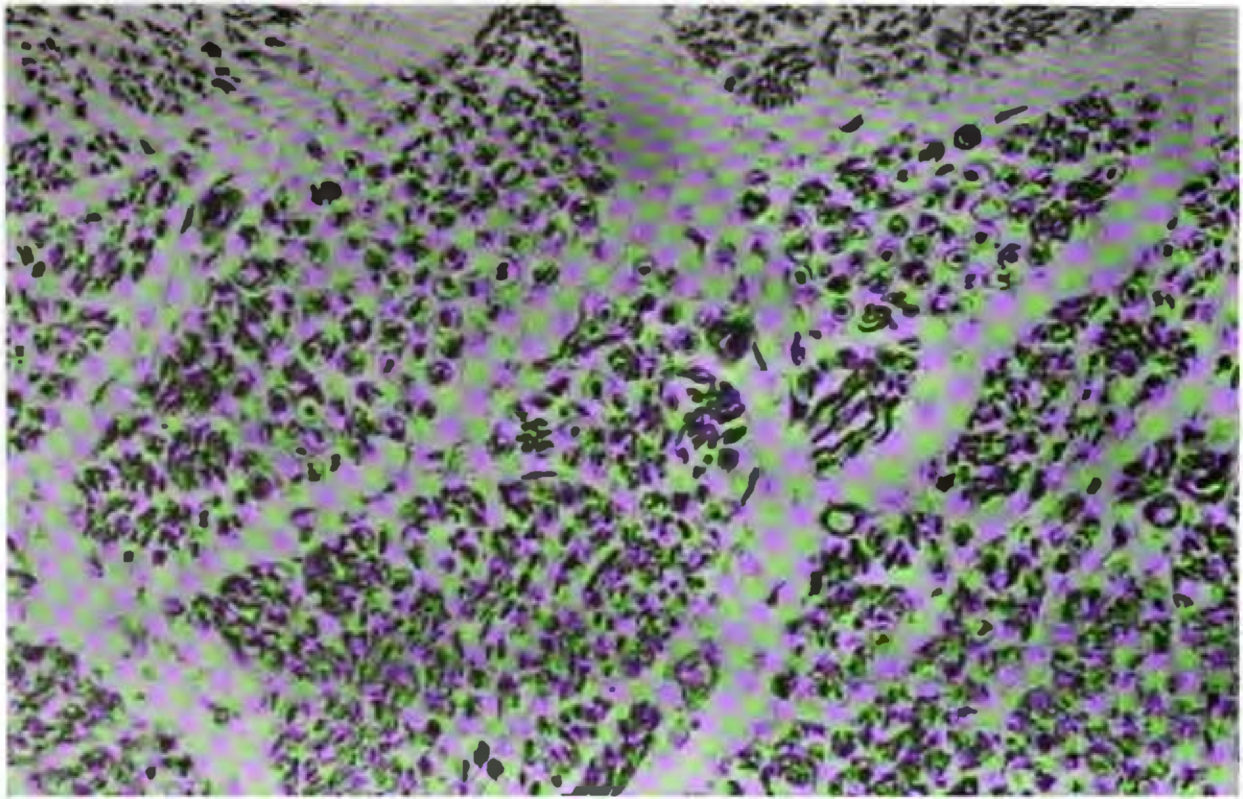


Plate 44. *Higher magnification of distal end of lesion (case 2) showing well-myelinated nerve fibers (430 x).*

In this case, however, those axons which were spared had already established better practical function of the hand than could be yielded by suture. The ulnar nerve is somewhat unique in that weak but coordinated intrinsic muscle function resulting from axon preservation is better than strong uncoordinated function resulting from axon regeneration. A tender neuroma which can be transplanted to a protected location is not in itself an indication for resection and its appearance can be deceiving in terms of the neuronal continuity and regeneration which actually exist. The satisfactory result of suture did not produce a functional end result comparable to the result here possible by preserving the lesion in continuity.

Case 3. In February 1951 a gunshot wound above the head of the fibula resulted in a total peroneal nerve paralysis. At 3 months after injury a palpable thickening could be felt in the peroneal nerve approximately 4 inches from its first motor branch to the peroneus longus. The only evidence for regeneration consisted in a Tinel's sign distal to the lesion, there being no sensory or motor function. EMG recording from the peroneus longus during nerve stimulation and voluntary effort showed no action potentials. Although the interval since injury was short, operation was advised.

Four months after injury operation revealed a definite thickening in the peroneal nerve trunk extending over a distance of 2 cm. When again no motor response, and only slight sensory response, occurred on direct stimulation of the distal trunk, it was elected to resect 2 cm. of nerve with subsequent suture. Gross appearance is shown in plate 45. The proximal cross section shows a high proportion of amyelinated fibers to suggest that damage has actually extended well above the proximal face of the section despite the normal gross appearance of the proximal nerve trunk. Distally there is the impression that fully 60 percent of the neurons have regenerated through the lesion as amyelinated fibers. This histologic picture might well have been correlated with adequate regeneration if a longer test of time had been allowed for physiologic evidence of innervation.

This patient was followed up to 14 months after operation. By 4 months he had developed a flicker of voluntary contraction in his peroneus longus but at 14 months both peroneus longus and tibialis anticus contracted just sufficiently to evert and to dorsiflex the foot against gravity, not against resistance. The action potentials on nerve stimulation amounted to only 3 percent of normal. This patient ultimately attained sufficient dorsiflexion to discard his brace but his result was below average for peroneal sutures near the knee.

Comment. Three months was an insufficient interval after injury for a test of the potentialities of spontaneous regeneration through this lesion. It was proper to explore the lesion with a high probability that a situation of minimal gross continuity would be found so as to call for early suture without further weeks of waiting for physiologic clarification. But with the finding of a gross lesion that could be consistent with regeneration it is mandatory to await the deadline for physiologic evidence of recovery. In

Plate 45. *Operative photograph showing hemostat pointing to a thickening of the peroneal nerve over a distance of 2 cm. (case 3).*

this particular situation an additional 2 months' waiting would have been indicated.

Case 4. A wound to the left forearm, four inches below the elbow, was incurred in February 1951 with paralysis of the ulnar nerve. Three months later it was seen that the ulnar forearm muscles were functioning well with the presumption that the nerve trunk was damaged at a point below their branches. No type of sensation could be perceived in the ulnar autonomous sensory zone and no motor function was elicited from ulnar intrinsic muscles on voluntary effort or on nerve stimulation. No motor units were seen on EMG recording from the abductor digiti quinti. There was a Tinel's sign progressing to the wrist. With 8 inches to grow to the first signal muscle, the abductor digiti quinti, it was believed another 3 to 4 months might be required to clarify the status of the lesion on physiologic grounds since the Tinel's sign could occur with only minimal continuity. Exploration of the lesion was therefore undertaken.

At 3½ months after injury, exploration of the ulnar nerve in the upper forearm revealed a lesion in continuity. The nerve was firm over a 3-cm. distance and showed a fusiform enlargement in the midpoint of this involved segment measuring roughly twice the diameter of the normal segments on either side. Stimulation of the distal trunk caused the patient to experience ulnar paresthesias but there was no motor response. Because the lesion was so firm as to suggest dense scarring internally, resection was carried out and the 3-cm. gap was made up by transplantation anterior to the elbow.

Microscopically the proximal cross section showed minimal connective tissue between the nerve fascicles and 80 percent of the axons showed myelinization. A cross section through the center of the fusiform enlargement suggested that at least 60 percent of the area was occupied by scar tissue while only a small proportion of the axons so diffused by this fibrous proliferation showed recognizable myelin sheaths. However, in the distal cross section (plates 46–47), one sees again very little connective tissue with axons numbering at least 50 percent of the amount observed proximally, while over half of these axons showed early myelinization. Here then is another example of a marked degree of interval scarring which, although diffused through the entire cross section of the nerve segment, has failed to prevent a high degree of regeneration into the distal segment.

Nine months postoperatively, with 8 inches to grow to the abductor digiti quinti, there was a barely visible contraction in this muscle on voluntary effort and a definite contraction was seen on nerve stimulation. A pain stimulus of 40 gm. could be felt in the ulnar autonomous zone. Fortunately, this patient had not developed the usual clawing of the fifth finger and showed already a relatively useful hand from a gross mechanical standpoint so that he was discharged with the anticipation that further ulnar motor and sensory function could be expected.

Comment. Here the surgeon resected a neuroma in continuity at 3 months after injury when the lesion was situated too far from the first signal muscle to allow a physiologic appraisal of potential for regeneration. The microscopic studies indicated that a regenerative process was under way which would have exceeded the best results achievable by suture. Resection should have been postponed until physiologic signs could clarify the degree of spontaneous regeneration, 2 to 3 additional months in this case. It is also worthy of note that electromyography did not assist in predicting the high degree of spontaneous regeneration which was taking place according to microscopic evidence.

Case 5. On October 16, 1950, a shell fragment produced a mixed laceration and crushing injury of the left forearm centered at a point 4 inches above the wrist. The left ulna bone was fractured, there was direct involvement of flexor muscles and tendons, and an immediate total ulnar nerve paralysis occurred.

At 9 months after injury, there were visible voluntary contractions in such ulnar intrinsic muscles as the abductor digiti quinti and the first dorsal interosseous; these were barely sufficient to cause abduction of these fingers. Nerve stimulation caused slightly stronger contractions than observed on voluntary effort. There was rigid clawing of the fourth and fifth fingers and fixation of joints which could be attributed to the combination of ulnar intrinsic muscle loss, direct soft tissue damage in the forearm to the flexor muscles, and a long period of splinting after resurfacing of the forearm by plastic procedures. From a sensory stand-

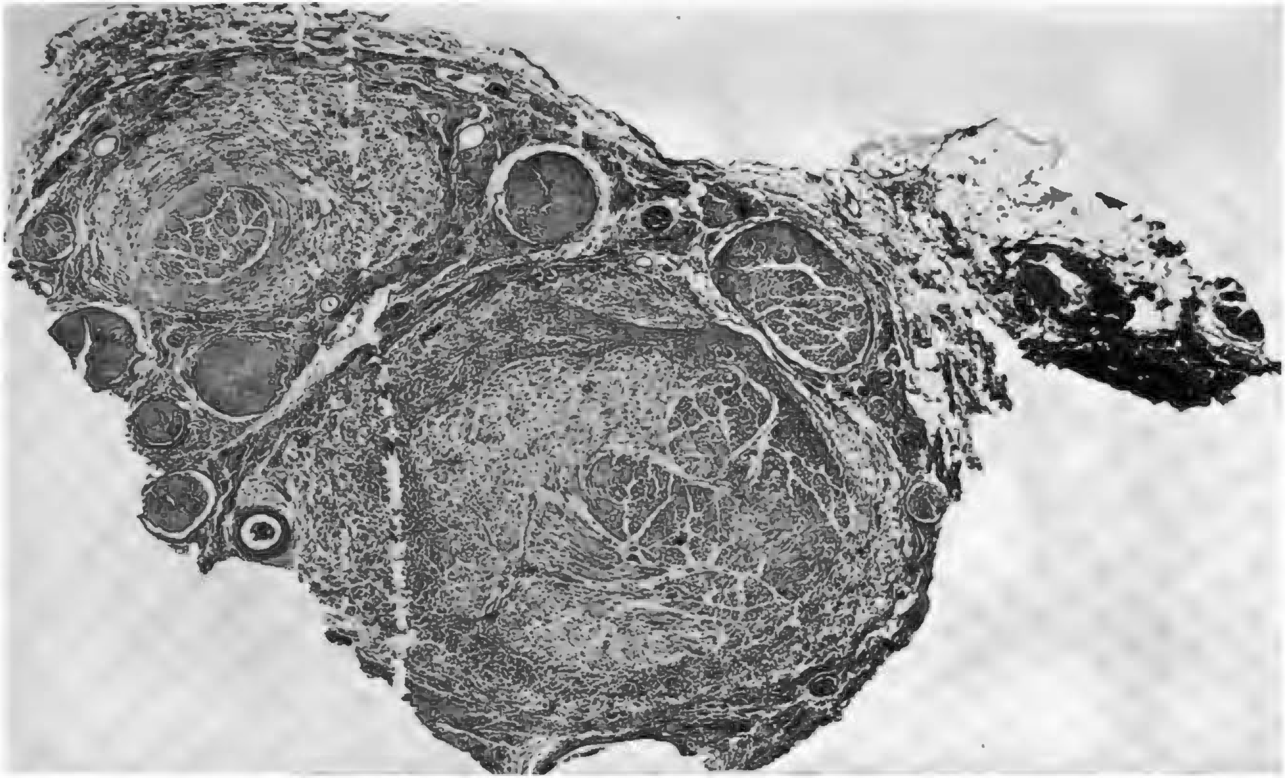


Plate 46. *Cross section through the distal end of the lesion (case 4) showing moderate degree of fibrous proliferation in the interfascicular and intrafascicular areas with relative sparing of some fascicles from this connective tissue reaction (30 x).*

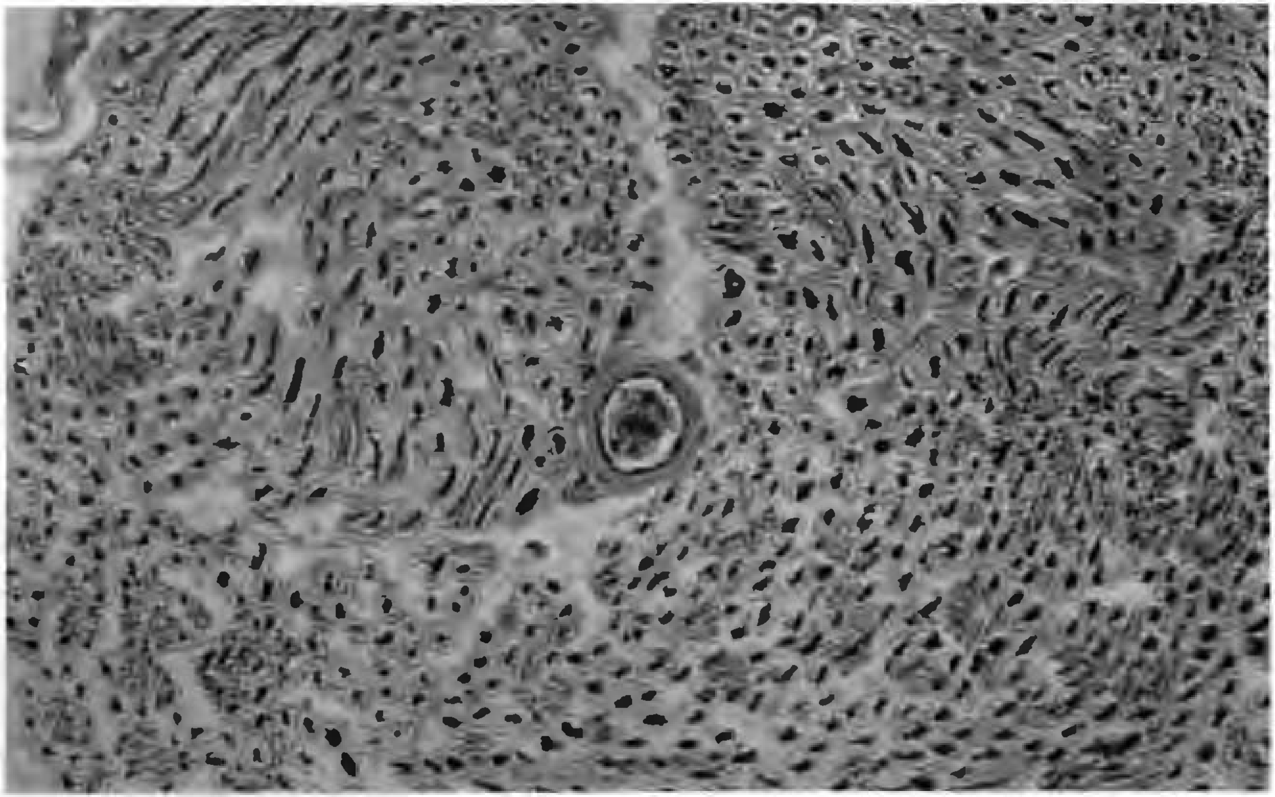


Plate 47. *Higher magnification of one of the spared fascicles (case 4) showing well-myelinated nerve fibers with no evidence of intrafascicular tissue reaction.*

point, 4 gm. pain and 1 gm. touch stimuli were perceived throughout the ulnar sensory area. In summary, with sufficient time elapsed to approach an end point in spontaneous regeneration, this lesion had permitted considerably better sensory recovery and slightly worse motor recovery than could be expected from a suture at this level. The marked clawing of the hand would not have been overcome by further motor recovery since there was a mechanical limitation imposed by flexor contractures and stiff joints.

Operative exploration was nevertheless carried out shortly thereafter with disclosure of a lesion in continuity extending over a 3-cm. distance. (See plate 48.) Because this lesion was stony hard and irregular in appearance, it was excised over this 3-cm. length with end-to-end approximation of the nerve ends.

The microscopic sections (plates 49 through 51) show a reasonably rich regeneration of amyelinated fibers into the distal end to suggest that roughly 40 percent of the proximal axons have regenerated past the lesion. At the same time a limited degree of myelinization is seen to be going on distally. This degree of microscopic continuity can be correlated with a functional end result, after 9 months' spontaneous regeneration, which is close to the level of function expected after a suture at this level if it is recalled that motor function would be limited by joint and tendon changes. It is also of interest that this extensive crushing type of injury had damaged the proximal nerve beyond the limits of resection of grossly abnormal tissue with the result that the proximal face of the suture gave the appearance of being downstream from an area of considerable damage.

By 6 months after suture, with some 5 inches to grow to the abductor digiti quinti, the patient still exhibited no voluntary action in this muscle but showed a definite contraction on ulnar nerve stimulation. Forty gm. pain stimulus could be felt in the ulnar autonomous zone. By 9 months after operation, at a time close to the end point of expected improvement from regeneration, there was approximately the same degree of weak action in the abductor digiti quinti and first dorsal interosseous as obtained preoperatively. Sensory thresholds had dropped to 20-gm. pain and 6-gm. touch with striking mislocalization. Tendon lengthening, capsulotomies at the joints, and sublimis transfers to the fourth and fifth lumbrical canals were being considered to correct the marked clawing of the fourth and fifth fingers.

Comment. Resection of the neuroma in continuity with suture yielded about the same amount of motor and sensory function that had been obtained by spontaneous regeneration. With satisfactory sensation initially, it would have seemed preferable to attempt improvement of mechanical function of the hand by orthopedic substitutive procedures since the limitations in movement were not to be altered by even a marked improvement in the motor function of the ulnar intrinsic muscles. With the long lapse of time since injury, the motor and sensory function of this neuroma in continuity was a much better indication of the regenerative process as

Plate 48. *Photograph of gross specimen (case 5). The grossly abnormal appearance is obvious. Suture identifies proximal end. Lines b and c indicate the regions from which subsequent figures were prepared*

Plate 49. *Cross section through the proximal end of lesion (case 5) showing the moderate interfascicular thickening and adherence of perineurium to surrounding tissues with relatively intact fascicles (30 x).*

Plate 50. *Cross section through distal end of lesion (case 5) showing marked degree of interfascicular thickening with preservation of a fair number of small fascicles (30 x).*

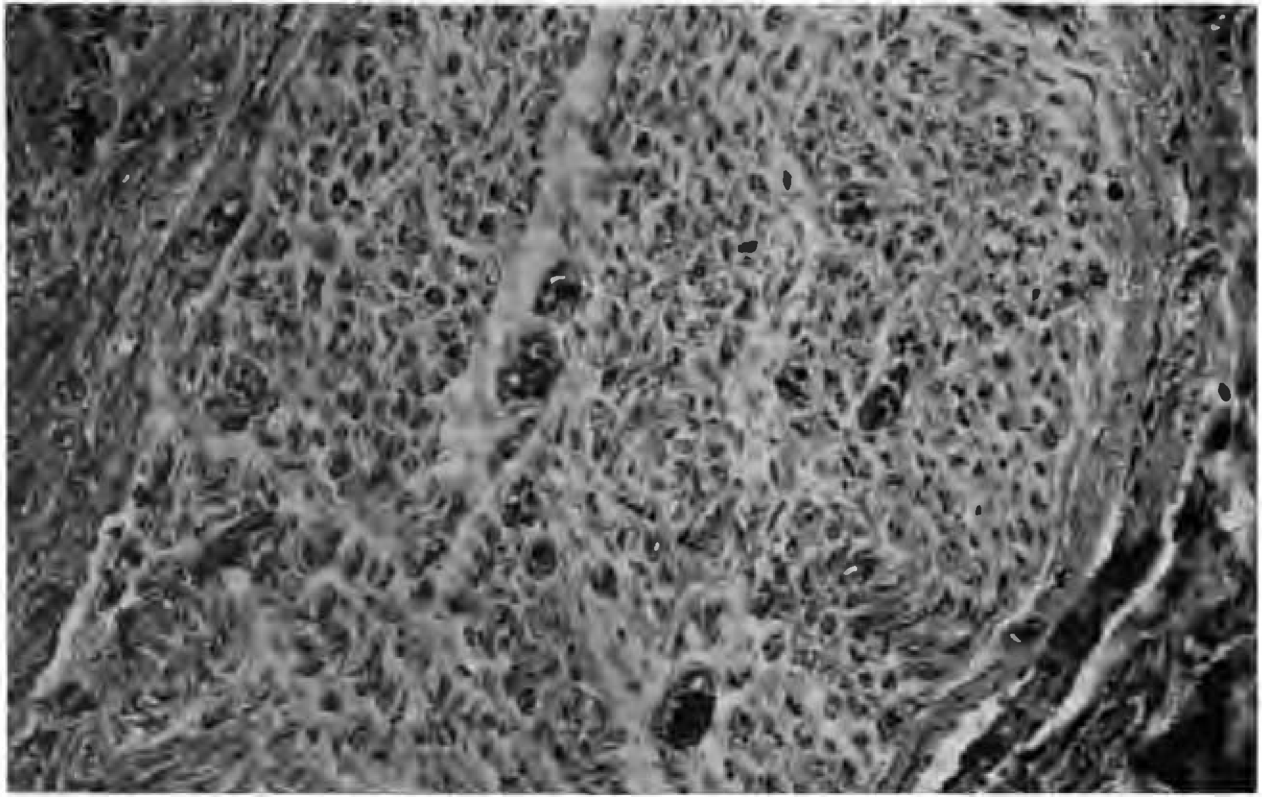


Plate 51. *Higher magnification of distal end of lesion (case 5) showing an area of well-myelinated nerve fibers (430 x).*

confirmed by histologic study than was the gross appearance of the lesion at operation. This particular histologic picture gives a roughly quantitative idea of that degree of anatomic regeneration which is correlated with a physiologic result that is achieved by the average suture in this location.

Case 6. This patient sustained a shell fragment wound at the right axilla on October 10, 1950, with immediate paralysis of the median nerve. Six weeks later he showed a definite voluntary contraction of the flexor carpi radialis without motor function distal to this point. There was no evidence of median sensory recovery. There was a Tinel's sign down to the elbow. At this short interval after injury, this appeared to be good evidence for satisfactory regeneration. However, at 8 months after injury, with 10 inches to grow to the median forearm muscles, there had developed only 25 percent function in the flexor carpi radialis and a trace of voluntary movement in the flexor indicis proprius. Stimulation of the median nerve resulted in only this same amount of motor response as was observed on voluntary effort with no action in the long flexor to the thumb or the intrinsic muscles of the hand. Tinel's sign had extended to the wrist and a pain stimulus of 40 gm. could be felt throughout the median autonomous zone. It was considered that this level of regeneration after 8 months was unsatisfactory and exploration should be carried out.

The median nerve was exposed in the axilla 8 months after injury and there was disclosed a fusiform neuroma in continuity, 2.9 cm. in length, with a rather firm consistency (plate 52). At its thickest point this lesion was roughly two times the diameter of the slightly shrunken distal trunk. Stimulation produced the same degree of limited motor response observed in preoperative testing. The involved area was resected and the nerve ends were approximated.

On microscopic examination the proximal cross section showed a minimum of connective tissue with roughly equal proportions of myelinated and amyelinated axons. The distal end showed that roughly 40 percent of these axons had traversed the scar and one-fifth of these showed myelinization.

By 6 months after suture there was again a flicker of voluntary action and some response to nerve stimulation in the flexor carpi radialis. Because it seemed unlikely that there would ever be any recovery of median intrinsic muscles, a tendon transfer was done to supply opposition of the thumb, utilizing the flexor carpi ulnaris. By 10 months after operation there was a 15 percent contraction in the flexor carpi radialis with no function in the thumb or index long flexors by voluntary effort or on nerve stimulation. Deep pressure could be felt as pain in the tips of the index and middle fingers but a 40-gm. pain stimulus could still not be perceived. The patient had excellent opposition of the thumb by virtue of this tendon transfer and was able to pick up small objects between thumb and middle finger with visual aid. He was limited chiefly by his median sensory deficit and was discouraged at this time since no further therapy was indicated regardless of the degree of subsequent recovery attained.

Comment. Although this man at 8 months after injury seemed destined for an unsatisfactory degree of spontaneous recovery, microscopic study of the resected lesion revealed a level of regeneration which, when seen in distal lesions of long standing, had been consistent with as much function as could be obtained with suture. In other words, with involvement of the median nerve at an unfavorable level high in the axilla, this patient was presumably on the way to better functional recovery than could be offered by suture at this location. He was not followed to an end point in his regeneration from suture but did show less nerve function 10 months after suture than he had exhibited by virtue of spontaneous recovery 8 months after injury. In retrospect, it seems clear that his relatively low grade median recovery

Plate 52. *Operative photograph illustrating the fusiform neuroma in continuity 2.9 cm. in length (case 6).*

should have been accepted as the best possible in the face of a high lesion. Motor deficits should have been corrected by tendon transfers when he was showing good sensory recovery. An attack on the nerve not only failed to improve motor deficits, for which there were alternative means of correction, but undoubtedly resulted in a lesser degree of final sensory recovery. Again this gross appearance of a bulbous neuroma in continuity is in contrast to the microscopic and physiologic evidence for a degree of regeneration certainly as good as could be achieved by suture.

Case 7. This soldier sustained a bullet wound to the lower left forearm in January 1951. Three months later there was a complete ulnar motor and sensory deficit. However, on EMG recording from the abductor digiti quinti there was a definite action potential in response to ulnar nerve stimulation. In addition, a Tinel's sign extended to the wrist.

Clearly there was some continuity through the lesion but since, with 5 inches to grow, an additional 2 months might be required to clarify the adequacy of regeneration by abductor digiti quinti function, surgical exploration was advised with consideration of resection and suture only if there were gross discontinuity.

At operation 4 months after injury a bulbous neuroma in continuity was discovered. Stimulation below the lesion resulted in ulnar paresthesias but, as expected, did not yield motor response. Because of the poor gross appearance of the nerve, resection was done and suture was accomplished after ulnar nerve transplantation at the elbow permitted approximation of the ends.

Microscopically the proximal and distal sections show little scarring with at least 40 percent continuity of axons although the proportion of myelinated axons has dropped from 70 percent to 10 percent. These findings suggest that satisfactory regeneration, or regeneration comparable to an average suture result, would have occurred spontaneously.

Actually this man maintained a useful hand with no clawing, despite his ulnar deficit and was discharged 9 months postoperatively, with good ulnar sensation (10-gm. pain and 4-gm. touch) and 50 percent strength in his abductor digiti quinti and first dorsal interosseous, a better than average suture result.

Comment. This man had a good result from ulnar nerve suture, yet the microscopic studies suggest he would have done as well if left alone. This example illustrates again the difficulty of deciding on the basis of gross appearance alone, when it is too soon for conclusive physiologic evidence, whether a lesion in continuity should be resected.

Case 8. This patient sustained a shell fragment wound 3 inches above the left elbow in August 1950 with a resulting ulnar nerve paralysis. The nerve was explored 4 months later and a firm, fusiform lesion in continuity was discovered. Because the gross appearance of the lesion was not clearly inconsistent with regeneration, with a short interval since injury, only a neurolysis was done at this time. At a time 8 months after injury, 4 months after lysis, the only evidence for regeneration was a Tinel's sign to the wrist.

There was no sensation in the ulnar autonomous zone. Although it was the clinical impression that there was slight activity in the ulnar forearm muscles, no visible response occurred on nerve stimulation nor was there activity in those muscles on EMG recording. Reoperation and suture were advised, but the surgeon who had visualized the original lesion in continuity preferred to give it a further test of time; reexamination at 10 months after injury showed an unchanged picture except that a flicker occurred in the flexor carpi ulnaris on nerve stimulation, a degree of motor function far below that consistent with adequate recovery after so long a time interval. A second exploration was done in August 1951, 12 months after injury. Once again the lesion appeared benign and the surgeon was loath to resect it, especially when stimulation produced a slight flexor carpi ulnaris contraction.

This patient was again evaluated in March 1952, some 19 months after injury, with physiologic evidence having suggested since 6 months after injury that regeneration would be poor. From a motor standpoint he now showed a barely visible flicker of motor activity in the flexor carpi ulnaris on voluntary attempt and on nerve stimulation, while deep flexors to the fourth and fifth fingers were able to move the distal finger tips against ¼ pound resistance, less than 2 percent normal strength. There was no voluntary function in the intrinsic hand muscles but on stimulation there was a visible flicker in the abductor digiti quinti and an action potential in this muscle in response to stimulation which was considered of normal amplitude. From a sensory standpoint, deep pressure could now be felt at the tip of the fifth finger as a diffuse painful sensation and pain stimulation of 40 gm. was perceived one time in four with mislocalization. Actually this patient had a useful hand from the standpoint of gross grasping function and had suffered minimal clawing. There seemed little point in trying to improve nerve function at this late date but he had developed marked tenderness over his neuroma above the elbow. This was considered an indication for operative resection in a situation where little could be lost in terms of nerve function. A third exploration was therefore carried out at 20 months after injury and the fusiform neuroma was resected after stimulalation had given motor response identical to that described in the testing just previous.

The specimen measured 4.4 cm. in length and showed a fusiform enlargement at its center. Microphotographs are shown in plates 53 through 56. The proximal face of this specimen shows equal proportions of myelinated and amyelinated fibers with minimal scarring. The center of the neuroma shows an abrupt decrease in the proportion of myelinated fibers with striking separation of the nerve elements by connective tissue. The distal segment shows 25 percent of the number of neurons seen in the proximal section and about 10 percent of these suggest myelinization. The presence of distal myelinated fibers and the occurrence of even slight motor function on nerve stimulation would constitute a favorable sign for adequate regeneration in the early lesion. However, in this 12-month old lesion

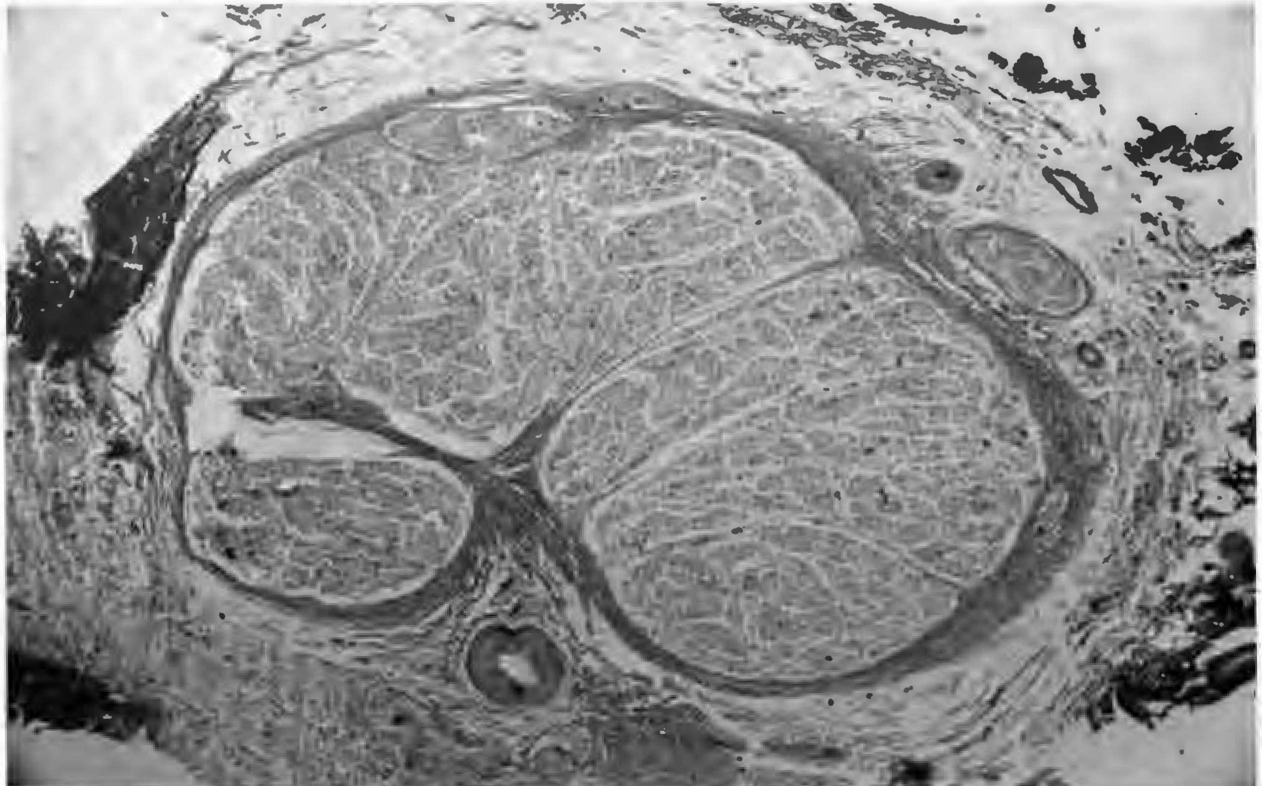


Plate 53. *Cross section through proximal end of lesion (case 8) showing large fascicles with minimal scarring (30 x).*

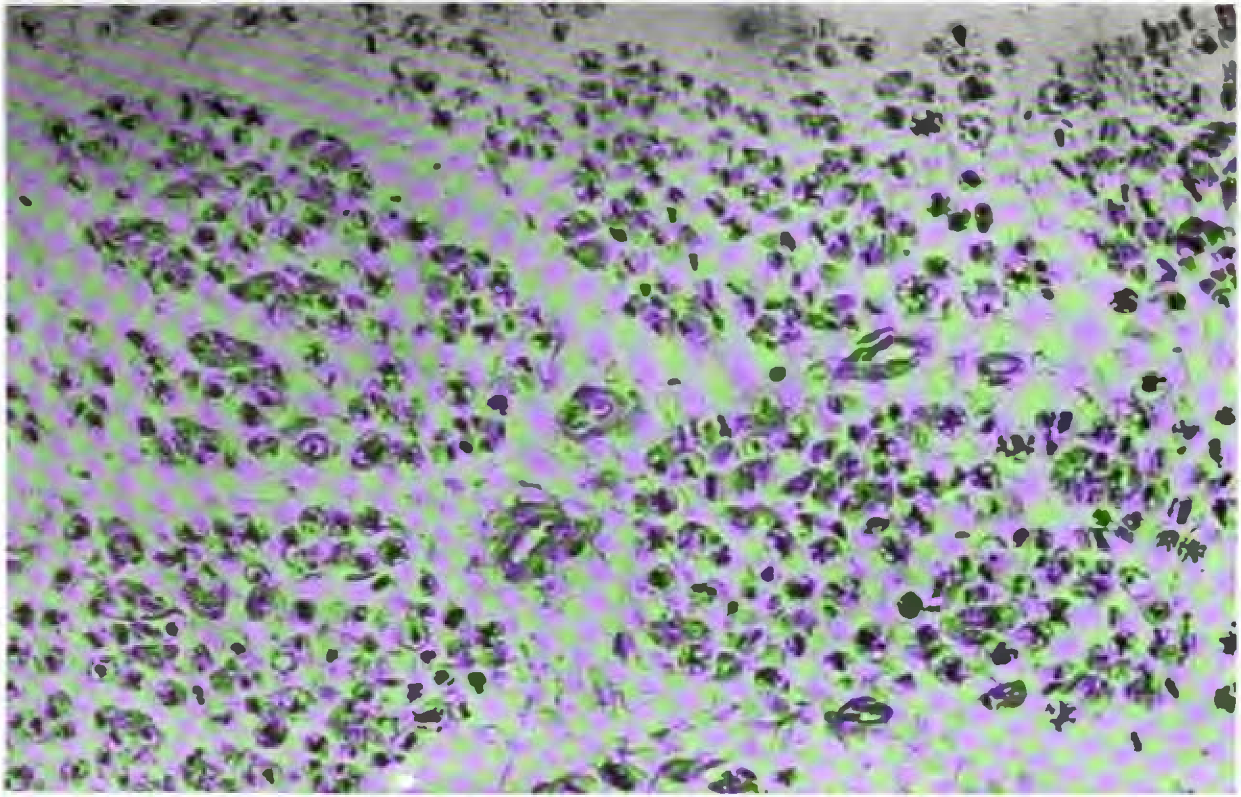


Plate 54. *Higher magnification of proximal end of lesion (case 8) showing equal proportions of myelinated and amyelinated fibers (430 x).*

Plate 55. *Cross section through distal end of lesion (case 8) showing moderate interfascicular and perifascicular scarring with well-preserved fascicles (30 x).*

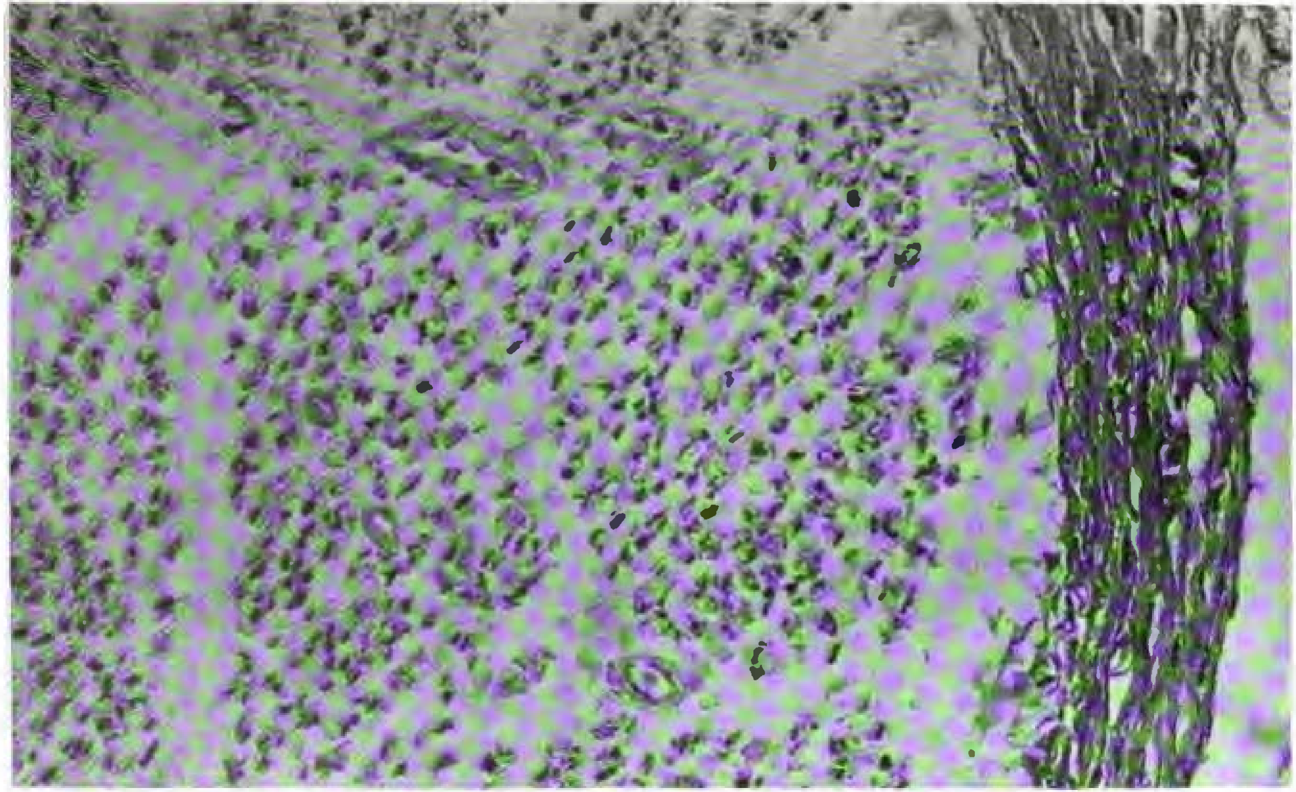


Plate 56. *Higher magnification through distal end of lesion (case 8) showing both myelinated and amyelinated fibers with perifascicular thickening (430 x).*

there is an excellent correlation between both anatomic and physiologic evidence for inadequate regeneration.

This patient was discharged 6 weeks after surgery since he had a relatively useful hand despite his total ulnar deficit and further treatment would not be contemplated regardless of the degree of regeneration he achieved from suture.

Comment. The gross appearance of this lesion in continuity was so favorable that even at 12 months the physiologic evidence for inadequate regeneration was cast aside by the operating surgeon. Adequate regeneration will occur within the limits of a definite time schedule if it is to occur at all. When there is minimal function in a muscle within 6 inches of a lesion at an interval 8 months after injury, further waiting, to 20 months in this case, will not see any practical increment in this function. This first failure in proximal recovery at the same time predicts a similar limitation in subsequent distal motor and sensory recovery. The surgeon was correct in awaiting further developments when he visualized a favorable appearing lesion 4 months after injury. The functional recovery to be expected became defined as inadequate by 6 months after injury when there was nothing to lose and the possibility of a large gain by radical resection and suture. Histologic studies demonstrate the striking discrepancy between the favorable external appearance and the unfavorable internal configuration of this lesion and define a level of regeneration as observed histologically which can be correlated with inadequate physiologic recovery after 20 months of elapsed time.

Case 9. This patient's left ulnar nerve was injured on September 16, 1950, by shell fragments at a level of 5 inches above the elbow. An associated fracture postponed consideration of the nerve lesion until 8 months after injury.

At this time a Tinel's sign extended over a distance of 8 inches below the elbow and it was the clinical impression that there was slight active movement in the deep flexors to the fourth and fifth fingers. There was no sensory recovery in the ulnar autonomous zone. Stimulation of the ulnar nerve above the elbow failed to cause any visible movement in the forearm muscles but a few action potentials could be seen by EMG. There was no evidence for neurotization in the intrinsic hand muscles. It was concluded that since sufficient time had elapsed for satisfactory regeneration of the forearm muscles and this had not occurred, suture of the ulnar nerve should be undertaken even if a lesion in continuity were discovered. At operation, 9 months after injury, the lesion was found to consist of a bulbous proximal end in perhaps 50 percent gross continuity with a mildly shrunken distal nerve end. Some 6 cm. were resected and a satisfactory suture accomplished.

Histologic study (plates 57 through 59) shows an apparently healtyh appearing proximal end containing a high proportion of myelinated fibers while in the distal end myelinization is scant and it is estimated that only 20 percent of the proximal neurons have continuity with distal amyelinated

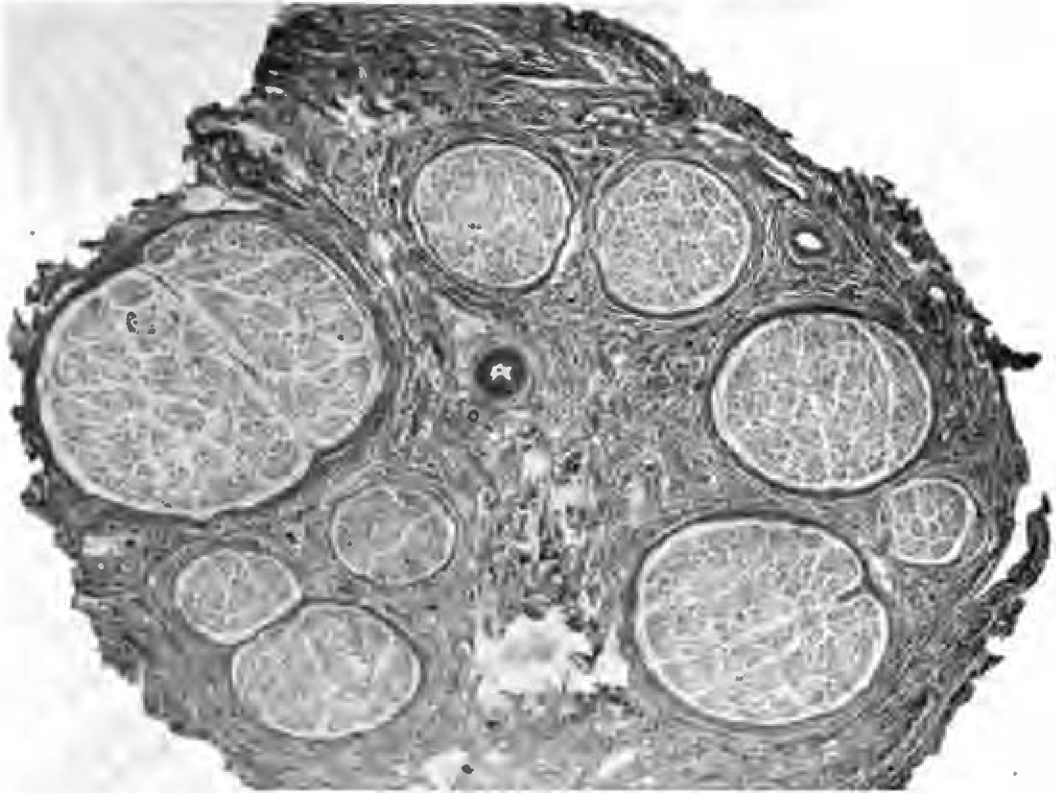


Plate 57. *Cross section through proximal end of lesion (case 9) showing moderate to marked interfascicular scarring with well-demarcated fascicles and patent central artery (30 x).*

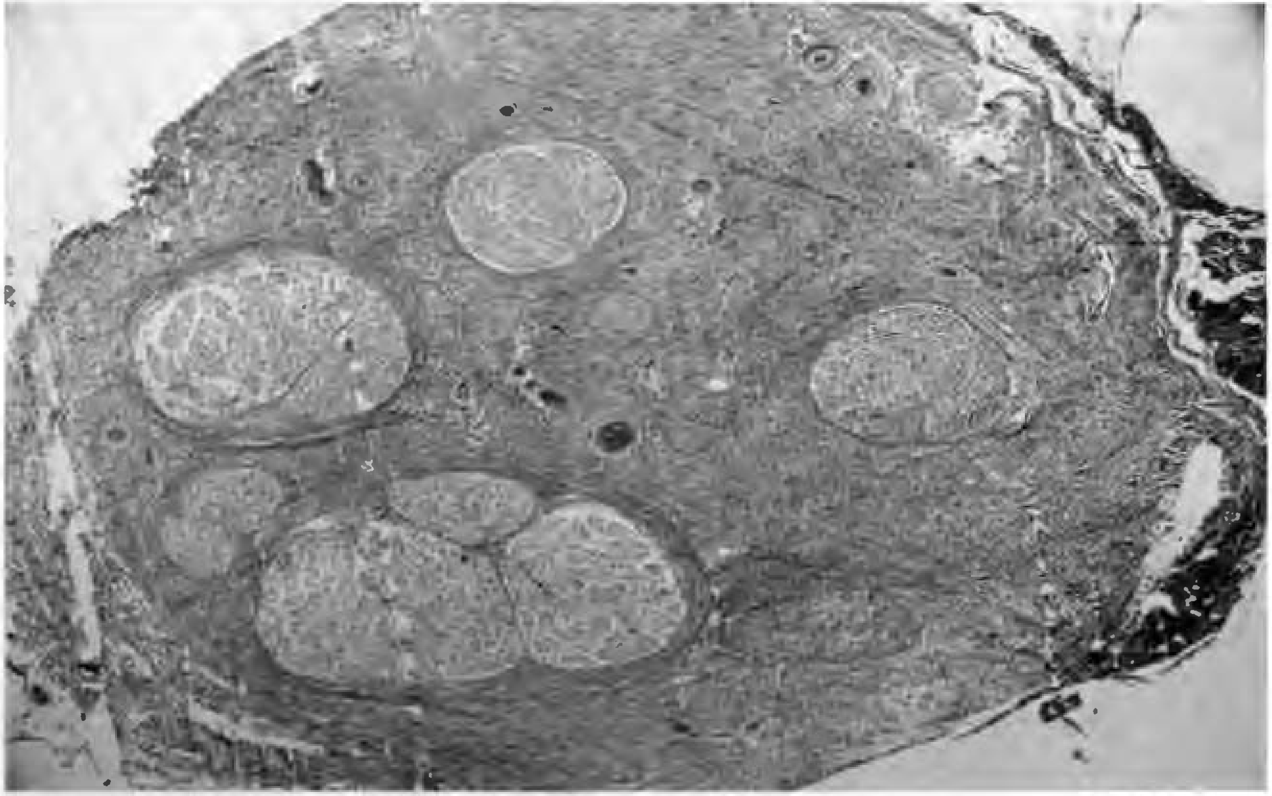


Plate 58. *Cross section through distal end of lesion (case 9) showing marked interfascicular scarring with preservation of several well-organized fascicles (30 x).*

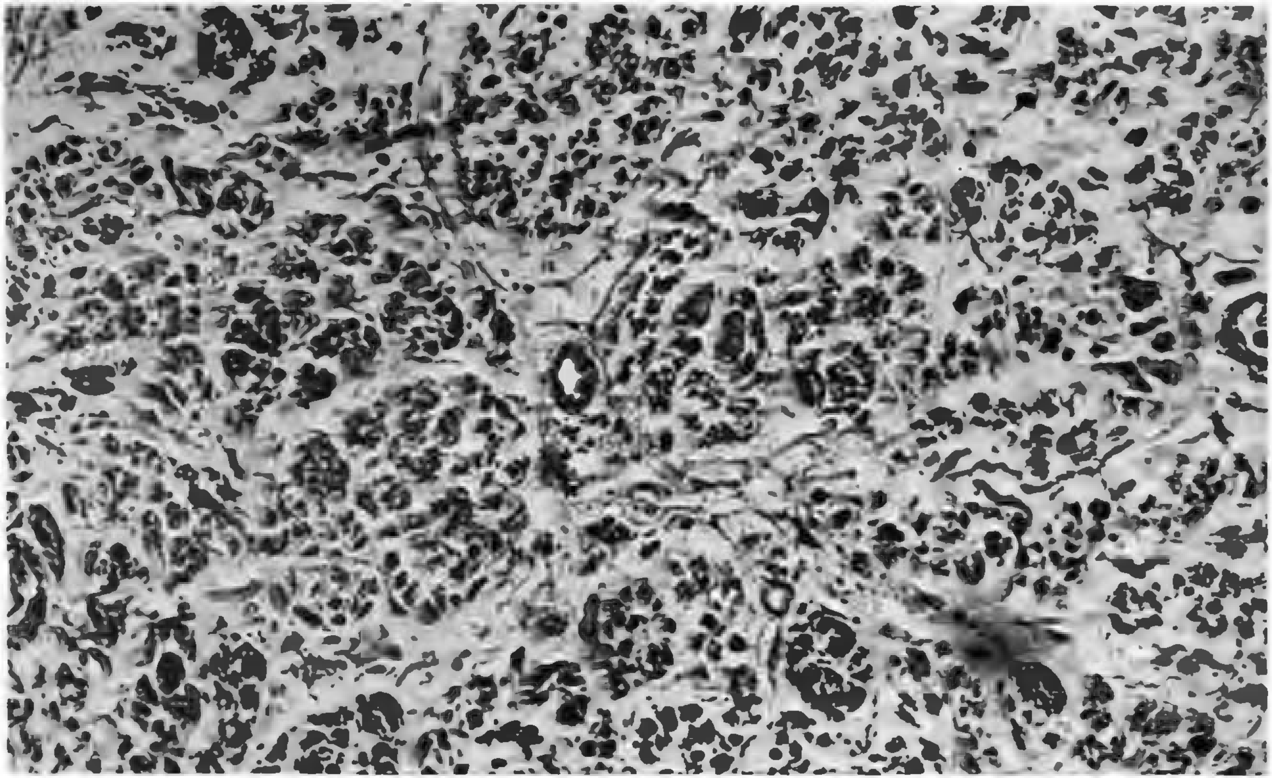


Plate 59. *Higher magnification of distal end of lesion (case 9) showing scant myelinated and many amyelinated nerve fibers (430 x).*

fibers. This degree of histologic regeneration is to be correlated with physiologic evidence for regeneration far below the level to be achieved by the average suture.

Eight months following suture there was over 50 percent strength in the ulnar forearm flexors while insufficient time had elapsed for any physiologic evidence of recovery to the intrinsic hand muscles. The earliest signs of sensory recovery were present in the ulnar autonomous zone in that deep pressure to the tip of the fifth finger could be clearly perceived as a spreading painful sensation. The patient already had a fairly useful hand from a functional standpoint with only minimal clawing of the fourth and fifth fingers.

Comment. The gross appearance of this lesion with partial discontinuity posed no problem to the surgeon concerning the indication for resection. It is only regrettable that a complicating fracture unnecessarily prevented the early resection and suture which were indicated. This case is included as an example of a degree of regeneration, as observed histologically, which is consistent with EMG activity and progressing Tinel's sign but not with a useful motor recovery where the test of time was sufficient.

Case 10. A wound to the left forearm, 4 inches above the wrist, was sustained in September 1951. This resulted in a complete loss of median sensation but the patient was not seriously considered for operation until 10 months had passed because excellent function of the thumb suggested some median nerve continuity. At 10 months after injury, the patient was able to oppose his thumb to each of his fingertips and to abduct this thumb at a right angle to the palm to the extent that 3 experienced observers concluded there must be some function of both the opponens pollicis and abductor pollicis brevis. However, because a total median sensory loss persisted with absence of any Tinel's sign below the wrist lesion, these motor phenomena were questioned. Stimulation of the median nerve at the wrist both percutaneously and on insertion of needle electrodes, failed to produce any movement in the thenar muscles or any action on EMG recording. Stimulation of the ulnar nerve caused a contraction of all the musculature in the thenar eminence which was considered to be composed of a remarkably hypertrophied flexor pollicis brevis. Incidentally, EMG recording on voluntary effort from what was assumed to be the abductor pollicis brevis gave normal-appearing motor units. This suggests that voluntary EMG studies are not of assistance in a situation of this sort when recording from the flexor pollicis brevis could not be avoided. Median nerve suture seemed indicated because of the sensory deficit and because it was first established by infiltration of the median with procaine that the excellent mechanical function of the thumb was in no way affected.

At operation a 3.5 cm. neuroma in continuity was disclosed (plate 60) which showed irregular lateral enlargements. One portion of this lesion was fairly soft in appearance and the surgeon estimated from gross findings that 30 percent of the nerve was probably intact. However, because of the lack of evidence of regeneration after 10 months and because stimulation below the lesion failed to give any motor or sensory response, resection and suture were carried out in a situation where the gross findings by themselves would have suggested conservative management.

Microscopic studies showed an excellent proximal end with little scar and myelinization of 40 percent of the axons. At the center of the neuroma and in the distal end not a single axon could be detected. Such findings could be anticipated from the physiologic evidence but certainly were not suggested by the gross appearance of the specimen.

At 4½ months after suture the mechanical function of the thumb remained excellent as before and there was already perception in the tips of the middle and index fingers of 10 gm. pain stimulus and 20 gm. touch, while for the first time sweating could be detected in these areas by skin resistance studies. This is a rather remarkable example of evidence of sensory recovery following late suture.

Comment. The presence of trick or compensatory movements of the thumb, probably due to anomalous innervation, prevented recognition of the complete median deficit in this patient until a failure in sensory recovery finally called for his careful evaluation at 10 months after injury. From a pathological standpoint, this is an example of a neuroma in continuity whose gross appearance, both to the surgeon and to the pathologist in the laboratory, suggested a major degree of axonal continuity, quite disproved by histologic study of the lesion and the distal nerve segment.

Plate 60. *Operative photograph showing irregular lateral enlargements extending over a distance of 3.5 cm. (case 10).*

3. Discussion

Ten cases of neuroma in continuity have been presented to emphasize, first of all, the marked discrepancy between the experienced surgeon's classification of the lesion according to gross appearance and consistency, and the actual regenerative capacity of the lesion as established by either anatomic or physiologic evidence. Four lesions, cases 1 through 4, considered unfavorable to surgical exploration, clearly were consistent with better recovery than was possible by suture. Three lesions, cases 4 through 7, were resected because of an unfavorable gross appearance when the spontaneous regenerative process was presumably comparable to that which is achieved by suture. Because of their favorable appearance, the last 3 lesions, cases 8 through 10, would not have been resected but for unfavorable physiologic evidence after long time intervals since injury. Here histologic study demonstrated minimal regeneration through nerve specimens whose gross appearance suggested minimal damage even to the pathologist.

It should be stressed that the status of a nerve lesion is usually clarified by surgical exploration and that the vast majority of lesions that will not permit satisfactory regeneration are associated with an unequivocal degree of gross discontinuity. Yet, when the gross appearance is conceivably consistent with major continuity, no amount of fusiform enlargement or firmness to palpation should of themselves constitute indications for resection and suture. If, with possible major continuity, the conscious patient does not experience nerve paresthesias on stimulation of the distal segment, resection is indicated. If, with x inches to the first muscle, more than the same x months have elapsed since injury, a failure in motor response on nerve stimulation is an indication for resection. But with major continuity suggested by gross appearance, positive sensory response, and no motor response in the early case, a final decision as to definitive management must await subsequent physiologic events, especially in situations where average suture results are characterized by limited functional recovery. Such situations, where strong conservatism seems indicated, include all high lesions with the possible exception of the radial, and even the lower median and radial nerve lesions. Spontaneous median sensory recovery of low grade is superior to good recovery of median sensation after suture with poor ability to localize stimuli in the working portion of the hand. Spontaneous ulnar motor recovery with weak intrinsic muscles whose action is coordinated to permit opening of fourth and fifth fingers is preferable to stronger uncoordinated intrinsic muscle action after suture with persistent fourth and fifth finger clawing.

It must be pointed out that the combination of findings calling for conservatism occurs rarely, despite the seven examples shown, and that an early look at the lesion associated with major dysfunction is still the best policy for accomplishing the vast majority of indicated sutures at an early interval after injury. It must be emphasized also that regardless of previous explorations or present favorable appearance of the lesions, cases 8, 9, and 10, the failure of development of satisfactory evidence for regeneration, at the scheduled time for its appearance, calls for prompt resection and suture unless the lesion is so proximal that suture has little to offer. The explored case is not settled as regards the possible need for suture until such evidence appears. In patients such as cases 8 and 9, with evidence for some regeneration, the tendency is strong to wait indefinitely for further improvement, but investigation of over 200 cases, where serial data are available, indicates further improvement does not occur beyond the scheduled time; the stream of neurotization does not receive late increments from above.

Certain assumptions have been made in classifying the 10 cases presented. The 40 percent neurotization seen in cases 5 and 6 were associated with a degree of function comparable to that achieved by suture; the 70 percent seen in case 2 with function in excess of suture result; while the 20 to 25 percent seen in cases 8 and 9 with function far below a suture result. With this much evidence for correlation between histologic and physiologic findings in late cases, it has seemed proper to believe that neurotization of less than 25 percent will not result in function comparable to the result of suture, that neurotization of 50 percent or more will result in function exceeding the result of suture. It is on this basis that those cases in which resection was done before the time for physiologic clarification are classified as improperly resected, cases 3 and 4, and probably not improved by resection, case 7. By the very limitations of therapy, no case is available in which a functioning suture was resected to determine directly that degree of neurotization, by histologic evidence, which corresponds to an average suture result.

Histologic study of the central or most scarred portion of those lesions having a high degree of distal neurotization, cases 1 through 4, shows a scattering of axons by interspersed connective tissue that would seem inconsistent with the findings in the distal segment. The surgeon's impression of dense internal scarring is certainly confirmed and one can question whether this scarring process would not finally result in a reduction of distal neurotization. However, such a concept runs contrary to clinical experience. In this experience, function regained through a traumatic lesion in continuity has never shown a late decrement, if the appraisal be confined to objective tests of muscle and skin innervation which are independent of the will of the patient to use the extremity, of stiffening joints and the like. Exceptions to this rule would appear to occur only when the nerve is subject to fresh external trauma, as in tardy ulnar paralysis, or increasing compression in a confined space by a growing aneurysm or tumor. It seems proper to conclude therefore that abundant distal neurotization is satisfactory proof for continuing good function despite a high degree of internal scarring seen in the central portion of the lesion.

E. ADMINISTRATION

The foregoing material is already sufficient in scope to indicate that the proper study of the peripheral nerve injury of warfare demands an exact organization of resources not only during the conflict but in advance of such episodes. Mention has been made in the introduction of the fact that the proper organization of the neurosurgical centers, and of subsequent studies such as these, was handicapped by a lack of such planning. Some brief mention is required at this point of important administrative factors. These include personnel, equipment, and the debatable problem of a wound policy factor that has to do with the priority which the various tissues of the extremity possess for treatment at various time periods following wounding. Other details of the organization of diagnosis and treatment groups appear elsewhere in the text.

1. Personnel

There is unanimous agreement among our investigators that the experience of the surgeon is one important controllable factor in the care of peripheral nerve injuries. This is not reflected in the data of earlier chapters since the relationship between prognosis and training is a complex one. It is to be recalled that less well-trained surgeons in this field, that is, general surgeons, conducted these operations largely under the supervision of a neurosurgeon. Where training was studied in a single center (Cushing General Hospital (40)) over a period of consecutive years, prognosis or the extent of neural regeneration improved with experience. Table 110 (p. 194) fails to confirm fully this impression. The corollary to this statement is that the trained neurosurgeon should control the initial or neurosurgical evaluation of peripheral nerve injuries. It has been further shown, in separate centers, that fixed professional personnel not subject to the vagaries of assignment shifts, will reflect their increasing experience in terms of both better peripheral nerve regeneration and limb rehabilitation.

The minimal personnel for this team includes a neurosurgeon with adequate experience in peripheral nerve surgery and sufficient less-experienced surgeons to allow the performance of the required number of peripheral nerve operations per week; 1 ward surgeon or physician to aid each operating surgeon with administrative detail and 1 neurologist with a specific interest in peripheral nerve injuries to supervise the pre- and post-injury evaluation of peripheral nerve injuries. With these should be integrated an orthopedic surgeon trained in hand injuries, a plastic surgeon, a physiotherapist and sufficient personnel trained in electrodiagnostic and electrophysiological procedures. The increasing importance of the hand surgeon familiar with the rehabilitation of peripheral nerve injuries must be emphasized.

This concept of the peripheral nerve team is based upon the declared urgency of peripheral nerve repair and upon the need of combining certain bone, blood vessel and soft tissue repair with that of peripheral nerve tissue within an early time period after wounding. A system which requires transfer of the patient from one center to another for each phase of repair, in order to reach experienced personnel in these fields, will obviously detract from the result to be expected when all of the specialized work can be planned and integrated at a single hospital. For example, although nerve suture should receive priority, it is difficult of accomplishment when a major fracture contraindicates the prolonged flexion of all joints that may be necessary for nerve approximation. On the other hand, attention first to open reduction of the fracture results in below average nerve regeneration when suture is accomplished months later. Only when orthopedist and neurosurgeon work together in combined surgical procedures can such obstacles to ideal management be overcome.

2. Equipment

a. Essential
  (1) Peripheral nerve diagnosis and operating room charts.
  (2) Modern operating room equipment and supplies, including atraumatic .003 tantalum wire and atraumatic ophthalmologic silk suture material.
  (3) Spring algesiometer.
  (4) Von Frey's hairs.
  (5) Spring scales for recording muscle strength.
  (6) Operating room nerve stimulator.

b. Desirable
  (1) Chronaximeter.
  (2) Electromyographic unit, consisting of oscillograph, preamplifier and precision stimulator.
  (3) Dermometer (Richter).
  (4) Skin temperature recorder.

3. Time and the Wound Policy Factor

In extremity wounds, the concept regarding the extremity as a total or whole functioning unit is universally recognized. The implication of this concept is obvious. Neither bone, nor vessel, nor soft tissue, nor nerve must be treated by the narrow-visioned specialist as a single tissue. The extremity must be rehabilitated in terms of all tissues as a whole. This concept includes an intelligent appraisal of the relative value and the relative ideal healing rate of the four major tissues of the extremity. There is ample evidence that the eventual outcome of an extremity wound depends in large part upon the extent of its peripheral nerve injury and the progress of peripheral nerve regeneration. This in turn depends upon definitive disposition of the peripheral nerve wound as soon as feasible following injury.

One of the most important and definitive conclusions that has been derived from these data concerns the influence of elapsed time after injury to operation upon peripheral nerve regeneration. In terms of motor recovery, it seems for all nerves generally well established by these data that the final level of motor recovery is maximal for early sutures, and that subsequent delay in suture involves a variable loss which averages about 1 percent of maximal performance for every 6 days of delay. The very earliest, or emergency, sutures done within 19 days of injury do as well at follow-up as other early sutures, but only after half of them have been resutured. Although the effect of time seems clearly a general one, its magnitude varies not only by nerve but also by muscle within the set innervated by a particular nerve. The effect seems especially large in distal muscles and in those innervated by the radial and the peroneal nerves. Whether the sutures were done overseas or in the Z/I in World War II was of no prognostic importance if one takes time into account; the real advantage of overseas suture seems adequately explained by the difference in time from injury to repair. The effect of time also confounds that of gap in motor recovery, there being a definite correlation between the two. Information about gap is of less prognostic value than information about time, but if time be ignored the effect of gap is a significant one; there is an average loss of about 6 percent per cm. from the optimal motor recovery following sutures on the shortest gaps, until the critical limit is reached when suture becomes impossible.

In contrast to the striking influence of time upon motor recovery is the well-established fact that there exists no significant evidence in these data that elapsed time from injury to operation exerts any influence upon the recovery of pain and touch modalities. Indeed, worthwhile sensory return appeared in a limited series of cases when suture was performed 400 to 700 days after injury. The limitation of the material studied makes it impossible to delineate more exactly the postinjury interval for each nerve after which motor or sensory recovery is impossible. This appears an academic point since functional motor recovery is exceedingly rare if operation must be postponed as long as 12 months postinjury and available data indicate sensory return should be sought, particularly for the median nerve, at any time period following injury.

It these data concerning time are relevant, it seems of primary importance that a wound priority system be established in which all peripheral nerve injuries of warfare would be referred for treatment, complicated or not, to neurosurgical centers. Further evidence for this concept can be presented by a survey of the potential influence of bone, blood vessel, and major soft tissue injury upon neural regeneration.

4. Influence of Associated Injuries

a. Bone. As earlier defined in this analysis, associated injuries were studied on the basis of *à priori* expectations that they might bear a direct and significant relationship to peripheral nerve anatomical regeneration. In this series, an associated bone or joint injury occurred in 47.7 percent of upper extremity nerve injuries and in 30.1 percent of lower extremity nerve injuries.

No unusual type of peripheral nerve pathology is implicated in these injuries although the factors of compression and stretch from bone fragments must be considered. The very magnitude of the orthopedic task in the care of large numbers of casualties makes any consideration of the combined wound a very important one. On the other hand, no complication of peripheral nerve injury is more apt to delay peripheral nerve repair if the group experience of the past be valid. If the repair of the respective tissues, bone and peripheral nerve, are compared in terms of eventual limb function, it is self-evident that peripheral nerve repair takes precedence. Bone repair is always feasible in terms of time. This implied direction of the combined bone-peripheral nerve injury to the neurosurgeon during the early months of injury does not discountenance the great importance of combined repair procedures. Indeed, only by this approach can the practical problem of handling large numbers of patients be solved.

On the average, a definitive suture was delayed 50 days by the presence of such associated injury or by other factors in turn associated with the orthopedic injury. In motor regeneration, the investigation was done on the basis of individual muscles, both power and ability to contract being examined in detail. Neither aspect of motor recovery appeared to have been influenced in any general way by the presence of such injuries or by the character of their healing. It is, however, interesting to note in table 75 on page 126 that the few muscles in which apparently deleterious effects were suggested by individual statistical tests are among those innervated by the radial and sciatic-peroneal nerves. The associated bone injuries, of course, involve the humerus and femur, and it is precisely here that the clinical problem really lies. Pain and touch thresholds were analyzed as well in respect to the presence and character of any associated bone injury; no significant evidence of any deleterious influence was found. The British summary of sensory regeneration was also employed as a sensory index with results entirely consistent with those already given.

In spite of the delay in peripheral nerve surgery, these regeneration studies suggest that a commendable approach to the combined bone-nerve injury was present under the conditions of World War II surgery. This was true and the importance of such combined approaches to nerve-bone injuries and the importance of early peripheral nerve repair were promptly recognized in World War II. The concept must be fully developed that no orthopedic complication or method of therapy must interfere with peripheral nerve repair within the early months after injury. Combined operative approaches must be encouraged and further developed. This is of major importance in high extremity injuries where the extent of peripheral nerve regeneration is already embarrassed by the distance between point of repair and muscle or sensory end organ. It is in this class of injury that wound priority direction will insure maximal results.

b. Arterial.[31] These data have shown that 16 percent of all 3,656 nerve lesions had associated injuries to major arteries on the same limb. They were much more common in the upper extremity (24.4 percent) than in the lower (2.8 percent).

When the site of the combined lesion is taken into consideration, usually high on the extremity, the weight of evidence favors the conclusion that an associated arterial lesion affects motor recovery adversely. If the percentage of muscles contracting against resistance is employed in developing

[31] The effect of nerve injuries upon the peripheral circulation is considered more extensively in a parallel VA Medical Monograph in preparation by Dr. Daniel C. Elkin and associated investigators.

an estimate of the average magnitude of the effect of arterial injury, one finds that muscles affected by such injuries contract against resistance with only 82 percent of the frequency observed from muscles not so affected and of comparable site. In no sensory modality was the observed variation sufficient to conclude that such an associated injury had any effect upon sensory regeneration.

This combined injury in an extremity manifests itself as a peripheral nerve injury in three aspects.

(1) *Tissue and therefore peripheral nerve ischemia.* There is no simple peripheral nerve injury more conducive to poor neural regeneration than that secondary to ischemia. With an otherwise intact peripheral nerve system, the treatment of peripheral nerve ischemia becomes a part of the treatment of extremity ischemia. Such therapy must be established at a very early time period after major vessel severance. If tissue ischemia is associated with major peripheral nerve injury, the therapy of ischemia holds precedence, with that of the peripheral nerve injury being carried out in the subsequent period following wounding.

(2) *Peripheral nerve injury may develop from compression of an expanding arterial aneurysm.* Peripheral nerve tissue does not withstand prolonged pressure without axonal degeneration and without local ischemic changes. The appearance of a developing peripheral nerve paralysis in an extremity with an arterial aneurysm is a signal for immediate treatment of the vascular lesion. Among all of the late sequelae of vascular injuries, the expanding arterial aneurysm is the only vascular lesion that should command precedence over the therapy of peripheral nerve injury. Smaller arterial aneurysms may actually erode peripheral nerve tissue.

(3) *Major peripheral nerve injury may occur in any pathologic form with major vascular injury.* The peripheral nerve injury should be evaluated as already described and a decision reached concerning operation. There is little doubt that a combined approach to peripheral nerve injury and vascular injury is preferable to separate operative interventions. Due to the complexity of the repair of both lesions, and due to the formidable nature of many arteriovenous aneurysms, it is a fact that in the past the repair of the peripheral nerve lesion has been deferred or, at best, has assumed a secondary role. This trend should be reversed. Except in the instance of expanding arterial aneurysms, the neurosurgeon must participate at all times in the repair of these combined injuries. Much further attention should be directed toward the proper care of these very crippling injuries of an extremity.

Because of the anatomic contiguity of neural and vascular structures in the neck, combined vascular and neural lesions of the last cranial nerves are common. Many such patients undoubtedly succumb to immediate hemorrhage. Treatment of the nerve lesion in those that survive needs only brief consideration. The neurological defect shows a strong tendency toward spontaneous resolution and direct repair of cranial nerve lesion is rarely indicated. More peripheral lesions of the spinal accessory and hypoglossal nerves may demand operation but such peripheral lesions are uncommon with vascular injury. Residual paralysis of the vocal cord may precipitate respiratory difficulty or aspiration of fluids. Repair of the vascular lesion does not favorably influence the cranial nerve injury, and this particular group of cranial-peripheral nerve involvements should be the responsibility of the vascular surgeon directly.

c. Soft Tissue. Roughly 10 percent of these cases were complicated by soft tissue injury that needed definitive plastic repair. A plastic procedure performed at the site of injury prior to nerve repair was found, particularly in the peroneal, median, and ulnar nerves, to be associated with an average loss of one-fifth in the expected percentage of muscles contracting against resistance. Any delay in definitive nerve suture as a result of such a repair was of too little moment to produce this effect, which probably depends in part upon loss of muscle substance. Sensory regeneration was not altered by the presence of a major plastic procedure.

World War II experience demonstrated that any adverse time influence dependent upon prolonged plastic repair could be largely obviated by combined operative approaches. Peripheral nerve injuries cannot be repaired through split thickness skin grafts. Again, the concept of placing such combined injuries under neurosurgical care during the early months following injury will prevent the occurrence of splendid skin repair and a functionally useless extremity. The first task of the plastic surgeon is to enable the neurosurgeon to repair peripheral nerve tissue; his major task may well be completed at a single procedure. If not, it should be reserved for a later period of rehabilitation surgery.

d. Chronic Infection. It has been pointed out that there is a considerable delay in nerve repair in cases with chronic infection. The effect of wound infection upon peripheral nerve regeneration is then a matter of elapsed time. In lesions complicated by infection, muscles were found to contract against resistance only about two-thirds as often as muscles not so complicated. There was no adverse effect upon sensory regeneration.

The foregoing observations appear sufficient to make well founded the statements that peripheral nerve surgery must be a part of total limb surgery, that peripheral nerve regeneration is adversely affected by time as perhaps no other tissue is in the extremity and that in the presence of associated injury, combined reparative procedures are indicated.

F. INFLUENCE OF TECHNICAL FACTORS OF SURGICAL MANAGEMENT UPON ANATOMICAL REGENERATION

There remains to be reviewed the general influence of several technical factors concerned with surgical treatment as this influence is reflected in terms of peripheral nerve regeneration in these cases. Such a discussion would be repetitious of the detailed data presented in the chapters devoted to motor and sensory regeneration, and the reader is referred to summaries on pages 191–197 and 308–309. It seems pertinent to point out that such technical factors as those concerned with suture material, cuffs, the trimming of nerve ends, and the minutiae of suture play little role in peripheral nerve regeneration, if conducted with reasonable skill and certitude, as compared to such factors as elapsed time, the management of associated injury, and the approach to peripheral nerve surgery as a part of total limb rehabilitation.

G. DISPOSITION TO DUTY

Only 2.3 percent of the men with 1,890 peripheral nerve sutures studied in this representative sample returned to some form of duty status during World War II. The variations among the 7 major nerves in this respect was in the range of 0.6 to 4.2 percent and these data may be found in the last pages of chapter II. It also appears a fact that men with sutured peripheral nerve injuries were hospitalized on the average for 523 days in military hospitals as compared to 54 days for all the wounded in World War II. Some of this enormous time period devoted to hospitalization was, of course, spent on leave or on work furloughs. The number discharged from hospital prior to day 200 was negligible. These and other relevant data may also be found in chapter II.

These studies upon anatomical and functional regeneration in this series of patients in terms of separate nerve injuries give considerable credence to the feeling that was held in World War II by experienced rehabilitation surgeons that time in hospital was, in general, excessive for these injuries. This feeling was reflected in part by the emphasis upon work furloughs by certain hospital centers where this manpower pool was used in noncombat or civilian type duties. This technique was not used widely and, in general, the convalescent hospital was developed to absorb a volume of patients quite well except for their treated nerve or other injuries. This mass of patients overwhelmed the capacities of available medical and ancillary personnel and scant progress was made in terms of exact observation of the extent, or the failure, of peripheral nerve regeneration. It appears essential, therefore, to present in this survey of surgical implications the broad essentials of the results of peripheral nerve repair for separate nerves and certain suggestions concerning disposition from hospital. The latter in turn have to do only with the proposed period of active hospitalization.

H. END RESULTS OF REPAIR, SUMMARY BY INDIVIDUAL NERVE

The decision that the patient will not benefit from further hospitalization requires knowledge of the best that can be expected of his nerve injury and the degree to which his existing disability can be improved by orthopedic techniques. The former knowledge has been described in considerable detail in preceding chapters and is summarized below under separate nerve injuries. The latter information can only be obtained when the neurosurgical center is associated with an orthopedic and hand center. Since the benefits of tendon transfer can be largely realized in a period of 6 weeks, such an association of special skills tends toward adequate treatment, increased therapeutic experience, and prompt disposition. Since the problem of achieving rehabilitation is quite different in arm and leg injuries, they will be discussed separately.

1. Lower Extremity Injuries

In these follow-up studies, the regeneration of nerve injuries has been rated in percent of anatomical regeneration, reflecting the degree to which motor strength has returned to involved muscles, and the degree to which sensory thresholds have been lowered in the involved skin. At the same time, functional recovery has been analyzed and reported in terms of a percentage of functional recovery. In the case of the lower extremity, functional recovery is measured largely by the distance the patient is able to walk in reasonable comfort. In the lower extremity, extreme discrepancies may be apparent between these two factors of recovery. One patient with no anatomical regeneration secondary to a high sciatic nerve division may show 60 percent functional return if he is free of foot ulceration and if he has a satisfactory padded shoe and a brace to hold the foot in dorsiflexion. On the other hand, examples are common of injuries to the sciatic nerve involving only the tibial component where nerve suture has given adequate motor power in all muscles of the calf, including the flexors of the toes, plus a reasonable appreciation of the modalities of pain and touch over the sole of the foot. This sensory return, however, may be so disagreeable, in spite of an adequately padded shoe, that walking for a distance of 2 blocks requires considerable effort. Although anatomical regeneration may be rated high yet this patient's functional recovery is of little value. The regeneration summaries of the sciatic, peroneal, and tibial nerves appear in tables 280 through 283.

Although a poor correlation exists between anatomical and functional regeneration, it is not so poor as to preclude the advisability of sciatic nerve suture. Such sutures must be done early after injury if any type of anatomical regeneration is to be expected. If the patient with a high sciatic nerve division has had a technically good suture by an experienced neurosurgeon, and if he has been fitted with shoe and brace so that he can walk comfortably without foot ulceration, a subsequent failure of improvement in nerve function is not an indication for reoperation. It seems clear that when a patient with a lower extremity nerve injury has secured complete functional rehabilitation, he will derive no benefits from further hospitalization. These studies have shown that no resuture of an original peroneal suture which had been performed adequately showed improved regeneration, and that resuture of a low tibial nerve injury that has been done adequately may increase or precipitate painful sensory reaction over the sole of the foot and increase functional disability. In most instances of uncomplicated lower extremity peripheral nerve injuries, discharge is indicated 3 to 4 months after peripheral nerve suture.

Table 280.—*Regeneration Summary: Sciatic-Peroneal*

Motor recovery, by site in thigh	Upper ⅓		Middle ⅓		Lower ⅓		All sites	
	P [1]	M [1]	P [1]	M [1]	P [1]	M [1]	P [1]	M
Tib. ant.	54	34	60	24	72	37	59	32
Ext. dig. long	37	31	43	20	59	28	43	23
Ext. hall. long	29	26	35	29	48	15	35	28
Peron. long	49	21	57	25	68	35	55	27

Sensory recovery		Autonomic recovery		Practical function	
	Percent		*Percent*		*Percent*
Pain threshold, 10 gm. or less	24	Increased SR	52	Median percent of normal function	60
Touch threshold, 5 gm. or less	19	Absent sweating	65		

[1] Percentage (P) of affected muscles contracting voluntarily, and mean (M) relative power of affected muscles capable of movement against resistance.

Table 281.—*Regeneration Summary: Sciatic-Tibial*

Motor recovery, by site in thigh	Upper ⅓		Middle ⅓		Lower ⅓		All sites	
	P [1]	M [1]	P [1]	M [1]	P [1]	M [1]	P [1]	M [1]
Gastroc. & sol.	94	56	94	53	91	62	95	64
Tib. post.	.....	.....	.....	.....	.....	.....	85	60
Flex. dig. long	17	36	37	21	41	[2] 100	65	37
Flex. hall. long	18	31	33	27	41	55	67	34
Inteross.	.....	.....	.....	.....	.....	.....	59	34

Sensory recovery		Autonomic recovery		Practical function	
	Percent		*Percent*		*Percent*
Pain threshold, 10 gm. or less	20	Increased SR	55	Median percent of normal function	60
Touch threshold, 5 gm. or less	18	Absent sweating	60		

[1] Percentage (P) of affected muscles contracting voluntarily, and mean (M) relative power of affected muscles capable of movement against resistance.

[2] Mean based on five cases.

Table 282.—*Regeneration Summary: Peroneal*

Motor recovery	All sites	
	P[1]	M[1]
Tib. ant	75	46
Ext. dig. long	66	32
Ext. hall. long	54	36
Peron. long	71	42

Sensory recovery		Autonomic recovery		Practical function	
	Percent		*Percent*		*Percent*
Pain threshold, 10 gm. or less	38	Increased SR	32	Median percent of normal function	60
Touch threshold, 5 gm. or less	37	Absent sweating	63		

[1] Percentage (P) of affected muscles contracting voluntarily, and mean (M) relative power of affected muscles capable of movement against resistance.

Table 283.—*Regeneration Summary: Tibial*

Motor recovery	All sites	
	P[1]	M[1]
Gastroc. & sol	94	64
Tib. post	85	60
Flex. dig. long	65	36
Flex. hall. long	67	34
Inteross	52	32

Sensory recovery		Autonomic recovery		Practical function	
	Percent		*Percent*		*Percent*
Pain threshold, 10 gm. or less	29	Increased SR	36	Median percent of normal function	76
Touch threshold, 5 gm. or less	26	Absent sweating	63		

[1] Percentage (P) of affected muscles contracting voluntarily, and mean (M) relative power of affected muscles capable of movement against resistance.

In summary, there is evidence that all peripheral nerve injuries of the lower extremity should not have any type of further operative intervention, even if anatomical regeneration is unsatisfactory. If an adequate early suture has been done and if functional rehabilitation has been completed, there is no need to hospitalize such patients, because evidence of neural regeneration may take 18 to 24 months to appear. This combined therapy should be completed by 4 months after suture and the patient discharged from the active neurosurgical center.

2. Upper Extremity Injuries

Whereas the leg will do its job satisfactorily if it functions as a comfortable support with full movement at the knee, a hand to be useful requires active innervation of a variety of movements plus satisfactory sensation to at least the domain of the median nerve. Since one missing movement may make the difference between a useless and a relatively useful member, the responsibility for terminating hospital care with an incompletely functioning hand is a heavy one.

The regeneration summary of the median nerve appears in table 284.

Table 284.—*Regeneration Summary: Median*

Motor recovery, by site	High		Low	
	P [1]	M [2]	P [1]	M [2]
Fl. car. rad	97	60	92	75
Fl. poll. long	88	42	91	56
Fl. dig. prof. #2	88	37	94	60
Opponens	76	34	92	45
Abd. poll. brev	78	35	83	32

Sensory recovery, percent	High	Low	Autonomic recovery, percent	Practical function, percent
Pain threshold, 10 gm. or less	39	49	Increased SR 43	Average (median) percent of normal function 59
Touch threshold, 5 gm. or less	49	48	Absent sweating 36	

[1] Percentage of affected muscles contracting voluntarily.
[2] Mean relative power of affected muscles capable of movement against resistance.

Even with the best sensory recovery after suture, the patient with a median nerve injury will still have difficulty in the organization of perceived pain and touch sensations that limit the hand's usefulness even though mechanical function with visual aid be good. Therefore, a median nerve injury must be followed until useful function has returned to the thumb and fingertip. If sensation does not return at the scheduled time, reoperation is indicated since this is the only way of establishing improved sensation. Reoperation may not be indicated if the nerve injury was extensive and everything possible, including nerve grafting, was done at the original procedure.

Sensory recovery is often reasonably good but the hand may be handicapped by loss of the opponens pollicis muscle preventing opposition of thumb pad to finger pad in picking up objects. Some patients with no opponens function compensate by the ulnar-innervated short flexor to the thumb. This is, however, not the rule. If the opponens has failed to recover on schedule, and if the patient can pick up small objects only by grasping them between the thumb and side of the index finger, compensatory tendon transplant is indicated. A variety of procedures for supplying opposition of the thumb have been described. With median nerve division above the elbow, the expectancy of recovery of normal thumb opposition is low. Tendon transplant repair of thumb opposition is indicated in such cases at an early period of hospitalization. Such a procedure seems preferable to waiting 14 to 18 months for opponens pollicis recovery, only to find that tendon transplant is required after all. In a few cases, there may be failure of innervation of the flexor digitorum longus and flexor pollicis longus with high median nerve injuries. The loss of flexion of the terminal phalanges of the index finger and thumb may be readily supplied by tendon transfers.

In summary, a patient with a median nerve injury should not be discharged from the hospital until he has regained useful sensation in the autonomous sensory zone of the median nerve, unless poor regeneration must be accepted because of the extent of the lesion. Such a patient should always be provided, by tendon transfer, with the ability to oppose the thumb to the tips of the index and middle finger, if this function has not returned as a result of reinnervation. In median nerve injuries above the elbow, early tendon transfer for such function is indicated. Study center records indicate that this failure to provide thumb opposition was one of the major defects in the management of peripheral nerve injuries in World War II. Some patients were found still willing to undergo operation years after injury in an effort to regain thumb opposition that would give them a useful hand.

The regeneration summary of the ulnar nerve is given in table 285.

The patient who is left with an irreparable ulnar nerve paralysis, even including the forearm flexors, still has a relatively good hand. Although the fourth and fifth fingers may be useless and clawed into the palm, he is able to grasp heavy objects and pick up small objects with the radial three digits. Even with a complete paralysis, function of the hand may be rated at 60 percent. If, on the other hand, the fourth and fifth fingers can be extended and used for grasping, hand usefulness is increased to an 80 percent rating. These figures are expressed in terms of disability in the average white collar

Table 285.—*Regeneration Summary: Ulnar*

Motor recovery, by site	High		Low	
	P[1]	M[2]	P[1]	M[2]
Fl. car. uln	96	66	97	72
Fl. dig. prof. 4–5	94	42	95	48
Abd. dig. quint	85	21	90	28
Add. poll	85	34	92	40
1st dorsal inteross	78	26	87	31

Sensory recovery, percent	High	Low	Autonomic recovery, percent		Practical function, percent	
Pain threshold, 10 gm. or less.	29	31	Increased SR	45	Average (median) percent of normal function.	73
Touch threshold, 5 gm. or less.	.....	39	Absent sweating	29		

[1] Percentage of affected muscles contracting voluntarily.
[2] Mean relative power of affected muscles capable of movement against resistance.

worker or laborer. The ability to set the lumbricals so that the fourth and fifth fingers may be extended is one of the last functions to return as the ulnar intrinsic muscles are reinnervated.

Although the functional disability of the clawed fourth and fifth fingers is minimal as compared to loss of thumb opposition, patients should not be discharged until lumbrical action has been established by reinnervation or by tendon transfer. Ulnar regeneration is notably spotty and particularly so in high injuries. When poor regeneration must be accepted, tendon transfer is indicated early in the course of hospitalization. When reinnervation is proceeding normally, since the functional disability is slight, patients may be discharged to duty, to return for reexamination.

Whether tendon transfer in these injuries is deferred or immediately contemplated, physiotherapy must provide relatively full motion in the interphalangeal articulations. Little can be done with fixed clawing and patients sometimes have not accepted amputation. The amount of extension of fingers possibly by tendon work can be roughly predicted by noting the amount of passive finger extension possible when the wrist is held flexed to relax the flexor tendons. The tendon transfer technique is commonplace.

Combined median-ulnar nerve injuries are extremely disabling since all the fingers become flexed into the hand and the only grasp possible is between the thumb and the side of the index finger. High injuries often also involve a vascular component. Forearm injuries are often associated with massive soft tissue and bone injury. These studies show that in combined high injuries, regeneration to the forearm flexors is surprisingly good but that intrinsic muscle function never recovers sufficiently to permit thumb to finger opposition. This is also usually true in low injuries. Emphasis, therefore, must be placed upon the restoration of median nerve sensory function and upon restoring opposition to the thumb using the best of the available flexors. In addition, lumbrical function must be supplied to at least the index and middle fingers, so that they will reach out to meet the opposing thumb, rather than curling past it into the palm.

The regeneration summary of the radial nerve is given in table 286.

These studies indicate that anatomical regeneration may be of the highest order in radial injuries and that satisfactory functional recovery can always be anticipated. In instances of poor regeneration, adequate orthopedic techniques are available for restoring wrist and finger-drop and abduction of the thumb. When good wrist extension has been established by reinnervation adequate finger extension usually follows. Abduction and extension of the thumb customarily follows in 4 to 5 months and it is a moot question whether patients need to be kept under observation for this period of time. If wrist extension fails to appear at the scheduled time, the question of tendon transfer should then be considered.

Table 286.—*Regeneration Summary: Radial*

Motor recovery	All sites	
	P [1]	M [1]
Triceps	100	69
Brach. rad	92	68
Ext. carp. rad	94	49
Ext. dig. comm	89	47
Ext. carp. ulnar	93	50
Abd. poll. long	78	37
Ext. poll. long	83	37
Ext. poll. brev	79	36

Sensory recovery		Autonomic recovery		Practical function	
	Percent		*Percent*		*Percent*
Pain threshold, 10 gm. or less	51	Increased SR	10	Median percent of normal function	78
Touch threshold, 5 gm. or less	56	Absent sweating	20		

[1] Percentage (P) of affected muscles contracting voluntarily, and mean (M) relative power of affected muscles capable of movement against resistance.

It seems probable that the routine exploration of open wounds of the brachial plexus is neither profitable nor justifiable since, in the brachial plexus, a suture of elements supplying the forearm and hand seldom adds significantly to function. Proximal muscles such as the deltoid and biceps do occasionally secure useful recovery through suture. Cases must, therefore, be surveyed individually because of the complex nature of the injury. If exploration is done, in spite of evidence that it fails to add perceptibly to anatomic regeneration, postoperative emphasis must be placed upon orthopedic rehabilitation measures.

I. FINAL NOTE

The history of military neurosurgery demonstrates the fact that succeeding generations often fail to use the accumulated knowledge of the past. Much of the basic information in this report can be found in books by Foerster and by Pollock and Davis and in the Medical History of World War I, and in other monographs devoted to this subject. A large amount of data is also available in papers published during and after World War II in this particular field. The concept of relatively early nerve suture carried out perhaps within 3 months following injury by an experienced team, the importance of peripheral nerve regeneration in total limb rehabilitation, the emphasis upon orthopedic hand surgery, the understanding of pathologic changes in peripheral nerve tissue, and the trend toward exact neurophysiological studies of peripheral nerve injury and regeneration are, however, relatively new. It is hoped that this final report of the peripheral nerve study centers will provide data in support of the surgical principles that have become accepted over the years and have been restated here. The military neurosurgeon, however, must not assume that these results cannot be improved.

Bibliography

1. ALLBRITTEN, F. F., and MALTBY, G. L.: CAUSALGIA SECONDARY TO INJURY OF THE MAJOR PERIPHERAL NERVES: TREATMENT BY SYMPATHECTOMY, Surgery *19*:407–414 (Mar.) 1946.
2. D'AUBIGNÉ, ROBERT M.: TREATMENT OF RESIDUAL PARALYSIS AFTER INJURIES OF THE MAIN NERVES (SUPERIOR EXTREMITY), Proc. Roy. Soc. Med. *42*:831–835 (Oct.) 1949.
3. BARNES, R.: TRACTION INJURIES OF THE BRACHIAL PLEXUS IN ADULTS, J. Bone & Joint Surg. *31–B*:10–16 (Feb.) 1949.
4. BEEBE, G. W., and DEBAKEY, M. E.: BATTLE CASUALTIES: INCIDENCE, MORTALITY AND LOGISTIC CONSIDERATIONS, Springfield, Ill., Thomas, 1952.
5. BERRY, C. M., GRUNDFEST, H., and HINSEY, J. C.: THE ELECTRICAL ACTIVITY OF REGENERATING NERVES IN THE CAT, J. Neurophysiol. *7*:103–115 (Mar.) 1944.
6. BOURGUIGNON, G.: LA CHRONAXIE CHEZ L'HOMME, ÉTUDE DE PHYSIOLOGIE GÉNÉRALE, NORMALE ET PATHOLOGIQUE, DES SYSTÈMES NEUROMUSCULAIRES ET SENSATIFS, Paris, Masson, 1923.
7. BOYD, A. M.: Pain-Causalgia: In CARLING, E. R., and ROSS, J. P., (ed.): BRITISH SURGICAL PRACTICE, vol. 6, London, Butterworth, 1950.
8. BRAZIER, M. A. B.: THE ELECTRICAL ACTIVITY OF THE NERVOUS SYSTEM: A TEXTBOOK FOR STUDENTS, New York, Macmillan, 1951.
9. BROOKS, D. M.: SYMPOSIUM ON RECONSTRUCTIVE SURGERY OF PARALYSED UPPER LIMB: TENDON TRANSPLANTATION IN THE FOREARM AND ARTHRODESIS OF THE WRIST, Proc. Roy. Soc. Med. *42*:838–844 (Oct.) 1949.
10. BROOKS, D. M.: OPEN WOUNDS OF THE BRACHIAL PLEXUS. In Seddon, H. J. (ed.): PERIPHERAL NERVE INJURIES, London, H. M. S. O., 1954.
11. BUCHTHAL, F., and MADSEN, A.: SYNCHRONOUS ACTIVITY IN NORMAL AND ATROPHIC MUSCLE, Electroencephalog. and Clin. Neurophysiol. *2*:425–444 (Nov.) 1950.
12. BUNNELL, S.: SURGERY OF THE HAND, ED. 2, Philadelphia, Lippincott, 1948.
13. CANNON, W. B., and ROSENBLUETH, A.: AUTONOMIC NEURO-EFFECTOR SYSTEMS, New York, Macmillan, 1937.
14. CHURCHILL, E. D.: THE SURGICAL MANAGEMENT OF THE WOUNDED IN THE MEDITERRANEAN THEATER AT THE TIME OF THE FALL OF ROME, Ann. Surg. *120*:268–283 (Sept.) 1944.
15. COHEN, B. M., BEEBE, G. W., and JABLON, S.: REPORT TO THE COMMITTEE ON VETERANS MEDICAL PROBLEMS ON THE PROGRAM OF RECORD FOLLOW-UP STUDIES, National Research Council, Mimeographed, 17 pp., 15 March 1953.
16. DAVIDSON, W. D.: TRAUMATIC DELTOID PARALYSIS TREATED BY MUSCLE TRANSPLANTATION, J. A. M. A. *106*:2237 (June 27) 1936.
17. DAVIS, L., MARTIN, J., and PERRET, G.: THE TREATMENT OF INJURIES OF THE BRACHIAL PLEXUS, Ann. Surg. *125*:647–657 (May) 1947.
18. DENNY-BROWN, D.: INTERPRETATION OF THE ELECTROMYOGRAM, Arch. Neurol. and Psychiat. *61*:99–128 (Feb.) 1949.
19. DICKINSON, C. J.: ELECTROPHYSIOLOGICAL TECHNIQUE, London, Morgan, 1950.
20. DOUPE, J.: STUDIES IN DENERVATION: B. CIRCULATION IN DENERVATED DIGITS, J. Neurol. & Psychiat. *6*:97–111 (July–Oct.) 1943.

21. Doupe, J.: studies in denervation: e. observations concerning adrenaline, J. Neurol. & Psychiat. *6*:121–128 (July–Oct.) 1943.
22. Doupe, J., Cullen, C. H., and Chance, G. Q.: post-traumatic pain and causalgic syndrome, J. Neurol., Neurosurg. & Psychiat. 7:33–48 (Jan.–Apr.) 1944.
23. Foerster, O.: die leitungsbahnen des schmerzgefuehls und die chirurgische behandlung der schmerzzustande, Berlin and Vienna, Urban und Schwartzenberg, 1927.
24. Foerster, O.: handbuch der neurologie, herausgegeben von bumke und foerster, ergänzungsband, Teil 2, Berlin, Springer, 1929.
25. Fulton, J. F. (ed.): howell's textbook of physiology, ed. 17, Philadelphia, Saunders, 1955.
26. Golseth, J. G., and Fizzell, J. A.: a constant current impulse stimulator, Arch. Phys. Med. *28*:154–158 (Mar.) 1947.
27. Groff, R. A., and Houtz, S. J.: manual of diagnosis and management of peripheral nerve injuries, Philadelphia, Lippincott, 1945.
28. Grundfest, H.: excitability of the single fibre nerve-muscle complex, J. Physiol. *76*:95–115 (Sept.–Nov.) 1932.
29. Grundfest, H.: biological requirements for the design of amplifiers, Proc. Inst. Radio Engrs. *38*:1018–1028 (Sept.) 1950.
30. Grundfest, H.: mechanism and properties of bioelectric potentials. in Barron, E. A. G. (ed.): modern trends in physiology and biochemistry, New York, Academic, 1952.
31. Guttmann, L. and List, C. F.: zur topik und pathophysiologie der schweissekretion, Z. ges. Neurol. Psychiat. *116*:504–536, 1928.
32. Haxton, H. A.: gustatory sweating, Brain *71*:16–25 (Mar.) 1948.
33. Haymaker, W. E., and Woodhall, B.: peripheral nerve injuries: principles of diagnosis, ed. 2, Philadelphia, Saunders, 1953.
34. Hendry, A. M.: symposium on reconstructive surgery of paralysed limb: the flail limb, Proc. Roy. Soc. Med. *42*:835–837 (Oct.) 1949.
35. Kendall, H. O., and Kendall, F. M. P.: muscles, testing and function, Baltimore, Williams and Wilkins, 1949.
36. Kirklin, J. W., Chenoweth, A. I., and Murphey, F.: causalgia: a review of its characteristics, diagnosis, and treatment, Surgery *21*:321–342 (Mar.) 1947.
37. Kwan, S. T.: the treatment of causalgia by thoracic sympathetic ganglionectomy, Ann. Surg. *101*:222–227 (Jan.) 1935.
38. Lapicque, L.: l'excitabilité en fonction du temps; la chronaxie, sa signification et sa mesure, Paris, Les Presses Universitaires, 1926.
39. Leriche, R.: la chirurgie de la douleur, ed. 3, Paris, Masson, 1949.
40. Lewey, F. H.: quantitative examination of sensibility in peripheral nerve injuries, Confinia Neurol. *9*:206–210, 1949.
41. Lewey, F. H.: Personal Communication.
42. Lewey, F. H., Kuhn, W. G., Jr., and Juditski, J. T.: a standardized method for assessing the strength of hand and foot muscles, Surg. Gynec. & Obst. *85*:785–793 (Dec.) 1947.
43. Littler, J. W.: tendon transfers and arthrodesis in combined median and ulnar nerve paralysis, J. Bone & Joint Surg. *31-A*:225–234, 1949.
44. Livingston, W. K., Davis, E. W., and Livingston, K. E.: "delayed recovery" in peripheral nerve lesions caused by high velocity projectile wounding, J. Neurosurg. *2*:170–179 (Mar.) 1945.
45. Lorente de Nó, R.: a study of nerve physiology. Studies 131 and 132, Rockefeller Inst. for Medical Research, New York, 1947.
46. Lyons, W. R., and Woodhall, B.: atlas of peripheral nerve injuries, Philadelphia, Saunders, 1949.
47. Macfarlane, W. V.: causalgic syndromes, Australian New Zealand J. Surg. *18*:191–208 (Jan.) 1949.

48. MAYER, L.: TRANSPLANTATION OF THE TRAPEZIUS FOR PARALYSIS OF THE ABDUCTORS OF THE ARM, J. Bone & Joint Surg. *9*:412–420 (July) 1927.
49. MAYFIELD, F. H.: CAUSALGIA, American Lecture Series, Springfield, Ill., Thomas, 1951.
50. MAYFIELD, F. H., and DEVINE, J. W.: CAUSALGIA, Surg. Gynec. & Obst. *80*:631–635 (June) 1945.
51. MEDICAL RESEARCH COUNCIL: AIDS TO INVESTIGATION OF PERIPHERAL NERVE INJURIES, Medical Research Council Mem. 7, Rev., ed. 2, London, H. M. S. O., 1944.
52. MINOR, V.: EIN NEUES VERFAHREN ZU DER KLINISCHEN UNTERSUCHUNG DER SCHWEISS-ABSONDERUNG, DEUTSCHE Z. FUR NERVENHEILKUNDE *101*:302–308, 1927.
53. MITCHELL, J. K.: REMOTE CONSEQUENCES OF INJURIES OF NERVES AND THEIR TREATMENT, Philadelphia, Lea Brothers, 1895.
54. MITCHELL, S. W.: INJURIES OF NERVES AND THEIR CONSEQUENCES, Philadelphia, Lippincott, 1872.
55. MITCHELL, S. W., MOREHOUSE, G. R., and KEEN, W. W.: GUNSHOT WOUNDS AND OTHER INJURIES OF NERVES, Philadelphia, Lippincott, 1864.
56. NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES: REPORT ON THE VALUE AND FEASIBILITY OF A LONG-TERM PROGRAM OF FOLLOW-UP STUDY AND CLINICAL RESEARCH, Washington, D. C., 1946.
57. NEWMAN, L. B.: A NEW DEVICE FOR MEASURING MUSCLE STRENGTH: THE MYOMETER, Arch. Phys. Med. *30*:234–237 (Apr.) 1949.
58. OBER, F. R.: AN OPERATION TO RELIEVE PARALYSIS OF THE DELTOID MUSCLE, J. A. M. A. *99*:2182 (Dec. 24) 1932.
59. POLLOCK, L. J.: THE PATTERN OF SENSORY RECOVERY IN PERIPHERAL NERVE LESIONS, Surg. Gynec. & Obst. *49*:160–166 (Aug.) 1929.
60. POLLOCK, L. J., and DAVIS, L.: PERIPHERAL NERVE INJURIES, New York, Hoeber, 1933.
61. PUCKETT, W. O., GRUNDFEST, H., MCELROY, W. D., and MCMILLEN, J. H.: DAMAGE TO PERIPHERAL NERVES BY HIGH VELOCITY MISSILES WITHOUT DIRECT HIT, J. Neurosurg. *3*:294–305 (July) 1946.
62. RASMUSSEN, T. B., and FREEDMAN, H.: TREATMENT OF CAUSALGIA: AN ANALYSIS OF 100 CASES, J. Neurosurg. *3*:165–173 (Mar.) 1946.
63. RICHTER, C. P.: NERVOUS CONTROL OF THE ELECTRICAL RESISTANCE OF THE SKIN, Bull. Johns Hopkins Hosp. *45*:56–74, (July) 1929.
64. ROSS, J. P.: CAUSALGIA, St. Barth. Hosp. Rep. *65*:103–118, 1932.
65. RUSHTON, W. A. H.: THE TIME FACTOR IN ELECTRICAL EXCITATION, Biol. Rev. *10*:1–17, 1935.
66. SEDDON, H. J.: THREE TYPES OF NERVE INJURY, Brain *66*:237–288 (Dec.) 1943.
67. SEDDON, H. J.: NERVE LESIONS COMPLICATING CERTAIN CLOSED BONE INJURIES, J. A. M. A. *35*:691–694 (Nov. 15) 1947.
68. SEDDON, H. J.: WAR INJURIES OF PERIPHERAL NERVES, Brit. J. Surg., War Surg. Supp. 2, Wounds of the Extremities, pp. 325–353 (Jan.) 1949.
69. SEDDON, H. J.: SYMPOSIUM ON RECONSTRUCTIVE SURGERY OF PARALYZED UPPER LIMB: TRANSPLANTATION OF PECTORALIS MAJOR FOR PARALYSIS OF THE FLEXORS OF THE ELBOW, Proc. Roy. Soc. Med. *42*:837–838 (Oct.) 1949.
70. SEDDON, H. J. (ed.): PERIPHERAL NERVE INJURIES, Medical Research Council Special Report Series, No. 282, London, H. M. S. O., 1954.
71. SEDDON, H. J., MEDAWAR, P. B., and SMITH, H.: RATE OF REGENERATION OF PERIPHERAL NERVES IN MAN, J. Physiol. *102*:191–215 (Sept.) 1943.
72. SHUMACKER, H. B., Jr.: CAUSALGIA: GENERAL DISCUSSION, Surgery *24*:485–504 (Sept.) 1948.
73. SPEIGEL, I. J., and MILOWSKY, J. L.: CAUSALGIA: A PRELIMINARY REPORT OF 9 CASES SUCCESSFULLY TREATED BY SURGICAL AND CHEMICAL INTERRUPTION OF SYMPATHETIC PATHWAYS, J. A. M. A. *127*:9–15 (Jan. 6) 1945.

74. SPURLING, R. G.: CAUSALGIA OF THE UPPER EXTREMITY. TREATMENT BY DORSAL SYMPATHETIC GANGLIONECTOMY, Arch. Neurol. Psychiat. *23*:784–788 (Apr.) 1930.
75. SPURLING, R. G., and WOODHALL, B.: EXPERIENCES WITH EARLY NERVE SURGERY IN PERIPHERAL NERVE INJURIES, Ann. Surg. *123*:731–748 (May) 1946.
76. STOOKEY, BYRON P.: SURGICAL AND MECHANICAL TREATMENT OF PERIPHERAL NERVES, Philadelphia, Saunders, 1922.
77. SUNDERLAND, S.: OBSERVATIONS ON THE TREATMENT OF TRAUMATIC INJURIES OF PERIPHERAL NERVES, Brit. J. Surg. *35:* 36–42 (July) 1947.
78. SUNDERLAND, S.: FACTORS INFLUENCING THE COURSE OF REGENERATION AND QUALITY OF THE RECOVERY AFTER NERVE SUTURE, Brain *75:* 19–54 (Mar.) 1952.
79. TINEL, J.: NERVE WOUNDS. SYMPTOMATOLOGY OF PERIPHERAL NERVE LESIONS CAUSED BY WAR WOUNDS. Transl. by F. Rothwell; rev. and ed. by C. A. Toll, London, Baillière, Tindall & Cox, 1917.
80. ULMER, J. L., and MAYFIELD, F. H.: CAUSALGIA: A STUDY OF 75 CASES, Surg. Gynec. & Obst. *83:* 789–796 (Dec.) 1946.
81. United States, Commerce, Department of, Bureau of the Census: ALPHABETICAL INDEX OF OCCUPATIONS AND INDUSTRIES, Washington, D. C., Government Printing Office, 1948.
82. United States, War, Department of: Directives Creating the Peripheral Nerve Registry:
    WD Circular No. 423, dated 27 Oct. 1944, Sec. II.
    ASF Letter SPX 701 (26 October 1944) SPMCQ–MP–M, dated 22 Nov. 1944, Subject: Peripheral Nerve Injury Report (Control Approval Symbol MCR–118) SG Form 941.
    ASF Letter SPXMP–M 701 (6 April 1945) SPMCQ, dated 18 April 1945, same subject.
    ASF Circular No. 244, dated 28 June 1945, Sec. VIII.
83. WHITE, J. C., and GENTRY, R. W.: RADIOGRAPHIC CONTROL FOR PARAVERTEBRAL INJECTION OF ALCOHOL IN ANGINA PECTORIS, J. Neurosurg. *1:* 40–44 (Jan.) 1944.
84. WHITE, J. C., HEROY, W. W., and GOODMAN, E. N.: CAUSALGIA FOLLOWING GUNSHOT INJURIES OF NERVES. ROLE OF EMOTIONAL STIMULI AND SURGICAL CURE THROUGH INTERRUPTION OF DIENCEPHALIC EFFERENT DISCHARGE BY SYMPATHECTOMY, Ann. Surg. *128:* 161–183 (Aug.) 1948.
85. WHITE, J. C., SMITHWICK, R. H., and SIMEONE, F. A.: THE AUTONOMIC NERVOUS SYSTEM: ANATOMY, PHYSIOLOGY, AND SURGICAL APPLICATION, ed. 3, New York, Macmillan, 1952.
86. WHITFIELD, I. C.: AN INTRODUCTION TO ELECTRONICS FOR PHYSIOLOGICAL WORKERS, London, Macmillan, 1953.
87. WOODHALL, B.: PERIPHERAL NERVE INJURIES: II. BASIC DATA FROM THE PERIPHERAL NERVE REGISTRY CONCERNING 7,050 NERVE SUTURES AND 67 NERVE GRAFTS, J. Neurosurg. *4:* 146–163 (Mar.) 1947.
88. WOODHALL, B., (ed.): PRELIMINARY REPORT, PERIPHERAL NERVE REGENERATION STUDY CENTERS 1951, Durham, N. C., Duke Medical School and Hospital, June 1953 (Reprinting of 1951 report).
89. WOODHALL, B., and LYONS, W. R.: PERIPHERAL NERVE INJURIES: THE RESULTS OF "EARLY" NERVE SUTURE. A PRELIMINARY REPORT, Surgery *19:* 757–789 (June) 1946.
90. YAHR, M. D., HERZ, E., MOLDAVER, J., and GRUNDFEST, H.: ELECTROMYOGRAPHIC PATTERNS IN REINNERVATED MUSCLE, Arch. Neurol. & Psychiat. *63:* 728–738 (May) 1950.

Index to Names

Index to Subjects

U. S. GOVERNMENT PRINTING OFFICE: 1957

Peripheral nerve
regeneration