Studies of the Upper-Extremity Amputee

I. Design and Scope

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Man's increasing dominion over his natural environment has been ascribed to three specific characteristics—a highly developed brain, binocular vision, and an apposable thumb. Although not particularly specialized from a biological viewpoint, these three attributes have enabled him to adapt to a varied physical environment and, perhaps more important, to alter the physical environment to suit his needs. Loss of any one of them deprives him of fundamental human capacities and seriously inhibits his ability to compete, to interact, and to manipulate the objective world around him. Impaired brain function is usually irreversible, and in the case of vision loss heroic measures are often required to obtain even a modicum of functional restitution. But the situation is somewhat different today with respect to the loss of an upper extremity. New concepts and developments in the field of limb prosthetics have increased the potentialities of arm amputees. Not all the problems are solved. Far from it. But systematic and concerted efforts in medicine and engineering are being applied toward reducing the limitations attendant upon the loss of an arm. It is perhaps ironic that historically these constructive efforts have been stimulated by the destructive forces of war.

HISTORICAL DEVELOPMENT

In the aftermath of World War II, a grateful nation spared no effort to alleviate the condition of those who had been wounded or maimed in its defense. Among its many other services, the Veterans Administration undertook the task of providing prosthetic and rehabilitation services to all veteran amputees. In pursuit of this goal, it soon became clear that existing artificial limbs fell far short of meeting the needs and expectations of their users. Perhaps because of the greater dependence of the leg amputee upon adequate service, and because of the consequent emphasis on attention to his problems, the major needs were found among upper-extremity amputees. Arm prostheses were found to be heavy, uncosmetic and unsanitary, and possessed of very limited function (Figs. 1 and 2). Too often they were relegated to the closet. Generally accepted standards of prosthetic quality were lacking. Better materials, improved design, new prosthetic components, and improved fitting and fabrication techniques were clearly required.

Not generally recognized was the need for highly individualized training to develop proficiency in the use of an artificial arm so that vocational and other skills could be acquired. Without a common ground of experience, the physician rarely took part in the prescription and fitting of prostheses. Thus, even the most skilled prosthetist, faced with the task of providing his patient with a well-fitting, comfortable, and highly functional prosthesis, sometimes found himself in the unfamiliar role of psychologist, therapist, and/or vocational counselor. In short, sound, complete, systematic rehabilitation programs for amputees were lacking. Officials of the Army, the Navy, and the Veterans Administration wasted little time in hand-wringing. Authority was

Fig. 1. Typical below-elbow prosthesis, vintage World War II.

soon forthcoming, and funds were made available for a broad attack on these problems.

The resources of science, applied during the war years to destruction and demoralization, were now directed toward the restoration of human loss and the enrichment of human life. The first step was the establishment, in 1945, of the Committee on Prosthetic Devices of the National Academy of Sciences—National Research Council, which later became the Advisory Committee on Artificial Limbs and which is today the Prosthetics Research Board. This led to the inception of the Artificial Limb Program and to the establishment of research projects for the scientific study of the problems involved. At the University of California at Los Angeles fundamental studies were undertaken of the biomechanical principles involved in normal prehension and of the problems of using artificial arms. At the same time, the industrial laboratories of Northrop Aircraft, as well as the Army Prosthetics Research Laboratory, were creating new materials, new devices, and new fabrication techniques, while New York University was assigned the task of evaluating these developments. The scientific facilities of both industry and government were thus employed to reduce the problem through efforts in basic and applied research.

The earliest results indicated that solving the problems and fulfilling the needs of the upper-extremity amputee was a task vastly greater than that of improving the mechanical aspects of fitting and fabricating prostheses. The finest artificial limb is of little value with-

Fig. 2. Typical above-elbow prosthesis, vintage World War II.

out training in its use. Further, the loss of a limb was seen to create important disturbances in the personality as a result of functional loss and distortion of the self-concept. The amputee entertains doubts as to how he will appear to and be accepted by his family and friends. He wonders, often with misgivings, about his economic potential. He has what appear to him to be insuperable problems, and he needs help in restoring his self-confidence as well as his lost function. In order to meet these amputee needs, a complete and rational system of rehabilitation programming was required, and since 1945 considerable progress has been made in developing such an approach to this problem.

After several years of organized effort, a great deal of research information became the basis for an all-around approach to the treatment of upper-extremity amputees. Through the development of models, the testing of hypotheses, and the experimental treatment of a number of arm amputees of all types, it became possible to indicate with some confidence how certain types of patients should be fitted, how their arms should be constructed, and how they should be trained to use them. As an added result, it is becoming a commonplace that all the amputee's needs cannot be served by a single individual, regardless of his professional status or training. With recognition of individual needs and the variety of amputee problems, it became clear that successful rehabilitation of these patients demanded the highly qualified and specialized services of a number of disciplines. Prosthetists, therapists, and physicians each have vital contributions in this enterprise, as may also nurses, social workers, vocational counselors, and psychologists. The modern concept then became the "team approach," the team consisting minimally of the doctor, the prosthetist, and the trainer and including such other specialists as each case required.

In order to evaluate these findings, a series of studies, which came to be known as the "NYU Field Studies," was conceived in 1951 at the Prosthetic Devices Study at New York University.

GOALS OF THE UPPER-EXTREMITY FIELD STUDIES

The NYU Field Studies of upper-extremity prosthetics developed as the logical consequence of two main preconditions—the laboratory research program and the prosthetics education program (page 9). As for the first, out of the laboratories had come a whole series of new devices which, on the basis of preliminary testing on relatively small groups, gave promise of being significantly improved components. Before some of them could be considered "proved" items of a prosthetic armamentarium, more definitive testing on broader, more representative samples under varying conditions seemed essential. But more than gadget-testing was involved. New fabrication techniques employing plastics had also been developed, and although arms made according to these procedures seemed superior to older types, it remained to be seen if the procedures could be mastered by limbmakers all over the country and economically and conveniently applied to the production of all types of artificial arms.

The second factor to be considered in planning the studies was the matter of broad and speedy dissemination of the new knowledge and skills. It was clear that the new procedures could not be evaluated in clinics whose personnel were not completely familiar with their use. Moreover, considerable urgency prevailed about making new developments and improvements available to all amputees as soon as possible. To fulfill this requirement, a prosthetics education program was organized to train clinic-team personnel. But it was generally observed that additional assistance was required in significant numbers of clinics before they could begin to process patients effectively.

For all of these reasons, the NYU Field Studies were designed in 1953 with three main objectives in view:

and the confidence it inspires in its user are as important in prosthetic service as are structural and mechanical adequacy. Each of these areas was explored.

2. To provide direction for future research in relation to practical field needs. Field-study operations should provide access to large representative samples of upper-extremity amputees. Clinical contact with these patients would furnish a means for determining existing prosthetic problems and, even more important, for evaluating the importance of these problems to amputees themselves. With this information available to the developmental laboratories through a feedback arrangement, their efforts could be directed toward the problems of most immediacy and importance.

3. *To extend the educational process by rendering administrative and technical assistance to newly organized prosthetics clinics.* Shortly after graduation from the prosthetics courses at the University of California at Los Angeles, potential clinic teams were to be visited by NYU representatives, the purpose being to encourage and aid in the establishment of a clinic procedure along the lines taught in the courses. The expeditious organization of a clinic served two functions—amputees would have early access to modern treatment, and a clinic treating patients according to these procedures was a potential participant in the field studies and a source of research data.

Before these concepts could be tested in the crucible of clinic practice throughout the nation, several preliminary steps were necessary. First, meaningful and reliable methods had to be found for evaluating the effect of prosthetic treatment procedures. Second, a number of clinics had to be organized to participate in the studies if valid inferences about the general utility of the experimental procedures were to be drawn. Third, training in the new prosthetic techniques and procedures had to be given to those who dealt directly with amputees. Actually, all three of these steps were undertaken at approximately the same time.

INAUGURATION of THE UPPER-EXTREMITY FIELD STUDIES

The staff of the Prosthetic Devices Study of New York University had been engaged in developing on a generally theoretical basis a philosophy and methodology for evaluating the status of arm amputees. The problem was approached directly, attempts being made to determine the most important outcomes in prosthetic restoration and to measure the extent to which the newer management procedures provided them. Accordingly, procedures and instruments were devised for determining the extent of residual function and the degree of adjustment to physical disability (Fig. 3). The status of the patient after treatment could thus be compared with his pretreatment condition as a basis for evaluation. But before these instruments could be applied on a broad scale it was necessary to

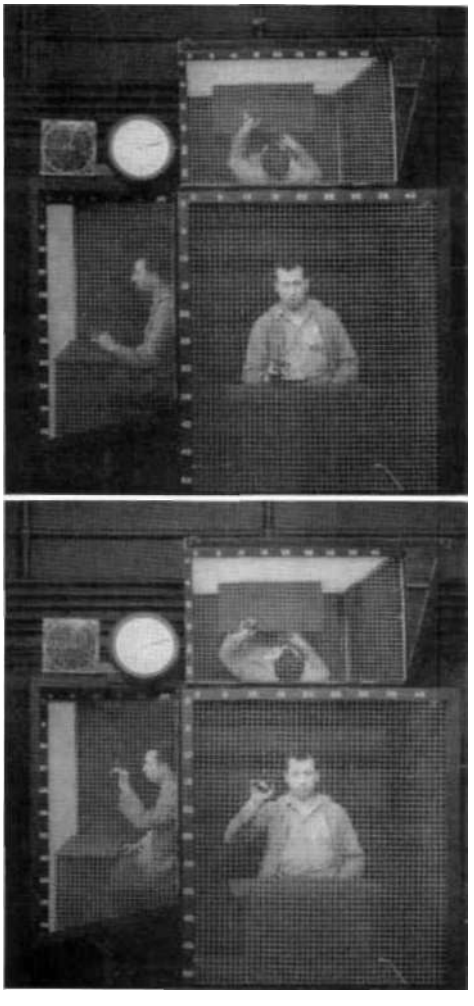

Fig. 3. Calibrated grid for measuring the arm movements required to perform certain common activities. Use of top and side mirrors provides information in three dimensions simultaneously. Clocks record time data.

test their reliability and administrative feasibility as well as to refine the procedures for their application. For this purpose, a preliminary "pilot" study was planned, and Chicago was selected as the test site.

THE CHICAGO "PILOT" STUDY

The pilot study carried out in 1952 called for a small number of surgeons, therapists, and prosthetists from the Chicago area to attend a special four-week course of instruction in upper-extremity prosthetics at the University of California at Los Angeles in order to familiarize the participants with the devices, fabrication techniques, and clinical procedures to be evaluated.[2] Upon their return to Chicago, they were joined by representatives of NYU's Prosthetic Devices Study, and the pilot study was launched.

This field trial of research instruments and procedures involved the screening of a number of amputees in the Chicago area and the selection of a group for treatment in the Veterans Administration clinic. To enable the clinic properly to prescribe the new prosthesis, each of the selected subjects was given a comprehensive evaluation prior to other treatment. In addition, research evaluations were conducted by NYU representatives to provide baseline data against which the effects of the rehabilitation procedures could be evaluated. The new arm for each participant was then prescribed in accordance with the prescription procedure taught in the UCLA course and was to be fabricated precisely as prescribed and according to the mechanical and cosmetic standards formulated. When the arm was complete, it was brought to the clinic for a checkout which consisted of a detailed examination by the clinic staff to assure themselves of the adequacy of the product. If revisions were required, they were made before the patient was given the arm; if none were needed, the clinic prescribed appropriate training treatments to be administered by the therapist.

After training was completed, the amputee was again seen by the clinic team; if the arm were still satisfactory and maximum results had been achieved through training, the patient was to wear the arm routinely in daily living. At the end of a two-month period of daily wear, the subjects were re-evaluated in a manner similar to the pretreatment evaluation.

As a result of the Chicago study, valuable experience was gained in the processing of patients. Research techniques were refined, clinic procedures were crystallized, methods for administering questionnaires and for taking measurements were standardized, and instruments were revised and augmented. With the end of the pilot phase, expansion of the upper-extremity field studies to national proportions began, an expansion made possible by the participation in the program of a number of widely distributed private clinics as well as Veterans Administration clinics.

ORGANIZATION OF PARTICIPATING CLINICS

The unprecedented nature of the projected field studies made the selection of a number of clinics a formidable task. It was first necessary to locate interested and qualified clinic personnel. Then it was necessary to orient them as to the nature of the program as well as to the need for special training. Steps for integrating the clinics into the field program required explanation, and specific operating procedures had to be worked out with individual groups. This task was undertaken by the Director of the Prosthetic Devices Study, Dr. Sidney Fishman.

After completion of the pilot study in Chicago early in 1953, and continuously for two years thereafter, Dr. Fishman and Dr. Miles H. Anderson, the Director of the Prosthetics Education Project at UCLA, visited many large population centers throughout the country in order to meet with medical and paramedical personnel interested in the treatment of arm amputees. On the basis of expressions of interest, and of an appraisal of the available facilities and potential case loads, a number of clinical facilities were invited to participate. During these discussions, research procedures were described, expected outcomes were explained, and the roles of the clinic

members and of the NYU research workers were defined. Arrangements were made for members of each clinic staff to attend the courses in upper-extremity prosthetics at UCLA (see below).

It was quickly realized that financial problems would be encountered both by private clinics and by participating limbshops. In the former, the newer training procedures called for increased services of therapists and doctors. In the latter, the employment of newer fabrication and fitting techniques required an initial investment on the part of the prosthetists in components, equipment, and materials. In addition, the checkout of an arm by the clinic team often resulted in revisions adding to initial fabrication costs. For these reasons, certain fiscal arrangements were indicated. Monies were made available to clinic teams to pay the training fees for amputee cases participating in the work. In order to spur the fabrication of the new-type arms and to permit participation in the program by the prosthetists, arrangements were made to purchase five experimental limbs from each shop participating in the studies. As a result of these efforts, 75 clinics representing 30 states and the District of Columbia (Fig. 4) participated in the field program. Each treatment center was directed and staffed by graduates of special upper-extremity prosthetics training courses. Of the total number of clinics involved, 28 were Veterans Administration installations and 47 were other public and private institutions.

PROSTHETICS EDUCATION PROGRAM

The new knowledge and techniques, organized into courses of instruction and revised after the pilot school, were offered in a series of 12 schools (Fig. 5) conducted at UCLA, the chief purpose being to familiarize doctors, therapists, and prosthetists with the new developments and to encourage the team approach to the prosthetic rehabilitation of the upper-extremity amputee. It thus became possible to teach to those with primary interest new concepts for the management of upper-extremity cases.

In effecting the transfer of information and skill to the primary amputee-treatment group consisting of the doctor, the therapist, and the prosthetist, academic tradition was broken. It seemed plain that if the "team approach" were to be taught, the members of the team should go to school together. Accordingly, in a unique educational enterprise, orthopedic surgeons, specialists in physical medicine, physical and occupational therapists, and prosthetics craftsmen became classmates. The six-week course offered at UCLA began with a three-week session of instruction for prosthetists only. During this portion of the course, prosthetists were exposed to a highly concentrated educational dose of prosthetic design and construction principles, plastics technology, anatomy, and kinesiology. Then they tested their knowledge by fitting patients under the direct supervision of their instructors.

In the fourth week, the prosthetists were joined by the therapists. This group began with a concentrated portion of mechanics, biomechanics, and the characteristics of a wide variety of both newly developed and the older prosthetic components. Under the supervision of the instructors, they also received experience in training the patients previously fitted by the prosthetist students.

At the beginning of the sixth week, the prosthetists and therapists were joined by the physicians and surgeons, who were given several days in which to review and digest the course materials. Practice clinic teams, consisting of the doctor as clinic chief and of at least one therapist and one prosthetist, were then organized. The entire class then proceeded to operate as clinic teams until graduation, whereupon each of the individuals returned home, a potential participant in the soon-to-follow upper-extremity field studies. The new knowledge and skills were broadly disseminated by these educational efforts, but their utility and effectiveness on patients could not be clearly seen until large numbers of varying types of patients had been treated and evaluated.

The Prosthetic Devices Study, charged with the responsibility for following up the program concepts, designed studies to evaluate the modern treatment methods. The central questions to be answered were deceptively

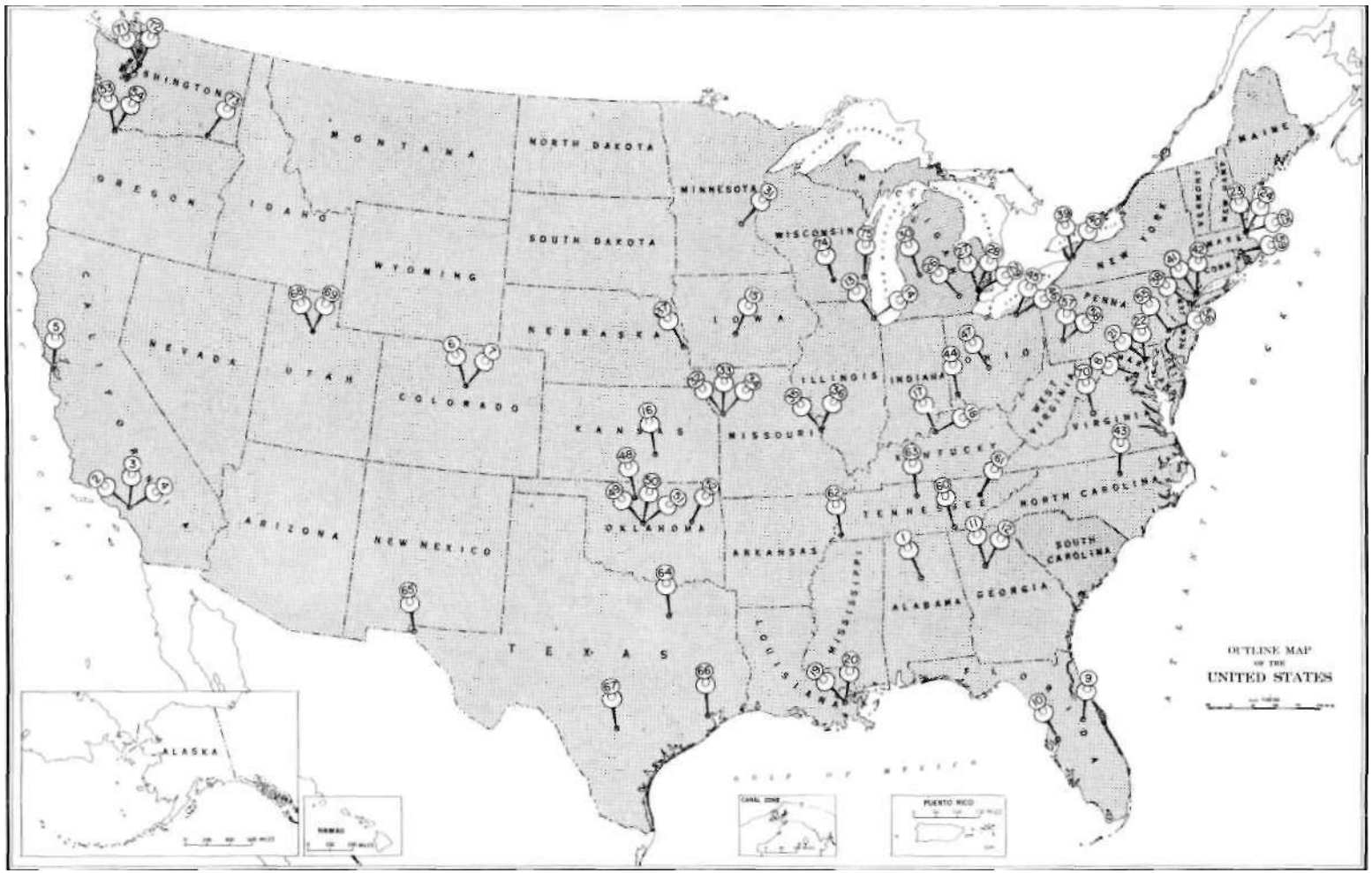

Fig. 4. Location of the participating clinics See facing page.

ALABAMA

Birmingham
1. Alabama Crippled Children's Commission

CALIFORNIA

Los Angeles
2. California Rehabilitation Center
3. Orthopedic Hospital
4. Veterans Administration Regional Office

San Francisco
5. Veterans Administration Regional Office

COLORADO

Denver
6. Denver General Hospital
7. Veterans Administration Regional Office

DISTRICT OF COLUMBIA

8. Veterans Administration Regional Office

FLORIDA

Orlando
9. Dr. Eugene L. Jewett's Clinic

Tampa
10. Dr. Albert A. Wilson's Clinic

GEORGIA

Atlanta
11. Dr. Harriet E. Gillette's Clinic
12. Veterans Administration Regional Office

ILLINOIS

Chicago
13. Rehabilitation Institute of Chicago
14. Veterans Administration Regional Office

IOWA

Des Moines
15. Veterans Administration Regional Office

KANSAS

Wichita
16. Wichita Clinic

KENTUCKY

Louisville
17. Louisville Rehabilitation Center
18. Veterans Administration Regional Office

LOUISIANA

New Orleans
19. Tulane University School of Medicine, Rehabilitation Unit
20. Veterans Administration Regional Office

MARYLAND

Baltimore
21. Johns Hopkins Hospital
22. Kernan Hospital Clinic

MASSACHUSETTS

Boston
23. Bay State Rehabilitation Center
24. New England Medical Center
25. Veterans Administration Regional Office

MICHIGAN

Ann Arbor
26. University of Michigan Hospital

Detroit
27. Detroit Rehabilitation Center
28. Henry Ford Hospital
29. Veterans Administration Regional Office

Grand Rapids
30. Michigan Crippled Children Commission

MINNESOTA

Minneapolis
31. Veterans Administration Regional Office

MISSOURI

Kansas City
32. Kansas City Rehabilitation Center
33. Katherine Payne Rehabilitation Center
34. Veterans Administration Regional Office

St. Louis
35. Firmin DesLoges Hospital
36. Veterans Administration Regional Office

NEBRASKA

Omaha
37. University of Nebraska Hospital

NEW JERSEY

Newark
38. Veterans Administration Regional Office

NEW YORK

Buffalo
39. University of Buffalo Chronic Disease Research Institute
40. Veterans Administration Regional Office

New York City
41. Bellevue Hospital
42. Veterans Administration Regional Office

NORTH CAROLINA

Durham
43. Duke University Hospital

OHIO

Cincinnati
44. Veterans Administration Regional Office

Cleveland
45. University of Cleveland Hospital
46. Veterans Administration Regional Office

Columbus
47. Ohio State University Hospital

OKLAHOMA

Enid
48. Dr. E. Evans Chambers' Clinic

Oklahoma City
49. McBride Hospital
50. Oklahoma Commission for Crippled Children
51. Veterans Administration Regional Office

Okmulgee
52. Okmulgee Rehabilitation Institute

OREGON

Portland
53. Portland Rehabilitation Center
54. Veterans Administration Regional Office

PENNSYLVANIA

Philadelphia
55. University of Pennsylvania Hospital
56. Veterans Administration Regional Office

Pittsburgh
57. Dr Murray B. Ferderber's Clinic
58. Veterans Administration Regional Office

RHODE ISLAND

Providence
59. Rhode Island General Hospital

TENNESSEE

Chattanooga
60. Erlanger Hospital

Knoxville
61. Dr. Walter J. Lee's Rehabilitation Center

Memphis
62. Campbell Clinic

Nashville
63. Veterans Administration Regional Office

TEXAS

Dallas
64. Veterans Administration Regional Office

El Paso
65. Providence Memorial Hospital

Houston
66. Methodist Hospital

San Antonio
67. Veterans Administration Regional Office

UTAH

Salt Lake City
68. Dr. Robert H. Lamb's Clinic
69. Veterans Administration Regional Office

VIRGINIA

Fishersville
70. Woodrow Wilson Rehabilitation Center

WASHINGTON

Seattle
71. Children's Orthopedic Hospital
72. Veterans Administration Regional Office

Walla Walla
73. Dr. C. Don Plattner's Clinic

WISCONSIN

Madison
74. University of Wisconsin Orthopedic Hospital

Milwaukee
75. Columbia Hospital

Fig. 4. Participating clinics, keyed to map on facing page.

Fig. 5. Students and instructors of one of the 13 courses in upper-extremity prosthetics offered at the University of California at Los Angeles. This particular course was held in the autumn of 1954.

simple: Are upper-extremity amputees better served by means of the program procedures? In what specific areas can improvement, detriment, or indifference be found?

AREAS of RESEARCH

In relatively unexplored fields, the formulation of meaningful research questions is often laborious, unsure, and time-consuming. Merely selecting the most scientifically promising problems from the many questions which arise is in itself an important research task. Many possible approaches to the field must be evaluated, and those selected for study must give promise of becoming part of and contributing to the solution of larger problem areas. The research plan developed at the Prosthetic Devices Study to achieve the objectives of the field-study program evolved in this way. It provided for three major interrelated study areas to be exploited concurrently.

The first of these, a census of amputees, called for interviewing large numbers of upper-extremity amputees in order to begin the organization of a broader body of knowledge concerning them and to provide a large population from which to select a sample for more detailed study. This was the "Survey Phase." Secondly, a segment of this population was selected for clinic treatment by means of the rehabilitation procedures under study. These efforts of the field operations, referred to as the "Clinical Studies," were designed to provide information about the feasibility of clinic procedures and prosthetic fabrication methods. The third study area provided for the pre- and post-treatment evaluation of a portion of the sample selected for clinic treatment. This approach, called "Evaluation Studies," was intended to elicit more detailed information about a smaller number of amputees than was possible in the survey and to provide a basis for evaluation of the methods and materials employed in the treatment procedure.

In its final form, the research plan provided for trips by NYU field representatives to attend the monthly meetings of each participating clinic. Consequently, a given member of the staff would be in the field approximately two weeks out of each month, and a routine field trip often took him to five or six cities, where he would visit perhaps six or eight clinics and observe 20 to 30 amputees under treatment. With 75 participating clinics to serve, a field staff of 10 representatives directed by two field supervisors was organized. Since clinic meeting dates and times were quite firmly fixed, and since the time required to be spent with each subject varied from fifteen minutes to four hours, depending upon the stage of treatment, the trips required considerable planning. To minimize loss of time, schedules were arranged by correspondence, and confirmed when possible, before each trip. Despite the difficulty of control, the attrition rate when the studies ended was low. Some-

what less than 10 percent of those initially selected failed to complete the full treatment course and follow-up studies.

The NYU representative served two main functions: he established liaison among the treatment centers in the field and between them and New York University, which resulted in interchange of information and coordination of effort, and he was responsible for the collection of the research information. These data were gathered in the field by means of interviews, questionnaires, tests, and measurements.

SURVEY STUDIES

Each arm amputee referred to a participating clinic was considered a prospective research subject, and each was given a screening interview, the purpose being to obtain pertinent information concerning the patient, his prosthesis, and his needs and aspirations. Initially, clinics screened only those amputees who were immediately in need of treatment. The information thus gleaned contributed to the survey to be made of the status of upper-extremity amputees in the United States and was also useful in the selection of subjects for more detailed study. On the basis of the screening data, two classes of subjects were selected. One group was to be treated only in the clinic by the prescribed procedures. The other, in addition to the clinic treatment, was to undergo a detailed pretreatment evaluation and a similar post-treatment procedure.

At the screening interview, the purposes and general procedures of the program were explained to the prospective participant, and information of an administrative and medical nature was collected. The common vital statistics dealing with age, height, weight, and marital and occupational status were recorded. In addition, the date, cause, and site of amputation were obtained, and the length, range of motion, shape, and condition of the stump were described. Detailed descriptions were compiled of prostheses worn by candidates, and their quality and the subjects' ability to use them were evaluated. The data contributed by each amputee were recorded on forms developed for this purpose (Appendices IA and IB).

The selection of amputees to be processed at the first and subsequent prescription meetings was made at the Prosthetic Devices Study on the bases of available information and the sampling requirements of the study. Factors taken into account in the selection of the subjects included type of amputation, general health and physical condition of stump, and motivation of patient (his interest and willingness to participate). The entire census included 1630 male upper-extremity amputees, of whom 826 were below-elbow cases, 668 had amputations above the elbow, 89 had disarticulations at the shoulder, and 47 were bilateral amputees of all types. The findings arising from these survey studies are described in the article by Berger (page 57).

CLINICAL STUDIES

The idea of the clinic team was the key concept of the newly developed management procedures. The clinic was viewed as a means and a method for focusing the special skills of all the necessary medical and ancillary specialists on the specific problems of providing the amputee with the best possible replacement for the lost member. The primary service group consisted of physicians and surgeons, therapists, and prosthetists. Other specialists, such as administrative personnel, vocational-rehabilitation counselors, social-service workers, or psychologists, were added according to the special needs of individual cases. The fundamental nature of the clinic was emphasized by the requirement that each of the basic members be present before an "official" meeting of the clinic could be opened. It was at these clinic meetings that the treatment concepts to be evaluated were applied. There were six basic steps in the clinic procedure—prescription, preprosthetic treatment, fabrication of the prosthesis, initial checkout, training, and final checkout. Of these, three—prescription, initial checkout, and final checkout— required meetings of the full clinic team.

Prescription

Prescription, during these studies, called for the selection of specific components from an armamentarium of tentatively approved devices for assembly into an individually

prescribed prosthesis. Most of these components were designed for specific types of cases or uses and were to be prescribed in accordance with their design purposes. The final prescription was to be the concensus of the clinic members as to the most applicable components in each case. In practice, however, the medical, surgical, and physical-therapy needs of each patient were considered, as were also personal and vocational indications for specific components and materials. Required was a written prescription specifying every component to be used, and all deviations from standard applications were avoided unless expressly written into the prescription. To standardize the type and quality of the information collected at these meetings, the prescription form in Appendix IIA was developed. This procedure not only was the first treatment step but it also permitted the collection of research data describing the specific devices fitted to the subjects. On the basis of subsequent acceptability and utility to the amputees, inferences could be drawn as to the worth of these components.

Preprosthetic Treatment

As part of the prescription process, the patient was examined for conditions which might produce difficulty in wearing or using an artificial arm. Particular efforts were made to institute treatment prior to fitting a limb and thereby to avoid the influence of these factors upon the acceptance and use of the prosthesis. Medical and surgical problems involving disease, infection, inflammation, redundancies, bone overgrowth, neuromata, and plastic alterations were referred to the physician for treatment. Muscular weakness and limitations in joint mobility considered amenable to treatment were referred to the therapist.

Fabrication of the Prosthesis

When the prescription was completed, instructions were given to one of the attending prosthetists to fabricate the arm. With strict adherence to the details of the prescription, the limbmaker produced the arm by use of the techniques of fitting taught by the program. He was encouraged to inspect the completed arm by means of a checklist embodying the structural, functional, and cosmetic standards that his product would have to meet at the next clinic meeting.

Initial Checkout

When the arm had been fabricated, it was brought to the clinic prior to being worn by the subject. At this clinic meeting, called "initial checkout," the standards developed in the program were applied. The initial checkout included an objective and subjective appraisal to see that the device fulfilled the prescription requirements and that it met established standards of fit, comfort, function, and appearance (Fig. 6). The information thus obtained described the ranges of motion available with the arm, the forces required to operate it, and stability, fit, comfort, and weight. In addition, some 30 items dealing with details of fabrication, appearance, color, specific components, and general quality were checked. These standards were considered to represent minimal levels of prosthetic adequacy. All the appropriate measurements and checks were recorded on a form similar to that shown in Appendix IIB.

These data were used to control the quality of the arms in order to permit valid generalizations about their worth. In addition, when compared with the outcomes of the treatment procedure, these data provided the basis for evaluation of the standards themselves.

The checkout was performed at a regular meeting of all members of the clinic. If the arm failed checkout, it was referred to the prosthetist for appropriate revisions (Fig. 7). Consequently, it was sometimes necessary for the subject to appear at the clinic more than the minimum of three times. If the prosthesis met all the requirements, the amputee was permitted to wear the arm regularly and was scheduled for training by the therapist, the next step in the clinic procedure.

Training

The training given to each subject by the therapist was organized in two parts—controls training and use training.

Controls Training. In the preliminary step, the objective was to familiarize the amputee with the mechanics of his appliance and to develop his ability to control its movements.

First he was taught to operate the arm freely so as to learn by kinesthetic reaction the motions and forces required to control it. Then various objects with abstract forms and of varying consistencies were introduced to develop prehension skill. When, in the opinion of both therapist and amputee, these control motions were adequately developed, the next training phase began.

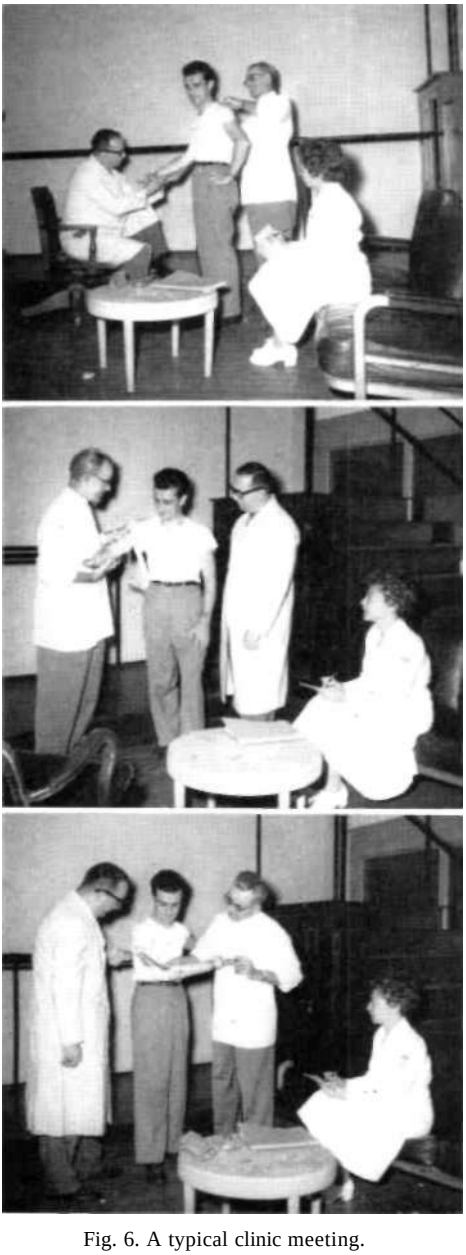

Fig. 6. A typical clinic meeting.

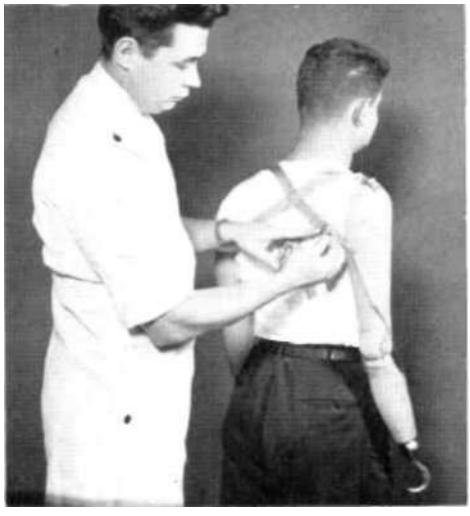

Fig. 7. Checkout. Final harness adjustments are made on a new arm prosthesis.

Use Training. Once the basic operating techniques were learned, they were applied to performing the practical activities of daily living, including self-help, home tasks, and vocational and social activities (Fig. 8). The training objectives were now to give the amputee confidence in his ability to use the arm by exploring a variety of activities and to achieve proficiency in performing them. In this connection, it was necessary to recognize that the prosthesis cannot replace the lost member and that at best it becomes an auxiliary of the remaining arm.

By application of this fairly standardized sequence of activities, it was possible to collect research information relating to achievement levels and to the number of hours of training required to achieve satisfactory performance. When the amputee seemed capable of satisfactory performance with his prosthesis, the therapist arranged for him to reappear at the clinic for a final checkout.

Final Checkout

The final checkout concluded the process of providing the amputee with an arm. In a

Fig. 8. Use training. The therapist explains how to approach, grasp, and manipulate a variety of common objects.

fashion similar to the pretraining initial checkout, it was conducted at a regular meeting of the clinic, all members present. The purpose at this time was threefold—to recheck the mechanical and functional adequacy of the arm after use in training, to assure the clinic that satisfactory proficiency levels had been attained, and to be sure that nothing further in the way of service could be offered the patient if the first two conditions were met.

The objective and subjective appraisal was again accomplished by means of the standardized checkout procedure (Appendix IIB). The arm was carefully inspected for signs of wear, and evidence was presented that the amputee was adequately trained. If the condition of the arm and proficiency of the subject in its use were deemed satisfactory, he was discharged with instructions to use the arm in accordance with his daily needs.

Recapitulation

Altogether, the group treated in the clinics included 378 below-elbow, 321 above-elbow, 46 shoulder-disarticulation, and 24 bilateral amputees. Of the total of 769, 410 received no further treatment, while 359 were extensively studied prior to and after completion of the treatment procedures.

The complete procedures employed in these studies are rather too complex for convenient presentation here in more than outline form. The full description and explanation of the most recent modification of these procedures is the subject of short-term courses of instruction currently being offered at the University of California at Los Angeles and at New York University. The manuals used in these courses *(1, 2)* contain detailed descriptions of the procedures and may be referred to for further information.

The results of these clinic studies are presented in the article by Springer (page 73).

EVALUATION STUDIES

The prosthesis for an upper-extremity amputee is a necessarily limited means of providing those motions lost through amputation—prehension, pronation-supination, wrist flexion-extension, and, in the case of the above-elbow amputee, the additional function of flexion-extension of the forearm. The chief goals of the evaluation procedures were to determine the extent to which a prosthesis provided functional as well as cosmetic replacement. A corollary purpose was to discover additional parameters of prosthetic utility and acceptability by increasing our knowledge of why an amputee accepts and uses more readily and efficiently one prosthesis in preference to another.

The extent to which prosthetic restoration is successful is dependent upon what each subject brings to the appliance in terms of physical and mental characteristics and on what the appliance brings to him in terms of functional capabilities and qualities of comfort and cosmesis. Evaluation procedures were, therefore, aimed at the analysis and understanding of both the human and the mechanical variables that are involved in the successful use of an arm prosthesis. Although the potential significance of the pre-injury personality was recognized, it was not investigated because of the difficulty of obtaining such information in a field study of this nature.

Some of the significant evaluation factors lent themselves to objective measurement; others, of a more personal and subjective nature, could be obtained only from the amputee himself. For this reason, the evaluation procedures and instruments were designed to collect both objective measurements and more subjective data dealing with the reactions and responses of the amputee.

In this connection, the measurement rationale underlying the collection of data should be understood. Quantitative data are convenient for systematic analysis. But quantification can be meaningful only within well-developed and clearly defined evaluation areas. The appraisal, for example, of certain functional characteristics of an arm lends itself readily to objective or quantitative measurement, since the problem area is defined by the extent to which the prosthesis replaces certain lost motions. The problem here is clear; the ranges of motion and the forces applied can actually be measured. In much the same way, an evaluation of performance may be made by scoring such objective aspects as speed, errors, and even some types of quality. On the other hand, in dealing with those effects of treatment procedures relating to feelings, attitudes, emotions, comfort, and fit, the parameters to be measured are not at all clear. For this reason, in such obscurely defined areas qualitative data deriving from interviews and from both structured and unstructured responses of the subject tend to be more valuable in outlining and clarifying the areas of study. Once this is done, the particular factors may become amenable to quantitative measurement.

Actually, only three possible sources of data were available—objective measurements describing events, the expert opinions and judgments of qualified observers, and the reactions of the subjects. Each of these sources was exploited. Specific mechanical and biomechanical factors were measured by objective methods. Prosthetic quality and proficiency in performance with an arm were appraised by trained observers whose reliability was periodically checked and re-established. Finally, the amputee himself provided information relating to his reactions to the arm, its quality, and its usefulness to him. Within two broad categories, the human and the mechanical, the following were studied:

Biomechanical Data

1. The strength and ranges of motion of the arm and shoulder girdle and the general physical condition of the amputee.
2. The ranges of motion permitted by the prosthesis, its efficiency, and the forces required to operate it.

Performance Patterns

1. Proficiency in accomplishing the basic activities of prehension, transportation, and release in various planes and at different levels.
2. Quality of performance of practical daily-life activities.
3. The range of activities in which prostheses are used and the extent of their importance.

Amputee Reactions

1. Importance and extent of use of prostheses in daily living.
2. Reactions to treatment procedures.
3. Appraisal of prostheses and components.

Psychological Reactions

1. Personal meanings of amputation and prosthetic restitution.
2. Social consequences of loss of limb and of prosthetic replacement.

Biomechanical Data

It is reasonable to assume that an upper-extremity prosthesis which affords the amputee a greater range of motion and which requires a minimal amount of energy or force for operation will be a more desirable appliance. While much more information is necessary before final judgment can be made, comparative data on these factors formed one of the bases for the evaluation of arm prostheses. This kind of data was obtained through direct measurement using such instruments as rulers, spring scales, and goniometers. They were used to measure pinch force between hook or hand fingers; efficiency of force transmission through the cable system; ranges of pronation, supination, and forearm flexion; socket displacement under axial load; and weight of the prosthesis. In the case of the above-elbow amputee, additional information was collected on force input required to flex the forearm, angular deflection of the humerus needed to produce given ranges of forearm flexion, and ranges of motion at the shoulder. These measures were recorded on the

instrument shown in Appendix IIIA. The outcome of these evaluations will be presented in an article in the next issue of ARTIFICIAL LIMBS (Autumn 1958; Vol. 5, No. 2).

Performance Patterns

The performance of the subjects in standardized, specially designed activities was observed and analyzed. This procedure was employed to provide information concerning the effectiveness and appearance of the performance patterns. Two approaches to the evaluation of performance were taken. Both abstract and practical function were evaluated. In the former, the ability accurately to grasp, transport, and release objects of varying sizes, shapes, weights, and consistencies was graded (Fig. 9). In the evaluation of practical function, amputees were graded on their performance of meaningful daily-life activities (Fig. 10). Proficiency scores and time-and-motion data were recorded on the forms appearing in Appendix IIIB, while activities were tabulated as shown in Appendix IIIC.

Fig. 9. Evaluation of abstract function.

Amputee Reactions

Analysis of Importance and Extent of Use of Prosthesis in Daily Living. In an attempt to appraise the importance of the prosthesis to the amputee, and to determine some of the specific ways in which prostheses were used, the interview technique was utilized. The subjects were asked if they used their prostheses in specific activity areas, including work, home tasks, social life, dressing, and eating. If their response was positive in any area, they were asked to specify the particular use they made of the arm. They also were asked to rate the importance they placed on their prostheses in each of the activity areas.

Fig 10. Evaluation of practical function.

The extent to which a subject used his prosthesis to accomplish the tasks of daily life seemed to be a significant factor in appraising the degree of functional restoration afforded by the prosthesis. For this reason information was gathered about the frequency with which the prosthesis was used in ordinary two-handed activities. In order to make this more meaningful, additional information was collected concerning the frequency with which each activity was encountered in the course of the daily life of the particular amputee. Additional information about common activities which were *not* done and the reasons therefor also was gathered.

The following key questions were used:

1. How often does the occasion arise for the amputee to perform each of a number of typical two-handed activities?
2. How often does the amputee use his prosthesis in performing each activity?
3. If the need for an activity arises more often than the prosthesis is used in accomplishing the task, why does the amputee not use his prosthesis?

4. What is the relative importance of each of a number of activities?

These evaluations were made by means of the instrument shown in Appendix IIIC. The results of this study will appear in an article in the next issue of ARTIFICIAL LIMBS (Autumn 1958; Vol. 5, No. 2).

Reactions to Amputation and Prosthetic Experience. The subjective reaction of an amputee to his prosthesis was deemed an important factor in its evaluation. Apart from his feelings about the characteristics of the prosthesis, his experiences in securing it and wearing it are also contributing factors in his acceptance or rejection of the arm, and information in this regard may be important to an understanding of his status. This type of information was obtained through the use of interviews and questionnaires. By these means, data were gathered relating to:

1. Time lapse between amputation and first prosthesis.
2. Preprosthetic physical therapy.
3. Procedures in prosthetic prescription.
4. Services of prosthetist.
5. Procedures in initial checkout of prosthesis.
6. Training in the use of the prosthesis.

The article by Springer (page 73) describes the findings of this study.

Amputees' Appraisal of Prosthesis and Components. An evaluation of the prescribed components was an essential aspect of the studies. An armamentarium had been developed, and components had been prescribed on the basis of their design features. In order to appraise the relative value of these components, the amputees were asked to comment on specific characteristics of all the components of their prostheses and to describe the suitability or inconvenience of any device with which they were familiar. The following information was elicited:

1. The extent of his acquaintance with prosthetic components.
2. His appraisal of certain specific characteristics of each device with which he was familiar.
3. His expression of the suitability of prosthetic components for activities.
4. A comparison of currently and previously worn prostheses.

These opinions and experiences were recorded as shown in Appendix HID. The results and significance of this study will appear in an article in the next issue of ARTIFICIAL LIMBS (Autumn 1958; Vol. 5, No. 2).

Psychological Reactions

It is frequently observed that some amputees fail to wear or use a prosthesis which seems to be well fitted and functional. Others, with properly prescribed and well-fitted arms, and even those with inadequate prostheses, accept and use them extensively. These reactions were attributed to the varying, highly personal meanings of amputation and prosthetic restoration. For this reason, a psychological analysis by means of interviews and questionnaires was undertaken to explore the significance of these factors.

The instruments used included a 57-item multiple-choice questionnaire (Appendix HIE) developed by the Prosthetic Devices Study. Completed by the subject in the presence of an NYU representative, it was designed to provide information about the feelings and behavior of amputees relative to amputation and prosthetic restoration. The following reactions were elicited: feelings of functional adequacy, acceptance of loss, sensitivity about disability, ability to cope with social situations, feelings of independence, and attitudes toward prostheses.

Another questionnaire (Appendix IIIF) contained nine open-end questions. This provided an opportunity for the subject to express his feelings about the effects of his condition and treatment upon his personality and social activities. It supplemented the more highly structured 57-item questionnaire (Appendix IIIE).

The third instrument (Appendix IIIG) was a novel (experimental) application of a projective device. It consisted of nine cartoons depicting common social situations in which the fact of amputation might lead to awkwardness or embarrassment. It permitted the amputee to select one of a number of possible responses to each potentially embarrassing situation. By his reaction, the patient was expected to express his feelings of independence, the degree to which he faced reality, his

acceptance of the amputation, and his sense of security. Each response represented a gradation of possible reactions to each situation.

A fourth questionnaire (Appendix IIIH) was employed specifically to elicit information from subjects who had never previously worn prostheses. It consisted of 15 multiple-choice questions relating to the amputee's knowledge of prosthetic components and his expectations regarding the functional, cosmetic, and comfort qualities of artificial arms. A series of open-end questions was included to determine opinions of prosthetic usefulness and difficulties of prosthetic wear.

Upon execution of these procedures, the evaluation of an amputee was complete, but the entire process was performed twice. The first appraisal, conducted by the NYU representative prior to the prescription meeting, provided a detailed description of the pretreatment condition of the patient with respect to his physical condition, functional capacity, experience as an amputee, quality and usefulness of his prosthesis, and his emotional reaction to disability. Approximately three months after a satisfactory final checkout, or six to nine months after fitting, the previously evaluated subjects were again processed for a post-treatment evaluation, the procedures followed being essentially the same as in the pretreatment evaluation. The instruments used are given in Appendices IIIE, IIIF, IIIG, and IIIH.

These data are analyzed and discussed in an article to appear in the next issue of ARTIFICIAL LIMBS (Autumn 1958; Vol. 5, No. 2).

SUMMARY

Some of the problems involved in prosthetic service to amputees just after World War II, and the steps taken by governmental and private organizations toward their solution, have been described in this section. The development of the Artificial Limb Program has been traced briefly from its inception through the initial studies in which problems were isolated and new methods and materials to solve them were developed. The dissemination of new knowledge through the organization of a prosthetics education program has been discussed, and the design and scope of the studies undertaken to evaluate the new developments have been described. "Survey Studies" were carried out to increase the available knowledge about amputees in this country. "Clinical Studies" were pursued to evaluate the effect of the newly developed treatment methods. And "Evaluation Studies" of the changes in amputees' conditions brought about by these treatments were planned and executed.

The evaluation instruments and techniques have been described briefly in this section in the interest of presenting a clear overview of the whole process. A total of 359 amputees were studied by means of these procedures. This group contained 168 below-elbow, 158 above-elbow, 23 shoulder-disarticulation, and 10 bilateral amputees.

The upper-extremity field studies represented a pioneering effort to apply special skills to special problems in a broad, only partially understood field. A multiplicity of interests, unique requirements, and a paucity of previous research combined to broaden the scope of the studies. The methods and instruments employed are considered a first step toward the establishment of more precise and valid methods for evaluating the condition of those with physical impairment. But despite the broadness of the field and the research requirements, service to the amputee was always a paramount consideration.

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