Prosthetics and Orthotics Research in The United States*

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The replacement of missing limbs has been a problem facing man since the beginning of his existence. Some prehistoric men must have survived crushing injuries resulting in amputation, and certainly some prehistoric children were born with congenitally deformed limbs amounting to amputation. In 1958 the Smithsonian Institution reported the discovery of a skull, dating back about 45,000 years, of a person who was deduced to be an arm amputee because the teeth apparently had been used in a manner to compensate for lack of limb. Leg amputees must have compensated for their loss partially by the use of crude crutches and in some instances by using peg legs fashioned from forked sticks or tree branches.

In relatively modern times the advancement of amputation surgery and limb prostheses had been closely linked with warfare. In the days of knighthood it was the warrior who received an artificial limb. Indeed, some were able to return to battle with the aid of prostheses. It was the French army surgeon, Pare, who reintroduced in 1529 the application of ligatures to control bleeding and led the way toward amputation methods in use today. Pare also devised artificial limbs for his patients.

The Napoleonic Wars, the American Civil War, and World War I all led to the development of improved surgical technics and better artificial limbs. World War II proved to be no exception to the pattern.

Research Program After World War II

Early in 1945 the Surgeon General of the U. S. Army requested of the National Academy of Sciences (see box on next page) advice concerning the provision of artificial limbs to the large influx of soldiers who had suffered amputation. A conference of surgeons, engineers, and prosthetists, conducted by the Panel on Amputations of the Division of Medical Sciences, National Academy of Sciences—National Research Council, revealed that little scientific effort had been devoted to the development of artificial limbs and recommended that a research program in this area be initiated.

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NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL

The National Academy of Sciences—National Research Council is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare.

The Academy was established in 1863 under a Congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the Federal Government in scientific matters. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency.

The National Research Council was established by the Academy in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the Academy in service to the nation, to society, and to science at home and abroad. Members of the National Research Council receive their appointments from the President of the Academy. They include representatives nominated by the major scientific and technical societies, representatives of the Federal Government, and a number of members-at-large. In addition, several thousand scientists and engineers take part in the activities of the Research Council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the Academy and its Research Council thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the Government, and to further the general interests of science.

Such a program was activated in the spring of 1945 by the National Academy of Sciences through its Division of Engineering and Industrial Research with funds supplied by the Office of Scientific Research and Development. The Academy, acting as the prime contractor, entered into agreements with some 16 private and public facilities for the conduct of research and development on a broad front. The program was directed by the Committee on Artificial Limbs.* Shortly after the cessation of hostilities, upon the dissolution of the Office of Scientific Research and Development, fiscal responsibility was assumed by the Office of the Surgeon General. Not long thereafter the Veterans Administration provided supplementary funds. Initially many felt that the solution to the problem of limb prosthetics was simply to devise better mechanisms and apply new materials.

Although certain advances were effected by such an approach, it was soon realized that fundamental biomechanical studies were necessary for the development of truly realistic design criteria. The responsibility for such studies was entrusted to the University of California, which established on the Berkeley campus a laboratory devoted to study of the lower extremity and on the Los Angeles campus a laboratory for study of the upper extremity. Groups elsewhere based their designs on criteria developed by the California laboratories.

* For a short time at the beginning the Committee on Artificial Limbs was known as the Committee on Prosthetic Devices.

In the spring of 1947 the Committee on Artificial Limbs considered that it had established a stable program and, in keeping with the policy of the National Academy of Sciences, recommended that interested governmental agencies contract directly with the research laboratories and that the Committee itself assume an advisory role rather than that of director. Also at this time the Veterans Administration assumed complete fiscal responsibility, but the Army and Navy agreed to co-operate by continuing operation of research laboratories within their own departments. The co-ordinating group within the Academy was designated as the Advisory Committee on Artificial Limbs, later as the Prosthetics Research Board, and currently as the Committee on Prosthetics Research and Development.

In 1948, upon advice of the Advisory Committee on Artificial Limbs, an independent evaluation laboratory was established at New York University for the purpose of testing the usefulness of devices and technics emerging from the development laboratories. Thus, an orderly pattern of transition of an idea from the concept stage to a completed item was possible.

To insure continuity to the program Congress, also in 1948, passed Public Law 729 authorizing appropriations to the Veterans Administration up to $1 million annually for research in the fields of prosthetics, orthopedic appliances, and sensory aids for the blind. Since 1954, under the provisions of Public Law 565, known as the Vocational Rehabilitation Act, the Office of Vocational Rehabilitation (recently renamed Vocational Rehabilitation Administration) of the Department of Health, Education, and Welfare (HEW) has been able to support research and training projects in prosthetics, orthotics, and other areas required in rehabilitation. Grants for the support of certain fundamental research have been made by the National Institutes of Health, the Easter Seal Research Foundation, and The National Foundation. Research in the area of prosthetics for children is supported by the Children's Bureau, HEW.

By 1952 a sufficient body of knowledge concerning upper-extremity prosthetics had been accumulated so as to change radically previous concepts of management of the arm amputee. The Veterans Administration, seeking an efficient method of transmitting this knowledge to its clinic teams responsible for care of amputees, supported the University of California at Los Angeles in establishing and conducting short-term courses in upper-extremity prosthetics for physicians, therapists, and prosthetists. So successful were these courses that it was necessary to establish educational programs at two other centers—New York University and Northwestern University. Today these three schools operate at full capacity and add courses as new material is developed in the research program. Because the requirements of the Veterans Administration represent but a small percentage of the population as whole, the major support of the prosthetics education programs in the universities is by funds administered by the Vocational Rehabilitation Administration.

From the inception of the Artificial Limb Program, those responsible for its conduct realized that the need for research in the allied field of orthotics* was just as important but felt that a sound program in prosthetics would eventually provide a firm foundation for research in orthotics, much of the fundamental data accumulated in prosthetics research being applicable

* Orthotics is a coined word designed to embrace the field of orthopedic bracing. In some quarters the word *orthetics* has been used, but in 1959 the Orthopedic Appliances and Limb Manufacturers Association (now American Orthotics and Prosthetics Association), after considerable consultation with numerous lexicographers, approved *orthotics* as the most appropriate nomenclature.

to orthotics. Beginning about 1956 funds for a limited amount of research became available through the Office of Vocational Rehabilitation and the Easter Seal Research Foundation. Today some 8 to 10 institutions are conducting studies aimed at furthering knowledge in orthotics, and the Committee on Prosthetics Research and Development has assumed the responsibility for correlating this work.

Results of Research Program

Virtually every aspect of the management of amputees has been influenced by results of the research program. The surgeon no longer holds to the "sites-of-election" concept because suitable devices and technics are available to fit every level of amputation.

Some of the major components and technics introduced by the research groups are the ischial-gluteal-bearing suction socket for above-knee amputees, the patellar-tendon-bearing socket in below-knee cases, the solid-ankle, cushion-heel (SACH) foot, the plastic Syme prosthesis, the Canadian-type prosthesis in cases of hip disarticulation and hemipelvectomy, an array of harnessing technics for arm amputees, the alternator-type elbow, the Army Prosthetics Research Laboratory (APRL) terminal devices, and plastic artificial arms.

The concept of the clinic team evolved from the inter-disciplinary research program, and as a result there is today a much closer relationship between the medical and prosthetics professions.

Also as a result of the program an entirely new body of knowledge concerning the functions of the extremities exists. This knowledge, still being expanded, has been helpful in the development of new devices and technics and should prove useful for a good many years to come.

Method of Operation

The 13-man Committee on Prosthetics Research and Development is composed primarily of engineers, physicians, and prosthetists but is not limited to these disciplines. Each member is appointed by the President of the National Academy of Sciences to a three-year term and serves as an individual rather than as a representative of an organization or institution. Members of the Committee serve without pay. A small staff is employed to carry out day-to-day activities.

The objectives of the Committee are to correlate the various prosthetics and orthotics research activities supported by the Veterans Administration, the Department of Health, Education, and Welfare, the Army, the Navy, and others; to keep the sponsoring agencies advised of the scope of the program and progress made; to insure that successful new devices and technics are made available promptly to the schools of prosthetics and orthotics education for inclusion in the curricula; to determine areas where research is required and stimulate initiation of such research; and to provide wide dissemination of the results of research.

The Committee on Prosthetics Research and Development meets at least twice yearly to receive progress and evaluation reports concerning the research efforts, to consider any problems posed by the sponsors, research groups, or others, and to recommend the course of further efforts. To consider problems peculiar to the juvenile amputee, there is a Subcommittee on Child Prosthetics Problems. *Ad hoc* committees are appointed to handle special problems as they arise. Conferences on specific topics are held whenever needed. During the past fiscal year special conferences were held on the total-contact socket for above-knee amputees, upper-extremity prosthesis design, and orthotics research. In addition, the Committee organized and sponsored a pilot school in total-contact above-knee sockets in order that this concept might be introduced into the prosthetics education program.

Funds for operation of the Committee on Prosthetics Research and Development are provided by the Veterans Administration, the Vocational Rehabilitation Administration, and the National Institutes of Health.

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Present Activity

At the present time at least 25 groups are conducting some type of research or development in prosthetics or orthotics, or both. A list of these groups along with their primary responsibilities is given below:

Organization	*Major Area (or Areas) of Investigation*	*Sponsoring Agency*
1. Army Prosthetics Research Laboratory (APRL)—John Butchkosky	Upper-Extremity Prosthetics Development and Materials Research	U.S. Army
2. Navy Prosthetics Research Laboratory (NPRL) — Robert C. Doolittle	Lower-Extremity Prosthetics Development	U.S. Navy
3. Veterans Administration Prosthetics Center (VAPC) — Anthony Staros	Testing and Development of Prosthetics and Orthotics	VA
4. Prosthetic Research Center, Northwestern University (NU) —Clinton L. Compere	Prosthetics Development (especially with respect to the older age group)	VA
5. Mauch Laboratories, Inc. (ML) —Hans A. Mauch	Development of Lower-Extremity Prosthetic Devices	VA
6. Adult Prosthetic and Orthotic Studies, New York University (APOS-NYU)—Sidney Fishman	Testing and Evaluation of Devices and Technics	VA and VRA
7. Biomechanics Laboratory, University of California (BL-UC) —Verne T. Inman and Charles W. Radcliffe	Prosthetics and Orthotics Design and Studies of Human Locomotion	VA and VRA
	Investigation of Post-Traumatic Epidermoid Cysts	VRA
	Energy Expenditure in Certain Types of Disabilities	VRA
	Energy Expenditure and Work Tolerance Studies in Hemiplegic Patients	VRA
	Clinical Evaluation of Experimental Orthotic Devices and Procedures	VRA
	Medical Aspects of Amputee Research—Lower Extremity	NIH
	Pilot Study in Brace Research	Easter Seal
8. Biotechnology Laboratory, University of California, Los Angeles (UCLA)—John Lyman	Research on Control of Externally Powered Artificial Arms	VA
9. John O. Esslinger c/o Gasow Veterinary Hospital, Birmingham, Mich.	Study on Semiburied Implants for the Attachment of External Prostheses	VA

10.	University of Michigan (UM)—James W. Rae, Jr.	Research and Development in Upper-Extremity Orthotics	VRA
11.	American Institute for Prosthetic Research (AIPR)—Henry H. Kessler	Development of Pneumatically Powered Upper-Extremity Prostheses	VRA
12.	NYU Post-Graduate Medical School (APS-NYU) — Sidney Fishman	Development of a Psychological Test Battery for Predicting Success in Amputee Rehabilitation	VRA
13.	Albert Einstein College of Medicine, Yeshiva University (ECM)—Sidney Weinstein	Experimental Analysis of Phantom Appendages with Special Reference to Somato-sensory and Experiential Concomitants of Amputation	VRA
14.	American Orthotics and Prosthetics Association (AOPA)—Lester A. Smith	Survey To Determine the State of Services Available to Amputees and Orthopedically Disabled Persons	VRA
15.	Los Angeles County Hospital (LACH)—Vernon L. Nickel and Robert Mazet, Jr.	Influence of Prosthesis Wearing on the Health of the Geriatric Amputee	VRA
16.	Attending Staff Association of Rancho Los Amigos Hospital, Inc. (RANCHO) — Vernon L. Nickel	To Investigate and Demonstrate Sources of External Power for Upper-Extremity Orthotic Devices Improvement of Mechanical Devices To Replace Losses Due to Very Severe Upper-Extremity Paralysis	VRA and The National Foundation The National Foundation
17.	Baylor University College of Medicine (BUCM)—William A. Spencer	Development of Upper-Extremity Orthotic Devices	VRA
18.	Harvard University (HU) — Ross A. McFarland	Evaluation of the Ability of Amputees To Operate Trucks or Other Vehicles	VRA
19.	New York University College of Engineering, Research Division (NYU)—Sidney Fishman	Analysis and Evaluation of Lower-Extremity Orthotic Devices	VRA and Easter Seal
20.	Case Institute of Technology (CIT)—James B. Reswick	Applicability of Digitally Programed Control in Prostheses and Ortheses; Development of Synthetic Muscle Motors for Use in Prostheses and Orthoses; Development of a Micro-Miniature Signal Transducer Unit for Implantation in Human Muscle	VRA
21.	Eugene duPont Memorial Hospital and Rehabilitation Center (duPont)—Arthur J. Heather	Development of Hydraulically Operated Elbow Unit for an Orthopedic Brace	VRA
22.	New York University College of Engineering (NYU) — Renato Contini and Rudolfs Drillis	Determination of Certain Body Segment Parameters	VRA
23.	Child Amputee Prosthetics Project, University of California, Los Angeles (CAPP)—Charles O. Bechtol, Milo Brooks	Development of Improved Prosthetic Devices and Training Technics, and Surgical Procedures for Child Amputees	Children's Bureau and NIH
24.	Child Prosthetic Studies, New York University (CPS-NYU)—Sidney Fishman	Evaluation of Children's Prostheses and Collection of Normative Data on Methods of Treatment in Country-wide Clinics	Children's Bureau
25.	Michigan Crippled Children Commission (MCCC)	Clinical Testing of Prosthetic Devices for Child Amputees and the Development of Improved Clinical Management Procedures	Children's Bureau

Most of the activities of the research groups can be classified as fundamental research, development, or evaluation. A list of most of the problems being pursued at the present time is given on pages 160-166.

Dissemination of Information

To accelerate and to insure dissemination of information concerning the management of amputees and others with orthopedic impairments are the responsibilities of the Committee on Prosthetics Education and Information, Division of Medical Sciences, National Academy of Sciences—National Research Council. Composed of representatives of all the disciplines involved in rehabilitation of the orthopedically handicapped, the Committee was formed in 1957 primarily to assist medical and paramedical schools in formulating their curricula with respect to prosthetics and orthotics, and to make available to practicing medical groups the results of research. To carry out these objectives the Committee on Prosthetics Education and Information has established a number of *ad hoc* committees.

Outlook for the Future

Significant as the contributions of the prosthetics research program have been, much room yet remains for advancement and the problems associated with orthotics have scarcely been touched.

Even though fitting technics have been improved vastly over the past decade and amputees in general go about their daily activities in a fairly normal manner, it can hardly be said that a comfortable socket exists. At best the level of discomfort is tolerable. The problems will continue to be studied.

More functional prostheses for the upper-extremity amputee are needed. To date it has not been possible to devote much effort to the special problems of the severely disabled with bilateral cases. Here recent advances in the use of compressed gas and electricity to operate prostheses and braces indicate hope for adding functions not heretofore possible.

Surgical studies for the development of technics that provide more functional, pain-free stumps are under way. A modest approach to determine the feasibility of attaching a limb prosthesis directly to bone in the stump is being undertaken.

Special problems of the geriatric amputee must be studied more thoroughly than has been possible in the past.

Concurrently with the studies leading to improved devices and management procedures, there should be great emphasis placed on eradication of the causes of amputation and other crippling conditions. Some work has been carried out in an effort to determine the causes of congenital malformation of limbs. The linking of thalidomide with congenital deformities offers an excellent opportunity for increasing our knowledge concerning the mechanism of malformation of limbs.

Research in the area of peripheral vascular diseases will no doubt result in the saving of large numbers of limbs. As our knowledge of the neurological system and the diseases affecting it increases, the relative need for braces will decrease. Meanwhile improved surgical procedures could eliminate in many cases the need for prosthetic and orthotic devices, and such studies should be encouraged.

Yet since as far as anyone can see there will always be a need for artificial limbs and orthopedic appliances, a continuing effort to improve both the devices and their application is needed.

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MAJOR STUDIES BEING CONDUCTED IN ORTHOTICS AND PROSTHETICS IN THE UNITED STATES

(For key to organizations conducting these studies, see pages 157 and 158)

FUNDAMENTAL STUDIES

PROSTHETICS

Lower Extremity

Impedance Plethysmography (NU)

Investigation of the impedance method of estimating blood flow to determine its application to stumps in the static weight-bearing condition.

Pressure Between Below-Knee Stump and Socket (BL-UC)

The determination of the distribution of pressure over the stump, during use of a prosthesis, to assist in the development of design criteria for below-knee sockets.

Force and Range-of-Motion Studies of Above-Knee Stumps (NU)

A study to determine the available forces throughout the useful range of motion while a socket is worn.

Amputation Surgery (BL-UC)

A study to evaluate known lower-extremity amputation technics and develop improved technics, with related clinical studies to aid in the diagnosis of pain.

Influence of Prosthesis on the Health of Geriatric Amputees (LACH)

A study designed to determine the indications and contraindications for fitting elderly amputees with lower-extremity prostheses.

Functional Characteristics of Above-Knee Legs in the Stance Phase (NU)

A study of alignment of various types of above-knee prostheses to determine required stump forces during the stance phase.

Upper Extremity

Body Sites of Control of Externally Powered Prostheses (UCLA)

The determination of suitable sources of energy for subconscious, or reflex, control of externally powered arms. Three separate investigations are under way—electromyographic signals, nerve transplantation, and functional isolation of muscle groups without surgery.