Atlas of limb prosthetics

SURGICAL AND PROSTHETIC PRINCIPLES

American Academy of Orthopaedic Surgeons

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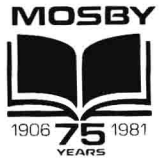

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Preface

The wars of the past 40 years have yielded untold numbers of young men in their prime whose limb loss has stimulated extensive research in the management of the amputee. Progress has been made in many areas of amputee rehabilitation, including new surgical techniques, better understanding of the biomechanical principles involved in normal and abnormal human locomotion, and improved design of artificial limbs using new materials and components.

In the lower limb, appreciation of biomechanical principles and energy costs, combined with the capability for more versatile prosthetic design, have altered many of our old concepts regarding "site of election" for amputation. Although the stimulus to improvement in care of the lower limb amputee can be traced to the tragedy of war, the cobeneficiary of such endeavors has been the patient with circulatory insufficiency, which commonly necessitates amputation of one or both lower limbs. In current practice, lower limb amputation accounts for over 80% of all amputations performed.

Upper limb amputation, by contrast, is far less frequent and presents a far greater challenge in prosthetic replacement. As in the lower limb, the success of rehabilitation can be correlated closely with the level of amputation. Nevertheless, immense problems remain in prosthetically restoring sensory capacity and manipulation of objects within the grasp, both of which are essential to optimum upper limb function. Major advances have been made in the areas of myoelectric control and powered components, but much remains to be accomplished.

In 1962, the Committee to Study Braces and Prostheses of the American Academy of Orthopaedic Surgeons published volume II of the *Orthopaedic Appliance Atlas,* a monumental work on limb prosthetics. This volume provided much needed information on the technical aspects of prosthetic substitution.

It is the purpose of this book to relate the surgical procedure of amputation to the rehabilitation of the amputee. Surgical procedures are presented primarily in the context of restoring maximum function to the patient following limb ablation. The text is organized to provide general information as an overview and specific information regarding surgical considerations, prosthetic replacement, and prosthetic rehabilitation for each level of amputation. The final part is devoted to the juvenile amputee, covering both acquired amputations and congenital limb deficiency. Outstanding authorities from the fields of amputation surgery, prosthetics, physical and occupational therapy, engineering, and numerous other allied professions have contributed material for this atlas. Thus a spectrum of information is provided to the reader regarding the amputee from the initial surgical decision to the completion of rehabilitation.

The material presented in this book has been made available by the American Academy of Orthopaedic Surgeons for educational purposes only. This material is not intended to represent the only, or necessarily best, methods or procedures appropriate for the medical situations discussed, but rather is intended to present an approach, view, statement, or opinion of the authors, which may be helpful to others who face similar situations.

It is hoped that all professionals involved with the care of the amputee will benefit from the con-

tents of this text, perhaps more from parts that are written by persons from disciplines other than their own. The ultimate beneficiaries of this work will undoubtedly be the amputee and the congenital limb-deficient individual. It is to this segment of our handicapped population that we have dedicated our effort.

The Committee on Prosthetics and Orthotics wishes to gratefully acknowledge the extensive financial and technical assistance provided by the Veterans Administration without which the publication of this book would not have been possible. To the many authors who have contributed material for this atlas, the Committee is indeed most appreciative and indebted.

Contents

PART ONE

Introduction

CHAPTER 1

History of amputation surgery and prosthetics

A. BENNETT WILSON, Jr.

No doubt artificial limbs of some type, such as a forked stick, have been used since the beginning of mankind, but the earliest recorded use of a limb prosthesis is that of a Persian soldier, Hegesistratus, who Herodotus[49] reported escaped about 484 BC from stocks by cutting off his foot and replacing it with a wooden one. The oldest known artificial limb in existence was a copper and wood leg unearthed at Capri, Italy, in 1858, which was supposedly made about 300 BC. Unfortunately, it was destroyed during a bombing of London in World War II.

Artificial hands made of iron were used by knights in the fifteenth century. The Alt-Ruppin hand, shown along with other hands from the fifteenth century in the Stibbert Museum, Florence, Italy, is a good example of the work of that age.

With respect to surgery, Hippocrates described the use of ligatures, but this technique was lost during the Dark Ages. It was reintroduced in 1529 by Ambroise Pare,[44] a French military surgeon. As a result, amputations came to be used more and more as a lifesaving measure, since the rate of survival was much higher when ligatures were used.

Morel[24] introduced the tourniquet in 1674, which gave another impetus to amputation surgery. Pare[44] carried out the first elbow disarticulation procedure in 1536. Sir James Syme[39] reported the Syme procedure for amputation at the ankle in 1843.

The introduction of antiseptic techniques by Lord Lister[25] (1867), a student and son-in-law of Syme, contributed greatly to the overall success of amputation surgery, as did the use of chloroform and ether about the same time.

The concept of kineplasty to power upper limb prostheses directly by muscle contraction was introduced by Vanghetti[55] in 1898 while trying to improve the function of Italian soldiers who had had their hands amputated by the Abyssinians. Vanghetti's associate, Ceci,[12] performed the first operation of this type on humans in 1900. Sauerbruch[48] (1916), in Germany, developed the skin-lined muscle tunnel, and Bosch Arana,[8] in Argentina, carried out clinical studies of this procedure in the 1920s.

Ertl in Germany (1949) developed the technique known as "myodesis," which consists of tying the distal ends of the cut muscle of the stump to the bone in such a way that reattachment is encouraged.[20] This idea seems to have been abandoned until much later, when it was revived by Dederich in the 1950s.[16]

Each major war seems to have been the stimulus not only for improvement of amputation surgical techniques, but also for the development of improved prostheses. World War II was no exception. Toward the end of World War II, amputees in military hospitals in the United States began voicing their disappointment about the performance afforded by their artificial limbs. To ensure

that they received the best care possible, the Surgeon General of the Army, Norman T. Kirk, an orthopaedic surgeon by training, turned to the National Academy of Sciences (NAS) for advice.

A COORDINATED PROGRAM FOR AMPUTEES

A conference of surgeons, prosthetists, and scientists organized by the NAS early in 1945 revealed that little modern scientific effort had gone into the development of artificial limbs, and a "crash" research program was launched later in 1945 through the NAS.[14] This effort was initially funded by the Office of Scientific Research and Development (OSRD). At the end of the war, when OSRD was disbanded, the Office of the Surgeon General of the Army continued support that was later assumed by the Veterans Administration, which had also inherited the responsibility for the care of amputees after discharge from the armed services.

For the first 2 years the NAS, through the Committee on Artificial Limbs (CAL), actually operated the program through subcontracts with several universities and industrial laboratories. On June 30, 1947, the CAL disbanded, and the role of the NAS became an advisory one to the Veterans Administration, which contracted directly with various research groups. In 1947, the Veterans Administration also established its own testing and development laboratory in New York City. The army and navy cooperated by supporting prosthetics research laboratories within their own organizations. From July 1, 1947, to December 1, 1955, the group within the NAS was known as the Advisory Committee on Artificial Limbs. The Prosthetics Research Board was created to carry out the NAS responsibility from December 1, 1955, to June 30, 1959. In July, 1959, the Committee on Prosthetics Research and Development and the Committee on Prosthetics Education and Information (later called the Committee on Prosthetics-Orthotics Education), both subgroups of the board, assumed this role until their dissolution by the parent NAS in 1976, the reason for which has never been made completely clear.

The Artificial Limb Program, as it came to be known, was started initially with the idea that physicians and surgeons could provide engineers with design criteria for components such as ankle and knee joints and that good engineering design based on these criteria and coupled with modern materials would result in devices that could solve many of the problems of the amputee. Although some progress by this approach was made early in the program, it soon became apparent that fundamental information on how human limbs function was needed before adequate design criteria could be formulated. To provide such information on lower limb function, a project was established at the University of California, Berkeley, as a joint responsibility of the Engineering and Medical Schools. Eberhart et al.,[18] who had collaborated previously in a biomechanical analysis of the shoulder, directed this program, which began by using the latest technology to refine and add to the existing knowledge of human locomotion. A concurrent program was initiated under Taylor in the Engineering School at the University of California, Los Angeles, on the function of the upper limbs.[14]

At the same time design and development projects were being carried out at Northrop Aviation, Inc.; Catranis, Inc.; the Army Prosthetics Research Laboratory; the U.S. Naval Hospital, Mare Island (which later became the Navy Prosthetics Research Laboratory, Oakland Naval Hospital); and a U.S. Army Air Force unit at Wright Field. New York University was engaged in 1947 to evaluate the devices that resulted from the research and development program. The Veterans Administration's laboratory in New York also performed evaluations primarily by means of mechanical and chemical testing projects; later this laboratory became part of the Veterans Administration Prosthetics Center (VAPC),* which contributed heavily to development and evaluation projects established within the program. Although progress was made with new devices and substitutions of materials, more significant advances were in the areas of socket design and alignment of the various types of prostheses.

As a result of a visit by a commission to Europe in 1946[54] a study of the suction socket for above-knee prostheses was made by the University of California.[19] The results of this study, coupled with information derived from the locomotion studies at the University of California, Berkeley, led to a biomechanical rationale for the design and fabrication of the socket and the alignment of above-knee prostheses.[3]

Innovative techniques for providing improved prostheses for Syme[60] and hip disarticulation[39] amputees were developed by McLaurin and his associates while working at Sunnybrook Hospi-

*As of July 1, 1980, the name Veterans Administration Prosthetics Center was changed to Veterans Administration Rehabilitation Engineering Center (VAREC).

tal, Toronto, under the auspices of the Department of Veterans Affairs of Canada. Much of this work was carried to fruition at the University of California, Berkeley, after Foort transferred there in 1955 from Toronto.[60] Variations on the early designs of Syme prostheses were made by VAPC prosthetists.[60] Thus a body of knowledge of management of Syme and hip disarticulation (and hemipelvectomy) amputees was developed and then disseminated to clinicians through a formal education program.

Concurrently, on the basis of a number of innovations in below-knee socket designs made by practitioners in various parts of the country, Radcliffe and Foort[46] developed the rationale and techniques of fabrication for what is now known as the "patellar-tendon-bearing (PTB)" prosthesis. Education in fabrication and application was first offered through university education programs in 1960. A number of variations in technique are now used successfully in practice, but the principles set forth originally by Radcliffe and Foort have stood the test of time.

In 1963 Weiss, an orthopaedic surgeon from Poland,[59] visited the United States under the auspices of the Office of Vocational Rehabilitation at which time he described techniques he was using in management of lower limb amputees. These included fitting of temporary prostheses immediately after surgery, adapted from Berlemont[6] and osteoplasty and myoplasty techniques adapted from Ertl[20] and Dederich.[16,35]

Weiss' presentations prompted the Veterans Administration in Seattle to initiate in 1964 under Burgess[10] a study to determine the feasibility of immediate postsurgical fitting, osteoplasty, and myoplasty. Projects were also started at the Navy Prosthetics Research Laboratory[26] and the University of Miami.[15] Just prior to this a team at Duke University[27] had been studying the effects of early fitting, that is, providing the patient with temporary prostheses with well-defined sockets within a month of the amputation.

As a result of these efforts many amputees are now being fitted with rigid dressings immediately after surgery and with definitive prostheses much earlier than was previously considered possible. Hospital and training costs for amputees thereby have been reduced considerably.

Pedersen[45] and others began, about 1958, to promote the idea that knee joints in many elderly patients with vascular disease could be saved if proper care were given postsurgically, although the classic instruction until then was to amputate above the knee when circulation was impaired, so that healing could be ensured. Weiss agreed with the view that knees could be saved and pointed out that the use of a rigid dressing should improve healing by reducing edema. Consequently, the ratio of above-knee to below-knee amputations since 1965 in the United States has almost been reversed from 70:30 to 30:70.[32] This has had a profound effect on the rehabilitation potential of dysvascular and geriatric amputees.

Although the Veterans Administration had no direct responsibility for children, it did provide indirect support to the Children's Bureau in adapting some of the devices and techniques developed for adults. Frantz[23] and Aitken[1] and the Michigan Crippled Children's Commission initiated a project to develop methods of management for child amputees in Grand Rapids in 1952. A similar project was launched at University of California, Los Angeles, in 1955, and New York University was funded to evaluate further the devices and techniques emanating from these projects. The Children's Bureau also provided the NAS with some funds for coordination of activities in child prosthetics. From this emerged the Child Amputee Clinic Chiefs Program, which has held meetings nearly every year since 1958, and the Inter-Clinic Information Bulletin, a small monthly that has proven to be useful for the dissemination of results of research and development.

AMPUTEE PROGRAMS IN OTHER COUNTRIES

In Great Britain, the Limb Fitting Centre at Queen Mary's Hospital, Roehampton, expanded its research effort shortly after the end of World War II and became known as the Biomechanical Research and Development Unit. The Scottish Department of Home and Health Services has sponsored research and development at the Limb Fitting Centre, Dundee; University of Strathclyde; and Princess Margaret Rose Hospital, Edinburgh. The work in Edinburgh is devoted mainly to children. At the University of Strathclyde, there has been established a 3-year education program in prosthetics and orthotics.

Work concerning children's problems is also being carried out in other places in Great Britain, namely at Chailey Heritage and the Nuffield Clinic, Oxford. Suppliers of artificial limbs in Great Britain also support research and development within their own organizations.

A number of research and development efforts were started in Germany after World War II, but there appears to have been little coordina-

tion of this effort. The work at the University of Munster in body-powered upper limb prosthetics has influenced practice elsewhere, as has the work at the University of Heidelberg with severely involved child amputees. A formal education program for prosthetists has been in operation in Frankfort for many years.

The thalidomide tragedy prompted the Swedish government to expand its research and development work in technical aids for the handicapped to include artificial limbs in 1962. This program continues today.

The French government in recent years has expanded its support of artificial limb research mainly through the Ministre des Anciens Combattants et Victimes de Guerre.

Research and development in artificial limbs in Italy have a long history. A research unit has been in operation at the University of Bologna for many years, and a group at the Prosthetic Centre in Budrio is very active in the development of externally powered upper limb prostheses.

Two projects in Poland that have made significant contributions to limb prosthetics are the Rehabilitation Center at Konstancin and the University of Poznan.

Not a great deal is known about activities in Russia but research units are located in Leningrad and Moscow. Their contribution has been the first clinically useful myoelectrically controlled hand.

The United States government, through the Surplus Agricultural Commodity Act (P.L. 480), has supported work in Poland, Yugoslavia, Israel, Egypt, India, and Pakistan.

Some prosthetic research has been carried out in Japan but as yet has had little effect on practices in the United States.

RELATED ORGANIZATIONS

The American Orthotics and Prosthetics Association (AOPA) is an organization of privately operated prosthetics and orthotics facilities in the United States and Canada to assist facilities in providing the best possible services. The parent group was organized in 1917 as the Artificial Limb Manufacturers' Association. The name was changed shortly afterward to the Orthopedic Appliance and Limb Manufacturers' Association when orthotists joined, and the present name was adopted in 1958. AOPA publishes quarterly *Orthotics and Prosthetics* for the purpose of reporting on the latest clinical practices.

The American Board for Certification in Prosthetics and Orthotics was established in 1948 as an accreditation body to certify the professional competence of practitioners and facilities in these disciplines. In addition to its accreditation activities, the board also seeks to advance the highest levels of competency and ethics in the prosthetic/orthotic profession.

In 1952 the International Society for the Rehabilitation of the Disabled (now called Rehabilitation International) appointed an International Committee on Prosthetics and Orthotics to promote the dissemination of knowledge of prosthetics and orthotics throughout the world. The chairman was Knud Jansen, and headquarters for the committee were established in Copenhagen, where a number of very successful international seminars were conducted in the late 1950s and 1960s. The committee also sponsored courses and conferences at other locations during this period and, in 1971, with the concurrence of Rehabilitation International, the members of the committee and others, formed the International Society for Prosthetics and Orthotics (ISPO) "to promote high quality prosthetics and orthotics care to all people with neuromuscular and skeletal disabilities." ISPO, an organization of all professionals associated with prosthetics and orthotics, conducts an International Congress at 3-year intervals to bring together clinicians, educators, research personnel, and administrators to exchange information and ideas and to make plans for cooperative programs. ISPO publishes three times a year *Prosthetics and Orthotics International,* which contains research reports and results of clinical evaluation of new devices and techniques.

The American Academy of Orthotists and Prosthetists (AAOP) was founded in 1970 by practicing prosthetists and orthotists as a professional society to promote the advancement of knowledge in the field of prosthetics and orthotics. Its goals and organization relate primarily to education. The AAOP publishes quarterly *Newsletter—Prosthetics and Orthotics Clinic.*

The Veterans Administration publishes the *Bulletin of Prosthetics Research* biannually, which summarizes current research in the field.

DEVELOPMENTS IN LOWER LIMB PROSTHETICS

Sockets and suspension

Prior to the United States' research program, the most common approach to the design of the