PROSTHETICS & ORTHOTICS

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Donald G. Shurr, CO, PT
Director of External Relations
American Prosthetics, Inc.
Iowa City, Iowa

Thomas M. Cook, PT, PhD
Assistant Professor
Physical Therapy Graduate Program
University of Iowa
Iowa City, Iowa

APPLETON & LANGE
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This book is dedicated to Marilyn, Carrie, Molly, Joan, Jenny, and Jonathan.

It is also dedicated to the unfinished work ahead, begun with one of our mentors, Mr. Harold E. Miller, CPO, whose untimely death did not allow us to learn from him all that he desired to teach, or we to learn.

Foreword

Too frequently, an amputation is assumed to be the final event in the care of a patient instead of the beginning of a critical phase in functional restoration and improvement of quality of life by the use of modern prosthetic and rehabilitative methods.

Too frequently, adults and children with neuromusculoskeletal disorders have been relegated to a life of disability instead of receiving attempts to overcome impairment by contemporary orthotic and restorative techniques.

This deplorable state of affairs results from two major problems in the education of health professionals: the lack of emphasis on the subject in curricular design and the heretofore absence of a thoughtfully prepared text designed to provide a coordinated overview for the serious student who needs an understandable distillate of an evolving, fragmented, and complex discipline.

The authors of this text deserve congratulations for undertaking the formidable task of helping correct these aberrations. I am honored to have worked with them and I have learned much from them over these past several years. I can attest to their comprehensive knowledge of the subject, their ability to teach, and their tireless dedication to the care of patients.

This inclusive volume with chapters on materials, mechanics, upper and lower limb prosthetics and orthotics, and spinal orthotics presents an overview and a method of approach that reflects, in a superb manner, both the art and science of the subject. It will be of great benefit not only to the beginning student but also to those who want to extend their working knowledge of the fascinating, dynamic, and increasingly important topic of prosthetics and orthotics.

I, and many of my colleagues, express deep appreciation to the authors for their time and effort in providing yet another service to patients through those whose education will be greatly enhanced by this text.

Reginald R. Cooper, MD
Chairman, Department of Orthopaedics
University of Iowa
Iowa City, Iowa

Preface

This volume has been developed while teaching prosthetics and orthotics to entry level physical therapy students over a period of seven years. During that time our students and others have asked us repeatedly to refer them to a single resource around which they could focus their learning. This book is our response to their prodding.

Although developed primarily for physical therapy students, this book should be useful for anyone without experience or background in prosthetics and orthotics. It should be appropriate for other health care professionals such as nurses, physicians, occupational therapists, vocational counselors, and so forth. The text assumes only a basic understanding of anatomy, kinesiology, and, to some extent, pathology.

The primary objective of this volume is to provide a sound overview of the art and science of prosthetics and orthotics as currently practiced in America. We fully recognize that there are distinct regional differences and preferences in P&O practice throughout this country and others. The reader should know that he or she may never encounter some of the devices described in this text and is very likely to encounter devices which vary significantly, or even drastically, from those presented herein. This book is not intended as an encyclopedic treatise of every possible P&O device. Such a work, if possible, would be overwhelming in size and outdated before it appeared in print. Rather, our intention is to address the fundamental concepts underlying the selection and application of common prosthetic and orthotic devices. Our hope is that the interested reader will use this information as a foundation for improving the quality of patient care in whatever setting he or she encounters.

A final comment must be made about the concept of combining both prosthetics and orthotics in one volume. Although traditionally considered as somewhat distinct topics, we have found an integrated approach to teaching these subjects to be very logical and effective. Recent developments in materials and fabrication methods and common functional goals for applying these external devices appear to blur some of the long-standing distinctions between these two disciplines. Perhaps some later edition of this or a similar book might well be entitled "Prosthotics"!

Donald G. Shurr
Thomas M. Cook

Acknowledgments

The preparation of this work was made possible through the unselfish efforts of many people. Thanks are extended to all the physical therapy students over the years who have provided the inspiration and feedback for this work during its various stages of development. We also thank Dr. Maurice Schnell, Dr. R. R. Cooper, Ben Wilson, Melvin Stills, CO, and Charles Pritham, CPO, for the interest they engendered in this field and for the hours they spent sharing their knowledge with us. We are also indebted to our colleagues at American Prosthetics, Inc., and at the University of Iowa for their tolerance and support in this endeavor. We especially appreciate the untiring efforts, patience, and attention to detail provided by Judy Biderman and Carol Lipsius during the seemingly endless revisions of the manuscript. Finally, we recognize the invaluable contributions of the patients, who have taught us far more than we have taught them.

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Contents

CHAPTER 1

Introduction to Prosthetics and Orthotics

This chapter will present a brief historical perspective on the development of the fields of orthotics and prosthetics followed by a description of orthotic and prosthetic services as currently provided in the United States. Overviews of prosthetics and orthotics include discussions of those factors common to all amputees and users of orthotic devices. The chapter includes a description of the prosthetics/orthotics clinic team.

HISTORICAL PERSPECTIVE

Brief History of Prosthetics

Historically amputation was often the only medical alternative in the definitive treatment of complex fractures or infections of the extremities. Although even Neolithic man was thought to have the necessary knowledge and tools to accomplish amputations, many patients most likely did not survive the procedure. By the sixth century BC, the physician Susruta wrote detailed works about proper surgical procedure that became standard technique. The more precise the procedure and the faster the amputations were done, the higher the survival rates.

Early prosthetists were blacksmiths, armor makers, other skilled artisans, and the patients themselves. Early limbs manufactured in Europe and later in America used metal, wood, and leather. Articulated knee and ankle joints eventually replaced stiff joints, and gradually metal was replaced by wood. These changes made the devices more functional and lighter in weight.

In 1860 A.A. Marks substituted a hard rubber foot for a wooden one. Soon after, J.E. Hanger, an amputee in the Confederate army, placed rubber bumpers in solid feet and thus produced the first articulated prosthetic feet. Hanger also popularized skin suction as a method of suspending an above-knee prosthesis. Prosthetics grew tremen-

dously during the Civil War, as over 30,000 amputations were performed on the Union side alone. Wooden socket limbs from Marks of New York sold at that time for $75 to $150 each and were available by mail order.

War continued to provide the major impetus for research and development in prosthetics. Details and materials have changed considerably since 1900, but little change has occurred in the basic designs of limb prosthetics. Following World War II, the Veteran's Administration (VA) financially supported the development of the patellar-tendon bearing and quadrilateral sockets for below-knee and above-knee amputees, respectively. These designs and techniques were taught to all prosthetists so that both veteran and civilian amputees would benefit. Following Vietnam, renewed funding by the VA led to further refinements in prostheses, including the provision of myoelectrically controlled upper-extremity prostheses and endoskeletal, modular prostheses.

Brief History of Orthotics

The development of the art and science of splinting and bracemaking, now referred to as the field of orthotics, very much paralleled developments in the field of prosthetics. Pictorial examples of splints and various assistive devices can be found among early civilizations, including ancient Egyptians and Greeks. The same materials, metal, leather, and wood, found in early prosthetic devices were also used in orthotic devices; and the same artisans, namely, blacksmiths, armor makers, and patients, were the first orthotists.

By the 18th and 19th centuries the manufacture of thin steel had reached such a refined state that splints and braces were sometimes mass produced and described in catalogues often published by enterprising "appliance makers." Pioneers in this early period were Ambroise Pare (1509–1590); Hugh Owen Thomas (1834–1901); and Sir Robert Jones, a nephew of Hugh Owen Thomas, who is considered to be the "father of orthopaedic surgery." All were accomplished and innovative bracemakers as well as "bonesetters." Eventually surgery replaced manipulation and bracing as the cornerstone of the practice of orthopaedics. Bracemakers then became professionals distinct from physicians.

The term *orthotics* has recently replaced the use of the word *bracing* to describe the control of body segments by external devices. *Orthotics* is meant to include dynamic control of body segments compared to the more limited, static connotations of the word "brace." The term was first used in the early 1950s and was originally adopted in 1960 by orthotists and prosthetists in America when they formed the American Orthotic and Prosthetic Association from the original Artificial Limb Manufacturers' Association.

Just as the wars of this century have caused a renewed interest in the development of prosthetics, the polio epidemics of the 1950s spurred increased interest in the field of orthotics. Beginning around 1970, many innovations in orthotic designs were made possible by the adaptation of industrial techniques for vacuum-forming sheet plastics. Because of the continuing introduction of new materials and methods, present-day orthotics practice is a growing, rapidly changing discipline.

PROSTHETIC AND ORTHOTIC SERVICES

Need for Services

The National Health Interview Survey[1] published in 1969 indicated that those using prosthetic legs numbered 0.6 per thousand. By 1977[2] the figures had jumped to one per thousand using an artificial leg. Total people reported to be using either artificial legs or arms in 1977 were 275,000.

For the same population survey, 6,250,000 people in America used orthoses, wheelchairs, canes, or special shoes in 1969.[3] By 1977[2] the number had grown to 6,500,000, or about 3% of the American population. Specifically, people using leg orthoses increased from 233,000 in 1969 to 400,000 in 1977. This represents roughly 1.2 people per thousand population in 1969 and 1.9 people per thousand in 1977, nearly twice the number using prostheses.

Professional Organization and Certification

Certification of both professionals and facilities is administered by the American Board for Certification (ABC) in Orthotics and Prosthetics, Inc. This board was established in 1948 through a combined effort of the orthotics and prosthetics industry and the American Academy of Orthopaedic Surgeons. The ABC promotes high professional standards and high-quality facilities and develops and administers examinations in prosthetics and orthotics. Additionally, the organization serves as an appeals committee for alleged violations of established standards of practice, ethics, or law.

Educational Programs

There are currently 10 practitioner-level programs located in the United States.[4] In addition, there are three technician, or assistant-level, programs. Using the enrollment figures published in *Orthotics and Prosthetics*, 184 students will graduate per year from these 10 schools. There are five approved residencies and one master's degree program. It should be noted that other students come from the Army orthotic school, whose model differs from most others in that no formal education is required prior to admission. According to the current standards of ABC, graduates of this program do not qualify to sit for the orthotics board examination and therefore will not increase the credentialed work force in the field for the future.

Currently there is only one subprofessional in orthotics and prosthetics, the technician.[5] Technician education programs are certified by ABC, and technicians are registered as opposed to being certified.

Number and Distribution of Prosthetists and Orthotists

Since 1949 there have been more than 880 prosthetist/orthotists (CPO), 1,392 orthotists (CO), and 1,232 prosthetists (CP) certified by the ABC in Prosthetics and Orthotics, Inc. On July 1, 1982 there were 817 COs, 739 CPs, and 580 CPOs in good standing.[6] This total of 2,136 represented the current certified work force in orthotics and prosthetics (Fig. 1–1). Assuming the present total of 2,136 professionals, together with an

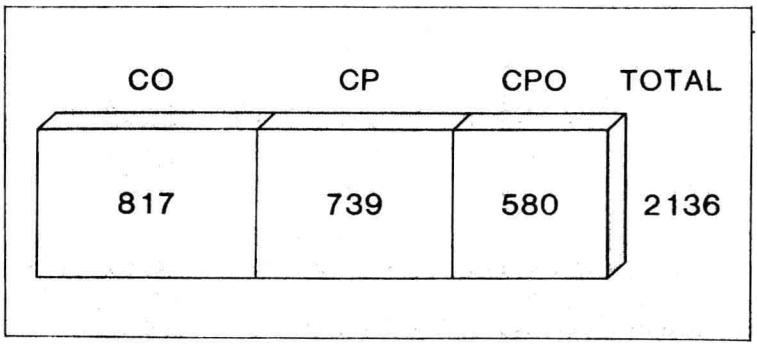

Figure 1–1. Numbers of certified orthotists and prosthetists in the United States in 1982 (CO = certified orthotist; CP = certified prosthetist; CPO = certified prosthetist/orthotist). (From Shurr DG. The delivery of orthotic and prosthetic services in the US—a physical therapist's view. *Orthot Prosthet* 1984; **38**:57, with permission.)

addition of 9% to 10% per year for eight years, and 1% to 2% annual retirement rate, by 1990 there will be approximately 4,000 orthotic/prosthetic practitioners in America. This is in contrast to 560,000 physicians, 2 million nurses, and 40,000 physical therapists (Table 1–1).

At this time in the United States, orthotists and prosthetists practice in five major settings. The first and most common of these settings is the private office. Beginning in the late 1880s,[7] orthotists began moving out of physicians' offices and hospitals in an effort to be independent providers of services and devices and to avail such services to many physicians and patients.

The second commonest practice setting for the delivery of prosthetic and orthotic services is the institutionally based service/consultation. Many large institutions such as hospitals, particularly children's hospitals, rehabilitation centers, and rehabilitation and research institutes provide orthotic/prosthetic services from an internal staff.

The third type of practice in which a prosthetist/orthotist might be involved is that of a supplier and fabrication manager. The use of a central production laboratory, which is physically different from the site of measuring and fitting, has grown rapidly in recent years and will probably continue to increase in America. The economic and professional advantages and disadvantages of this type of arrangement will be discussed more fully in Chapter 2.

TABLE 1–1. PROJECTIONS OF HEALTH CARE PROFESSIONALS IN 1990

Registered nurse (RN)	2,000,000
Physician	560,000
Physician (orthopaedic surgeon)	17,500
CP/CO/CPO	4,000
Physical therapist	40,000

From Shurr DG. The delivery of orthotic and prosthetic services in the US—a physical therapist's view. Orthot Prosthet *1984;* **38**:*57, with permission.*

In the 10 programs available for orthotic or prosthetic entry-level preparation, there are full-time professional faculty responsible for this education. According to a 1976 report,[5] there were 17 full-time certified prosthetists, 24 full-time certified orthotists, and 13 full-time certified prosthetists/orthotists in this area of practice.

Finally, few, if any, individuals work in America today doing only basic research in orthotics/prosthetics. This does not, however, include those practitioners who are working on the cutting edge of materials, design, or rehabilitation engineering as part of their daily clinical practice.

The Prosthetics/Orthotics Clinic Team

Due to the complexity of many prosthetic/orthotic cases, referral is often made to a clinic team. Included on this team are likely to be the physician, prosthetist/orthotist, nurse, physical therapist, social worker, vocational counselor, and, most importantly, *the patient*. It is impossible for this clinic team to function meaningfully without the contributions of the patient.

Clinic teams provide evaluation, prescription, delivery, and follow-up prosthetic/orthotic services. Follow-up is important, since the possibility of changes in either the device or the patient necessitate regular re-evaluation by the experienced team. This is extremely important when caring for children, as growth and configuration may change rapidly, requiring concomitant changes in the prosthesis or orthosis. All devices demand some maintenance or replacement and for that reason should be evaluated regularly for proper function.

AN OVERVIEW OF LIMB PROSTHETICS

The term amputation refers to the process whereby a part is severed from the body. The term prosthesis refers to an artificial device used to replace a missing part of the body. The portion of the limb that remains intact following the amputation is referred to as the residual limb, or stump, and the portion of the prosthesis that is fitted over the residual limb is called the prosthetic socket. With proper care the amputee (the individual who has undergone an amputation) can return to a useful life, and amputees can be found in nearly every occupation. When the proper surgical techniques have been employed and when sound training methods and devices are used in providing the prosthesis, the amputee can be expected to participate in many of his or her previous activities.

The Amputee Population

Figures 1–2 and 1–3 summarize statistics on the relative incidence of amputation as reported by Kay and Newman in 1975.[8] Figure 1–2 shows the relative distribution of amputees by site of amputation, and it is clear that the large majority of amputations occur in the lower extremities. As a general rule, it is estimated that there are about 11 lower limb amputees for every upper limb amputee.[8] Figure 1–3 shows the distribution

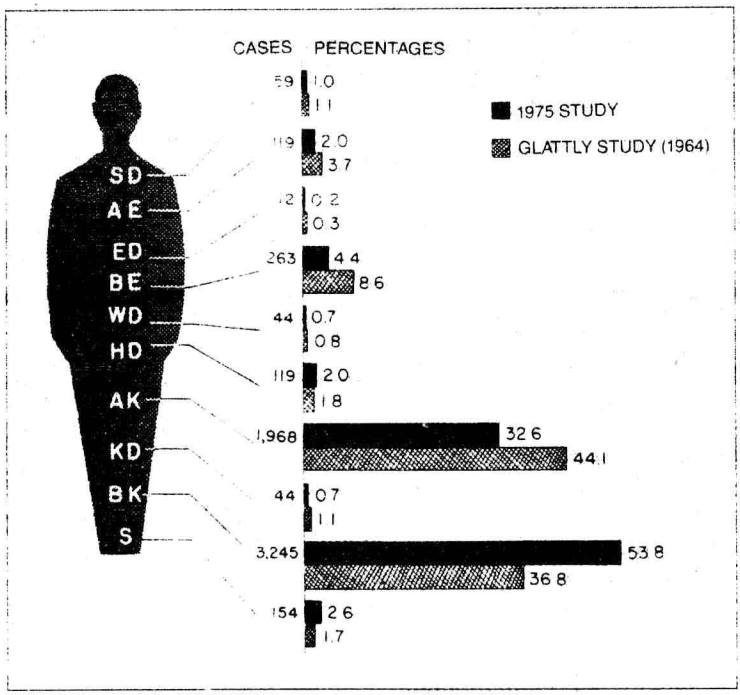

Figure 1–2. Distribution of amputees by site of amputation, comparing studies done in 1975 with 1964 (SD = shoulder disarticulation; AE = above elbow; ED = elbow disarticulation; BE = below elbow; WD = wrist disarticulation; HD = hip disarticulation; AK = above knee; KD = knee disarticulation; BK = below knee; S = Syme's). (From Kay HW, Newman JD. Relative incidence of new amputations. *Orthot Prosthet* 1975; **29**:8, with permission.)

of amputees by sex and cause of amputation. It can be seen that the leading cause of amputation is vascular disease, with an approximate equal incidence between males and females. It is also clear that most vascular amputations occur to people aged 61 to 70 years, with approximately equal occurrence in ages 51 to 60 years and 71 to 80 years.

Level of Amputation

Amputation may occur through joints or through bone. In general, the site of amputation is described by the joint or nearest joint through which the amputation has been made. Common descriptors of sites of amputation are shown in Figure 1–2. An amputation of the lower limb makes standing and walking difficult, while an amputation of the upper limb poses a different set of problems related to activities of daily living (ADL).

Causes of Amputation

Causes of amputation may be grouped into four major categories: trauma, disease, tumor, and congenital. Amputation may be the result of trauma or the result of a life-saving surgical procedure intended to arrest a disease. Additionally, a small percentage of individuals are born without a limb or limbs or with defective limbs that require surgical conversion to a more appropriate level.

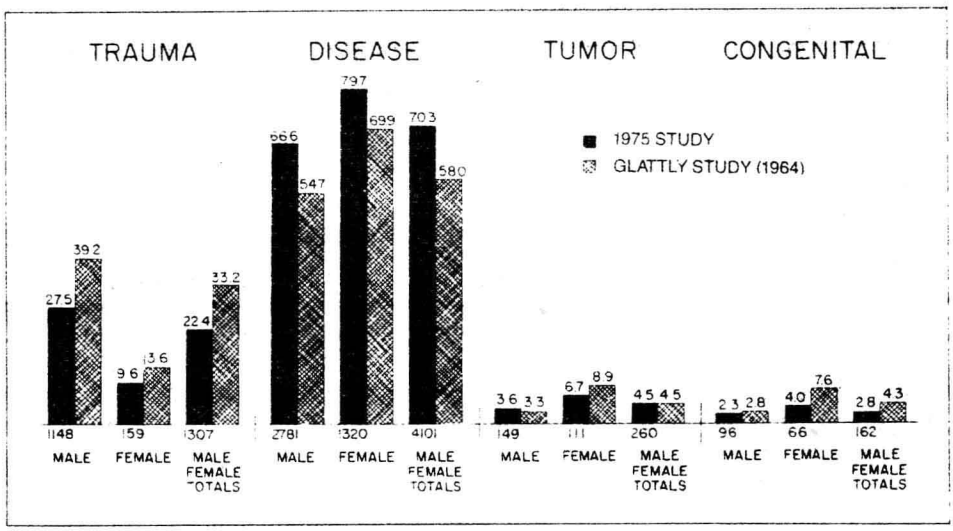

Figure 1–3. Distribution of amputees by cause and sex, comparing studies done in 1975 with 1964. (From Kay HW, Newman JD. Relative incidence of new amputations. *Orthot Prosthet* 1975; **29**:8, with permission.)

Trauma. In some accidents or trauma, part or all of the limb may be removed completely, or autoamputated, because of the accident; or the limb may be damaged to such an extent that removal of the limb may be required following the accident. Figure 1–3 from Kay and Newman[5] demonstrates a 22.4% trauma-related cause for amputation. Common accidental causes of traumatic amputation include the following: automobile accidents, farm machinery accidents, fire arms, freezing, electrical burns, and power-tool accidents. In some cases, as in severe brachial plexus injuries, damage to the nervous system results in paralysis to the limb that is debilitating enough to require amputation. These levels are said to be elective, since they are usually not life threatening and often may be performed at a level elected by the surgeon. Knowledge of prosthetic restoration is critical so as to elect the most functional level for the patient.

Disease. Vascular disease may lead to amputation. Diseases that may cause vascular or circulatory problems are diabetes, arterial sclerosis, and Buerger's disease. In these instances the blood supply to the limb is inadequate, so that necrosis or dry gangrene of the tissues occurs. In such cases it is usually the lower limb that is principally affected. Circulatory disorders are more common among elderly individuals, and thus the majority of amputations for vascular reasons occur in the lower limbs of these elderly persons. Kay and Newman[5] reported 70.3% of all new amputees to be of vascular disease origin. Furst and Humphrey[3] reported an 85% vascular or metabolic origin for 5,000 amputations annually in England and Wales. Of these 85%, men were two times as likely as women to need amputation, and overall 70% of all new amputees were 60 years of age or older. On another note, Furst and Humphrey[3] surveyed the wives of below-knee amputees to identify their perceptions of the commonest causes of amputation. Four of

five wives felt that trauma was the leading cause and that the average age for amputation was 40 years less than it actually was. Often younger, nonvascular, below-knee amputees are the most visible amputees in our society. They are also a small minority of the entire amputee population. Infection is also a potential cause for amputation, although more recently, with the advent of more effective drugs, the number of amputations for this cause has been reduced.

Tumor. Amputation may also be undertaken as treatment for tumorous conditions. Primary bone tumors occur frequently in adolescents but can occur at any age. Figure 1–3 from Kay and Newman[5] shows that about 4.5% of all reported limb fittings are due to tumors. Figure 1–4 further demonstrates that 33.5% of these amputations occur between the ages of 11 and 20 years. Of further concern is the fact that bone tumors tend to occur more proximal in the limb, making high-level limb ablation necessary.

Congenital Amputations and Malformations. In some instances all or part of a limb is deficient at birth. These absences may be either the result of a congenital amputation or a limb deficiency or defect. Congenital amputations, although rare, connote the one-time presence of the limb and its amputation, in utero, often the result of a constriction band or ring. Limb deficiencies are malformations of the limb bud, occurring around day 28 in utero, yielding something less than a normal extremity. Although both may be treated in a similar manner prosthetically, limb deficiencies tend to require nonstandard prostheses and are often surgically converted to more standard anatomic and/or prosthetic levels. One such common condition is the congenital absence of the left forearm, the so-called terminal-transverse–congenital-limb deficiency of the forearm. Limb deficiencies, however, can occur anywhere and in any combination.

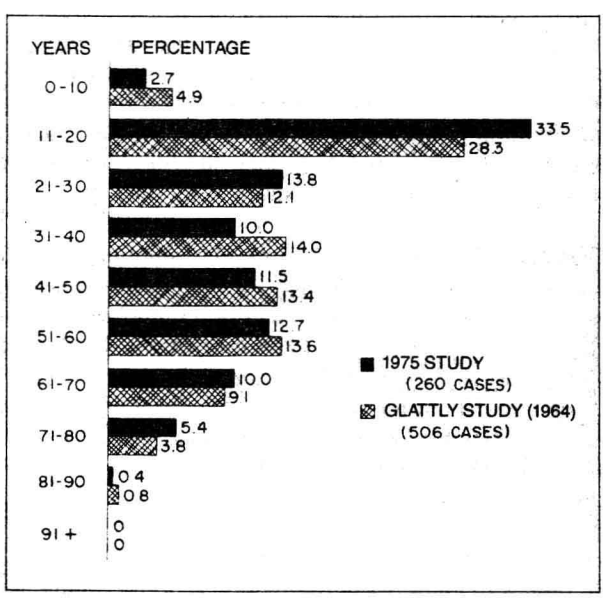

Figure 1–4. Occurrence of tumor-related amputation by age, comparing studies done in 1975 with 1964. (From Kay HW, Newman JD. Relative incidence of new amputations. *Orthot Prosthet* 1975; **29**:8, with permission.)