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Amputation Surgery and Rehabilitation

The Toronto Experience

Edited by
John P. Kostuik, M.D.

Robert Gillespie, M.D.

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FOREWORD

I am honored to have been invited to write the Foreword to this excellent book, *Amputation Surgery and Rehabilitation: The Toronto Experience*, which has been edited by my orthopedic colleague, John Kostuik, with contributions by seven additional colleagues at The University of Toronto Division of Orthopaedic Surgery as well as by other surgeons and allied health professionals in Toronto.

Orthopedic surgery in the University of Toronto has a splendid heritage in the field of amputation surgery and the rehabilitation of amputees. Beginning with World War I our university can be proud of the significant contributions to this important field by such orthopedic surgeons as Robert I. Harris, Arthur B. Lemesurier, and Gordon Dale all of whom gained world renown. Sir Isaac Newton has written that "we see so far because we stand on the shoulders of giants." Certainly these three men were orthopedic giants.

Standing on the shoulders of these giants, Dr. Kostuik and his fellow contributors have put together, in a highly informative and readable form, the now extensive "Toronto experience" with the total care of amputees. As Dr. Kostuik has mentioned in his Preface, this up-to-date reference book is directed toward "the early and intermediate student" in all disciplines relevant to amputations: orthopedic, vascular, plastic, and general surgery, rehabilitation medicine, physical and occupational therapy, nursing, social work, bioengineering, and prosthetic design.

I am much impressed by the breadth as well as the depth of this book. In addition to chapters covering such traditional subjects as history, epidemiology, indications, principles, and specific amputations on a regional basis in both children and adults, this book includes innovative and imaginative chapters on such contemporary subjects as vascular surgery, replantation of extremities through microsurgery, biomechanics, externally powered prosthetics, and compassionate rehabilitation at all ages. Of particular educational value is Chapter 35, with 227 practical questions with answers.

This book, which truly represents the "Toronto experience" with amputation surgery and rehabilitation, has been extremely well written and well edited. Indeed, I predict that it will become a classic in the field!

Robert B. Salter, O.C., M.D., M.Sc.,
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Preface

Since World War II several large strides have been made in both the surgical and rehabilitation aspects of amputation care. Initial efforts saw the development of better mechanical devices such as the quadrilateral above-knee socket and hydraulic knee units for above-knee amputees, patellar-tendon bearing prosthesis, and the Canadian hip disarticulation prosthesis. From Poland and Germany came the concepts of immediate postoperative fittings. Subsequent modifications of below-knee amputations by the Burgess technique produced a complete reversal of the pattern of amputations in peripheral vascular disease from above-knee to below-knee level as the optimal site in most cases.

The thalidomide disaster provided a great impetus toward the development of improved externally powered upper-extremity prostheses as well as toward the organizational and social rehabilitative needs of the amputee and led to the generally accepted development of the clinic concept of rehabilitation.

The formation of the International Society for Prosthetics and Orthotics (I.S.P.O.) and its affiliates, largely due to the impetus of Professor Knud Jansen, has provided an international educational forum.

As a result of the past developments and increasingly complex efforts in all aspects of amputee care, from the preoperative evaluation to the long-term assessment, the amputee has benefited greatly. Despite these efforts, however, there exists a major educational gap. This lies primarily at the early and middle educational level, where education of students who require knowledge of amputee care lags behind the available material.

This book attempts to fill that gap and is aimed primarily at the early and intermediate student whether he or she is a nurse, physiotherapist, prosthetist, social worker, or resident in orthopedic surgery, general surgery, or rehabilitation medicine. In-depth information is provided in a clear and simple fashion in order to provide ease in the acquisition of knowledge in the care of the amputee. Highly complex technical details, for example, prosthetic construction, are not provided, as we feel that these details are rarely necessary for the early and intermediate student or the average clinic situation and, moreover, they are rapidly changing. The chapters on mechanics, we feel, are simple and easily understood and provide insight not only into the amputee gait but also into the basic locomotor function of all lower-extremity problems. The chapter on reimplantation is unique and will continue to play an even greater role in the future of amputation surgery. Finally, an attempt has been made to provide, in the final chapter, answers for many of the questions posed to us in the clinical situation.

John P. Kostuik, M.D., F.R.C.S.(C)

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1

History of Amputations and Prostheses

Mercer Rang, M.B., F.R.C.S.(E), F.R.C.S.(C)
George H. Thompson, M.D.

Amputations have been practiced since the beginning of mankind. Archaeologic evidence dates to the Neolithic period; knives and saws of bone and stone of this period have been found with skeletal remains with amputated bone stumps. Ancient amputations were generally performed to remove gangrenous or severely damaged limbs; later, amputations were used for ritual sacrifice, riddance of demonic possession, appeasement of gods or idols, punishment, and in some cases, beautification.

The word amputation is derived from the latin, *amputatio*, meaning a "cutting around," and was originally used to describe the removal of limbs or portion of limbs by the knife. However, the term was also used to describe the removal of other parts of the body, such as a breast or testicle.

The history of medical amputation closely follows the development of the surgery itself, and especially of orthopedic surgery. The ancient surgeon was primarily a military surgeon, since most procedures were done for battle casualties. In such cases, fractures and soft tissue injuries of the extremities were, of course very common and could be treated with considerable success compared with cranial, thoracic, or abdominal injuries. The military surgeon, therefore, was essentially a bone surgeon and his most common major surgical procedure was the amputation.

Among the major contributions to surgery made by amputational surgery include the use of tourniquets and ligatures to control hemorrhage, appropriate handling of soft tissues, secondary wound closure to prevent infection, and recognition of the importance of cleanliness. These, plus the introduction of anesthesia and antisepsis in the mid-nineteenth century, constitute some of the basic principles of modern

surgery. In this section we will trace the history of amputations as it relates to the development of these basic surgical principles.

Amputational surgery logically led to the need for a replacement or substitute for the amputated part so as to restore function. Ancient prostheses were, by modern standards, very sophisticated, but were quite bulky and heavy. Many of the principles of modern prosthetics were developed and applied many years ago. The major prosthetic contributions, from which modern principles have been derived, will be discussed in the next section, on the history of prostheses.

AMPUTATIONS

Ancient History: 500 B.C. to 200 A.D.

Hippocrates and his teachings dominated the period from 500 B.C. to 200 A.D.; medicine and surgery were relatively sophisticated. The earliest scientific account of amputation occurs in the Hippocratic treatise *On Joints*, in the latter half of the fifth century B.C.; Hippocrates stated that:

When gangrene supervenes in a fracture, the soft parts separate quickly; as for the bones, they become detached at the limit of their exposure; but much more slowly. It is necessary to remove whatever dies first below the lesion from the healthy parts avoiding pain as far as possible, for patients die from fat emboli.

Thus Hippocrates recommended amputations to remove diseased limbs, to reduce invalidism, and to save lives. He also recommended that the procedure be performed through the devitalized tissue so as to reduce pain and hemorrhage. The remaining margin of gangrenous tissue eventually sloughed, and the stump healed by granulation-tissue formation. This undoubtedly required considerable time.

Amputation between healthy and gangrenous tissues was first recommended by Celsus, in the first century A.D. When, said Celsus, gangrene did not yield to other treatment:

Between the sound and the diseased part, the flesh is to be cut through with a scalpel down to the bone, but this must not be done actually over a joint, and it is better that some of the sound part be cut away than that any of the diseased part should be left behind. When the bone is reached the sound flesh is drawn back from the bone and undercut from around it, so that in that part also some bone is bared; the bone is then to be cut through with a small saw as near as possible to the sound flesh which still adheres to it; next the face of the bone which the saw has roughened, is smoothed down, and the skin drawn over it; this must be sufficiently loosened in an operation of this sort to cover the bone all over as completely as possible. The part where the skin has not been brought over is to be covered with lint; and over that a sponge soaked in vinegar is to be bandaged on.

The technique of Celsus is very similar to that in modern amputations, as was his use of vinegar which, unknown to him, provided a bactericidal dressing that undoubtedly contributed to a moderate success rate. Celsus later described the use of double ligatures on arteries, with division of the vessel between the ligatures to control hemorrhage in war wounds; and although he does not mention this technique in amputations, it was surely used.

By 100 A.D., surgical techniques were well advanced, and the medical indications for amputation had been expanded to include chronic ulcers, tumors, injuries, and deformities, in addition to gangrene.

Ligatures were used to control major arterial bleeding, although these were sometimes difficult to apply, and definitely increased the operating time. Archigenes and Heliodorus began using a tight circular bandage above the amputation site. The resultant decreased bleeding made the use of ligatures easier, decreased pain, and aided in wound exposure by retracting the skin. Archigenes identified the major vessels and ligated them before completing an amputation, and twisted the smaller vessels after transfixing them with a small hook. When the ligatures failed, cautery with red-hot irons or boiling oil were used to obtain hemostasis.

These techniques and recommendations were followed by Galen and other physicians through the second century A.D. After this, and associated with the fall of the Roman Empire, there was a gradual decline in civilization generally, including education, culture, the arts, religion, and especially medicine and surgery.

Middle or Dark Ages: 200 A.D. to 1500 A.D.

During the first half of the middle ages, there was a steady decline in amputative technique that eventually resulted in the abandonment of the use of ligatures and the increasing use of cautery. Paul of Aegina (640 A.D.) describes with approval the procedures of Leonides of Alexandria, a Greek surgeon at Rome (c. 300 A.D.) who, following an amputation, applied red-hot irons to the vessels to stop the bleeding, dressed the stump, and took measures to induce suppuration. It was a common belief during this period that suppuration increased healing. Roger (1170 A.D.) and Roland (1230 A.D.) are commonly credited with the thesis that provoking suppuration encouraged healing, although suppuration had been honored by generations of surgeons who hailed the appearance of "laudable pus."

Minimal improvements in surgical technique were made until the end of the eleventh century when Albucasis, one of the ablest Muslim surgeons, reintroduced the use of the constricting circular bandage to control bleeding. In his great medical encyclopedia, Albucasis wrote extensively on cauterization, a special feature of Arab medicine, and described a different cautery for each part of the body and each disease. However, Albucasis advised cauterization following amputations only if hemorrhage was severe.

It is doubtful if any patient required revival following an amputation performed with the patient awake and without anesthesia. But until Hugh of Lucca (c. 1250 A.D.) developed a crude anesthetic technique, analgesia and sedation using wine and alcoholic beverages were the only forms of anesthesia available for persons undergoing surgery. In Hugh's technique, a sponge was saturated with a soporific solution containing opium and mandrake, and was dried in the sun. Before an operation, the sponge was soaked in hot water for 1 hour, held under the patients nose, and the fumes inhaled, thus providing a mild analgesic and sedating effect, but not true anesthesia. After the operation the patient was "revived" by applying a sponge soaked in vinegar. Although there is no record of Hugh using this technique in an amputation, his pupil, Theodoric, did use it for amputations, and was cited as having some success. Muslim surgeons during this time also reportedly used drugs or potions in an attempt to induce sleep, lessen pain, and allow more time for surgery. That these methods did not gain wide acceptance is probably an indication of their value.

Toward the latter part of the middle ages, the need for amputations increased greatly. This was due in part to the devastating effects of leprosy and ergotism, and in part also to the introduction of gunpowder and firearms. Cannon shot was first used at the Battle of Crecy in 1346, and half-pound gunshot in 1364 at Perugia. The resulting wounds to extremities were frequently so mutilating that amputation was necessary. This led to the development of battlefield surgery, with which came improvement in surgical methods and technique.

Ambrose Paré: 1510 to 1590

It was Ambrose Paré, the great French army surgeon and the father of French surgery, who made the most significant contributions to amputation (Fig. 1-1). Paré became an army surgeon in 1536, and was surgeon to four successive French kings. He is credited with performing the first elbow disarticulation in 1536, and with demonstrating that gunshot wounds in soft tissue were not poisonous and did not require cauterization. Paré also reintroduced the use of ligatures in amputations in 1552 and discontinued the use of cauterization to control hemorrhage. He invented spring-loaded artery forceps to assist in holding a vessel closed while ligatures were applied, emphasized the importance of removal of all dead tissue in an amputation for gangrene, and introduced the modern surgical doctrine of appropriate site selection for amputa-

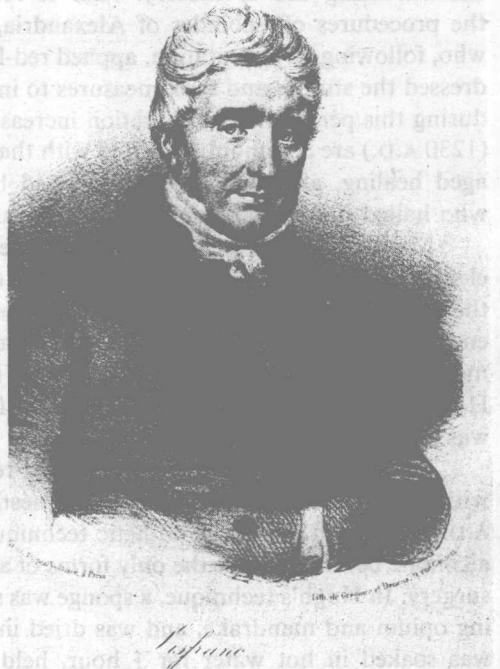


Fig. 1-1. Ambrose Pare, 1510–1590. The father of French surgery, he made notable contributions in amputation surgery, including reintroduction of the ligature to control hemorrhage, appropriate site selection for amputations, and the design of upper- and lower-extremity prostheses. (By courtesy of the Wellcome Trustees.)

Fig. 1-2. Jacques Lisfranc, 1790–1847. A French surgeon, he developed the tarsometatarsal amputation while a surgeon in Napoleon's army. He did not describe the tarsometatarsal fracture dislocation that is named for him. (By courtesy of the Wellcome Trustees.)

tion with respect to future prosthetic use. He was vitally interested in rehabilitating the amputee, and designed and had manufactured several prostheses for both the upper and lower extremities. Paré described reamputation of an officer's foot that had been shot off with an "iron bullet," because the healed stump was too long for a prosthesis. This is the first recorded revision of an amputation for prosthetic reasons, a procedure commonly performed today.

Other significant sixteenth century contributions to amputation were made by Gersdorff, Fabry, and Lowe. Gersdorff (c. 1517), a military surgeon whose publication on military surgery contains the first woodcut illustration of an amputation, used two constricting circular bands a fingerbreadth apart, and amputated between them. He had an elaborate recipe for a styptic that was applied over the wound and held in place with the bladder of a bull, ox, or hog. Despite this innovative approach Gersdorff too resorted to cauterization when necessary. Fabry was the leading German surgeon of his period. In his monograph on gangrene in 1593 he, like Paré, recommended amputation above the diseased part, and is credited with the first amputation through the thigh. Fabry controlled bleeding by means of a band tightened by twisting with a stick. Peter Lowe, a Scottish army surgeon, published the first original, English-language description of the use of ligatures in 1596. He advocated ligatures to control hemorrhage in the absence of suppuration, but employed cauterization when infection was present.

Preanesthetic Period: 1600 to 1846

The period from 1600 to 1846 is marked by improvements in surgical technique with respect to hemostasis, site selection, timing, soft tissue handling, stump coverage, prevention of infection, and rehabilitation. However, speed was still paramount and postoperative wound infection frequent and devastating.

The discovery of the circulation of the blood by Harvey in 1616 led to the invention of more modern, efficient tourniquets. Morel's tourniquet in 1674—commonly known as the Spanish windlass—and Petit's tourniquet in 1718, plus the use of ligature, allowed amputations to be performed with minimal blood loss. Cautery was still being used, but primarily in cases of infection. Richard Wiseman (1672), a great military surgeon of the seventeenth century, recognized the antiputrefactive quality of cautery, and spoke of it in this capacity. Use of cautery in this manner continued into the nineteenth century.

Attempts at better soft tissue coverage of the stump were made during the eighteenth century. Alanson of Liverpool (1779) and Hey of Leeds (1803) describe a "triple incision" in which the skin and fascia were divided in the first incision and retracted proximally. In the second incision the bone was amputated with a saw; the closure then allowed soft tissue coverage of the bone stump, thus preventing protrusion of the bone through the skin, providing more comfort in prosthetic use.

Flap methods were devised and used during the eighteenth century by Verdun of Amsterdam (1696), Rovaton (1739), and Vermale (1765). Similar techniques are still used today.

At the beginning of the nineteenth century, amputation techniques reached their peak of advancement and perfection prior to the advent of anesthesia and asepsis. This was primarily due to the writings of Napoleon's surgeon-in-chief, the French Baron Dominique Larrey (1766 to 1842), and to the famous English military surgeon George Guthrie (1785 to 1856).