# Amputations and Prostheses

Miroslaw Vitali
Kingsley P Robinson
Brian G Andrews
Edward E Harris

Baillière Tindall

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**MIROSLAW VITALI** MD, FRCS

*Principal Medical Officer, Department of Health and Social Security Limb Fitting Centre, Roehampton; Honorary Consultant, Queen Mary's Hospital, Roehampton, and the Westminster Hospital, London; Honorary Adviser in Prosthetics and Prosthetic Surgery, Institute of Orthopaedics, Royal National Orthopaedic Hospital, Stanmore, Middlesex*

**KINGSLEY P. ROBINSON** MS, FRCS(Ed), FRCS

*Consultant Surgeon, Queen Mary's Hospital, Roehampton, and the Westminster Hospital, London*

**BRIAN G. ANDREWS** FRCS

*Consultant Orthopaedic Surgeon, Queen Mary's Hospital, Roehampton, and Westminster Hospital and Medical School, London*

**EDWARD E. HARRIS** MA, MRCS, LRCP

*Formerly Medical Officer, Department of Health and Social Security Limb Fitting Centre, Roehampton; Formerly Staff Surgeon, Committee of Prosthetic Research and Development, National Academy of Sciences, Washington, USA*

BAILLIÈRE TINDALL · LONDON

A BAILLIÈRE TINDALL book published by
Cassell & Co. Ltd
35 Red Lion Square, London WC1R 4SG
and at Sydney, Auckland, Toronto, Johannesburg
an affiliate of
Macmillan Publishing Co. Inc.
New York



First published 1978

ISBN 0 7020 0570 3

Printed by Butler & Tanner Ltd
Frome and London

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**British Library Cataloguing in Publication Data**

Amputations and prostheses.
1. Amputation 2. Artificial limbs
I. Vitali, Miroslaw
617'.58 RD553
ISBN 0–7020–0570–3

# Amputations and Prostheses

*This book is dedicated to Mr St John Dudley Buxton FRCS, the late Mr Leon Gillis FRCS and the late Mr R. Langdale Kelham FRCS, who pioneered this important field and made Roehampton an international centre of amputation surgery and prosthetics*

# Preface

Queen Mary's Hospital, Roehampton, was founded in 1915 for the treatment of disabled soldiers in the First World War and the Limb-Fitting Centre was built in 1932; since then has played a major international role in amputation surgery and rehabilitation. In 1948 it became the major United Kingdom centre for amputation services and at present cares for some 15 000 amputees.

There has been a significant change in the incidence of amputation over the past few decades. There are fewer military casualties, in many parts of the world, though civilian trauma retains its importance, but the increasing life-span of the population in developed countries necessitates more operations for vascular disease and for extensive neoplasia. Amputees, both young and old, now demand a better quality of postoperative life than in the past, and this has led the surgeon into earlier involvement with his patients and subsequently into longer-term rehabilitation programmes. The difficulties inherent in the level of amputation, the surgical techniques to be employed, the clinical management of the patient and his later rehabilitation are therefore discussed in relation to the main causes of amputation.

A number of operative procedures have been developed, varied and improved at all levels. These are described at some length and are clearly illustrated to assist those who are not familiar with the techniques involved, especially younger operators and those who perform amputations only occasionally. However, our intention has been to give the surgeon an understanding of the philosophy behind treatment as well as a practical guide to the operations themselves. If the finished stump is to be suitable for fitting with a modern prosthesis, the surgeon must have some appreciation of the prosthetist's problems. Biomechanics are discussed only in sufficient detail to ensure that the descriptions of prostheses are comprehensible, and

specialized texts should be consulted for more extensive treatment of this subject. Prostheses for the various amputation levels are discussed in detail, with a realistic assessment of their advantages and limitations, so that the surgeon can select the one most suitable for his patient.

The amputee has suffered a major assault, both physical and psychological, and the importance of rehabilitation, starting well before the operation itself, cannot be overemphasized. The surgeon and his team should always bear the necessity for rehabilitation in mind, as only with this as the spearhead of their approach can a successful outcome for the patient be assured.

*January 1978*

MIROSLAW VITALI
KINGSLEY P. ROBINSON
BRIAN G. ANDREWS
EDWARD E. HARRIS

# Acknowledgements

We would like to thank Sir Henry Yellowlees, Chief Medical Officer of the Department of Health and Social Security, for his encouragement to write this book and our many colleagues who have helped us with their constructive criticisms. Dr D. S. McKenzie, Principal Medical Officer and formerly Director of the Biomechanical Research and Development Unit, read the original draft and made many detailed and helpful comments. Our thanks also go to J. E. Hanger and Co. Ltd and Queen Mary's Hospital, Roehampton, for permission to reproduce certain photographs; and especially to Dr D. May, their technical director, for his help and criticism on the chapter about biomechanics. Charles A. Blatchford & Sons Ltd at Queen Mary's Hospital, Roehampton, and Hugh Steeper (Roehampton) Ltd gave ready permission to reproduce many illustrations and offered us much advice on the final chapter, Future Developments. Much collection of data and checking of references was kindly carried out by Mr A. C. M. Mather, librarian of the Biomechanical Research and Development Group. Miss Diana McLean patiently and meticulously translated our drafts into the line drawings which are such a valuable feature of the book. Finally, we would like to thank our ever-helpful and always enthusiastic secretaries, especially Emilia Walden, Betty Turner and Rosemary Hughes.

M.V., K.P.R., B.G.A., E.E.H.

# Contents

# 1

# A Brief Historical Survey

Amputation is a destructive operation which removes but does not cure; but it can be constructive when it removes disability and disease to restore ability and ease. The dictum of Sir William Ferguson that 'Amputation is one of the meanest yet one of the greatest operations in Surgery; mean when resorted to where better could be done—great as the only step to give comfort in life' is as true today as when first written.

To restore function at most levels of amputation requires the use of an appliance or prosthesis which is attached to the body. This prosthesis may be simple in design and crude in appearance, such as a peg leg or arm hook. If nothing better is available these may be accepted by patients for their practical use. Through amputation the patient has lost not only part of his body but also part of his body image, so that to restore function involves psychological as well as physical replacement. He seeks a prosthesis which replaces the lost member in appearance, feel and movement; that is to say, an artificial limb. Prostheses currently in use usually resemble the lost limb in appearance but are normally of hard materials such as metal or wood so that they do not feel natural to the patient or to others. In many countries efforts are now being made to use methods of construction which will give some softness to touch.

Movement is an essential part of appearance and function and requires a source of power. External power has severe limitations in providing enough of either quantity or quality and is likely only to supplement power derived from the body rather than to replace it. The amputation stump and body, therefore, are the major, and usually the only, source of power for the operation of the prosthesis

and need to be fashioned to join with it to give the best use if the prosthesis is to be an artificial limb.

This book is about the union of the stump and the prosthesis to form a single locomotor unit.

Neolithic man is known to have survived amputation and archaeologists claim that the remains of Neanderthal man show evidence that he lived after having lost a limb. Amputations among these primitive peoples were probably by accident, for punishment or during magic ritual rather than with surgical intent. There is no record of amputation in the Old Testament nor do the Egyptian medical papyri give any account of it. Although artificial limbs have been found on mummies with congenital or traumatic limb deficiencies, they are considered to be examples of the embalmer's art only and there is no evidence that they were ever used in life. In the Rig Veda of 1500 to 800 B.C. it is said that there is a reference to artificial limbs, but it is usually considered that the first account of amputation as a purposeful medical procedure is in the Hippocratic treatise *On Joints*, which has a modern ring about it for it is concerned with amputation in vascular gangrene. Indeed, surgical amputation in warfare, with which the condition is usually associated, does not seem to have been common until the use of gunpowder.

The early surgeon had knives and saws with which to amputate but lacked anaesthetics, tourniquets and ligatures. His enemies were shock, haemorrhage and sepsis. Mid-thigh and above-elbow amputations were rare because they were usually fatal. William Clowes (1588) is credited with the first known successful above-knee amputation. It must be doubted, however, whether this was indeed the first, for Paré in his *Œuvres* (1575) illustrates a complex prosthesis for the above-knee amputation. John Hunter said in about 1786 that 'an amputation below the knee in most cases would not kill by its haemorrhage'. The smaller bore of the vessels in the forearm and below the knee, combined with arteriospasm and surgical shock, would prevent fatal haemorrhage before the blood clotted. Hippocrates, who advocated amputation for vascular gangrene, advised that it should be through the ischaemic tissue at the joint below the boundaries of the blackening. He also described amputation by disarticulation at the knee.

Hippocrates also refers to the use of cautery for haemostasis and it has remained in use through the succeeding centuries to the present day. There are many references to the use of cautery in the ancient surgical treatises of Avicenna and Abulcasis, for example. It not only controlled haemorrhage from smaller vessels but was used by later surgeons for its anti-putrefactive qualities; Peter Lowe (1597) preferred 'the ligature for haemorrhage when suppuration is not present; when it is, the cautery'. Even Paré used the cautery

in gangrenous wounds and as late as 1924 Cullen was using cautery to control phagedenic gangrene.

The cautery would not control haemorrhage from major vessels; for this ligation was necessary. Celsus in the first century and Yperman in the thirteenth both used ligatures, although it is not recorded specifically that they used them in amputation. It was Ambroise Paré who reintroduced ligation for large vessels during amputation; this did not supplant the cautery for smaller vessels until the introduction of the tourniquet and anaesthetics. The surgeon worked without skilled aid. Two assistants restrained the patient, one plied him with pain-relieving drugs or drinks and a fourth handed the instruments. Speed was essential to lessen shock but became for many surgeons an objective in itself; Ferguson (1845) said that any surgeon should be able to amputate in 30 seconds and complete the procedure in three minutes. To tie ligatures in these circumstances without modern artery forceps must have been difficult. It is not surprising, therefore, that Guillemeau (1594), who was Paré's pupil and biographer, gave up ligation because of these difficulties.

The use of the tourniquet made ligation easier. Its invention is usually attributed to Morel (1674) during the siege of Besancon, but many earlier surgeons such as Botallus (1560) and Fabricus von Hilden used one or more tight bands round the limb, amputating below or between them, with the object of reducing pain and lessening bleeding. Later Petit (1718) used a compressive tourniquet and in 1873 Esmarch introduced the rubber bandage. A tourniquet is still part of the postoperative bedside equipment to stop any secondary haemorrhage.

Styptics such as alum, vitriol and turpentine were used to control oozing but their benefit, particularly that of oil of turpentine, may have been in their antiseptic properties. For if the patient survived the shock and haemorrhage of the operation he might be lucky to survive the subsequent sepsis. It is difficult to realize that surgeons seemed almost to glory in avoiding even normal social cleanliness in their professional work, so that it was even said that it was less dangerous for a patient to have his thigh amputated by gunfire than by a surgeon. Malgaigne (1842) reported a mortality of 62% in thigh amputations from nine Paris hospitals. Indeed to have even a digit amputated was not without risk. This is not surprising when the description of Dupuytren operating is that 'he wore a dirty white apron, superfluously protecting a dirtier pair of trousers, a greasy threadbare coat and well-worn carpet shoes'. Pirogoff (1864) wrote of the sepsis in the surgical wards and of the few of the many thousands of amputees whom he knew to have survived; but Pirogoff, operating without gloves, suffered for 16 years from an intractable diarrhoea which only relented during periods of vacation. Bigelow's assistants at the Massachusetts General Hospital carried their sutures in the button-holes of their operation coats in the 1870s and

as late as the 1880s assistants in some New York hospitals held the sutures in their mouths. This despite the writings of Thomson and Blackadder in the early years of the century that '*pouriture d'hôpital*' was transferred from patient to patient only by soiled dressings. There were others whose standard would have been more acceptable in the present day. Monro (1752) reported on 99 amputations in Edinburgh Royal Infirmary with only eight deaths and in 1782 Alanson of Liverpool reported 35 without mortality. Among other surgeons who advocated cleanliness and had similar results were Maunoir (1825) of Geneva, Lister (1841) of London and Eve (1846) in Augusta.

The postoperative treatment of the wound changed with the centuries. The early hippocratic practice of amputating through devitalized tissue made it necessary for the wound to be left open so as to heal by granulation. When Celsus operated through viable tissue he divided the bone at a higher level than the soft tissues, thus allowing them to fall together over the bone. Ambroise Paré approximated the edges of the wound with adhesive strips, which Von Gersdorff also did at a later date, using an animal's bladder for cover in addition, and Brunschwig used a combination of sutures and bandaging. The method of amputation was circular until Yonge and Lowdham (1679) introduced the flap amputation which made closure easier. The risk of developing a haematoma led many surgeons to delay dressing the wound for several hours. Liston had cold water compresses applied to the wound every ten minutes for seven hours or longer until it developed a glazed appearance before closing it with adhesive tape. Primary closure was, however, often contraindicated by the presence of contamination, and many military surgeons would agree with Stephen Smith (1862) when he wrote 'in the after treatment of the amputation . . . it is good practice to leave the wounds open to heal by granulation'.

The advent of modern surgery, with the introduction of anaesthetics and later antiseptics and asepsis, enabled the surgeons to develop techniques before the First World War which were very similar to those in use today in that muscle flaps were used. Unfortunately the surgeon's art then began to outstrip the limb-maker's craft. Although that war saw the extended use of the light metal limb, in the post-war years good amputation operations were revised to their detriment or abandoned to meet the requirements of the limb-makers. The suturing of muscles over the divided bone ends was abandoned and muscles were allowed to retract in order to produce a 'conical' stump. The bulbous end-bearing stumps produced by knee disarticulation and Syme's amputation were taboo because they could not be introduced into a tube from above. It required the aftermath of a Second World War to stimulate once again the study of amputations and prosthetics as a unity.

Prostheses themselves have a history as old as amputation. There

is a reference in the Rig Veda to artificial limbs, but the earliest reference to amputation itself is usually considered to be Herodotus (424 B.C.) who tells of Hegistratus of Elis, a seer who was condemned to death by the Spartans. He was tethered by his leg to await execution but escaped by amputating his foot himself and travelling 30 miles to Tregea. At Zaccynthius he was again captured by the Spartans who this time put him to death, but recorded that he had been provided with a wooden foot. Simple peg legs made of wood are known to have been used in early times from illustrations such as the mosaic in the cathedral of Lescar in France; this shows one, used after an amputation by disarticulation at the knee, which resembles one both described and illustrated by Paré as well as the 'Chelsea' peg used up to the present day. The earliest surviving example of a prosthesis was Roman, dated about 300 B.C.; made of bronze and wood, it can be called an artificial limb as it was shaped to resemble the thigh, knee and calf. Unfortunately it was lost with much else when the Royal College of Surgeons' Museum was destroyed in an air raid.

The wooden peg—simple and cheap to make, stable in use and easy to maintain—was the prosthesis of the peasants and poor throughout the ages but did not satisfy the aesthetic needs of the rich, who had servants to carry them over short distances and horses for longer. The bearers of arms turned to their armourers to produce prostheses to resemble their armour. Many of these were functional as well as decorative, but were fashioned in iron and therefore heavy. One leg in the fine Stilbert collection in Florence has a rigid knee which is semi-flexed, suitable neither for standing nor for sitting but adequate for riding astride a charger. Paré devised and illustrated artificial legs made of iron which were of considerable complexity. Verduin (1696) produced the first artificial limb for below-knee amputees which had a leather socket and thigh corset with articulated side steels. It is not known when wooden artificial limbs other than simple legs were first introduced, but the simple wood 'clapper' limb was probably introduced by makers such as Grossmith who was working in London in 1750. Crowdero in Samuel Butler's *Hudibras* published in 1662 wears an oak peg. James Potts of London is said to have introduced the wooden leg in 1800. His limb showed great craftsmanship as well as ingenuity; the ankle and knee movements were coordinated by means of artificial tendons. Potts' most famous patron was the Marquis of Anglesey who lost his leg at Waterloo and whose name is still used for limbs made in this fashion.

The simple hook for the forearm amputation has been in use for many centuries, providing a useful tool for those earning a livelihood but wholly unacceptable aesthetically. Prostheses resembling the shape of a hand appeared early and showed considerable ingenuity in their construction. Pliny reports that Marius Sergius, who lost his right hand in the Second Punic War (218–202 B.C.), was

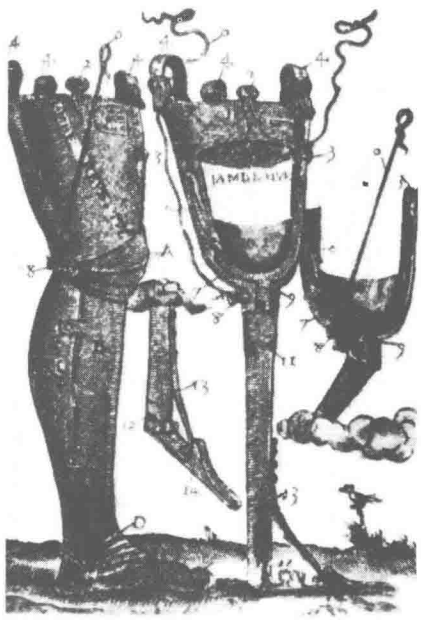

Fig. 1. Artificial limbs designed by Ambroise Paré, primarily for wounded soldiers, and illustrated in his *Instrumenta Chirurgiae et Icones Anatomica* (1564).

**Fig. 2.** An iron artificial left hand and arm, dated about 1602. The thumb is fixed but all the fingers are movable. (*By courtesy of the Wellcome Trustees*)

fitted with an iron hand. The alt-Ruppin hand, discovered in A.D. 1800 along the river Rhine and preserved in the Stilbert collection, is dated about A.D. 1400. It is made of iron and has a rigid thumb fixed in opposition and flexible fingers operating in pairs which were flexed passively, locking into position with a ratchet mechanism; it also has a movable wrist.

Perhaps the most famous user of an iron hand was a German knight, Gotz von Berlichingen, mentioned in a poem by Goethe, who lost his hand at the siege of Landshut (1509). Several versions of the iron hand which he used exist. The fingers of this hand also could be flexed passively by the other hand and locked into position by a ratchet. '*Le petit Lorraine*' is another iron hand described and illustrated by Ambroise Paré.

All these ingenious and elaborate hands are extremely heavy and of limited use, as they depend on the opposite hand for operation. It was not until 1818 that the prosthesis was given any power of prehension by harnessing the shoulder girdle muscles, a system devised by a Berlin dentist called Peter Ballif. This was for a forearm amputation only. The same principle was not applied to the above-elbow prosthesis until 1844 when a Dutchman, Van Peetersen, used it for elbow flexion. By 1855 the Comte de Beaufort was demonstrating an arm with elbow flexion activated by pressure of a lever against the chest and in 1867 he published an illustration of an operating harness which resembles the harness in use today.

Today's surgeons and prosthetists are therefore working in a field which has been well trodden before. They can learn from the mistakes of their forerunners and also from their successes. Sometimes good ideas failed because of the lack of suitable materials, sometimes they were just forgotten. Amputations and prosthetics are part of the ancient inheritance of the surgical arts. What is right does not become wrong merely by the passage of time. The practice of amputation and prosthesis-making achieved much in the past. When it failed it was often because it was ahead of its time and did not have the materials or techniques required. The modern surgeon and prosthetist should not deny their past but should acknowledge and improve upon it.

# 2

# Statistics and Trends

The number of people who undergo amputation and survive to have a prosthesis of any kind depends upon the types of disease present in the population and on the quality of medical aid. In primitive societies without medical care the unfortunate either die or continue to drag out an existence with their disability. As these societies develop and medical aid becomes available the indigenous diseases are those most needing treatment. Later the use of machinery for agriculture, industry and transportation introduces trauma, from industry and road traffic, which then becomes an increasing cause of amputation. In highly developed industrial nations the expectation of life is higher, although the complexities of life have increased, and the number of traumatic amputations and degenerative diseases in which people outlive their limbs is becoming a major problem.

Statistics on the causes and number of amputations are naturally not available from developing communities. Many of the estimates which have been published are based either on too few numbers or on unrepresentative samples. Even now it is not possible to give accurate figures for the number and causes of amputation per head of population in any large nation. Most of the major combatant nations in two world wars have produced well documented figures about service and even civilian casualties, but until recently they have shown little interest in preparing similar information about their peace-time civilian population.

Since 1957 the health authorities of England, Wales and Northern Ireland have kept records of all new patients referred to their Limb Fitting Centres, which is probably the largest existing survey of a total population. They do not, however, include patients who have

amputations but are not referred to the Centres and are therefore to this extent incomplete. But they are similar in quality to other statistics of peace-time amputations from European and North American sources and provide useful information on the extent of the problem.

Unfortunately, in the world as a whole war is still a major cause of amputation; injury, both traffic and industrial, is common in populations recently exposed to modern technology. Disease, particularly tropical diseases and leprosy, is a major cause in many parts of the world. The statistical figures of the West do not therefore apply, at any rate as yet, to the East.

Amputation was formerly an infrequent operation in peace-time. Muirhead Little quotes E. M. Corner of St Thomas's Hospital, London, as reporting that in 1913 there were 5403 operations in that hospital of which only 34 were amputations. Little also states that the Royal Surgical Aid Society, a charitable organization for the needy, had supplied only 384 artificial legs compared with 39 290 other surgical appliances in 1915. He compared this with 41 050 British service casualties from the First World War who had amputations, 26 262 of whom were treated at Roehampton. The number of amputations among service casualties was much less in the Second World War, although civilian casualties were considerably higher, with about 20 000 being treated at Roehampton. The type of warfare in which the British troops were involved probably accounts for this in part but the improved medical services can claim considerable credit.

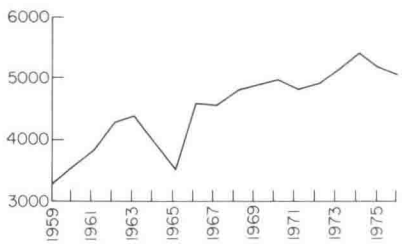


**Fig. 3.** The total number of patients attending limb-fitting centres in the United Kingdom, 1959–75.

The Limb Fitting Services of England, Wales and Northern Ireland cooperate closely and provide prostheses almost without exception for all who are eligible under the National Health Service, including private patients. In the United Kingdom there are now about 5000 new patients each year.

The total number of patients referred each year for the 15-year period 1959–75 is given in Fig. 3 and shows an increase of 52%. The total number of amputees seen at the centres under the age of 60 decreased 8.7% and fell as a percentage of the whole from 49.1% to 29.1%. The total number of arm cases decreased during this time by 18.6%. Lower limb amputations increased by 68.9%. The ratio of lower to upper limb patients which was 5.7:1 in 1959 had become 14.1:1 by 1973. The total numbers of patients fitted in 1973 are shown in Table 1.

**Table 1.** Total number of patients seen in artificial limb and appliance centres in the UK in 1973

| *Artificial limb* | *No. of patients* |
|---|---|
| *Arm* | |
| Single | 303 |
| Double | 4 |
| Total | 307 |
| *Leg* | |
| Single | 3867 |
| Double | 158 |
| Double, with previous single | 317 |
| Other | 16 |
| Total | 4358 |
| *Overall total* | 4665 |

The change in numbers is accounted for by the steady increase in the elderly who suffer from the diseases of old age, especially atherosclerosis. The changes in the 15 years in the number attending from various causes are shown in Fig. 4. Congenital deformities and trauma had increased by only 3.4% and 3.8% respectively by 1968 (which is within the normal population growth rate) and subsequently fell dramatically by 68.3% and 15% respectively in 1973.