John Kirkup

A History of Limb Amputation

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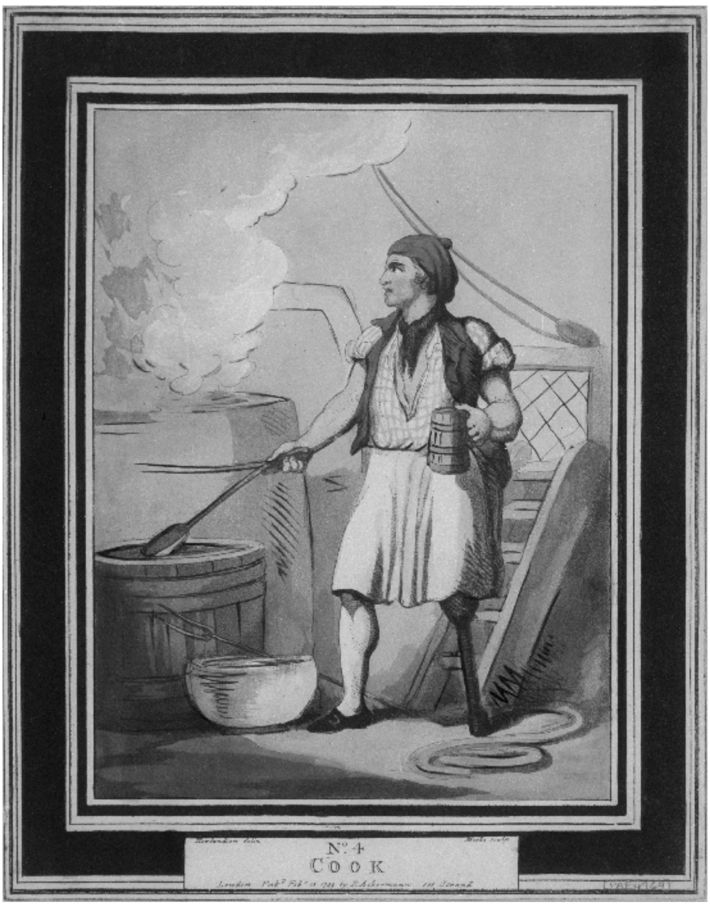

Ship's cook with peg-leg after below the knee amputation. Coloured engraving after drawing by Thomas Rowlandson, c. 1789. (© National Maritine Museum, London, UK)

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A History of Limb Amputation

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John Kirkup, MD, MA, FRCS, Dip Hist Med
Former Consultant Orthopaedic Surgeon, Bath Clinical Area, UK; Honorary Curator, Historical Instrument Collection, Royal College of Surgeons of England, London, UK;
Lecturer in Surgical History, Society of Apothecaries, London, UK

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Preface

This book is intended to explain and inform, not to dismay and shock, despite undertones of disapproval inherent in the term amputation, so deeply implanted in popular imagination, as epitomizing cruel and barbaric surgery before general anaesthesia. Yet many patients accepted this painful last resort in an endeavour to survive with three limbs rather than die with four, at a time when, we must reflect, no mechanism for effective pain relief existed. It is our knowledge of anaesthesia and aspirin which distorts perceptions of a very different world when pain acceptance was strongly bolstered by powerful convictions, often religious in character. Even today, as we shall see, certain victims entrapped by a limb, alone and remote from assistance, will perform their own amputations in grim determination to cheat death, despite self-induced agony. Similarly isolated, you or I would probably react in the same way.

It has been well said that amputation is not the end of treatment but its beginning, a long process in which the amputee has to readjust psychologically to their mutilation and a supportive team has to achieve a healed stump, to provide a functional prosthesis and to guide the amputee towards maximal rehabilitation. Before safe surgery was established, postoperative problems were formidable from secondary haemorrhage, infection and slow healing with indifferent stump scarring. If today these perils have been reduced, the fitting of a suitable prosthesis remains an individual problem, yet functional recovery can be remarkable, even among elderly amputees.

Broadly speaking, the evolution of amputation can be divided into five time periods: (i) that of thousands of years (at least from the Old Stone Age) when amputees were victims of nonsurgical loss, the result of congenital factors, disease, frostbite, accidents and ritual or punitive action; (ii) that of tentative surgery in historic times when gangrenous limbs were separated at the junction of dead and living tissues; (iii) that of elective but painful surgical amputations, precipitated by gunshot injuries between the 15th and 19th centuries, aimed to save lives and obtain a healed stump; (iv) that of pain and haemorrhage control, aided by anaesthesia after 1846; and (v) that of pain, haemorrhage and infection control after 1867, accompanied by sophisticated prosthetic designs, especially during the 20th century.

As no comprehensive historical study linking these topics has been traced, it is submitted the subject is of sufficient significance, socially and medically, to be examined in more detail. Importantly, before elective surgical amputation, the long period of nonsurgical dismemberment has received little attention; furthermore, until some societies eventually tolerated amputees in their midst, it is surmised no question of "surgical" amputation was possible. Related to this toleration are the protean convictions and philosophies of divergent societies, patients and surgeons faced with the dilemma of a mutilated or gangrenous limb.

The first period described relies on commonsense deductions, information from non-industrial societies observed by explorers, missionaries and others, mainly in the 19th century, and a certain amount of classical literature. The remaining periods are surveyed utilising written evidence and, when possible, by quoting recorded patient histories. The study also focuses on legal amputations, auto-amputation in extremis, iatrogenic sources and the development of alternative surgical solutions to amputation, all factors which persist in the 21st century. Surgical publications, and latterly prosthetic publications on elective amputation, are massive in their extent; hence only a proportion of available literature has been studied, mainly restricted to English and French communications. Readers may well conclude my contribution is but an introduction to the subject. Certainly, much more detail could be added.

As a former surgeon familiar with amputations, principally for trauma and diabetes mellitus, I lay no claim to all aspects of this rapidly developing branch of surgery and have to thank various individuals for their advice and assistance. In particular, I am most grateful to Kingsley Robinson, MS FRCS, Advisor in Amputee Management at Queen Mary's Hospital, Roehampton, the UK national centre for amputee problems, who kindly agreed to enlarge Chapter 13 on artificial limbs with his expertise on recent developments and future possibilities. I must also thank one of his former colleagues at Roehampton, Brian Andrews, FRCS, for reading Chapter 12 on amputation stumps and for his assistance in tracing sources. My friend Krishna (Ravi) Kunzru, MS FRCS, a former surgical registrar at Roehampton, was most helpful with Chapter 4 on ritual causes of amputation, especially with respect to former practices in India, and my close colleague Mick Crumplin, FRCS, Honorary Curator of the Historical Instrument Collection at the Royal College of Surgeons of England, kindly corrected Chapter 10 on surgical instrumentation and equipment and provided several important illustrations. I am also indebted to Dr. Jean-Claude Rey for information and to Geoffrey Walker, FRCS, hugely experienced in orthopaedic management of developing countries, for help in elucidating the problems of gangrenous limbs following imperfect fracture splintage. Professor Leslie Klenerman, ChM FRCS, has also been most supportive and helpful in finding my publisher. Although I have collected works on amputation for many years, inevitably assistance has been sought from several medical libraries, but I am mostly indebted to the late Ian Lyle, Thalia Knight, Tina Craig and their staff of the Library at the Royal College of Surgeons, Lincoln's Inn Fields, London, for tolerating countless requests for assistance. I also thank John Carr of the Photographic Department of the Royal College of Surgeons, the Medical Photography Unit of the Royal United Hospital, Bath, for several illustrations, Melissa Morton and Eva Senior of Springer and Barbara Chernow of Chernow Editorial Services for their helpful guidance and important corrections of the manuscript.

It is hoped this work will interest medical historians, surgeons and nurses responsible for amputations, prosthetic limb fitters and manufacturers, engineers and scientists advancing prosthetic design, general historians, the public at large and, importantly, amputees themselves.

John Kirkup, MD, FRCS
Weston Hill, Bath, UK
December 2006

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1
Introduction and Sources

". . . after the loathsome stinch of his putrid limbe was removed . . . he began to cheere up, and . . . from day to day was refreshed more and more . . . as a tree refresheth after the dead bowes are pruned off."

Woodall, 1639[1]

"Oh I know, Sir, my leg cannot be saved . . . I wish it had been off at first . . . the sooner the better."

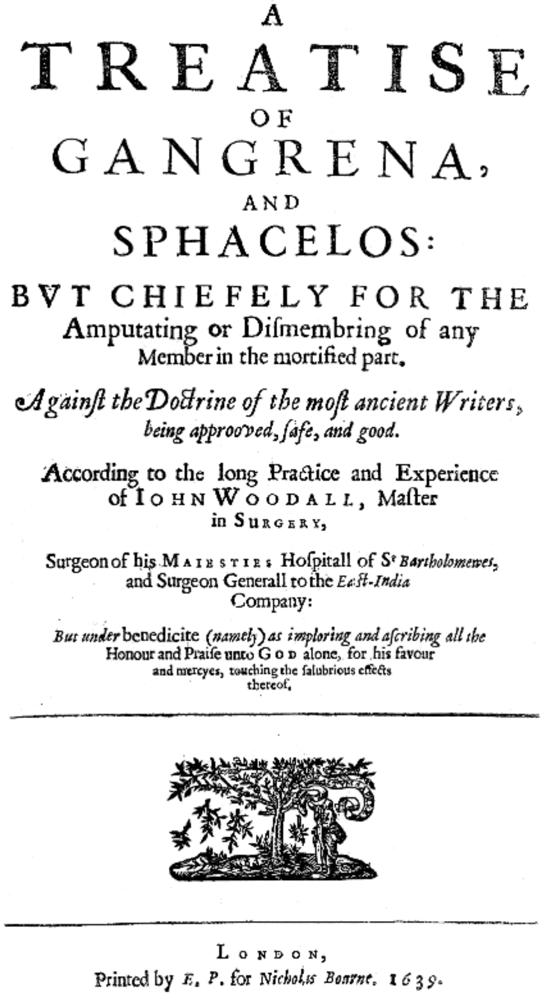
A soldier after gunshot wounding, c. 1828[2]

Definitions and Usage

Amputatio, the Latin noun from the verb *amputare*, to cut off or cut away, derived from *amb*, about and *putare*, to prune or to lop, was little used in Roman texts and never, it is believed, to indicate a surgical amputation; however, the verb *amputare* was employed with reference to cutting off the hands of criminals.[3] Its deriviative in the English language, amputation, was not assigned to limb excision by surgeons much before the 17th century. One of the first to record the word in English, in a written work, was Lowe in *A Discourse of the Whole Art of Chirurgerie* (1612) when he headed a chapter, "The maner of amputation"[4]; he also used the term extirpation, perhaps reflecting his long experience in France, but not the word dismembring. Soon after, Woodall entitled a chapter in his *Surgions Mate* (1617), "Of Dismembring or Amputation,"[5] although in subsequent discussion on indications and procedure, he referred only to dismembring, including the dismembring knife and dismembring saw. In a later edition, of 1639, Woodall employed both amputation and dismembring, the former as often as the latter, suggesting gradual abandonment of the term dismembring[6] (Fig. 1.1). Among earlier works, no description of limb excision as an amputation has been found before that, in French, of Pare, in 1564, who wrote a chapter headed "*Du lieu ou il faut commencer l'amputation*" and advised "*sans delai . . . couper et amputer*" for gangrene.[7]

Among alternative expressions, we find the following. Gale wrote in 1563: "*. . . in those wounds wyche are greate and perilous with shotte, I would have them straite waye to dismember the patient . . .*",[8] without employing the word amputation. In 1596, Clowes wrote: "*The maner and order of the taking off a mortified and corrupt legge or arme, which cometh oftentimes, by reason of wounds made with Gunshot, . . .*" and advised: "*. . . make a speedy dispatch to cut off the member . . . ,*"[9] hence excluding both dismembring and amputation. In the English translation of Vigo's *Practica in arte chirurgia copiosa* of 1550, a section is headed: "*Membres, the division of them,*"[10] whilst a translation of Brunschwig's *Buch der Cirurgia* of 1525 stated: "*. . . after that was ye hande cut of. . . .*"[11] An early 15th-century Middle English account of *The Cyrurgie of Guy de Chauliac* has a paragraph headed "*The rewle in kyttyng of of a dede membre*" (The rule in cutting off of a dead member) and, in the adjacent text, only employed the terms cutting and sawing.[12] In 1750, Dionis suggested employing the Greek word *acrotiriasmos*, to mean cutting off the extremities of the body,[13] but no other reference has been traced.

Despite the introduction of amputation as a common descriptive term by 1638, Read still



A
TREATISE
OF
GANGRENA,
AND
SPHACELOS:
BVT CHIEFELY FOR THE
Amputating or Dismembring of any
Member in the mortified part.
Against the Doctrine of the most ancient Writers, being approoved, safe, and good.
According to the long Practice and Experience
of IOHN WOODALL, Master
in SURGERY,
Surgeon of his MAIESTIES Hospitall of S^t^ *Bartholomewes*,
and Surgeon Generall to the *East-India*
Company:
But under benedicite (*namely*) *as imploring and ascribing all the*
Honour and Praise unto GOD alone, for his favour
and mercyes, touching the salubrious effects
thereof.

LONDON,
Printed by *E. P.* for *Nicholas Bourne.* 1639.

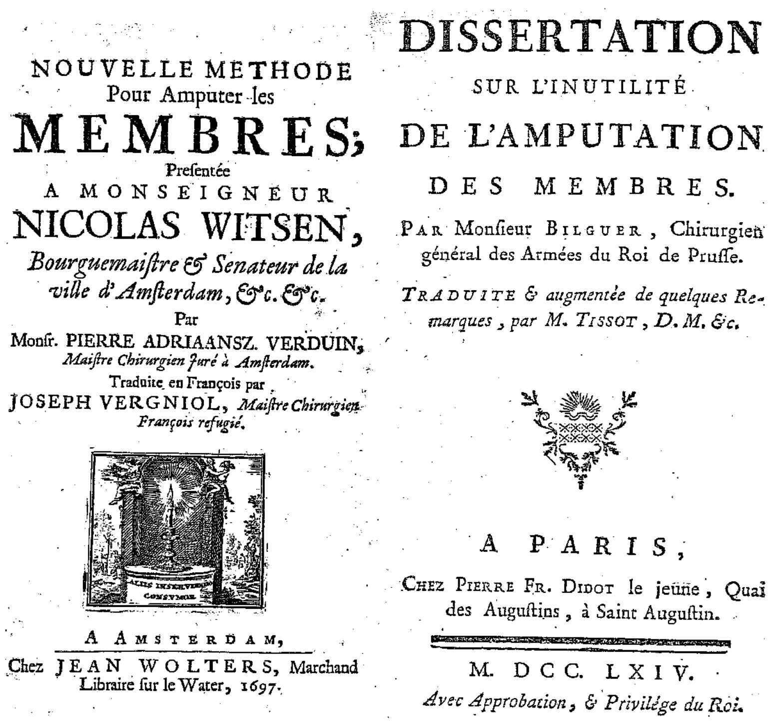
FIG. 1.1. Title page of John Woodall's treatise on gangrene, a sectional part of his *The Surgeon's Mate*, 1639.[6]

mentioned dismembring to the exclusion of amputation,[14] whereas later 17th-century British authors Cooke and Wiseman only employ amputation.[15] In more-recent times, the expression *limb ablation* has been employed, more particularly to extirpate malignant bone tumours by amputation.

Dismember, in the sense of limb excision, is derived from Old French *desmembrer*, now reduced in Modern French to *démembrer*, from the original Latin *membrum*, a limb. As suggested in works already mentioned, dismemberment preceded amputation as a description of surgical limb excision, perhaps for half a century or so. Before that, according to the Oxford English Dictionary, dismemberment was employed from the 13th century to describe the lopping or pruning of tree branches and for human limb destruction or limb removal by accident, in combat or for legal reasons. Curiously, in the English translation of Brunschwig, dismembering is applied to joint dislocations; *"Of the dyslocatyon or dysmembrynge of every joynt in generall."*[16] Despite its French origin, *desmembrer* has not been traced in French surgical works which employed, in the 16th and early 17th centuries, phrases such as *"extirper les extremitez du corps,"* or *"extirper les membres,"*[17] to extirpate limbs, or words such as *débiter* or *retrancher*, as well as *couper*, to cut off. Even in 1811, Sabatier defined amputation as *"le retranchement des membres."*[18] In Boyer's *Le Dictionnaire Royal* of 1759, *démembrer* is translated as to tear off limbs, to pull to pieces or to divide.[19] Two centuries before that date, the prominent and active surgeons Pare and Guillemeau (Fig. 1.2) had promoted and established *amputer* and *amputation*[20] in French surgical terminology. Both De La Charriere in 1692 and Verduin in the French version of his book *Nouvelle Méthode pour Amputer les Membres* of 1697 employed *amputation* exclusively for limb excision.[21] Importantly, Verduin's small monograph was one of the first devoted exclusively to surgical amputation (Fig. 1.3).

Later commentaries by medical historians on early publications usually transcribe, whether from a foreign language or English, all reference to limb excision as amputation, perhaps to communicate more readily with modern readers. Apart from the occasional use of dismembering, the writer intends to pursue a similar course, in studying the protracted evolution of limb loss or limb removal. We must also note the description "disarticulation," also known as "amputation in contiguity," indicating removal through an articulation or joint, such as the knee or shoulder, that is without dividing bone. In addition, complete transections with sword or axe, cutting the skin and bone at the same level, are now called guillotine amputations, even when these took place before the word guillotine originated in 1791 (after Dr. Guillot, who devised a bladed machine for beheading during the French Revolution). In 1833, Mayor described the guillotine procedure as *tachytomie*, derived by him from the Greek *tachy*

Fig. 1.2. Instructional scene of synchronous below-knee and below-elbow guillotine amputations with concave knife, bow saw and, in front of the box, crows-bill forceps, cauteries and needle with thread. (From Guillemeau J. *La Chirurgie Francoise*, 1594[20]; part of title page.)



NOUVELLE METHODE
Pour Amputer les
MEMBRES;
Presentée
A MONSEIGNEUR
NICOLAS WITSEN,
Bourguemaiſtre & Senateur de la ville d'Amſterdam, &c. &c.
Par
Monſr. PIERRE ADRIAANSZ. VERDUIN,
Maiſtre Chirurgien Juré à Amſterdam.
Traduite en François par
JOSEPH VERGNIOL, *Maiſtre Chirurgien François refugié.*

A AMSTERDAM,
Chez JEAN WOLTERS, Marchand Libraire ſur le Water, 1697.

DISSERTATION
SUR L'INUTILITÉ
DE L'AMPUTATION
DES MEMBRES.
PAR Monſieur BILGUER, Chirurgien général des Armées du Roi de Pruſſe.
TRADUITE & augmentée de quelques Remarques, par M. TISSOT, D. M. &c.

A PARIS,
CHEZ PIERRE FR. DIDOT le jeune, Quai des Auguſtins, à Saint Auguſtin.

M. DCC. LXIV.
Avec Approbation, & Privilége du Roi.

Fig. 1.3. a. Title page of an early monograph devoted to flap amputation by Pierre Verduin, 1697. **b.** Title page of an early monograph questioning the utility of amputation by J.H. Bilguer (French translation annotated by Tissot, 1764[52]).

or rapid, and *(o)tomie* or cutting, a term not found elsewhere.[22]

This is not to say that amputation (or disarticulation), in the elective operative sense, has worldwide usage, for many communities believe such surgery destroys bodily integrity and must be refused, whilst some nonindustrialised societies, now rapidly diminishing in numbers, have no knowledge of such treatment. Commenting on the Mano tribe in Liberia, in 1941, Harley stated "*amputations are unheard of.*"[23] By contrast, the loss of fingers, toes and limbs, as a consequence of natural and accidental causes, is a universal phenomenon which ultimately paved the way towards prudent acceptance of elective amputation, in many communities, when facing the alternative of limb death complicated by destruction of the victim.

Despite its original definition, amputation is not applied currently to horticulture or "tree surgery," whereas it is sometimes assigned to the surgical excision of the nose, ear, genitalia and breast as well as the subjects of this study, limbs, fingers and toes. However, to the population in Western societies at least, amputation is now identified specifically with surgical limb excision, usually accompanied by an intake of breath and a general feeling of revulsion for this mutilation, often overlooking the victim's wish to survive despite operative pain and attendant dangers. It is clear the route to elective surgery was preceded by many centuries when the outcome of natural and accidental amputations were witnessed, and subsequently by the accumulation of tentative experiences in removing gangrenous limbs beyond the painful zone. A major objective of this book is to consider this lengthy prelude to elective amputation through sound flesh to obtain a healed and usable stump, a procedure not confirmed by case evidence before the malevolence of complex gunshot injuries precipitated this bold action, towards the end of the 15th and beginning of the 16th centuries.

Irrespective of planned elective amputation, both before and since the Renaissance, fingers, toes and limbs have been cut off in extremis, particularly in circumstances associated with entrapment, often by the victims themselves, if we are to be guided by recorded observations. An example, in 1867, described the experience of a lumberjack splitting logs with wedges, on his own, in a remote area of the Rocky Mountains of North America as follows:

"Soon a yawning crack opened along the log, and in a brief space it would have been in two, but by some mischance the man slipped, the wedge sprung instantly and allowed the crack to close upon his foot. Having tried every means available to free himself, but in vain—shouting he knew to be useless, as there was no one within hail, and night was coming on, and he was well aware that the bitter cold of a northern winter must end his life long before any help could be reasonably anticipated—in his agony of mind and intensity of bodily suffering, with mad despair the poor fellow seized the axe, and at a single chop severed his leg from the imprisoned foot."[24]

Although he crawled to shelter, the accident proved fatal. Other reports confirm desperate and instinctive efforts of extrication by the victim, for example deep-sea divers trapped by their fingers (see Chapter 3). It is concluded that similar instinctive amputations aimed at survival took place, long before written evidence appeared, by victims obliged to act as their own surgeons.

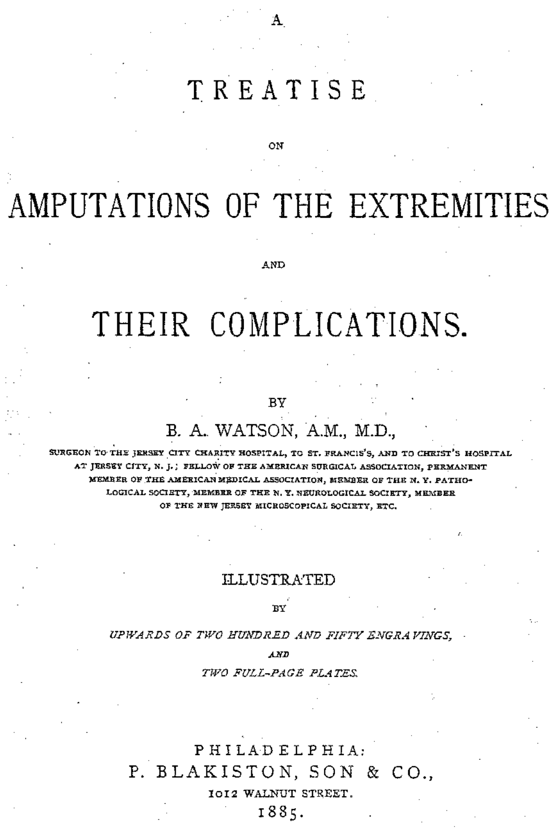
In passing, we notice mankind was and is familiar with animals adopting comparable measures, using their teeth to free limbs entrapped in snares and, also, of awareness that certain animals, such as salamanders, tadpoles and some lizards, are capable of regenerating lost limbs and tails, doubtless regretting that humans do not have this remarkable healing capacity. Recent research informs us that human embryos operated on in utero heal without a trace of scarring, and scientists at Manchester University are searching for the genes responsible in amphibians, with a long-term aim to develop drugs or gene therapies to activate these mechanisms in the human.[25] Further, an experimental mouse at the Wistar Institute in the United States has been shown to regenerate lost toes, joints and tails, whilst foetal liver cells from this animal injected into ordinary mice also gained the power of regeneration. Long term, this work raises the question whether human amputees may benefit?[26]

It seems probable that instinctive limb dismemberment took place in prehistoric times, either for dry gangrene, for limb entrapment or to dispose of crushed and virtually amputated limbs in the presence of open fractures, making use of the fracture site or cutting through joints, especially those of the fingers and toes. Experimentally, Hollander has shown the bones of the forearm can be sawn through with serrated Neolithic stone blades in 6 to 7 minutes,[27] although it is probable that stone or bronze axes or heavy swords were applied urgently by victims or by sympathetic bystanders to detach damaged limbs rapidly by guillotine section, even if, as we know from later records, the larger bones of the tibia, femur and humerus splintered badly when severed in this way, rendering complete section messy and healing tedious.

Previous Work on Amputation History

Cumulatively, published accounts and studies of both nonsurgical and surgical amputations available in surgical literature, in the press and other media, and even general literature, and in many languages, are immeasurably extensive. Complete monographs are few, but most early surgical textbooks contain comprehensive chapters on amputation, some with a historical sketch, whilst many monographs and university theses are limited to particular aspects of this subject. Countless lesser communications concentrate on personal experience and case histories, or isolated aspects of the etiology, pathology and indications for or against amputation, and especially on operative techniques, instrumentation, postoperative management, problems of amputation stumps, the fitting and manufacture of prostheses, or the statistics of surgery in relation to operative procedures. Only a few authors mention the possibility of prehistoric limb loss before elective surgical methods developed.[28] In particular, no comprehensive account of nonsurgical amputations and amputees has been traced, despite their positive contributions towards eventual surgical methods. In studying the background to earlier as well as recent attitudes and practice, many communications have been examined, although doubtless many sources have been overlooked, especially non-English accounts, for which the writer apologises. As a basis for this study, the following selection of works adopting a more-complete approach to amputation have proved important guides, both in their own right and by means of their bibliographical contribution towards further investigation. The first four items are monographs on surgical amputation which include introductory accounts of its history and evolution. The remaining works are comprehensive book sections, chapters or journal communications noting historical factors.

1. B.A. Watson's *A Treatise on Amputations of the Extremities and their Complications* of 1885 (Fig. 1.4) is an encyclopaedic volume having origin in the author's experience during the American Civil War of 1861–1866 and later in Jersey City where more railroads terminated than in any other American city; train wheels remain a significant cause of traumatic amputations.[29] The first chapter, on the history of elective amputations, commences with conjectures from classical


A

TREATISE

ON

AMPUTATIONS OF THE EXTREMITIES

AND

THEIR COMPLICATIONS.

BY

B. A. WATSON, A.M., M.D.,

SURGEON TO THE JERSEY CITY CHARITY HOSPITAL, TO ST. FRANCIS'S, AND TO CHRIST'S HOSPITAL AT JERSEY CITY, N. J.; FELLOW OF THE AMERICAN SURGICAL ASSOCIATION, PERMANENT MEMBER OF THE AMERICAN MEDICAL ASSOCIATION, MEMBER OF THE N. Y. PATHOLOGICAL SOCIETY, MEMBER OF THE N. Y. NEUROLOGICAL SOCIETY, MEMBER OF THE NEW JERSEY MICROSCOPICAL SOCIETY, ETC.

ILLUSTRATED

BY

UPWARDS OF TWO HUNDRED AND FIFTY ENGRAVINGS,

AND

TWO FULL-PAGE PLATES.

PHILADELPHIA:
P. BLAKISTON, SON & CO.,
1012 WALNUT STREET.
1885.

Fig. 1.4. Title page of a comprehensive treatise on amputations, with a historical appraisal, by B.A. Watson, 1885.[29]

authors and finishes with details of antiseptic wound management (his book is dedicated to Joseph Lister); much historical material is incorporated into subsequent chapters. If Watson does not refer to ritual or punitive amputations, or to auto-amputation, he provides a detailed study of conditions affecting the results of amputation and on indications, instruments and equipment, and the control of haemorrhage and infection. Watson mentions recent work on germs but displays no knowledge of thermal sterilisation techniques, just starting in Europe. Only one chapter is devoted to operative techniques, well illustrated with 96 graphic engravings. Studies of postoperative wound care and stumps and artificial limbs are extensive. The work terminates with three chapters, virtually a separate treatise, on wound complications, mentioning haemorrhage, fever, pyaemia, septicaemia, erysipelas, gangrene and osteomyelitis at length, with only sparse references to amputation.

2. Leon Gillis' *Amputations* of 1954 reflects the experience of an orthopaedic surgeon attached to the principal limb-fitting centre in Britain, at Queen Mary's Hospital, Roehampton, where he advised many victims of World War II.[30] Gillis commences with definitions and a brief history devoted mainly to developments of saws, knives, artery forceps, tourniquets, anaesthetics, surgical techniques and artificial limbs. His last chapter notes amputations in unusual circumstances, including brief consideration of ritual loss and auto-amputation. Other chapters are devoted to indications, standard and special amputations, and to congenital anomalies and short limbs in children requiring prostheses, to phantom limbs and to after-care. Six chapters consider the problem of painful stumps and their management, a topic which Gillis studied in detail, doubtless due to experience at this special hospital, perhaps the most profitable element of the book. Some reamputated specimens removed by Gillis were presented to the Royal College of Surgeons of England and are now displayed in the Museum of Anatomy and Pathology (see Fig. 12.5). Gillis also wrote a further volume on artificial limbs, to be referred to later.[31]

3. Miroslaw Vitali, Kingsley Robinson, and Brian Andrews, et al., who wrote *Amputations and Prostheses* (second edition, 1986), aimed at surgeons, emphasised that amputation and prosthetics were not separate entities and postulated union of the stump and prosthesis as a single locomotor unit.[32] An introductory historical survey stated Neolithic man survived amputation but found no evidence in the Bible or Egyptian papyri related to amputation, considering "artificial limbs" found with mummies were postmortem additions to replace congenital or traumatic deficiencies. They believed Hippocrates performed dismemberment for gangrene but considered gunshot injuries were the stimulus to elective amputations. The significance of Petit's vital screw tourniquet is understated and Lister's revolutionary contribution is not mentioned. However, a longer section on prosthetic evolution is very helpful and is amplified by a chapter on statistics and trends. Reference is made to other sections of the book later.

4. George Murdoch and A. Bennet Wilson edited *Amputation: Surgical Practice and Patient Management* in 1996 to reflect the views of some 35 authors worldwide, focussed firmly on the surgeon who is advised not to amputate without an understanding of the biomechanical and prosthetic factors involved.[33] A brief introductory chapter mentions a few historical features including the fearsome immersion of stumps in boiling oil. Tourniquets and anaesthesia are not included but recent developments are prominent; Wilson has written much more fully on these, in a symposium essay "*The modern history of amputation surgery and artificial limbs.*"[34]

5. Samuel Cooper's *A Dictionary of Practical Surgery* was first published in 1809 and subsequently in six editions; those of 1822 (fourth) and especially of 1838 (seventh)[35] have been consulted, the latter amplified by new material particularly from American practice. Cooper's amputation account is extremely detailed and his bibliography extensive. At the outset he emphasised: "*. . . it is not enough for a surgeon to know* <u>*how*</u> *to operate; he must also know* <u>*when*</u> *to do it,*" and then listed conditions which might require solution by amputation. These situations were compound fractures, especially caused by gunshot violence and crushing, lacerated wounds with a damaged arterial supply, limbs partly carried away by a cannonball, mortification, diseased joints, large bony exostoses and bone necrosis, and cancerous diseases

and tumours, a choice somewhat skewed by his military experience in the Waterloo campaign. A detailed history of surgical amputation follows, commencing with the Hippocratic era. Significantly, Cooper believed nature was a guide in confirming, long before written accounts, that gangrenous limbs sometimes separated spontaneously with survival of the patient and hence encouraged early practitioners to resect at the dead and living junctions, carefully avoiding the blood vessels. However, he agreed Celsus and Archigenes performed sectioning through sound flesh for the first time, although he doubted they fully understood how to control haemorrhage; he found Galen and Arabic authors much less adventurous. Noting the introduction of gunshot injuries in the 14th century, Cooper considered an effective surgical response to their destructive damage was delayed until 1517 when Gersdorff demonstrated elective amputation above injury level (Fig. 1.5), combined with skin conservation to secure sound stump healing, as well as to save life. The subsequent history of elective amputation is detailed, ending with the works of Velpeau (1832), Liston (1832), Dupuytren (1834) and Malgaigne (1834); this period is surveyed in later chapters.

6. Alfred Velpeau's *Nouveaux Eléments de Médecine Opératoire*, first published in 1832, provides a brief historical outline[36] with similar conclusions to Cooper in 1822 and a detailed analysis of indications meriting amputation. These indications were partially divided limbs or fingers, established gangrene including traumatic and hospital gangrene, frostbite and severe burns, open fractures, especially due to gunshot, severe bone infection, carious joints, cancer and sarcoma, severe leg ulceration, supernumerary fingers and toes, and rarely exostoses, severe joint contractures, tetanus and hydrophobia. Velpeau mentioned contraindications briefly and outlined his general operative organisation, instrumentation, types of procedure, dressings and complications, before describing specific levels of amputation in great detail[37]; these are considered in subsequent chapters of this volume.

7. Thomas Longmore's pamphlet *Amputation: an Historical Sketch* of 1875 is historically sketchy although generally accurate. He emphasised early lack of knowledge to control bleeding, the importance of Petit's tourniquet, and recognised the significance of hygiene and Lister's antiseptic school. However, as a military surgeon (he was Medical Director of the British Army) he considered antiseptic management very difficult in time of war. He then commented briefly on operative developments.[38]

Fig. 1.5. The first book illustration of an amputation scene showing ligature-tourniquet, knife and saw; the background figure has an injured hand, perhaps having lost fingers to encourage the victim. (From Gersdorff H, *Feldtbuch der Wundartzney*, Strassburg: Schott, 1517.)

8. Joseph Lister's (Fig. 1.6) amputation chapter in Holmes & Hulke's *A System of Surgery*, edition of 1883, commenced:

"Amputation is often regarded as an opprobium of the healing art. But while the human frame remains liable to derangement from accident or disease, the removal of hopelessly disordered parts, in the way most conducive to the safety and future comfort of the sufferer, must ever claim the best attention of the surgeon." and he added, *"It is instructive to trace the history of the improvement of this department of surgery."*[39]

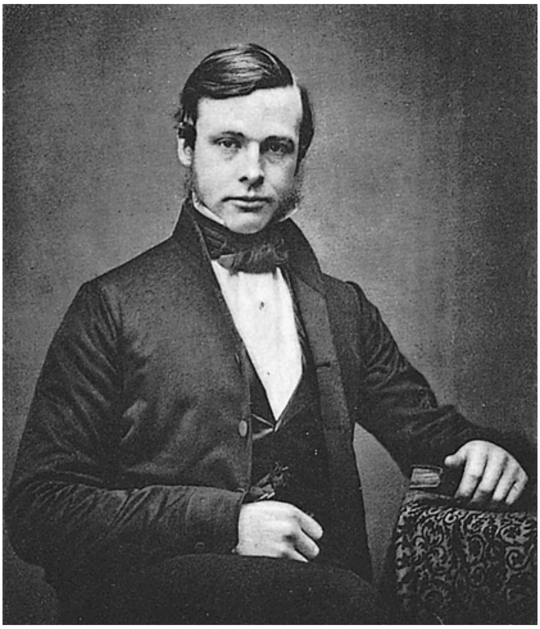


Fig. 1.6. Portrait of Joseph Lister aged about 28 years when working with James Syme in Edinburgh. (From Godlee R, *Lord Lister*, London: Macmillan, 1917.[54])

Lister's historical survey forms a major portion of his article. He debated Celsus's views and concluded he advised amputation through sound tissues with ligature of the vessels, a scheme thereafter overlooked, due to Galen's timid teaching, until Pare's reintroduction in the 16th century. Even so, Lister believed subsequent progress was slow until efficient bleeding control emerged with Morel's tourniquet and particularly Petit's screw tourniquet in 1708. After describing instrumentation in detail, he concluded with relatively brief accounts of recommended amputation procedures. Curiously he did not mention his own revolutionary antiseptic system, published in 1867, specifically to reduce the mortality of amputation after compound fractures.[40]

9. Ernst Gurlt's *Geschichte der Chirurgie*, volume 3 of 1898, contains a section entirely devoted to the history of amputation from classical times to the end of the 16th century.[41] Within this restricted period, Gurlt noted the contributions of surgeons mentioned earlier, and many others, with particular emphasis on their instrumentation and equipment which are illustrated comprehensively; he devoted a long paragraph to limb prostheses.

10. L.-H. Farabeuf concentrated most of his *Précis de Manuel Opératoire* of 1885 (Masson) to amputation, providing an extremely detailed account of operative developments in the 19th century illustrated with 414 figures mostly drawn by himself.[42] Whilst not aiming to write amputation history, he cannot be ignored for his exhaustive review of procedures in the 19th century, most of which were overlooked by others, and are now forgotten; reference to these appears later. A similar view applies to P. Huard's *Etudes sur les Amputations et Desarticulations des Membres* of 1940, which concentrates on surgical techniques, reviewing progress through the nineteenth and early twentieth centuries, principally from a French viewpoint. Huard also gives prominence to M. Duval, who in 1849 counselled precise methodical amputations, then possible under anaesthesia, when colleagues still operated in reflex haste, as if the patient remained conscious, with poor results.[42] As late as 1960, the author, then an apprentice surgeon, was reprimanded for lack of speed during an amputation; today a meticulous approach is demanded.

11. Owen Wangensteen, Jacqueline Smith and Sarah Wangensteen's substantial communication, *"Some highlights in the history of amputation reflecting lessons in wound healing,"* of 1967, details the preanaesthetic and preantiseptic challenges of haemorrhage control and especially wound care based on historical accounts of amputation management.[43] Particular attention is paid to the evolution of bleeding control with cautery, caustics, vessel ligatures and tourniquets, to wound care by primary or delayed primary suture or by open methods and to applications including wine, turpentine, water, silver nitrate and finally carbolic acid. American experience is emphasised, including the bitter schism over Listerian antisepsis summed up in the words of B.A. Watson as late as 1883:

> *"The great objections come not from those who have tried Listerism, but from those who are willing to raise their hands and thank God that they have neither witnessed its application nor used it."*[44]

The authors quote experience from the two World Wars and the Korean Wars which reinstated open circular amputations and primary suture as mandatory for gunshot wounds, confirming former preantiseptic practices. They concluded:

"Historical appraisals of accomplishment in a technical discipline may be heightened when complemented by an assessment including the realistic and chastening lessons of experience that only active participants in such disciplines can provide."[45]

Their bibliography is extensive and important.

12. Peter Alden and William Shaw's paper "*The evolution of the surgical management of severe lower extremity trauma*" of 1986[46] postulated: "*The evolution of extremity trauma surgery reflected the development of surgery as a speciality,*" without indicating why the upper extremity was ignored in subsequent discussions. As specialists in plastic surgery, they argue that from routine high amputations emerged regional amputations which conserved length, followed by flap reconstructions, wound debridements, vascular repairs, limb replantations, and the current concept of reconstruction. Their detailed historical appraisal of lower limb wound care is divided into the ancient era, the Middle Ages, Pare and the beginning of modern trauma surgery, later refinements in amputation, the effect of anaesthesia, the American Civil War, antisepsis, both Great Wars and recent advances. In particular, Aldea and Shaw outline the gradual rise of reconstructive techniques which have reduced many indications for amputation. They also emphasised the surgeon's predicament in counselling prolonged complex surgery when this might not surpass the functional results of immediate amputation and prosthetic fitting. Finally, they remind us of the words of Samuel Gross voicing the ancient dilemma of, if and when to operate, in 1862:

"The cases which may reasonably require and those which may not require interference with the knife are not always so clearly and distinctly defined as not to give rise, in very many instances, to the most serious apprehension . . . that, while the surgeon endeavours to avoid Scylla, he may not unwittingly run into Charybdis, mutilating a limb that might have been saved, and endangering life by the retention of one that should have been promptly amputated."[47]

13. Kingsley Robinson's comprehensive chapter in "*The Evolution of Orthopaedic Surgery*" of 2002, edited by Leslie Klenerman, traced "Amputation surgery from 1800 to the present."[48] Attention is drawn to the dominance of immediate amputation in military practice during the Napoleonic period and the development of flap procedures in the 19th century. Anaesthesia, antisepsis and accurate haemostasis are recognised factors improving primary stump healing, although the role of asepsis is excluded. The evolution of standard amputation levels is described, followed by that of prostheses, an important section on immediate fitting of prostheses and on recent advances, stump pain and secondary surgery, ending with a discussion of limb reimplantation.

Although these studies are important, especially to the development of elective amputation, none considers in any detail the long presurgical period contributing towards ultimate yet relatively recent surgical action and, also, they overlook many advances in general surgery, derived directly from pioneering amputation techniques. Additional historical sources are indicated in the reference list.[49]

To comprehend more fully the eventual development of surgical amputation, examination of natural, accidental, ritual, punitive and legal dismemberment is rewarding, not only for technical reasons but for social implications, vital to acceptance of a mutilating procedure performed under horrendous circumstances, before the introduction of general anaesthesia. In addition, in various societies ancient beliefs, taboos and religious convictions were important influences determining whether elective amputation was accepted or, as in the case of Islamic teaching, rejected or accepted with difficulty. The circumstances of acceptance was also significant; for example, during the 16th and 17th centuries in Western Europe, both patient and surgeon were encouraged to go to mass, or to pray earnestly before operation: *"For it is no small presumption to Dismember the Image of God."*[50] At the same time, the surgeon was constrained to perform amputation in the morning and to avoid the day of the full moon! If not always expressed, the fears of cruel operative pain, of death from bleeding or from subsequent sepsis, and anxieties about the quality of the stump to bear weight, and future rehabilitation weighed heavily in the calculations of both patient and surgeon who was encouraged to transmit these to relatives, as Clowes advised his surgical readers in 1596:

". . . have ministered unto them some good exhortation, concerning patience in adversitie, to be made by the

minister or preacher. And you shall likewise advertise the friends of the patient, that the worke which you go about is great, and not without danger of death."[51]

Even when elective amputation was accepted as a branch of surgical management for gunshot wounds, it continued to pose many technical problems which, by degrees, stimulated remedies. Hence, the major drawbacks of pain and blood loss, followed by stump sepsis and failed healing, generated many attempts to counter them. Stump infection or the threat of infection provoked a torrent of mostly unhelpful applications and dressings, until Lister's antiseptic prophylaxis with phenol transformed the management of compound fractures, hitherto a source of dangerous infection with or without amputation. His publications on this method, in 1867, heralded the birth of safe elective surgery which, eventually, revolutionised all surgical practices permanently.

Before the assistance of anaesthesia, a persistent search for more-effective instruments, aimed to speed amputation, resulted in significant advances in their design aided by new materials and sophisticated manufacture, frequently with benefit to other surgical operations. In addition to improvements in the efficiency of arterial forceps and tourniquets, blades became slimmer and straighter, hacksaws and tenon saws became smaller or, in some instances, were replaced by narrow or chain saws, and methods of vessel ligature and skin suture were refined employing tenacula and needle-holders.

Not all surgeons and few patients were comfortable with radical solutions and by the 18th century, a more-conservative approach to gunshot fractures became evident, particularly following the monograph of Bilguer translated as *A Dissertation on the Inutility of the Amputation of Limbs* in 1764[52] (see Fig. 1.3). Eventually, alternatives to amputation were found including joint excision for disease, ligature for expanding aneurysms, decompression of bone abscesses, improved fracture splintage, antiseptic and aseptic wound care, and the applications of X-ray diagnosis, arterial reconstruction, blood transfusion, open debridement, antibiotic therapy, bone tumour excision and prosthetic replacement, and intensive emergency care, including evacuation by helicopter. The evolution of alternative procedures continues to the present and forms a section in Chapter 7. Unfortunately, such measures have their limitations, especially for injuries caused by ever more sophisticated weaponry of increasing velocity and destructiveness, especially the indiscriminate dispersal of antipersonnel mines, deliberately manufactured to maim by irremediable destruction of the feet, rendering surgical amputation at a higher level the only option, when patients accept this advice. Such acceptance depends as much on patients as the society in which they live, for society's approval has always been desirable if surgeons are to advise and patients accept dismemberment with confidence. Yet some societies have been and remain opposed to such surgery in

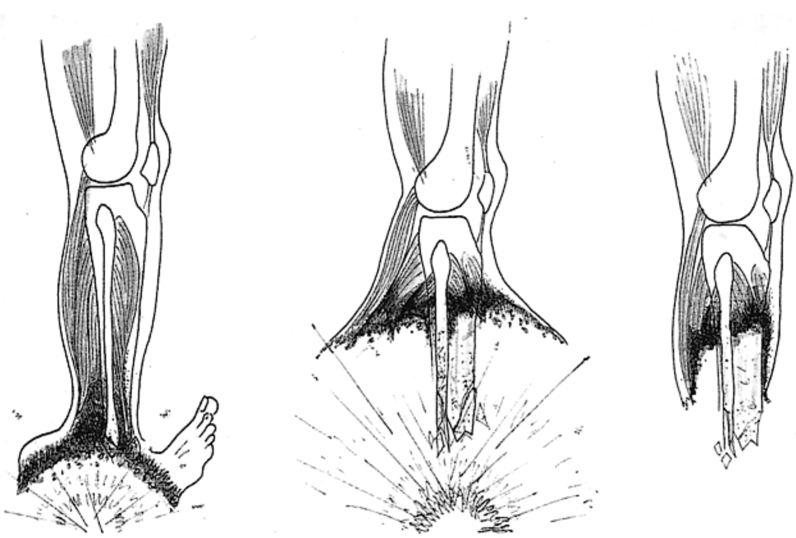


Fig. 1.7. Land-mine explosion: diagrammatic sequence of destructive effect on a foot and lower leg. (From Coupland RM. *Amputation for War Wounds*, 1992,[53] with permission of the International Committee of the Red Cross.)

principle, regarding loss not just as a mutilation but an assault on the completeness and sanctity of the physical corpus. Coupland, who has recent experience of gunshot and mine injuries in Red Cross hospitals (Fig. 1.7), confirmed the persistence of this cultural attitude in 1992, stating:

"The patients may prefer a useless limb to a functioning prosthesis, whilst many others may prefer to die from their wounds rather than suffer amputation. Such views must be accepted and accommodated in decision making."[53]

This enigma is addressed in Chapter 9, where the concepts of society and the undeniable fears of patients as well as the numerous concerns of surgeons are examined in more detail.

Summary

In describing limb loss, alternative terminologies are noted before the word amputation was established in English at the beginning of the 17th century. Since then, written evidence of elective amputation is cumulatively enormous, stimulated initially by the impact of gunshot wounds. However, the long preamble of natural amputations and nonsurgical amputees, extending back to prehistory, has received little consideration and is developed further. This chapter reviews selected written sources reflecting historical perspectives, recognising this is incomplete. Attention is drawn to numerous alternative procedures introduced since the end of the 18th century to avert amputation and to certain societies who oppose amputation for religious reasons.

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2
Natural Causes of Dismemberment

"Even today chronic ergot poisoning is not unknown in Europe, and is characterised by a chronic gangrene of the extremities leading to loss of the fingers and toes."

Singer and Underwood, 1962[1]

Despite current preventive measures and sophisticated medical care, natural causes of limb failure remain prevalent and often precipitate gangrene, terminating in operative amputation, a combination of events more evident in elderly populations. It is postulated, firstly, that most natural causes have a prehistoric origin and exerted similar pathological effects then as now, and secondly, long before modern elective surgery, spontaneous natural amputations with survival yielded otherwise healthy amputees whose future, as disabled tribal members, hinged on the attitude of their active companions. In a harshly competitive environment where survival depended on avoiding wild beasts, on strenuous days hunting for food and on resisting enemy incursions, complete physical fitness was vital and an amputee must have been viewed as a weak link in a community's survival chain. Eventually, when not despatched or abandoned, as was probable in the case of leg amputees who were members of a nomadic tribe, some victims received support by their immediate family. Whether amputees were viewed in the same light as those born crippled is not clear, for often such births were seen not only as feeble contributors to the community but as evil portents or as sources of shame and disgrace, leading to their rejection. Sigerist commenting on Plutarch's account of Sparta stated:

"When a child was born it was inspected by government experts . . . If it was weak or crippled, it was thrown into a deep pit on Mount Taygetus and thus destroyed. There was no reason to bring it up, since it would be useless to the state and a mere burden to society."[2]

Even when tolerated to escape death, the deformed and crippled might be deemed unworthy or unfit for certain responsibilities, irrespective of any physical limitations as the constraints of ancient Jewish law indicate when Moses spoke to Aaron on this matter:

". . . let him not approach to offer the bread of his God. For whatsoever man he be that hath a blemish, he shall not approach: a blind man, or lame, or he that hath a flat nose, or anything superfluous. Or a man that is brokenfooted or brokenhanded . . ."[3]

However, were amputees considered second-class tribal members to be ostracised or derided in the same way as those with major defects, dwarves, the blind, the deaf and cripples? We cannot be sure, especially if they were active contributors to their community before amputation. At some point during mankind's progress, in certain societies at least, amputees were accepted and perhaps found work, around the hearth or, if the upper limbs were intact, in fashioning tools or weapons. What then are the causes of natural amputations?

Congenital Absence or Near Absence

Absence of one or more fingers and toes at birth is not uncommon today, resulting in minimal functional disturbance, rarely needing reparative

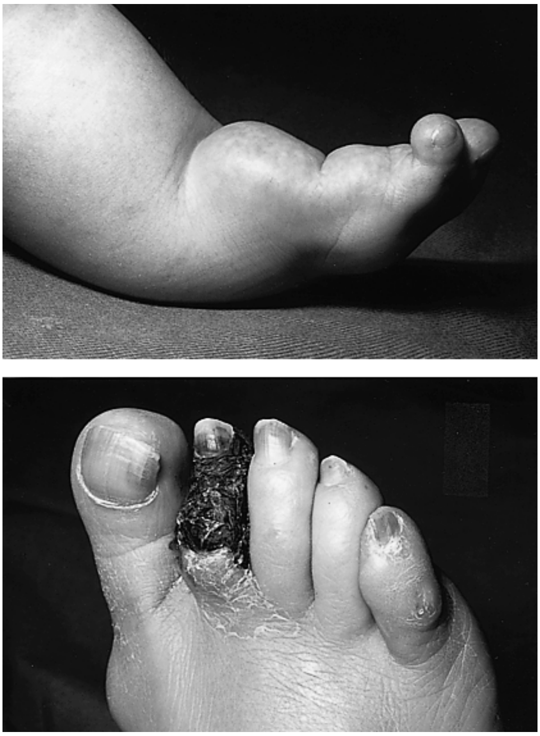

Fig. 2.1. *Upper*. Congenital absence of the fibula with short tibia, only two foot rays and a foot remnant in non-weight-bearing attitude. Treated at 1 year by amputation and prosthesis. *Lower.* Gangrenous second toe resulting from poor blood supply and local trauma. Treated by local amputation. (From author's cases.)

surgery. It is assumed such defects have a long history and those affected in the distant past were either accepted, unless function was grossly impaired, or they were viewed as a source of malign influence. Total congenital absence of a hand and foot (apodia) or the distal part of a limb (hemimelia), or of a complete limb (amelia) are less common,[4] resulting in significant crippling and probable tribal rejection; even in recent times parents have imprisoned such children in a cellar or attic to hide their "failure" from society. More commonly limbs are foreshortened, so-called phocomelia, particularly associated in the 1960s with the ingestion of thalidomide, yet occurring both before and since this epidemic due to unknown factors.[5] Phocomelic limbs often bear a hand or foot at their foreshortened limb extremities and, consequently, may function better than amputation stumps. Nonetheless, they present many of the problems of amputees and, without cosmetic prostheses in the past, doubtless were viewed by their peers as cripples. Even today other congenital deformities can be severe, for example, complete congenital absence of the fibula with a deficient foot twisted severely (Fig. 2.1a), for which amputation and rapid mobilisation with a prosthesis in infancy is preferable to repeated surgery in childhood to correct by degrees what, at best, will always prove a crippled short limb requiring, in any event, an orthosis.

Arteriosclerosis and Vascular Failure

Degenerative arterial disease leads to vessel narrowing, irregularity, ulceration, thrombus formation, aneurysmal weakness or combinations of these, its morbidity increasing with age. Any of these complications, especially in the lower limb, may precipitate acute failure of the arterial circulation leading to gangrene (Fig. 2.1b) and a high rate of amputation or, alternatively, a chronic state of ischaemia, characterised by painful claudication on activity, with only some 10% ending in amputation.[6] Whatever the precipitating cause of limb mortification, death of the tissues is caused by failure of cellular oxygenation transported by red blood cells in arteries which are narrowed, blocked, divided or ligated. Today, the resultant tissue blackening or mortification is described as gangrene, but in the past the term *sphacelos* or *sphacelus* (from the Greek and Latin meaning mortification) was also employed. Indeed, from the Hippocratic writings until the 17th century (see Fig. 1.1), gangrene and *sphacelus* were viewed as distinct conditions, as Paul of Aegineta indicated in the 8th century:

"*. . . we give the name of gangrene to mortifications arising from the violence of the inflammation, when they are not yet formed but forming; . . . But when the parts thus affected become totally insensible, the affection is no longer called gangrene, but sphacelus.*"[7]

Fabry (Hildanus) wrote *De Gangraena et Sphacelo* in 1593, noting the importance of frostbite, plague, toxins, ergot and the effect of tight splints He was one of the first to emphasise the importance of amputating above the level of gangrenous demarcation[8] and also to undertake above-knee amputation.

In 1676 Wiseman wrote:

"Gangrene is a tendency to Mortification: it invades the softer Parts, as the Skin, Flesh, etc. and is the beginning of a Sphacelus. Sphacelus is a perfect Mortification, with the extinction of the native Heat and privation of Sense, not only in the Skin, Flesh, Nerve, Artery, but the very Bones. They differ from one another, as the Mortification is more or less . . . Sphacelus is distinguished from Gangrene by the total Corruption and Stink, it being also insensible both of Knife and Fire."[9]

Heister, who visited many European surgical centres before writing his much-translated treatise in 1718, differentiated sphacelus from gangrene and wrote the former was distinguished when the part lost all sensation to pinprick and incision, when the local muscles became paralysed and the part turned black. Heister listed causes as internal, principally erysipelas, scurvy and poor circulation by reason of old age, and as external, that is, injuries from the air, cold water, noxious topical remedies, and hurts and accidents producing wounds, fractures and dislocations.[10] By 1749, Quesnay maintained the term sphacelus was confusing and served no purpose, adding it was more important from the point of view of clinical presentation and of treatment to distinguish between wet and dry gangrene.[11] In 1750, Sharp had discarded *sphacelus* for mortification, and even this term he found unhelpful:

". . . a Gangrene is defined to be the Beginning of the Disorder; a Mortification (Sphacelus) the last stage of it; it is a Division however of little use, and not strictly adhered to by those who mention it, ..."[12]

These descriptive differences have been laboured here, as early writers considered gangrene and *sphacelus* distinct conditions requiring different management, that of *sphacelus* having no remedy save speedy separation of dead tissues, assisted either by the surgeon or by nature. For the past two centuries this distinction has not been preserved, and *sphacelus* has lapsed from the medical literature. It may be clearer to differentiate a pregangrenous state when ischaemia caused by arterial circulatory failure is evident but reversible, followed by a gangrenous state when tissue death, however small, is clinically visible and irreversible (Fig. 2.2a).

Acute failure or ischaemia may follow an arterial embolus associated with atrial fibrillation, thrombotic occlusion caused by disruption of the internal lining of a weakened vessel, and obstruction following aneurysmal bleeding with dissection of a vessel wall, often associated with high blood pressure and excessive cigarette smoking. Before modern reconstructive surgery, amputation was the only treatment for resultant vascular failure and gangrene. Although arteriosclerosis or vessel calcification has been observed in mummies as illustrious as the pharaohs Rameses II and Merenptah,[13] any earlier history is uncertain and, as it is believed, most humans died young in the prehistoric period, fully developed arterial disease was probably rare. By contrast, in the aging population of the 21st century senile gangrene is a common complication of arteriosclerosis and a frequent source of amputation.

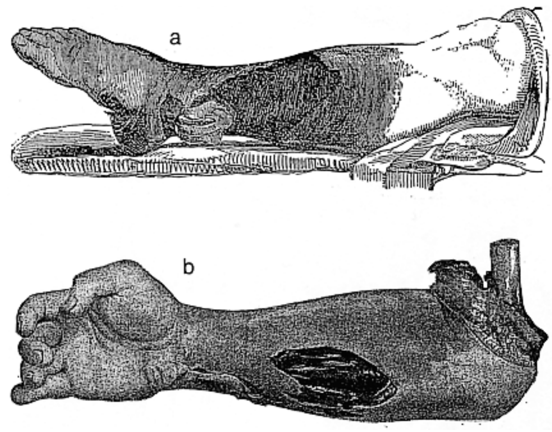

Fig. 2.2. a. Dry gangrene of foot and lower shin caused by vascular disease, showing early separation of necrotic tissues. (From Spence J, *Lectures on Surgery* Edinburgh: Black, 1875, vol 1, fig. 12.[49]) **b.** Arm amputation for gas gangrene of forearm from missile wound during World War I. (From Hull AJ. *Surgery in War*. London: Churchill, 1918,[35] fig. 24.)

Frostbite and Immersion or Trench Feet

From mankind's beginning to the present day, freezing conditions or prolonged exposure to wet conditions compromise the circulation of unprotected feet and hands, leading to spasm and thrombosis of small vessels, damage to the soft tissues and local gangrene. Indeed, young children were particular victims of frostbite, as Woodall makes clear in 1639 when commenting on the natural separation of mortified limbs:

". . . the which may be often seene in poore people, men, women, and children, but most commonly in poore children, who by Gangreenes upon their toes, whole feet, fingers, and hands, yea on their legges, and armes, proceeding of cold, or by weaknesse of nature, where sustenance, dyet, and naturall warmth is wanting. . . . Nature doth of her selfe exfoliate, and cast off the part putrid, from the whole part, by a separation in Nature, without offending or indangering the parts thereto adjacent at all."[14]

Mountaineers, polar explorers and air crews exposed to extremes of cold, even with protective clothing, are vulnerable to frostbite, especially if the limb becomes wet, as for example when falling through ice. A combination of drunken stupor and freezing conditions is a further potent source of peripheral gangrenous change. Even with modern resources, gangrene of frozen toes and fingers may prove irreversible to expectant treatment and require amputations.

Despite an absence of frost conditions, continued wetting of the feet in water and mud reduces the skin temperature and if prolonged may promote vessel spasm, rather like wind-chill factor. Although it is claimed the problem of soldier's trench feet can be recognised in Larrey's clinical notes made during the winter campaign in East Prussia, in 1806,[15] it was World War I experience that crystallised its menace on a huge scale. Static warfare exposed men to muddy and flooded trenches in the open, for long periods, without changes of wet socks and boots, to compromise their foot circulation. Significant numbers were disabled, reducing effective manpower in the winter of 1914–1915, to stimulate urgent research which concluded important factors were swollen feet after long marches, standing upright and generally immobile in a muddy water-filled trench for several days, wearing tight boots and, in the case of British soldiers, constriction of the circulation by puttees wound around legs, the puttee contracting when wet. French troops also wore puttees, to suffer similarly, whilst German troops wearing long boots suffered much less.[16] Fortunately, only a few developed irreversible gangrene of the toes and feet, usually associated with bacterial infection, leading to amputation.[17] By the following winter, preventive measures included larger boots to enable two pairs of socks to be worn, regular powdering and drying of the feet, a fresh pair of socks daily and instructions that a tour of duty in a waterlogged sector was not to exceed 36 hours; this greatly reduced the incidence of trench feet.[18] In subsequent wars, this problem diminished due to moving battle conditions and the absence of static fighting in cold muddy trenches, whereas during World War II, many seaman and some airmen were marooned in open boats for long periods, resulting in similar pathology, described as "immersion feet."[19]

Ergot and Other Toxins

Epidemics of ergot poisoning are especially associated with the Middle Ages when ergot entered the diet as a contaminant of bread made of rye infested with the fungus *Claviceps purpurea.* Rye bread was a staple of the poorer classes, who were the main victims of what was called *ignis sacer* (sacred fire), *ignis infernalis* (infernal fire) or St Anthony's fire (Fig. 2.3). Garrison stated that St. Martial, St. Genevieve and St. Benedict were also regarded as patron saints of ergotism.[20] However, ergotism was sometimes confused with erysipelas, a bacterial infection with streptococci which also caused burning symptoms and reddening of the skin. Ergot produced by the fungus caused contraction of the arterioles and intravascular clotting and, in excessive amounts, lead to gangrene of fingers and toes; this process often spread to higher levels depending on the amount of toxin consumed. Victims experienced limb coldness, then intense burning pain followed by discolouration and the blackening of frank gangrene; ulcers might form and introduce infection. If internal organs escaped and the victim survived, a line of demarcation formed between normal and gangrenous tissues, leading to eventual spontaneous separation of the affected digits or limbs. In severe epidemics, whole limbs might separate spontaneously without blood loss and with stump healing; for some unfortunate victims all four limbs were lost.

Fig. 2.3. St. Anthony, a patron saint of ergotism, with his faithful swine and a victim, who has lost a foot, on a primitive peg-leg with a crutch and a flaming hand (St. Anthony's fire) representing the intense pain of developing ergot gangrene of the arm. (From Gersdorff H, *Feldtbuch der Wundartzney*, Strassburg: Schott, 1517.[50])

The first reported epidemic is noted in the Annals of the Convent at Xanten on the Rhine, dated about A.D. 857[20]; further epidemics were recorded sporadically during the Middle Ages, the fungus arriving in toxic proportions during poor harvests in wet summers. The Parisian basin was badly affected in the 10th and 11th centuries, later spreading into Aquitaine, Spain and Flanders, touching Germany and England to reach a peak in Western Europe in the 12th century.[21] However, epidemics continued and in 1517 Gersdorff illustrated (see Fig. 2.3) the effects of ergot with St. Anthony, alongside a victim wearing a prosthesis following dismemberment of his lower leg and with a flaming hand to convey the agonising pre-gangrenous symptoms of the disease. At about the same time, Hieronymous Bosch (c. 1455–1516) depicted a variety of amputees with prostheses and crutches, including many young people who were considered victims of ergot poisoning (see Figs. 2.4 and 12.1). One unfortunate apprentice whose hands and legs rotted off is said to have been given to idleness, stealing, lying, swearing, drunkeness and uncleaness with women, suggesting these were the causes of his diseased limbs, ending in his death in 1677; however, ergot was a possible factor.[22] A remarkable account of a previously healthy English family, attacked in 1761, is recorded by Woolaston when an infant died and the other seven members sustained gangrene, precipitating the loss of nine lower limbs, highly indicative of ergotism.[23]

Garrison believed some early accounts of ergotism were confused not only with erysipelas but bubonic plague and gangrene due to other causes.[20] And Cameron, translating the Anglo-Saxon of Bald's *Leechbook*, recorded:

"About blackened and deadened body: The disease comes most often from erysipelas; after the inflammation of the disease has gone away, the body sometimes becomes blackened."[24]

Before the precise discoveries of modern medicine and especially bacteriology, a number of other factors added to the confusion. Until the late 19th century, erysipelas was viewed as an inflammation of the skin, sometimes triggered by injury, sometimes after a surgical operation, sometimes without apparent cause, generating redness, swelling, great pain and a sensation of burning heat, affecting areas of skin from the scalp to the feet; inflammation might involve a whole limb and when associated with compound fracture caused widespread tissue necrosis, precipitating surgical amputation.[25] Lockwood commented in 1895:

"One of the most characteristic local subjective symptoms of erysipelas is the intense irritation, smarting, or burning pain which accompanies it. To this last may be owing its popular name of 'St. Anthony's fire'."[26]

Shortly after, erysipelas was shown to be a bacterial infection with streptococci, and by coincidence the disease declined both in severity and case numbers, perhaps because the organism became less virulent. In 1960, a popular textbook stated:

"This condition, which is as old as medical history, appears to have changed its character during the present century. A hundred years ago it was a dreadful condition, but today it is unusual to see a patient with a severe attack although in infancy and old age it can still occasionally endanger life."[27]

Other bacterial conditions not fully elucidated until the late 19th century include bubonic plague with limb changes, cholera and gastroenteritis with vascular collapse, complicated scarlet fever and wound infections triggering gas gangrene. Frequently, associated gangrene was not differentiated on clinical grounds from other forms of rapidly advancing gangrene, although death for other reasons often supervened before amputation was an issue. Many gangrenous changes precipitated by bacterial infection including erysipelas, as well as ergot toxicity, were doubtless aggravated by poor nutrition, vitamin deficiency, especially scurvy, chronic ill health and poor social conditions.

Gas Gangrene and Related Sepsis

Bacterial infections, including gas gangrene, are considered natural causes capable of precipitating amputation, although it is pertinent to recall these infections usually gain hold on tissues previously damaged, that is, by accidental or deliberate trauma, factors reviewed in more detail in subsequent chapters.

Before Welch and Nuttall discovered the anaerobic bacterial origin of gas gangrene, identifying clostridial infection in 1892,[28] it is believed this condition was not separated clinically from similar rapidly spreading tissue infections much before the mid-19th century.[29] Peltier points out that, about this time, Malgaine investigated the gas produced in the muscles of certain wounds and identified inflammable carburetted hydrogen (methane), now known to be a product of severe gas gangrene.[30] In 1895, Cheyne called this condition "acute traumatic gangrene," adding that anaerobic organisms had only been found experimentally in animals and had yet to be isolated from human tissues, explaining:

"... no doubt on account of the great rarity of this trouble at the present time ..." and, *"Among their products are large quantities of gases, chiefly hydrogen and carburetted hydrogen, and the great characteristic of this form of gangrene is the very rapid development of gas in the tissues."*[31]

The rarity suggested by Cheyne is supported in 1897 by a military surgeon, Stevenson, whose book *Wounds in War* omits any mention of gas formation complicating wounds, perhaps reflecting battle experience in terrain (Africa) uncontaminated by anaerobic bacteria.[32] On the other hand, Ricard, writing in 1896, claimed that gaseous septicaemia (a term he preferred to gas gangrene) was identified by Hippocrates, Pare and Fabry (Hildanus).[33] Following the research of Malgaigne, Ricard noted several 19th-century authors mentioning gaseous gangrene, including Salleron, who described 65 cases during the Crimean War.[34] However, these examples, mainly unconfirmed bacteriologically, pale into significance compared to the thousands of gunshot wounds contaminated with gas gangrene (see Fig. 2.2b) and other septic organisms seen during World War I. Hull wrote:

"In the year 1914 gas gangrene, a disease hitherto unexpected and unprepared for, added an additional terror to military surgery. At the time of the outbreak of hostilities this disease was entirley unknown to all but a few of the surgeons engaged in war."[35]

This dangerous disease was associated with fighting in the trenches of Flanders or similar agricultural land where the soil was rich in farm animal manure contaminated with the spores and bacteria of clostridial anaerobes which readily infected deep penetrating wounds, especially muscle lacerated by shell fragments; bullet wounds were less likely to be infected. Infection was severe in bulky muscles and proved particularly lethal for compound fractures of the thigh. Minor cases which reached surgical care swiftly were excised of gangrenous muscle or amputated, in either case were left open to drain, and might recover, unlike immobilised soldiers sustaining femoral fractures who needed evacuation by stretcher, often delayed, from hostile no-mans-land.[36] When the victim was not already dead from ascending infection, amputation was the only resource likely to save life, provided gas formation and gangrene were below the groin and axilla; for the most part, arm injuries could be evacuated much more rapidly with improved chances of effective surgery. As an official military memorandum for medical officers stated in July 1915:

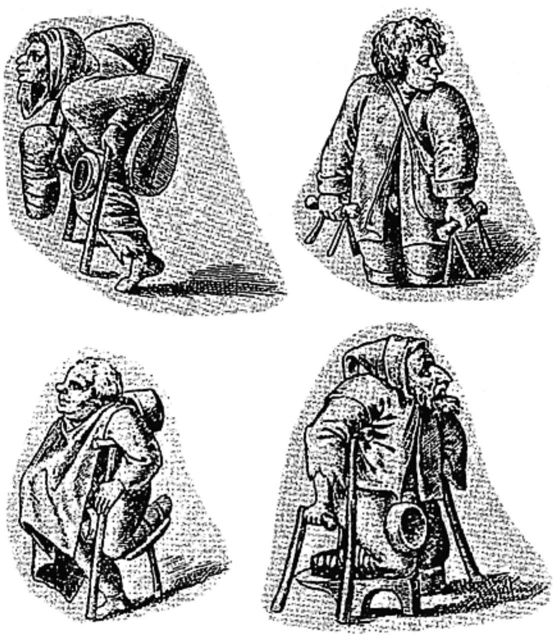

FIG. 2.4. Amputees using crutches and primitive prostheses; two at least have bandages suggesting unhealed stumps. Selected from the engraving *A Procession of Cripples* by H. Bosch, 15th century. (From Peltier L, *Orthopedics*, San francisco: Norman Publishing, 1993 frontispiece, with permission of Norman Publishing.[61])

"The most important complication of wounds in this war is their infection by anaerobic organisms derived from dung. . . . The conditions which favour the development of gangrene may be summarised thus: (a) The retention of extravasated blood and of wound secretions, (b) interference with the circulation, (c) the presence of large masses of partially devitalized or dead tissues, (d) extensive fracture and comminution of the long bones, (e) the soaking with blood of dressings or clothes which are left in contact with the wound for a long time."[37]

These were exactly the problems faced by totally disabled men with femoral fractures marooned in no-mans-land, exposed to extreme cold or excessive heat, or with wounds drenched with rain or covered in flies and, in any event, contaminated with mud or dust. Some survived for days before stretcher bearers were able to reach them, to then endure long hand-carries through difficult terrain, followed by horse or motorised transport on rough roads before final surgical assessment at a Casualty Clearing Station, some 25 miles behind the front.[38] Commenting on open femoral fractures in 1917, the military surgeons Hurley and Weedon saw survivors between 36 hours and 7 days (average, 3 to 4 days) after injury and of these 38% died of sepsis, mainly gas gangrene, within 48 hours of admission irrespective of surgery.[39] Eventually, improved immobilisation with a Thomas splint and swifter evacuation methods presented gas gangrene cases earlier, in better condition for conservative measures or life-saving amputation. Later wars never experienced gas gangrene on such a scale for reasons of rapid evacuation, especially by helicopter, and the use of effective antibiotics, gas gangrene serum and blood transfusion.

Latterly, children with meningitis or other severe infections may develop a septicaemia severe enough to produce gangrene with the loss of up to all four distal limbs.

Diabetes Mellitus and Sensory Neuropathies

The passing of excess urine or polyuria, associated with great thirst, is a condition noted by Aretaeus in the 2nd century A.D. but, according to Adams, neither he or any other ancient writer appears to have known of an association with sweetness of the urine[40]; this is first attributed to Willis, who wrote:

"A Nobleman in the vigour of his Age, became very prone to an excess of Pissing . . . in the space of twenty four hours, he voided near a Gallon and a half of clear water, and wonderfully sweet, as though Honey were mixt in it." And *". . . we need not wonder that the urine of those labouring with the Diabetes is not salt. But why that it is wonderfully sweet like Sugar or hony."*[41]

Sadly, the remedy for diabetics, insulin, the internal secretion of the pancreas, was not isolated before 1922 by Banting and Best.[42] Its association with gangrene was probably determined in the 19th century. Lyot wrote in 1896:

"We find a few sparse observations of diabetics with gangrene before 1845, at which time, apparently, Carmichael was the first to establish a relationship between glycosuria and gangrene."[43]

Treves, noting the hazards of operating on diabetics in 1895, observed:

"Diabetic gangrene of a limb is determined by many causes, among which especial attention must be given to inflammatory conditions, atheroma of vessels and peripheral neuritis. There was a time when amputation for diabetic gangrene was considered to be absolutely

hopeless. Of recent years, however, this operation has been carried out with success."[44]

In any event, sugar diabetes is believed to be an ancient ailment and a source of gangrenous complications caused, in younger patients, by loss of protective sensation in the peripheral nerves, especially of the feet, and in those surviving to middle life, to arteriosclerotic changes, or to combinations of the two pathologies. The sensory loss, especially absent pain sensibility, exposes the toes and feet to damage undetected by the victim unless they, or others, observe skin changes and ulceration visually; the broken skin may also become infected, aggravating control of the diabetic state and accelerating local tissue damage.

Modern management with controlled sugar levels, suitable footwear, the use of mirrors by patients to inspect the soles of their feet regularly, and antibiotics may prevent or resolve early tissue damage or limit surgery to toe amputations. Before insulin therapy and even since, severe diabetics with arterial pathology developed irreversible gangrene of the lower limb requiring below-knee amputation, often symmetrically bilateral. Latterly, antibiotics and arterial reconstruction may save some limbs whilst above-knee amputation is less frequently indicated. Outlining these measures, Eastcott concluded:

". . . control of infection may be decisive. Diabetic gangrene is a complex condition in which major occlusive arterial disease, lesions in small vessels, and sensory neuropathy may each play an important part."[45]

Other forms of peripheral neuritis which involve loss of pain sensibility, skin breakdown, infection and bone necrosis include hereditary sensory neuropathy with loss of toes and feet, and leprosy, which may also involve the hands.

Nutritional and Vitamin Deficiency

Tropical populations subsisting on diets deficient in protein and vitamins are prone to leg ulceration, if the limb is injured and infected with bacteria, especially *Bacillus fusiformis*. In the 18th century, these conditions sometimes affected sailors deprived of a balanced diet and most notably prisoners of war in Japanese camps of the tropical zone during the Second World War. Without a suitable dietary intake, skin injuries of the lower limbs failed to heal and becoming infected, progressed to involve bone and threaten life, often precipitating amputation in rudimentary operating conditions.[46]

Massive Benign and Malignant Tumours

Before modern operative surgery, certain benign bony tumours proved so massive, painful and crippling that painful and slow radical amputation was acceptable to patients (Fig. 2.5).[47] Today,

Fig. 2.5. Massive cartilaginous tumour arising from the lower femur, said to have followed a fracture; the limb was amputated although no outcome is stated. (Drawn by Charles Bell in his *Surgical Observations* of 1816,[47] plate IX.)

benign tumours would be excised before reaching intolerable proportions. Malignant tumours of the limbs, some complicating chronic osteomyelitis, perhaps associated originally with varicose ulceration but more especially bone sarcomata, were usually treated by amputation until management changed dramatically during the late 20th century. Treatment by careful local excision, replacement of excised bone and joints with implanted prostheses, and chemotherapy not only avoids amputation but has superior survival rates.[48]

Summary

Natural causes of limb loss precede elective surgical amputation by many millennia and include congenital absence, arterial disease, frostbite, ergot and other toxins, wound infections, diabetes mellitus, dietary deficiencies and tumours. Most of these causes persist today, although reconstructive measures often avoid amputation. It is postulated that societies' acceptance of naturally caused amputees was necessary before elective surgical amputation was approved.

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3
Accidental Causes for Amputation: Auto-Amputation

"Life without injury can hardly be imagined."
Calvin Wells, 1964[1]

"Plus il y a de gens qui profitent de la plage, plus il y a de risques de finir amputé ou digeré par un requin." ("The more that people enjoy the beach, the greater their risk of being amputated or devoured by a shark")
Anonymous, 2004[2]

It is certain early mankind was liable to accidental injuries by a variety of causes, often precipitated in circumstances not unfamiliar to modern man. Tripping when running, falling from heights, being crushed by falling trees or rocks and being savaged by wild animals, produced injuries which we recognise today. It can also be surmised the risks to life and limb for those living a nomadic existence in temporary shelters were especially menacing, not much lessened by more-regulated existence in caves or permanent dwellings; in any event, major accidental injury was probably commoner than for current urban societies. In particular, early mankind's constant hunt for food exposed tribal members to dangerous wild animals and to the hazards of fishing, especially in the open sea and in fast-flowing rivers.

At a later stage, the establishment of mining, the building of major structures, for example, the Pyramids and Stonehenge, the construction of furnaces, water-mills and powered machinery added their toll to the causes of accidental injury. High-velocity injuries resulting from horseback riding and chariot racing began a trend which has recently accelerated due to the greater power of train, bicycle, motorcycle, car and plane accidents which, at the same time, promote a greater likelihood of death. However, such high-velocity accidents concern but a small section of the population for, in reality, most of us travel without coming to grief whereas, by contrast, to satisfy a desperate need for food before the cultivation of crops, it is probable primitive hunting was much more hazardous to a higher proportion of the population.

Unfortunately, few accurate case records of accidents resulting in amputation are known before the 17th century when specific detailed observations concerning victims and their treatment began to be published.[3] Today, only a few victims suffer immediate limb amputation as a consequence of an accident, and even these are "tidied" surgically. In this chapter, we also discuss auto-amputation, that is, procedures undertaken in extremis by victims on their own limbs, usually trapped as a consequence of an accident, remote from immediate help and trained surgical assistance. As will be evident, the majority of elective amputations for trauma are sequelae to complications of open fractures, especially when a limb's blood supply is also compromised or when wounds are overwhelmed by spreading infection.

Complete or Near-Complete Transections

Apart from obvious complete severance of a limb, it is proposed to include injuries where the transection is incomplete yet sufficiently destructive that surgical completion of the severance appears mandatory, to both patient and surgeon. Many crush injuries without an open wound may require immediate amputation, according to surgical opinion, yet this advice is resisted by the patient and relatives who ignore, or fail to understand, the significance of an interrupted blood supply until gangrene develops.

Traumatic amputations of the fingers and toes were probable early examples of complete transection, due to the use of stone hand axes and other tools, crushing by rocks or building stone and accidents in mines; a shoeless society was particularly vulnerable to injuries of the feet. Eventually, metal tools and, ultimately, industrialisation with mechanically motivated machinery became major sources of hand injuries. Most accident services are familiar with wood machinists who sustain circular saw amputations; indeed the writer recalls treating a carpenter who had a series of saw injuries over many years and had to retire having, on this occasion, lost his last remaining finger, although he still retained his thumbs; this occurred before reattachment of digits was practised.

Traumatic amputations through the shin, forearm, thigh and upper arm demand severe and well-localised linear violence, for example, by powerful animal bites, by railway train wheels, occasionally by the high impact of a motorcycle collision, and at sea by hawsers snapping under tension or uncoiling rapidly to entrap limbs. In 1678, Yonge described a sailor sustaining a virtual complete amputation in this way:

"John Boddam . . . standing in the coyle of an Halcer (hawser), *by which the Ship was fastened: he was drawn forward, and griped therin: so that both legs were shattered in pieces, . . . one of them hung by a tendon or two above the Ancle. In fine, an Amputation was inevitable."*[4]

Similar leg injuries were noted by Woodall in 1639[5] and by Boyle working in Sierra Leone, West Africa, in 1831 who recorded the following accident when an emergency anchor was lowered to prevent a ship running aground:

"Whilst this anchor was being dropped from the bow of the boat, one of the men unguardedly allowed his leg to become entangled in a coil of running cable, and in a moment the limb was literally torn to pieces, the only continuity remaining being one or two of the extensor tendons in a greatly lacerated and injured state. The poor fellow was rescued from the additional peril of being dragged overboard by the cable."[6]

The victim was then transported 18 miles for an immediate formal below-knee amputation from which he eventually recovered. Arms were not immune to this mechanism of injury as De La Motte recounted, in 1711, when a ship's captain trapped his thumb in a cable round a capstan which pulled his arm in to above the elbow; De La Motte saw him 4 days after injury when the arm was gangrenous and undertook amputation close to the shoulder, with a good result.[7] To bring this relatively rare but dramatic accident nearer our own time, the recent obituary of a former merchant marine officer recorded that in 1944 he sustained compound fractures of both legs when a rope, mooring a 20,000-ton vessel, parted and the recoil knocked him off his feet. He was in hospital for 3 years and, despite modern treatment with antibiotics and skin- and bone grafting, one leg proved so disabled that eventually it was amputated.[8]

Arms and legs are also vulnerable to the bites of sharks and crocodiles. Boyle recorded four victims of shark bites involving young sailors swimming or simply dangling their feet in the Sierra Leone River between 1827 and 1830. Of the three who came to amputation, the following patient is remarkable for surviving extensive and severe injuries. Boyle wrote:

"On the 28th September, 1828, I was suddenly called to visit Thomas Corrigle, an apprentice on board the Britannia merchant-ship, (about 17 years old), who, it was stated was dreadfully mutilated by a shark whilst bathing up the river Sierra Leone, where the vessel was employed loading with timber.

On proceeding to examine the injured parts, I found that the left fore-arm had been removed within about two and a half inches of the elbow joint; the joint having been deeply penetrated by the animal's teeth, and the head of the ulna broken off from the body of the bone remaining attached.

The metacarpal bones of the right hand were denuded and fractured, whilst the ligamentous attachments of the wrist superiorly were all cut through, and both radius and ulna fractured at their lower extremities. There was also a deep ragged wound in the palm of the hand, exposing the flexor tendons."[9]

In addition, there were wounds of the right groin, the scrotum and the right thigh which Boyle described as *"the most appalling spectacle I had ever seen before in the form of a wound"* extending from the hip joint to within 4 inches of the knee; the neck of the femur was marked by the animal's teeth. It was clear the left forearm transection required formal amputation above the elbow and the right forearm was amputated above the wrist; the question of amputating the right leg at the hip was debated but considered too hazardous, and the wound was cleaned and sutured. Boyle concluded: *"All this the heroic boy bore without a murmur . . ."* After 4 days of slight fever, he steadily recovered, the amputation stumps healing gradually, and on December 25 he walked without a limp and took passage for England.[10] Sharks continue to be an agent of accidental amputation as well as death, and indeed a growing factor, as the quotation heading this chapter suggests (Fig. 3.1). A recent victim near Brisbane, Australia, aged 21 years, had both upper limbs bitten off and despite being airlifted to hospital died of blood loss.[11]

Fig. 3.1. Photograph of leg subjected to shark attack with traumatic amputation above the knee. (From *Journal Choc*, No. 5, 2004,[2] with permission.)

Nevertheless, with modern management, survival after severe accidental amputations has improved. In 1971 Johansson and Olerud described the case of a boy aged 10 years sitting on a combine harvester who lost the whole of his right leg and hemipelvis when his foot was caught and the frame of the machine acted as a "blade." Strenuous resuscitation enabled him to survive and eventually walk with a prosthesis.[12]

Natural disasters such as earthquakes, volcanic eruptions, severe storms and tidal waves were doubtless ancient sources of major limb transections and, as contemporary reports of earthquake and tsunami disasters confirm, continue to be so. During the last century, we can add the innocent civilian amputee victims of warfare, aerial bombardment, minefields and of suicide terrorists. Since its introduction, the heavily laden wagon wheel, especially that of railway traffic, has been a potent cause of limb transection or near-transection. Lucas of Leeds communicated the following observation to Alanson:

"November 27th, 1780, Esther Pearson, aged seventy-three, was admitted my patient at the Infirmary, for an accident she had just received; which had broken both legs. A heavy coal-waggon had run over them, and shattered the bones of both in such a manner, that one required immediate amputation; the haemorrhage being difficult to restrain . . . The amputation was made above the knee . . . The other leg was so shattered, that it was thought necessary to remove three or four inches of the tibia."

The amputation healed completely in about 6 weeks but the outcome of the other leg is unrecorded.[13] Another victim reported by Alanson sustained severe injuries to one leg crushed by two wheels of a coal-waggon; in addition to compound fractures and muscle damage, bleeding was profuse and immediate below-knee amputation was performed with, ultimately, a good result.[14] In the mid-19th century, Erichsen remarked that primary amputation is commonly required in civil life for crushing limb injuries due to accidents in mines, on railways and by waggons.[15] Spence detailed a number of such accidents in 1882 including the following:

"Alexander R., whilst in a state of intoxication, fell under the wheels of a railway carriage, and sustained a compound comminuted fracture of both legs in the one communicating with the knee joint, whilst the other limb was almost completely cut off below the knee. Amputation of both limbs performed at lower third of femur. Patient never rallied, and died on the third day."[16]

Similar injuries on modern underground and overground railway tracks are noted in national media reports from time to time.

The arm was not immune to accidental amputation and was an especial hazard for those working with moving unguarded machinery. Spence noted several in his *Clinical Cases and Commentaries* of 1882, of which the following is an example:

"On the morning of the 9th December 1847, James Watt, millwright at a large paper-mill in the vicinity of Edinburgh, when inspecting the machinery, perceived that a part of it was loose. While engaged in fastening the loose part, the sleeve of his jacket was caught, and the right arm dragged between two wheels and rapidly crushed . . . The injured arm presented a frightful appearance; the limb was completely detached from about three inches above the elbow, and the humerus was again broken through obliquely, immediately below the insertion of the deltoid, leaving the attachment of that muscle entire; but on the inner side the fracture had splintered the bone to within an inch of the joint; the middle part of the humerus, together with the soft parts, were hanging in shreds. On the right side of the chest the integuments had been entirely removed to within two inches of the sternum; . . . Although, from the nature of the injury, and the state of the patient, I had almost no hopes of his recovery, I thought it right to give him the only chance—viz, by amputation at the shoulder joint."[17]

Operation was performed under chloroform, the full effect of anaesthesia being obtained in 3 minutes. This point is significant as Simpson had introduced chloroform for anaesthesia only a month earlier in November 1847[18]; indeed, Spence observed that this was his first great operation under chloroform. After a few days illness, the patient steadily improved, his wound becoming sound after about 2 months.

Compound Fractures and Severe Soft-Tissue Wounds

Any accidental compound limb fracture may interrupt the distal arterial circulation and almost certainly contaminate the wound. Even without a comminuted fracture, the blood supply can be compromised, and the injured segment becomes pale or blue and cold and, in the absence of reconstruction of the disrupted vessels, gangrenous changes can be anticipated. Almost until the mid-20th century when arterial repair became commonly available, such limbs were subjected to amputation, either immediately or later, depending on the assessment of the surgeon and reaction of the patient. Sometimes the decision to operate was made too late to prevent extension of the gangrene, with or without complicating infection. Despite a good blood supply, crushed and contaminated tissue damage may produce spreading infection which, if not controlled, becomes an indication for amputation. Further, if infection stabilises to reach a chronic state, the patient may take the lead to be rid of a useless and foul-smelling appendage, as a 9-year-old boy demanded in the 17th century. His surgeon Hugh Ryder wrote:

"A Lawyer's Son in Fetter-lane, . . . having eleven Fistulaes in his Leg, and Thigh: for about a Twelve-month, had been under the hands of several Surgeons; who at length despairing of his cure, let him off. The Boy calling to mind, that some four years before, I had cured him of two Ulcers in his Leg (for this accident was since, and hapned (sic) by a Contusion from a Cart-wheel, hurting his thigh and Leg, from whence afterwards Apostemations and Fistulaes were produced) desired his Father to send to me, . . . I accordingly went; but found him so discarned, that he was almost a Skeleton, having for twelve weeks been detained by a Diarrhaea. From his Ulcers, and Fistulaes flowed a filthy matter, stinking beyond all comparison, his Heel stuck to his Buttock, and his Knee disjoynted; for the head of the Tibia met not with the Os Femoris (which overhung it) by above an Inch, the Ligaments being all eaten asunder, by the matter there contained. I told his Father, I had considered, the circumstances he lay under, were so severe, that I thought, there was no likelyhood of his recovery, nor possibility of Cure; to which the Boy very heartily replied, he knew he should be well, if I would cut off his Thigh; and if I would lend him a Knife, he would cut it off himself;"[19]

Persuaded by the boy, Ryder's high thigh amputation healed well and the boy recovered both health and strength. A similar history is noted by Spence in 1874, concerning a girl of 9 years with her left calf in contact with the thigh due to severe knee contracture, associated with chronic infection of the femur and ulceration, possibly following a fracture. Her hamstrings were divided and bony sequestrae removed but she did not improve as the infection extended towards the hip. Under anaesthesia, hip disarticulation was performed and she did well, returning home on crutches[20] (Fig. 3.2).

Much of the debate on whether and when to amputate was fuelled by military and naval surgeons with extensive experience of gunshot trauma who, in general, argued for early amputation. However, we must remember missile injuries were particularly associated with embedded foreign material, a focus of deep infection, which altered the whole basis of management (see Chapter 5). Nevertheless, as a result of this influence (before antiseptic surgical techniques were available), battlefield practice promoted amputation which, until the later 18th century, became almost a routine recommendation for any compound fracture, of any source, even before gangrene or infection was observed. If the fractures involved a major joint then this alone was an indication for immediate amputation because, before antiseptic surgery, it was believed persistent disabling joint infection would follow.

FIG. 3.2. Disarticulation at the hip for protracted bone infection of the femur and fibula in girl aged 9 years. She recovered using crutches, with general health restored. (From Spence J. *Lectures on Surgery*, vol 2. Edinburgh: Black, 1875: fig. 92.[50])

Interestingly, at least three prominent surgical authors who sustained compound fractures of the shin, two at least caused by their horses, managed to avoid amputation when the climate of opinion was otherwise: Pott in the 18th century, who was thrown from his horse,[21] Wiseman in the 17th century,[22] and Paré in the 16th century, who was kicked by his horse, and whose detailed record serves to illustrate the complications of such injuries and how amputation was avoided, despite significant illness. Paré (Fig. 3.3) wrote:

"*. . . intending to pass over the Sein* (Seine) *. . . I endeavoured to make my horse take boat, and therefore switched him over the buttocks: The Jade madded herewith, so struck at me with his heels that he brake both the bones of my left leg, some four fingers bredth above my ankle. Then I, fearing some worse mischief, and lest the Jade should double his blow, flew back; and as I fled back, the broken bones flew in sunder; and breaking through the flesh, stocking and boot, shewed themselves, whereby I felt as much pain as it is credible a man was able to endure; . . .*"

Having crossed the river in absolute agony he pleaded treatment from a fellow surgeon, Richard Hubert:

"*. . . that he would stretch my foot straight out, and if the wound was not sufficiently wide, that he would enlarge it with his Incision-knife, that so he might the more easily set the broken bones in their due place; that he would with his fingers (whose judgement is far more certain than the best made instruments) search, whether the splinters which were in the wound were quite severed from the bone, and therefore to be taken forth; . . .*"

Paré submitted to this management and, after the fractures were reduced and splinted, he was taken home and bled 6 ounces from an arm. He continued to control his treatment and decided to eat little, only 12 stewed prunes, 6 morsels of bread and sugared water daily! Becoming constipated, he took soap suppositories. On the 11th day he developed a fever and an abscess in the wound causing muscle spasms and loosening of the splints, with displacement of the fracture and increased pain. After 7 days fever and discharge of

FIG. 3.3. Portrait of Ambroise Paré, aged 45 years. Frontispiece in his *Anatomie Universelle,* du Corps Humain, Paris: Le Royer, 1561.[51]

infected matter, he suddenly improved. He ordered various wound applications and took a diet rich in the "tendinous and gristly parts of beasts" which he considered helped bone union. He concluded:

"Simple fractures of the leg are usually knit in fifty days, but through the occasion of the Wound . . . and other accidents which befel me, it was three whole Moneths before the fragments were perfectly knit, and it was also another Moneth before I could go upon my Leg without the help of a Crutch."[23]

It is probable many surgeons, including Paré, would have suggested early amputation in such circumstances, if treating a patient with similar pathology. Another form of equine injury which produced an amputation is recorded by Wiseman in 1676:

"A Gentleman aged 54 years, of an ill Habit of body, passing in the Street by a Coach, one of the Horses snapt off the end of his Finger with the Glove."[24]

After a period of infection, the stump healed with difficulty. It is probable such a stump proved tender for a long period and easily broke down after minor trauma. A more-extensive injury to a youth of 17 years is recorded by Spence in 1882:

"While leading a horse by the bridle the animal seized the forearm with his teeth, and inflicted a compound comminuted fracture. He was under treatment for ten days previous to being sent to hospital. Conservative measures were tried, and a fortnight after admission several pieces of bone were removed. Under the prolonged discharge from the wound, and from the ulcers which formed over the sharp prominences of the condyles, his general health became impaired. The

inflammatory action extended towards the wrist, and in the fourth week suppuration ocurred within the joint. Under such circumstances there could be no hesitation in removing the limb. The operation was performed below the middle of the arm by a long external and short internal flap formed by transfixion. Recovered."[25]

In general, falls from a height sufficient to compromise the limbs severely are more likely to produce death from a head injury. However, Spence reported the following about 1882:

"P.L. fell down a height of thirty-five feet, and was brought to hospital suffering from a compound comminuted fracture of the femur, communicating with the knee joint, and a similar fracture of both leg bones. Amputation at middle of thigh. Cured."[26]

The fact that the knee joint was opened and fractured was a convincing indication for amputation before antibiotics were available. Wangensteen and Wangensteen complained:

"One looks in vain in textbooks of surgery or monographs on fractures in the late eighteenth to mid-nineteenth century for factual accounts of the outcome of treatment of open fracture. It is as though the great surgeons of that period were in collusion not to expose their tragic results."[27]

However, in 1802, Crowther reported the healing of 28 consecutive compound fractures without amputation when he applied wood tar to the wounds (see Chapter 7).[28] By 1867, Lister offered detailed histories of open fractures as pivotal cases to prove his antiseptic system and, after 1871, Spence published many similar observations. Antisepsis and asepsis greatly improved results, only diminished by gunshot compounding associated with embedded foreign bodies and, in the 20th century, injudicious attempts to stabilise fractures with metal implants before antibiotics were available.

Puncture and Dissection Wounds

Occasionally minor puncture wounds, especially of the hand, produced serious infection, abscesses, general septicaemia or death, rarely avoided by amputation. Anatomy students in the dissection room were particularly vulnerable and several well-known surgeons were also victims. This problem was highlighted by a report on the deaths of 33 Parisian medical students between 1826 and 1846.[29] Practitioners were infected particularly after performing postmortem examinations or operations, before gloves were used, from pus collections in the pelvis or abdominal cavity, These cases included Hewson, an anatomist who died 13 days after an infected dissection injury in 1774,[30] Paget, a surgical pathologist, who was extremely ill after a postmortem examination and developed multiple abscesses of the axilla and chest wall which caused him to retire from active surgery in 1871,[31] and Davies, a chest surgeon, who cut his right hand during an operation for an empyema in 1916, to develop infection and septicaemia for which initial advice to amputate was cancelled, leaving him with a crippled arm, also leading to retirement from surgery.[32] Sometimes amputation was undertaken to prevent infective spread via the lymphatics towards the trunk but usually too late to save life. Nurses were also exposed to this threat as Wheeler indicated when writing about his hospital stay in Spain during 1814:

"One of those men I knew, he was a Serjeant of the 82nd Regiment, his wife was nurse to the ward, she pricked her finger with a pin left in one of the bandages, caught the infection, her finger was first amputated, then her hand, the sluff appeared again in the stump, she refused to undergo another operation, the consequence was she soon died."[33]

Venomous Bites and Stings

Although apocryphal tales suggest amputation was a remedy for poisonous bites and stings of the extremities, reports of such action are rare in medical literature. In 1000 A.D., Albucasis recommended amputation of a finger, a hand or even a whole forearm, and as high as the knee for the leg, depending on the site of the sting, for bites of marine scorpions, vipers or venomous spiders; he offered no case observations.[34] However, De La Motte recorded that a woman's middle finger, bitten by a viper, developed massive swelling as far as the elbow over the next 4 days, accompanied by vomiting; only then did she seek help and an above-elbow amputation was performed. Unfortunately the stump failed to heal and became infected, leading to death a month later.[35] In

Medical Zoology and Mineralogy, Stephenson stated the only means of saving the lives of our soldiers who were stung by scorpions in Egypt was amputation, but he provided no case histories.[36] In general, before specific vaccines were available, local treatment was best and included digging out or sucking out the venom using a venous tourniquet. Unless the poison was overwhelming, recovery after an illness was not uncommon and, it is concluded, amputation was an added hazard for the patient with uncertain effects.

Fig. 3.4. Engraving of Samuel Wood, a miller, whose arm was caught by a rope attached to the moving cogs of a mill, suffering an avulsion of the arm and attached scapula, in 1737. He survived, having bled very little, as it was observed the stretched arteries clamped down immediately; the wound was simply dressed and healed over gradually. (From Cheselden W. *The Anatomy of the Human Body*. London: Bowyer, 1741:320.[37])

Traumatic Avulsion at the Shoulder and Hip

An example of forequarter separation at the shoulder (Fig. 3.4) was described by Cheselden in 1741 as follows:

"Samuel Wood a miller, whose arm, with the scapula was torn off from his body, by a rope winding round it, the other end being fasten'd to the coggs of a mill. This happen'd in the year 1737. The vessels being thus stretch'd bled very little, the arteries and nerves were drawn out of the arm; the surgeon who was first called plac'd them within the wound, and dressed it superficially. The next day he was put under Mr Ferne's care, at St Thomas's hospital, but he did not remove the dressings for some days: The patient had no severe symptoms, and the wound was cur'd by superficial dressings only, the natural skin being left almost sufficient to cover it;"[37]

This type of injury has since been associated with fast-moving belts of powered machinery, the belt drawing in the arm until blocked by the trunk and, it is assumed, reflex resistance by the victim to produce separation of the shoulder girdle from the trunk with tearing of attached soft tissues, predominately muscles, vessels and nerves. As Cheselden noted the arteries are stretched and bleed very little, presumably because they shut down immediately after tearing due to retraction of the elastic inner and middle coats of the vessels within a sheath of the tougher outer fibrous layer. The writer has seen a very similar shoulder avulsion involving a coal miner whose arm was caught in a moving belt; despite this massive injury he was able to walk some distance to the cage bottom before evacuation and, on reception in the accident department, was barely shocked. Exploration demonstrated the torn vessels had sealed themselves, presumably at the moment of rupture, due to severe stretching of the elastic vessel walls with little blood loss. He made a good recovery as an amputee. This mechanism has been reported to cause bilateral avulsion at the shoulder with survival, an extremely major disability.[38]

By contrast, hindquarter avulsion is even more traumatic, based on the history of two victims described by McLean in 1962.[39] One was a 23-year-old mine labourer whose right ankle was entwined in the coil of a steel rope which was attached to a powerful winch. When the winch operated, he was thrown into the air and his right leg was completely avulsed. Admitted to hospital severely shocked, the whole of the right side of his pelvis and much musculature including the psoas and gluteal muscles were missing; the urethra was torn across (Fig. 3.5). After resuscitation and surgery he developed various complications but ultimately walked with sticks. The second patient sustained a similar injury but avulsion took place at the hip joint, removing only part of the acetabulum and the ischium; although the gluteal muscles were avulsed, there was no urethral injury. Wound contamination required a temporary colostomy; he left hospital with a lower limb prosthesis after 3 months.

In the 18th century several lesser "pull-offs" were described in the *Memoires de l'Academie de Chirurgie* of Paris, mainly fingers and toes, but included was an observation by Benemont concerning a boy of 9 or 10 years who, jumping on the back of a passing coach pulled by six horses, put a leg between the spokes of a wheel which pulled off the limb at the knee joint, exposing the lower femur. Holding on to the coach until it stopped, he was found to have lost little blood and, having seen his detached leg, he demanded the surgeon to reattach it before telling his mother about the accident! Lacking the technology to perform this modern miracle, the surgeon noted the vessels were stretched and sealed off, and after shortening the femur the wound healed uneventfully.[40] It is intriguing to reflect the concept of reattachment was raised by a small boy two centuries before its eventual execution.

FIG. 3.5. X-ray of pelvis and upper femora of mine worker, aged 23 years, whose right foot was caught in a wire coil attached to a powerful winch which suddenly avulsed his leg and most of the hemipelvis, and part of the left pubis, with a urethral tear. He survived and later formed a bladder calculus but was able to mobilise with crutches. (From McLean EM. Avulsion of the hindquarter. *J Bone Joint Surg* 1962:44B:384–385, with permission from *Journal of Bone and Joint Surgery*. © British Editorial Society of Bone & Joint Surgery.)

Auto-Amputation in Extremis

According to recent media reports, this dramatic form of self-amputation is not as rare as may be imagined, although such cases always achieve headline exposure usually as grotesque mutilations, rendered difficult to imagine by most readers, despite the victims intention of preserving their lives when trapped, alone and denied help. Here, it must be emphasised we are discussing auto-amputation performed by the mentally stable, precipitated generally by an accident or by acute pain, and not wilful self-amputation performed without indication or self-preservatory objective, by those of unsound mind, or to avoid military service, or to exhibit to the public for money.

One of the oldest recorded self-amputations, described by Herodotus in the 5th century B.C., concerns an escape from punitive imprisonment. The prisoner, Hegesistratus, chained by his lower leg, was able to free himself by amputating his foot, most probably assisted by gangrenous changes due to the chain; subsequently he had a wooden leg made, an early reference to an artificial limb.[41] In the year 1000 A.D., Albucasis recorded the history of a patient who allegedly performed auto-amputation twice:

"He had a blackening of the foot, with a burning like that of fire. The disease, to begin with, was in one toe, but it

went on to involve the whole foot. When the man saw the disease spreading and felt the violent pain and burning, he hastened of his own accord to amputate it at the joint, and he got better. After a long time had passed the very same kind of disease arose in the forefinger of his hand . . . and eventually the whole hand was involved in the disease. He urged me to cut off his hand, but I did not wish to do this, hoping I should be able to overcome the superfluity, and also fearing he would die at the amputation of his hand, for the man's strength was on the decline. When he despaired of me he went back to his own country, and I then heard he had gone and cut off his whole hand, and got well."[42]

Probably the pain, burning and blackening were due to ergot poisoning and the victim assisted what was often spontaneous separation at the gangrenous demarcation line. Albucasis preceded this history with clear recommendations to amputate for gangrene as high as the knee and elbow joints, yet failed to pursue this course for the patient's blackened hand.

Pain as a factor in precipitating auto-amputation is noted by Kidd in 1904 when a man with a painful corn in Swaziland amputated the offending toe through a joint with a chisel, and also by Crawford, medical officer to a Gurkha regiment, who treated a soldier who had amputated a finger for a painful whitlow using his Kukri sword.[43] We have noted the lumberjack trapped by his foot when splitting logs who severed his leg in an endeavour to survive (see Chapter 1). A similar entrapment involving a tree-feller in Tasmania, in 1887, is described by Hunt:

"In splitting a big tree, one of the wedges slipped and the great trunk closed over his hand, holding him fast. The poor lad's axe was just out of reach. He was found dead two months later and from the marks on his wrist he had tried to gnaw his hand off."[44]

As is well known, animals caught by their legs in traps may succeed in freeing themselves by auto-amputation. A happier account is recorded in the *Lancet* of 1865:

"A boy of twelve . . . in the neighbourhood of Grenoble . . . amused himself bird-nesting, and having discovered one in a trunk, he climbed the tree, put his hand on a branch and plunged his left hand into the hole which had a narrow aperture . . . He had some trouble in getting his hand in but succeeded at last, though then his wrist was caught tight by the neck of the hole. At that moment the branch broke, and he remained suspended by the hand a few inches from the ground. Thus he remained for some time in great agony, when at last he seized a bill-hook which hung by his side and severed the hand at the wrist. When freed he arrested the haemorrhage by pressure and walked back home. The boy was eventually received into Grenoble hospital, where by a little trimming the surgeon made a good stump."[45]

In 1951, a newspaper reported the experience of a deep-sea diver trapped 27 feet under water at Holyhead Docks, Anglesey:

"Two fingers were caught by a wire rope. Trapped and unable to control the air valve in his diving suit, he gave the signal to be hoisted up. One finger was torn off but he was still caught, so he cut off the other finger with his diving knife and was pulled to the surface . . . He had brought up all his gear and tools and walked unaided to the hospital."[46]

Two recent cases emphasise the determination of certain individuals to survive in extremely difficult circumstances. A television programme on the endurance of pain reported the experience of a fisherman working alone collecting lobsters in the Atlantic, off the coast of Maine. When his left hand became trapped in a winch, his boat lurched and he was suddenly thrown overboard, at which moment the left shoulder dislocated, leaving him suspended by the trapped hand. By a superhuman effort he managed to haul himself back to realise the boat was steaming out to sea with no help in view. Steeled by burning determination that he must survive to give his three daughters away in marriage, with a pocket knife, he amputated his arm through the elbow joint. Wet through, losing blood and in great pain from his dislocated shoulder, he guided the boat home with one hand and eventually returned to fishing as an amputee; we imagine he attended his daughters' weddings in due course.[47]

In 2003, a newspaper reported the saga of a climber in a canyon in the Rocky Mountains who was trapped when a dislodged rock weighing 360 kg settled on his hand, from which it was impossible to escape (Fig. 3.6). With his feet taking his weight, he remained upright on the rock face, with his rucksack, and reflected that, despite the pain in his crushed hand, if he was patient, someone would notice his car parked nearby and find assistance. However, at the end of 3 days no help had arrived and his small supply of food and water was

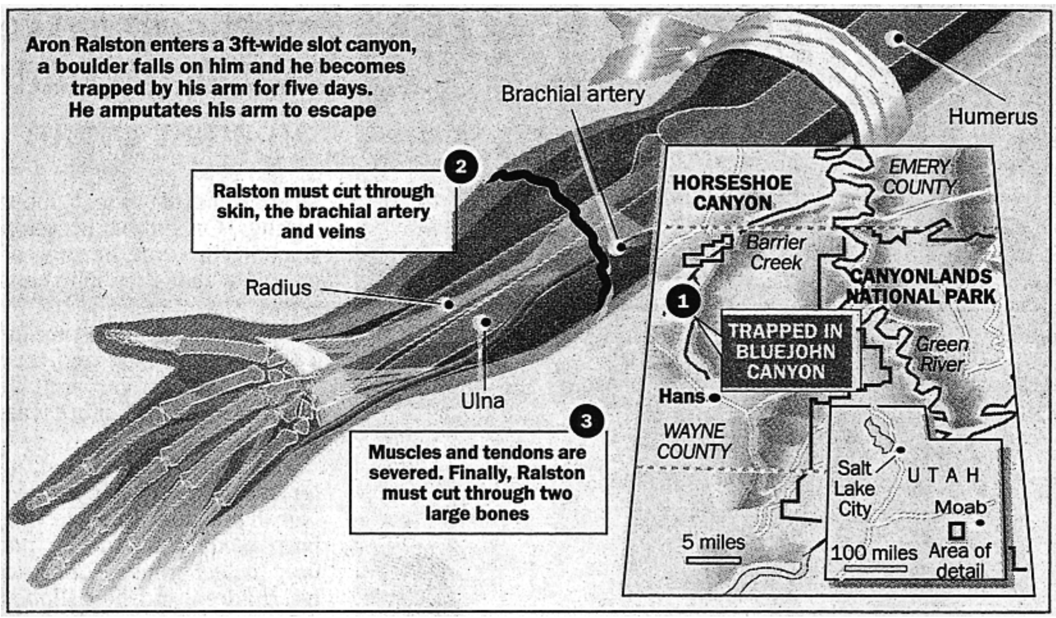

Fig. 3.6. Diagrammatic view of climber's arm trapped by a massive boulder in the remote Bluejohn Canyon, Utah, for 5 days, in 2003. Alone, having lost hope of rescue, he amputated his arm, walked to find help and was transferred for hospital care. (From Ref. 48. © NI Syndication.)

exhausted; on the fifth day he accepted that self-amputation of the arm was the only option if he was to survive. Using some cord as a tourniquet, an 8-cm penknife and a first-aid kit, he amputated the hand and lower forearm, lowered himself 25 m to the canyon floor and staggered back towards his car. Fortunately, he met some walkers who were able to alert an air ambulance to take him to hospital for surgery. Since utiliscing a prosthesis he has resumed climbing.[48]

Even with bystanders at hand, victims may have more determination to resolve their difficulties than colleagues, as Duhamel indicated during World War I:

"Auger was an engineering sapper. A shell had fractured his thigh and almost torn off his foot. As the foot was still held on by some skin, Auger took his pocket knife and completed the amputation: then he said to his comrades frozen with horror. 'Well boys, all's well! Nothing much has been lost, Get me out of here."[49]

Presumably Auger realised instinctively that the trailing foot was an impediment and that only he could undertake a task from which his comrades recoiled. It may be the earliest deliberate amputations took place in similar circumstances.

Summary

Life without accidents cannot be imagined, and many of the causes are as familiar today as in the past. Falls when running or from heights, crushing by trees, savaging by crocodiles and sharks, and the effects of earthquakes, tsunamis and violent storms would have been familiar to our ancestors as sources of limb section. They would have been aware that lesser trauma often ends in gangrene and limb failure. Histories of such accidents are rare before the 17th century, and some later examples are described. Attention is drawn to avulsion injuries and to remarkable auto-amputations performed by those trapped by a limb, isolated from help, lacking surgical knowledge and restricted to primitive instrumentation: for such individuals, the will to survive is powerful.

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4
Ritual, Punitive, Legal and Iatrogenic Causes

"In numerous tribes ritual mutilation is widely practised, and yet these tribes generally fail to develop medical amputation or other major surgery."

Ackerknecht, 1967[1]

"As for gangrene . . . in fractures which undergo greater compression than is opportune, and in other cases of tight bandaging, the intercepted parts come away in many cases."

Hippocrates, 4th century B.C.[2]

"More limbs have been lost by the use of tourniquets than have been saved."

Watson-Jones, 1943[3]

Removal of limbs or parts of limbs for ritual, punitive and legal reasons serves no medical purpose, yet this practice has a long history, continuing in some societies today, as a source of community-regulated rites, punishments or legal sentences. By contrast, iatrogenic causes are the consequence of surgical and medical treatments which become complicated by unintended vascular injury or infection with limb failure, leading to amputation as an emergency attempt to preserve life.

Ritual Amputations

In 1967, Ackerknecht wrote:

"Amputation of the fingers for ritual reasons is well known to us from South and North American Indians. The custom seems even more widespread in Africa and Oceania. In an excellent survey, Lagercrantz mentions no less than fourteen tribes in black Africa practising ritual finger mutilation. Soderstrom gives almost the same number for Oceania."[4]

The discovery of "mutilated" human hands outlined in paint on the walls of prehistoric caves in France and Spain suggested, initially, these were paintings of hands with partial amputations of fingers and, surprisingly, thumbs. In the case of the Gargas Cave in France, dated about 25,000 years before the present, 92 hand outlines are readable (Fig. 4.1), and Janssens supposed the missing digital parts had been removed for ritual reasons,[5] as indeed was known to take place more recently, excepting the thumb, very rarely involved in known ritual amputation. By contrast, Janssens noted that Van den Broeck considered the Gargas representations were a form of signature or "visiting card." A further study by Leroi-Gourhan suggested the positions of the absent digits corresponded to the most easily flexed finger positions and, hence, the imprints could have been painted from normal hands in various attitudes, acting as a stencil for outline painting. As additional explanation, it was suggested the digital outlines represented hunting signs or a similar code.[6] A later study by Hooper in 1980 concluded the images were of actual mutilations.[5]

Whatever the explanation of these paintings, ritual finger amputation has been confirmed in a number of societies and, indeed, still occurs in 2005 (see following), and was recorded in 1961 by cine-film among the Dugum Dani tribe, New Guinea, the amputations taking place to express family grief and to placate the ghost of a tribesman killed in battle. The sacrificial victims were little girls, linked to the dead man by blood, who had one or two lesser fingers amputated with a stone adze, without anaesthesia other than a

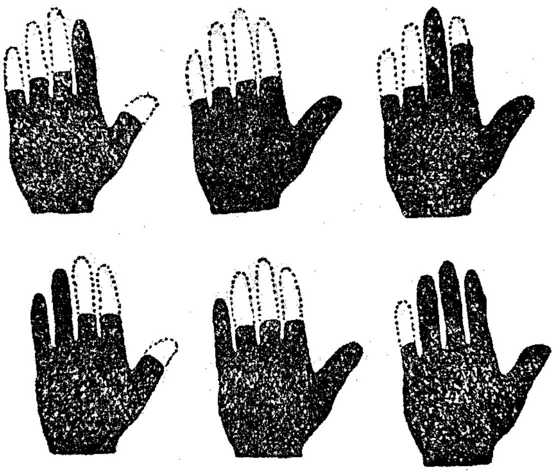

Fig. 4.1. Reproductions of the commonest hand prints showing apparent deformity, in the Gargas cave, c. 30,000 B.P. (From Ref. 5. Copyright the Trustee, The Wellcome Trust, reproduced with permission.)

hard rap on the elbow which may have contused the ulnar nerve to numb the little and ring fingers. The stumps were dressed with ashes and clay, wrapped in leaves and the girls held their hands vertically with clumps of grass at their elbows to soak up oozing blood (Fig. 4.2). Some Dani women were seen to have had all their fingers amputated at the proximal joints and yet remained quite dexterous.[7]

In similar fashion, several American Indian tribes in northwest Canada sacrifice fingers after serial family deaths in anticipation of halting the mortality. Sollas wrote:

"*. . . when death is too assiduous in his visits to a family: the survivors . . . place the little finger on the edge of the coffin and sacrifice the first joint, in order, as they say, 'to cut off the deaths'.*"[8]

Among Pygmies, finger amputations are performed as a sign of mourning or a means of securing a peaceful death later, and among Hottentots the ring finger is sacrificed to avert serious illness.[9]

An extraordinary sacrifice of a thumb, chronicled in an ancient Hindu legend of the epic battle of Mahabharata, concerned Prince Ekalavya of the lower Hunter's Caste, an expert archer instructed by Drona, a veteran of fighting techniques. When Drona demanded his teaching fee, he said callously: *"O Ekalavya, if thou art really intent on making me a gift, I should like then to have the thumb of thy right hand."* Having promised there was nothing he would not give his teacher and despite the cruel demand, Ekalavya cut off his thumb and gave it to Drona. On resuming archery, his former lightness of hand and accuracy had vanished. Since then, the archers of the tribes of Bhils have made a ritual incision on the right thumb and drawn their bowstrings with their

Fig. 4.2. Girls of the Dugum Dani tribe, New Guinea, 1961, immediately after ritual amputations of their little fingers, dressed with ashes and clay, and bandaged; they soak up blood as it trickles down their forearms, with handfuls of grass. (From Majno G. *The Healing Hand.* Cambridge: Harvard University Press, 1975:20–23.[7] Copyright Peabody Museum Harvard University.)

index and middle finger knuckles.[10] Also in India, Janssens reported:

"In the course of consecration rites among the Indians of the Mandan tribe, the first and fourth fingers of the left hand are amputated; the motive for this unknown." And: *"In the hope of ridding himself of an enemy, an Indian would cut off three fingers of his left hand."* And also: *"In India there is a tribe called the Berula Kodo, or 'finger cutters'. Every three years, during a religious ceremony, they cut off the second and third fingers of some of their women; the reason is not known. Sometimes this mutilation is performed for practical reasons, as where certain tribes of native fishermen remove the fourth fingers of their women to facilitate their task in making nets."*[9]

Rogers, who considered limb amputation a rarity in non-westernised Africa, nevertheless noted ritual finger amputation among Bushmen as a symbol of mourning. He stated:

"Hottentots occasionally amputate a finger by first tying the finger with sinew above the joint and then cut through the flesh and ligaments with a knife. A Hottentot widow who marries a second time must have the distal joint of her little finger amputated. Another joint is removed each time she marries."[11]

Rogers also recorded:

"The Assiniboin and Crows of North America have often amputated fingers as a form of mourning sacrifice. This is done with a sharp knife or with a tomahawk which was struck after the finger was placed on a block. Usually the first and second joints are sacrificed but with men the thumb and middle finger on the left hand and the thumb and two forefingers of the right hand are preserved for the use of bow or rifle. Young Sioux warriors cut off the little fingers of the left hands after the Sun Dance ritual."[12]

Such ritual amputations continue, even in sophisticated societies such as Japan where a South Korean doctor was arrested, in 2005, for aiding and abetting a self-inflicted finger amputation by administering a local anaesthetic to a businessman, witnessing the amputation performed with a hammer and chisel, placing the digit in a bottle of formaldehyde which he gave to its former owner and then invoicing the medical costs to the Japanese health system. It was explained that the businessman was bankrupt and indebted to a gangster of the Japanese mafia or "yakuza" for which the ancient punishment was "yubitsume" or finger-cutting, self-inflicted by the offender to demonstrate his sincerity and tolerance of pain, and, it can be supposed, to identify and expose the offender permanently in society and before his fellows for breaking their rules. "Yakuza" organisations have their origin in medieval guilds of gamblers and pedlars and regard themselves as heirs to the ethics of the "samurai." Bungling and incompetent "yakuza" sometimes end up amputating more than one fingertip or even most of a finger (Fig. 4.3).[13]

A frankly criminal self-amputation was reported in 2005 concerning a Dutch dentist who chopped off a finger and faked a car crash to make a claim from insurers equivalent to £1.2 million. No particular finger is mentioned in a brief news item but perhaps he weakened his extraction grip? He was heavily fined and given a suspended jail sentence.[14] Another bizarre and doubtless more-ancient method of extracting money is noted by Gillis, who wrote:

"Cases have been reported in the East, where itinerant beggars, in order to arouse sympathy, have, by a process

Fig. 4.3. A member of the Japanese mafia or "yakuza" drinking with the left hand, to demonstrate self-amputated fingers, known as "yubitsume," for offending the mafia code. (From *London Times*, July 13, 2005.[13] Copyright Bruce Gilden / Magnum Photos.)

of gradually tightened cords, severed one or both of their feet. These interesting articles were then tied by string around their necks and used as an additional incentive to extricate charity from passers-by. Two such mummified feet are on view in the Museum of the Royal College of Surgeons of England. They were purchased from a footless Chinese beggar and sent to the Museum."[15]

Unfortunately, these specimens cannot be traced and are considered victims of the College bombing in 1941. Another approach was taken by an elderly South Korean woman and her son, who severed their little fingers as a means of political protest over a disputed barren, rocky islet lying between Japan and South Korea, without resources itself but important for defining a 200-mile economic zone with fishing rights and potential geological riches. The demonstrations took place in front of the Japanese Embassy in Seoul where the mother used a meat cleaver and her son a pair of secateurs. Such transverse guillotine amputations would heal poorly unless receiving surgical reamputation to promote acceptable healing and comfortable stumps; there is no comment on the after-care of these bizarre auto-amputations.[16]

Fig. 4.4. Section 58 of the Bayeux Tapestry showing advancing Norman horseman and in the lower margin dead and mutilated English soldiers, one demonstrating 'guillotine' amputation of an arm. (From Bertrand S. *La Tapisserie de Bayeux*. L'Abbaye Sainte-Marie de la Pierre-Qui-Vire: Zodiaque, 1966:143. Copyright Desclee de Brouwer.)

Punitive and Legal Amputations

Differentiation between punitive and legal grounds for amputation is not always clear. Pure and simple punishment of prisoners of war, obvious when victorious opponents attack the defeated whether injured or not, as happened in the Dark Ages, may result in severed limbs (Fig. 4.4). However, many prisoners may be subjected to a form of legalised amputation based on the whim of a king or official, or on religious grounds, yet hardly determined by a fair trial supported by a legal representative. It has proved difficult to isolate purely punitive severances, so often related to ancient unwritten customs towards enemy prisoners.

In the Book of Judges, reference is made to Judas and Simeon, successors to Joshua, having taken the king of Canaan, Adonibesek, as prisoner; they immobilised him by cutting off his two thumbs and two great toes, or according to another interpretation, the extremities of both hands and feet. Adonibesek was familiar with such punishments, having meted out the same mutilations on his prisoners formerly taken in combat, saying:

"Three-score and ten kings, having their thumbs and their great toes cut off, gathered their meat under my table: as I have done, so God hath requited me . . ."[17]

After the battle of Bannockburn in 1314, it is reported three English soldiers in the King's service suffered punitive amputations of their hands and, subsequently, the Master Brethren of three medieval hospitals (presumably in England) were directed to provide them maintenance for life.[18] And in medieval France, captured English bowmen were subjected to amputation of their bowstring fingers (right index and middle) to prevent further participation in battles. Le Vay reported the following legalised punishment:

"In 1579, on a stage set up in the market-place at Westminster. John Stubbs, a religious writer, and William Page, his publisher, 'had their right hands cut off by the blow of a butcher's knife with a mallet struck through their wrists' for having produced a pamphlet criticising

Queen Elizabeth's marital ambitions. 'Stubbs, so soon as his right hand was cut off, put off his hat with the left and cried aloud, 'God save the Queen!'"[19]

In their study of acquired amputations before the 16th century, Padula and Friedmann based their conclusions on Peruvian practices, largely by their examination of surviving ceramic pieces from the Moche culture of the north coast of Peru, dated between 300 B.C. and 600 A.D. The examples selected show deformities and amputations with evidence, in some instances, suggesting cup-shaped prostheses were worn (Fig. 4.5). They concluded that, although leprosy, leishmaniasis, frostbite and tuberculosis were possible diseases precipitating amputation, punishment for infringing tribal laws was probably the major reason, stating:

"Theft in Peru was punished by amputation of one hand. Both arms were ablated for rebellion. One foot was taken off for laziness . . . amputations of the legs were ankle disarticulations or below knee amputations, primarily ankle disarticulations . . . other pots available show amputation almost invariably through, or above, the elbow. There are a number of figures showing bilateral upper limb amputation above the elbow. These figures . . . have ear plugs and head-dresses indicating that the individual was from the upper classes. This seems to indicate that bilateral amputation was probably the punishment for rebellion in upper class individuals."[20]

FIG. 4.5. Ceramic bottle of the Moche culture, Peru, showing lower limb amputations and a cup-shaped "prosthesis," probably to protect an unhealed stump, circa 300 B.C.–600 A.D. (From Padula PA, Friedmann MD. Acquired amputation and prostheses before the sixteenth century. *Angiology* 1987;38(2):133–141.[20] Copyright Westminster Publications.)

In the late 18th century, Tipu Sultan of Mysore, the staunchly anti-British prince, ordered amputations of the right hands and noses of captured Indian civilians serving the East India Company, for presumed treachery.[21] Packard noted that the North American Seneca Indians immobilised their war prisoners by performing a very neat amputation of the forefeet so that, although still able to stand and walk awkwardly on their hind-feet, they had no power of positive push-off due to absent toes and were unable to achieve a full running posture and, hence, easy escape was diminished; additionally, they left characteristic footprints making them easy to track, if indeed they did escape.[22]

More recently, an Afghan who became a prisoner of the Taleban described in graphic detail his punishment of simultaneous right hand and left foot amputations, actually witnessing the procedures himself. This took place in 1999 in the middle of a football stadium packed with people and supervised by mullahs; the victim suspects he was chosen in place of a rich Pashtun who having committed a crime, paid a sum of money to the mullahs so that a prisoner of war received punishment instead. He said:

"Seven doctors approached me. They wore grey uniforms, surgical masks and gloves. I could see one was crying. They injected me. After five minutes my body was numb though I was still conscious. Then they put clamps on my hand and foot and began to cut them off with special saws. There was no pain but I could see what they were doing . . . I was transfixed by the sight of my foot being removed. There was a sigh and murmur from the crowd when they finished. It had taken about five minutes."[23]

It is written in the Koran:

"Those that make war against God and His apostle and spread disorder in the land shall be put to death or crucified or have their hands and feet cut off on alternate sides."[24]

However, moderate Muslim scholars today conclude such edicts can no longer be taken literally and should be interpreted within the context of the times when originally written. Moreover, Islamic societies are not alone in practising punitive hand and foot amputations, as noted earlier in this section and, as recently revealed in the Congo during the Belgian colonial regime. A newspaper report in 2005 does not state any precise reason for hand amputations, although punishment for theft seems likely; it commented:

"... 45 years after the central African country gained its independence the Belgians are finally, and painfully, confronting a very different version of their colonial past: forced labour, mass murder and the routine severing of hands in what was probably the most bloody of all colonial regimes."[25]

Perhaps the most ancient reference to judiciary or legal amputations of the hand concerns this drastic penalty for medical practitioners whose treatment contributed to the death of a patient. This reference forms part of the Code of Laws established by Hammurabi, Amorite king of Babylon about 2000 B.C. In addition to specifying precise fees for the treatment of wounds, fractures or eye disabilities, it was stated that if an operation ended fatally or if an eye operation resulted in the loss of an eye, the physician's hands were cut off. However, if the patient was a slave, lesser penalties prevailed so that the physician had to replace the slave, or if an eye was lost the physician had to pay half the slave's value.[26] Sigerist considered these laws would have inhibited surgeons from taking any risks and suggests they were a warning for untrained practitioners to be very circumspect and, hence, were not applicable to reputable practitioners. It is unlikely we shall ever know for sure. A supposed edict of a related nature, in this instance for faultless workmanship, determined the cruel fate of the artisans and craftsmen responsible for building and decorating the magnificent Taj Mahal in India who underwent hand amputations to prevent them creating a rival construction in the future; Kunzru however recalls another version.[26a]

In 1639, Woodall remarked that it had been reported to him by *"sundry credible Surgeons"* who had spent time in the East Indies that they had seen men who had their feet chopped off at the ankles, by censure of the laws of their countries for committing trespass; Woodall then elaborates on their subsequent use of bamboo prostheses.[27] Daniell reported legal hand amputation for female infidelity on the Island of Fernando Po, West Africa in 1849, as follows:

"In amputation of the hands, a cruel penal sentence summarily inflicted on all women guilty of conjugal infidelity, the bleeding is restrained by the application of a piece of iron, or dipping the stumps in boiling oil, the resulting eschar, when separating, not being followed by any ill effects or further haemorrhage. Females thus mutilated may be seen daily wandering about the streets of Clarence."[28]

Similar amputations, especially of the hands for theft, have been legally conducted under Sharia law and indeed, in the 21st century, this remains a routine legal penalty in some Moslem countries.

When discussing traditional Ethiopian medicine, Pankhurst stated that in former days amputation was undertaken as a punishment for severe crimes including robbery.[29] He referred to a report of Courbon in 1861 who said the operation might be effected with a knife some 18 cm long and 3 cm wide and carried out with dexterity, almost according to the rules of European surgery, presumably an amputation of the hand at the wrist joint. First the skin was cut, then the tendons and finally the ligaments. The wound would then be cauterised with hot irons, or covered with leaves or cinders, or other powder.[30] Boyes, one of the few eye-witnesses to leave an account of such a legally sanctioned operation, recalls:

"I was fascinated. I was rooted to the spot. I could not move until the job was finished. There was no excitement, they were all chatting as if nothing untoward was happening. I must admit that he was making a good job of the operation ... As soon as the operation was over the stump was dipped in the pot of boiling fat to stop the bleeding."[31]

Iatrogenic Causes

It is an unfortunate fact that medical treatments prescribed in good faith, usually within limited boundaries of knowledge of certain practitioners, may be complicated by an irreversible interruption of limb circulation or wound infection, or both, to precipitate an emergency amputation to save life. Often the intended initial treatment may be adequate but is continued too long, as in the case of the emergency application of tourniquets.

The causes of iatrogenic amputation include the following.

Misapplied Fracture Splints and Bandages

Misuse of bandaging is one of the commonest reported complications of surgical management and must have an early history lost in the mists of time; it was certainly known to Hippocrates, as a quotation at the head of this chapter confirms. In 1676, Wiseman provided several instances of this complication, stating:

"Of Gangrenes from strict Bandage you may see several Instances in this Book . . . the cause may be so easily removed by the loosening of the Bandage. I shall give you one Instance here of a fractured Leg set in the Country by one pretending to Bone-setting."[32]

In this instance, Wiseman found the splints sticking in the skin, the leg much swollen and the foot a dark red colour. After suitable treatment the patient recovered and the fracture healed. Of Wiseman's other cases of threatened gangrene, subject to tight splintage, he intervened in time to prevent disaster and thus offered no actual examples requiring amputation. Doubtless practitioners were reluctant to report such an outcome. In 1798, Folly, a Danish army surgeon working in Tranquebar, near Madras, studied the surgical skills of the Malabar doctors of south India and reported:

"The Malabar doctors generally bandage fractures in such a way that 19 out of 20 die of gangrene . . . The first cover was a kind of potter's clay which was very dry and hard, and underneath this I found a lot of thin bamboo sticks close by each other and closely wrapped in twine. Under this, the arm was wrapped in strips of linen which had been soaked in a kind of varnish oil . . . During the time I have been here, I have had five or six cases (of wrist fracture) *which had been dressed the same way, and of these, only one, who also had a fractured forearm, was saved by an amputation."*[33]

In 1966, Swann and Walker, reporting on amputation practice in developing countries, drew attention to gangrene following tight splints applied by local bone-setters and about the same time, Hedley Hall observed six children with gangrenous arms after simple fractures, similarly treated, requiring amputation when he worked briefly in Northern Nigeria[34] (Fig. 4.6a). In 1988, Ofiaeli reported the details of three similar cases, all three seen in a period of 3 months, and initially

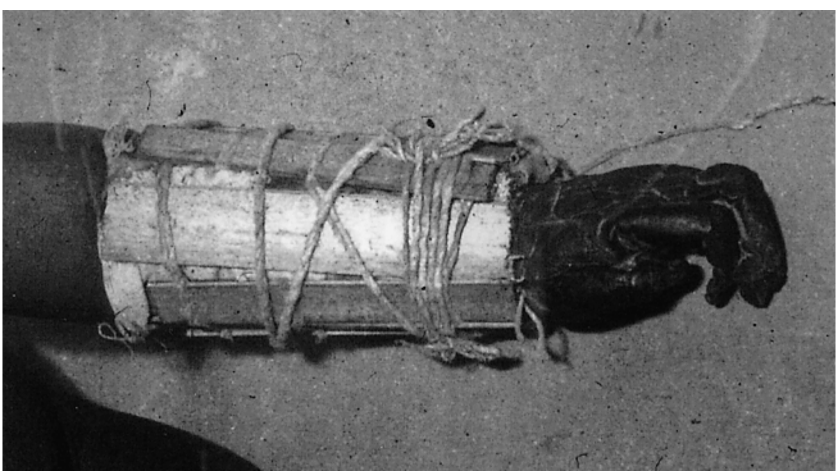

Fig. 4.6. a. Forearm splinted tightly for a simple fracture producing gangrene of the hand, requiring amputation, Ethiopia, 20th century. (From Eschete M. The prevention of traditional bone-setter's gangrene. *J Bone Joint Surg* 2005;86(B):102–103,[36] with permission from *Journal of Bone and Joint Surgery*. © British Editorial Society of Bone & Joint Surgery.) **b.** Gangrenous forearm and hand subsequent to tight elastic rubber tourniquet (Esmarch) for 45 minutes, U.K., 20th century. (From Watson-Jones R. *Fractures and Joint Injuries*, vol 1. Edinburgh: Livingstone, 1943:129–130,[39] with permission from Elsevier.

treated by traditional healers of the Igbos, Nigeria. One of these was an 11-year-old boy with a closed fracture of the distal third of the radius (just above the wrist) treated with bamboo splints and tightly bandaged; this resulted in dry gangrene of the forearm and required amputation through the upper arm 15 days after injury. Ofiaeli concluded:

"These practitioners (traditional) are very well patronised all over Nigeria. The reason for this lies in a deep conviction amongst the Igbos and other ethnic groups that orthodox doctors have little or no understanding of the principles of fracture treatment."[35]

A recent survey by Eschete, in Southern Ethiopia, described 25 gangrenous limbs after splintage by traditional bone-setters and, subsequently, a marked reduction of gangrene after they attended an educational programme in fracture management.[36]

Gangrene has also been observed in so-called advanced societies, after the immediate application of closed plaster of Paris casts for fractures which cause tension to rise inside the plaster as natural swelling accumulates and, if not relieved, sufficient pressure to arrest the circulation. Watson-Jones commented:

"The application of an unpadded plaster cast to a fractured limb within a short time of injury and before reactionary swelling has occurred is dangerous. Pressure within the rigid cast may become so great as to obstruct arterial flow and cause not only ischaemic contracture but even gangrene."[37]

Experienced practitioners will agree with his advice that all such plasters should be split lengthwise as soon as applied to accommodate swelling, or if the circulation remains in doubt, the front half of the plaster should be removed.

Misapplied Tourniquets

Instances of field tourniquets applied to control arterial bleeding on the battlefield and overlooked under dressings or for lack of communication are a known cause of gangrene. During World War I, a guide for medical officers dated July 1915 reminded them of this hazard.[38] In 1943, Watson-Jones was of the opinion that more limbs have been lost than saved by using tourniquets; he had seen tourniquets applied at pressures low enough to obstruct the veins but not the arteries, or at very high pressure so as to cause irremediable arterial spasm (Fig. 4.6b). For wounds, he believed local pressure over the bleeding point was safer and, if tourniquets were used, these should be of the pneumatic variety with a pressure gauge.[39] Even in the calm of civilian surgery, rubber tube tourniquets applied at the base toes, for bloodless field operations, have been left in error, hidden by dressings and overlooked until permanent gangrene was established in the affected toe.

Venesection and Gangrene

In the early 17th century, Fabry (Hildanus) described an observation concerning a man who was bled by venesection at the elbow and subsequently developed a gangrenous arm, presumably as a result of infection. Fabry was obliged to perform amputation close to the axilla, which the patient survived.[40] In 1771, De La Motte was asked to see a nun in a convent who 4 days previously had been bled by venesection near the foot. He found evidence of gangrene around the venesection site and swelling of the leg which he treated by scarification, fomentation and a cataplasm. Matters did not improve and when she lost all sensation below the knee, the question of amputation was suggested and accepted by the patient. However, she deteriorated very rapidly before the operation was arranged and died, probably of ascending infection.[41]

Setons, Issues and Fontanelles

These forms of counter-irritation, popular until the mid-19th century, aimed to produce a controlled discharge from a surgically induced ulcer in the hope of deviating the cause of an illness. For white swellings of joints, that is, tuberculosis, local setons or issues, formed above or below a knee joint, were observed to lead to deep seated infection and local gangrene.[42] However, no actual case requiring amputation has been traced.

Wound Infections

Despite current knowledge concerning bacteria and methods of avoiding surgical wound infections, suppuration still takes place in hospitals, especially when associated with septicaemia, more especially with organisms resistant to antibiotics. Such complications of the limbs may cause infection and gangrenous fingers and toes, sometimes ascending to higher levels, necessitating amputation. Before the discovery of bacteria and antiseptic techniques, upper limb infections were not uncommon amongst medical practitioners and students who cut or scratched a hand in the dissecting room, operating theatre and especially in the postmortem room, as we noted in Chapter 3. Amputation was sometimes a desperate last resort to prevent ascending infection.

Lack of Knowledge

Before the discovery of safe methods to control haemorrhage and infection, it is easy to criticise methods which often lead to death after amputation. Yet some practitioners obtained better results than others, as, for example, the Crowther brothers using a wood tar dressing and Alanson, who segregated amputation cases away from infected cases, as noted in Chapter 7. Generally, it was safer to be treated at home rather than in hospitals where cross-infection was frequent and "hospital gangrene" became rife. Unfortunately, lack of communication and blind prejudice often prevented sensible application of improved methods and new discoveries, as in the case of Lister, who, despite Pasteur's research, had considerable difficulty in persuading many surgeons to pursue a safer prophylactic antiseptic course.

Inappropriate Advice and Poor Choice of Amputating Technique

Before anaesthesia, it was never easy for either surgeons to recommend and, more especially, it was extremely difficult for patients to accept amputation. As Gross observed,[43] many limbs were removed unnecessarily and many retained that should have been promptly removed. And even today, there are situations when experienced surgeons find the choice of action an equivocal dilemma. In the past, bad advice could certainly prove disastrous. For example, Usmah, a 12th-century Arabic writer, reported that a crusading knight was receiving treatment for a leg ulcer from a Lebanese physician with some success when a Frankish physician interfered, asking if the knight preferred to live with one leg or die with two. When the knight replied one leg, the Frankish physician called for an axeman who laid the leg on a block of wood and severed the limb after two blows, the first failing to do so; unfortunately, the knight died, perhaps because of infection.[44]

Summary

Ritual, punitive and legal amputations confer no medical advantage in curing local pain, in removing deformity, infection or gangrene, or in saving lives, and only iatrogenic causes, leading to urgent section, can be considered to approximate to an accidental cause for elective amputation, as discussed in Chapter 3. More than a dozen reasons for ritual finger loss are described, practised by many communities on a worldwide scale, in which process the female is the predominant loser. How long these practices have existed is unknown, whereas it is probable punitive amputations have a more-extensive history arising on the battlefield or within intertribal feuds. Purely legal amputations are likely to be more recent. Instinctive efforts to straighten and bind fractures tightly to stop painful movement must also have a long history, although complications such as established gangrene had no effective remedy until recent centuries.

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5
Cold Steel and Gunshot Causes

"If we investigate those who lose their lives on the battlefield, we find three-quarters die from haemorrhage."

Morand, 1769[1]

"Gun-shot Wounds are attended with much worse consequences than Wounds that are made by sharp Instruments, for the Parts are more shattered and torn, especially when the Shot fall upon the Joints, Bones, or any considerable Part."

Heister, 1743[2]

Astride his horse, his right knee smashed by grapeshot, the Earl of Uxbridge exclaimed, *"By God, sir, I've lost my leg."* To which the nearby Duke of Wellington responded, *"By God, sir, so you have."*

Battle of Waterloo, 1815[3]

In this chapter, we consider instant traumatic amputations or injuries leading to amputations as a consequence of aggressive actions caused by blunt trauma, cold steel wounds and gunshot missiles, in the pursuit of all-out warfare. In the process we cross the boundary between nonsurgical dismemberment and the onset of elective surgical amputation precipitated by the introduction of gunpowder.

Primitive Weapon and Cold Steel Injuries

It can be supposed disagreements at a personal level and between various opposing groups ending in violence, have a long history, at least as far back as the Old Stone Age, although we have no clear prehistoric facts. Today's newspapers and television programmes confirm such disputes are part and parcel of "civilisation," which is not to say the participants concerned are aiming to achieve amputations, for other forms of maiming and mayhem are much easier to attain. Manually inflicted injuries with stones and clubs were unlikely to sever limbs, although doubtless crushed fingers complicated by infection and gangrene sometimes separated from living tissues. The appearance of stone axes and other cutting tools increased the possibility of limb severance, although the writer considers clean section through the tibia, humerus and femur would have been difficult if not impossible to attain with a single blow. Apart from fingers and hands severed during sword fights, major limb amputations must have been rare before the Iron Age: a heavy bronze axe might amputate an arm but an iron or steel axe would have proved more efficient.

At the Battle of Hastings as depicted in the Bayeux Tapestry, scrutiny shows many axe-men and several decapitated military figures in the lower margin but only one dismembered limb, apparently at the level of the elbow joint (see Fig. 4.4), perhaps inflicted on a wounded or dead soldier. Complete transection through major bones was not easily obtained, as described in Chapter 4 by a 12th-century Arabic writer reporting on the treatment of a crusading knight with a chronic leg ulcer. If "guillotine" amputations were encouraged by some surgical authors during the 17th century, Woodall restricted chisel and mallet amputation to fingers and toes,[4] although Scultetus was prepared to section as high as the lower forearm and ankle joint with a very heavy chisel or massive bone nippers (Fig. 5.1).[5] Fabry (Hildanus), who considered these actions unworthy of rational surgeons, as nerves and tendons were contused rather than sectioned cleanly, nevertheless had faith in a massive machine with weighted blades intended to 'guillotine' arms and legs, although he presented no actual case observations.[6] Purmannus, one of the last authors to illustrate an amputation chisel for fingers and toes, in 1706, did provide witness accounts of two guillotine sections through the shin, between weighted blades: the first required two drops of the upper blade ending with badly splintered bone and the other needed completion with knife and saw. He concluded:

"So that, all things considered, the Ancient way in cutting through the Flesh with a Knife, and through the Bone with a Saw, is more practicable, safe and certain then (sic) *any of the new Inventions."*[7]

Notwithstanding these conclusions, in 1835, 11 years before the introduction of general anaesthesia, Mayor raised the possibility of instantaneous cutting once more, having concluded pain was inversely proportional to the time taken to amputate, that is, less pain was experienced if the section was swift. He recalled earlier attempts with chisels and admitted this resulted in profuse haemorrhage and the impossibility of closing the wound immediately, and at best resulting in paper-thin scars. Despite this, Mayor pursued the concept of instantaneous cutting, which he termed 'tachytomie,' putting forward an imaginary and entirely theoretical solution, in the form of giant secateurs whose precise mechanism he left to scientists and mechanics to resolve, a challenge never mastered.[8] Guillotine section of limbs inevitably resulted in shortage of skin and soft tissues to cover bone ends, resulting in prolonged healing and painful stumps, and the practice disappeared in the early 18th century. However, in 1941 Harley reported the Masai of Lake Victoria, Kenya, were noteworthy for cutting off a damaged limb with a single stroke of a large sword, although neither the level of amputation nor the postamputation progress is recorded.[9]

If we examine reports of cold steel injuries sustained in battle, it is astonishing how soldiers survived multiple wounds which rarely involved division of limb bones. Wiseman stated:

"I shall now consider of Wounds with loss of Substance made by Bill, Pole-axe, Sword, etc., some cutting twice or thrice in one or near one place, whereby the Wound is large, transverse, yea and oblique, . . . These kinds of Wounds are often seen in times of Peace, but in the Wars

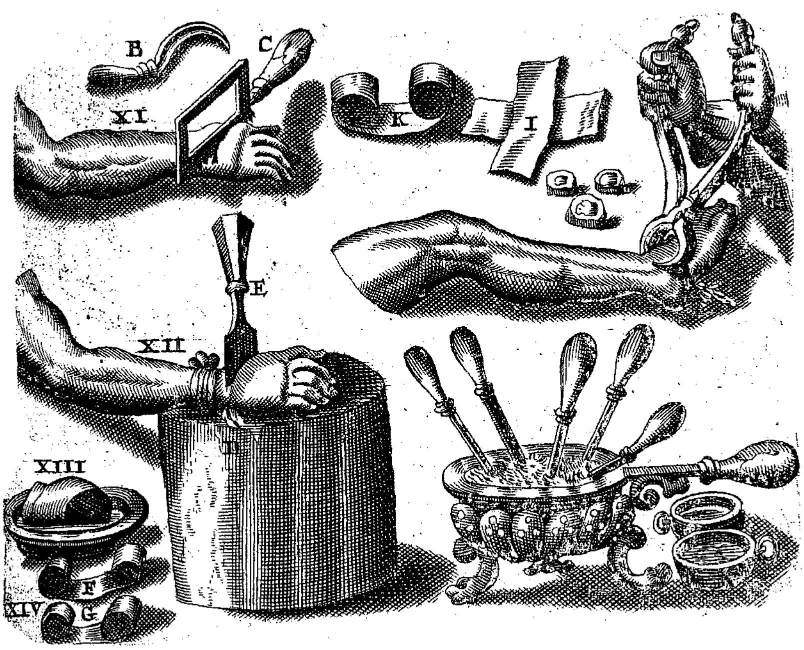

Fig. 5.1. Guillotine amputations performed with knife and saw, massive bone-cutters and chisel (mallet not shown); also brazier with heated cauterise, c. 1655. (From Scultetus J. *Armamentarium Chirurgicum*. Ulm: Kuhnen, 1655:12; part of plate XXVII.[5])

they are frequent, especially when the Horse-men fall in amongst the Infantry, and cruelly hack them; the poor Soldiers the while sheltring their Heads with their Arms, sometimes with the one, then the other, until they be both most cruelly mangled . . . And if they fly, and the Enemy pursue, his Hinder parts meet with great Wounds, as over the Thighs, Back, Shoulders, and Neck."[10]

Here Wiseman speaks about survivors, for many others received severe open wounds of the skull from which they died; he does not mention limb severance but again such victims may have perished before receiving medical assistance.

In an important study of military surgery published in 1768, Ravaton devoted a significant section to cold steel wounding and observed that if weapons, especially sabres, divided limb bones, they also divided main vessels and nerves, causing rapid collapse due to haemorrhage. When brachial or femoral vessels were divided and soldiers survived, the only course was a formal amputation. Overall, Ravaton considered sabre wounds of the upper limbs were less troublesome than those of the lower limbs. In describing case histories of several survivors with severe wounds, he offered no details of any amputations.[11] Ravaton divided cold steel injuries into those caused by pointed weapons, that is, stab wounds, and those due to cutting weapons, that is, open wounds.[12] In his experience, the former were caused by rapiers, bayonets and sabres, and because of their depth, were much more troublesome and dangerous than the latter, caused mostly by slashing sabres, when the wounds although extensive were less deep, easily inspected and open to surgical remedy. Ravaton illustrated his work with large numbers of personal observations, including the history of a soldier who sustained a puncture wound of his upper arm in 1740 and bled a great deal; Ravaton ligatured the brachial artery, only for the wound to become infected, necessitating an amputation.[13] He also described a number of penetrating wounds of the brachial and femoral arteries which produced recurrent haemorrhages and severe infections, some ending in death.[14] Ravaton concluded wounds of the main arterial trunks of the arm and thigh caused either early death from blood loss or, in fortunate cases, a life-saving amputation.

After the battle of Waterloo in 1815, Thomson visited the surviving wounded evacuated from the field and noted:

"The incised wounds which we saw had been inflicted by the sabre. They were chiefly among the French prisoners at Antwerp, and were for the most part upon the upper region of the head, or upon the temples, face, back part of the neck, and shoulders."[15]

Again, no clear evidence of cold steel limb severance is mentioned, and we conclude any such wounded rarely survived, except for the fingers of the sword arm which, it is probable, were considered unworthy of note as nonfatal minor amputations. Based on wide experience of military surgery, Hennen wrote about cold steel injuries in 1820, as follows:

"The gigantic blows by which long bones are divided and limbs severed are not a frequent occurrence in modern days. Most serious incised wounds are, however, inflicted by the sabre; the cavities of the joints are laid open, their appendages injured, the tendons divided, and the bones so deeply wounded, that, without the greatest attention, the preservation of the power of the limb becomes questionable."[16]

Apart from penetrating wounds caused by bayonets, cold steel injuries diminished during the 19th century whereas gunshot injuries became much more dominant. Penetrating bayonet wounds which did not kill could introduce infection and precipitate life-saving amputation. In 1897, Worsnop recounted an extraordinary amputation involving an Australian aborigine injured by a spear penetrating his shin about 1850, who was interviewed by Wollaston, Assistant Colonial Surgeon in Western Australia:

"At King George's Sound, Mr Wollaston had a native visitor with only one leg: he had travelled 96 miles in that maimed state. On examination, the limb had been severed just below the knee, and charred by fire, while about 5 cms of calcined bone protruded through the flesh. This bone was at once removed by saw, and a presentable stump was made . . . On enquiry the native told him that in a tribal fight a spear had struck his leg and penetrated the bone below the knee . . . He and his companions made a fire and dug a hole in the earth sufficiently large to admit his leg, and deep enough to allow the wounded part to be level with the surface of the ground. The limb was then surrounded with live coals or charcoal, and kept replenished until the leg was literally burnt off."[17]

This report seems hardly credible, and yet the stoicism of Australian aboriginals is well known; perhaps the victim thought the spear was poisoned? In any event, this method of amputation ensured uncomplicated control of haemorrhage by heat cauterisation and complete asepsis of the wound by thermal sterilisation, factors which raise the question of dipping stumps in boiling oil or tar.

Despite widespread scrutiny of surgical texts illustrated by case observations, the writer has found no case under the direct management of surgical authors which authenticates plunging stumps in boiling liquids. All allusions to this horrendous practice stem from second-hand accounts without direct witness by a physician or surgeon. For example, in 1679, Yonge when complaining about a physician who asserted he had used oleum terebinthnae (turpentine oil) before him, was supposed to have told Yonge:

"Some Chirurgeons using the Levant, had told him, That the Turks, as soon as they have amputated, use to dip the stump in hot Tar, and that they thereby securely restrained the Flux, and laid the foundations of a very good digestion: The way seeming too brutish and terrible to be imitated, he considered how to contrive it more neatly . . . none seeming more like it than Turpentine;"[18]

In 1875 Syme wrote that before the ligature some surgeons used the summary method of applying hot pitch or tar over the face of the stump and gave this account of a sailor he met who had been injured on a whaling vessel:

". . . for lack of other aid, the ship's carpenter amputated. Whether from his acquaintance with ancient surgical authorities, or simply acting on the rules of his craft, he "paid" the stump with hot pitch. The man recovered well . . ."[19]

Although Yonge used hot turpentine, this was applied on pledgets to the bleeding points or trickled into penetrating wounds, which he then held in place with his finger, suggesting it was not boiling. As a naval surgeon, Yonge added it was difficult if not impossible to use heated volatile turpentine in great sea fights due to the danger of fire and the difficulty in keeping it hot. In 1861, Boyes witnessed (see Chapter 4) a legal amputee's stump being dipped in a pot of boiling fat in Ethiopia, perhaps as a part of the punishment? In any event, this and any other stump dipped in hot liquids would prove a difficult physical manoeuvre with the victim surely fighting and screaming, causing the skin and much muscle to retract well away from other soft tissues which, apart from the nerves, would be less sensitive. In holding the patient down the "helpers" were also in danger of scalding as the vessel could easily be tipped by the struggling victim. I suggest that any hot oil used by Paré and others was applied on small pledgets or wisps of wool to the mouths of the vessels, just as the hot iron cautery was applied, the problem for the patient being the inadvertent application to nerve stumps. Unless concrete case histories can be traced, considerable mythology surrounds tales of dipping stumps in boiling oil or tar. Any exposure of the skin to scalding and burning would be completely counterproductive to wound healing, which was difficult enough after a guillotine section.

Gunshot Missile Injuries

Gunpowder and Wound Dressings

Although gunpowder reached Western Europe from China by the middle of the 13th century, no significant account of specific injuries caused by gunshot missiles is found before the work of Brunschwig, who illustrated an amputation saw in 1497[20] (Fig. 5.2). Shortly after, Gersdorff, another wound surgeon from Strasbourg, published further information on gunshot injuries and illustrated, for the first time, a surgical amputation scene (see Fig. 1.5). He also indicated that many contemporary surgeons debated whether the blackening of gunshot wounds by gunpowder was responsible for the poor prognosis of these injuries for, at that time, weapons were fired at close range to achieve accuracy and penetrating velocity, causing the wound area to be blackened by discharging powder.[21] Vigo firmly believed wounds were poisoned by this powder and advised all gunshot wounds should be cauterised with oil of elders, scalding hot and mixed with a little treacle.[22] As a young surgeon Pare followed this advice until he ran out of hot oil one day and was forced to treat wounds with cold applications. Fearing these patients would do badly, he was amazed the following morning to find their wounds were in better condition and more comfortable than those subjected to burning hot oil.[23]

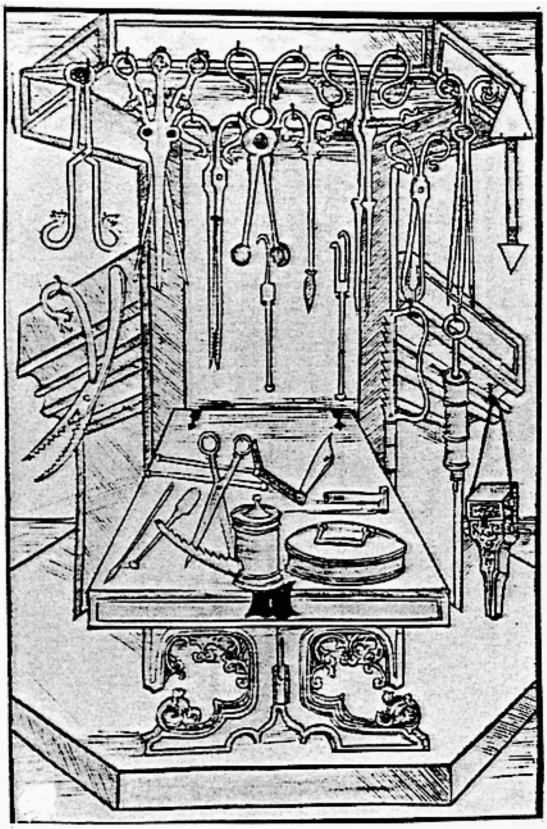

Fig. 5.2. Brunschwig's armamentarium of 1497 showing, suspended *above*, many instruments for the extraction of arrows and bullets; to the *right*, a bow saw, urethral syringe and pocket case for minor items; on the *table*, probes, folding knife, scissors, drainage tube and box of ointments; *in front*, possibly a lantern for night work. (From Brunschwig H. *Dis ist das Buch der Cirurgia. . . .* Strassburg: Gruniger, 1497.[20])

He concluded wound blackening with gunpowder was not poisonous and hot applications were detrimental to healing.

Foreign-Body Contamination

Pare and others soon discovered that gunshot wounds were uniquely sinister because, in addition to tissue damage, the depths of the wound were contaminated by in-driven missile material, clothing, armour and other foreign bodies, causing deep suppuration, unless extracted promptly.[24] In addition, larger artillery pieces produced cannonballs, chain-shot, and exploding shells which literally tore body and limbs apart, and if not severing limbs completely (Fig. 5.3), rendering them candidates for immediate amputation. In 1774, Alanson received a strong healthy man who:

". . . was ramming a cartridge into a cannon that had been just fired; some part of the wadding being yet alive in the breech of the gun fired the new charge; and he having his right arm opposite to the mouth of the gun, was blown from aboard the vessel into the river: he was taken out apparently but half alive, and brought to the Infirmary. On examination, it appeared that the right arm was carried off high up, just below the insertion of the deltoid muscle; the remaining bone and muscular substance were so much injured, that in consultation, it was determined to amputate at the articulation with the scapula."[25]

Suffering from adjacent burns, the patient's progress was initially slow but, within a month, stump healing was complete but for a small sinus. Of similar destructive magnitude, the Earl of Uxbridge's knee injury quoted at the head of this chapter required a formal through-thigh amputation to ensure a healed stump (Fig. 5.4), from which he made a good recovery and went on to pioneer the Anglesey artificial limb[26] (see Fig. 13.5). Such massive wounds made decisions to

Fig. 5.3. Soldier struck by cannon fire at the Battle of Waterloo who experienced a severe episode of tetanus before surgical excision of the upper humerus and ultimately stump healing. (From Bell C, *Surgical Observations,* London: Longman, 1816, plate VII.[44])

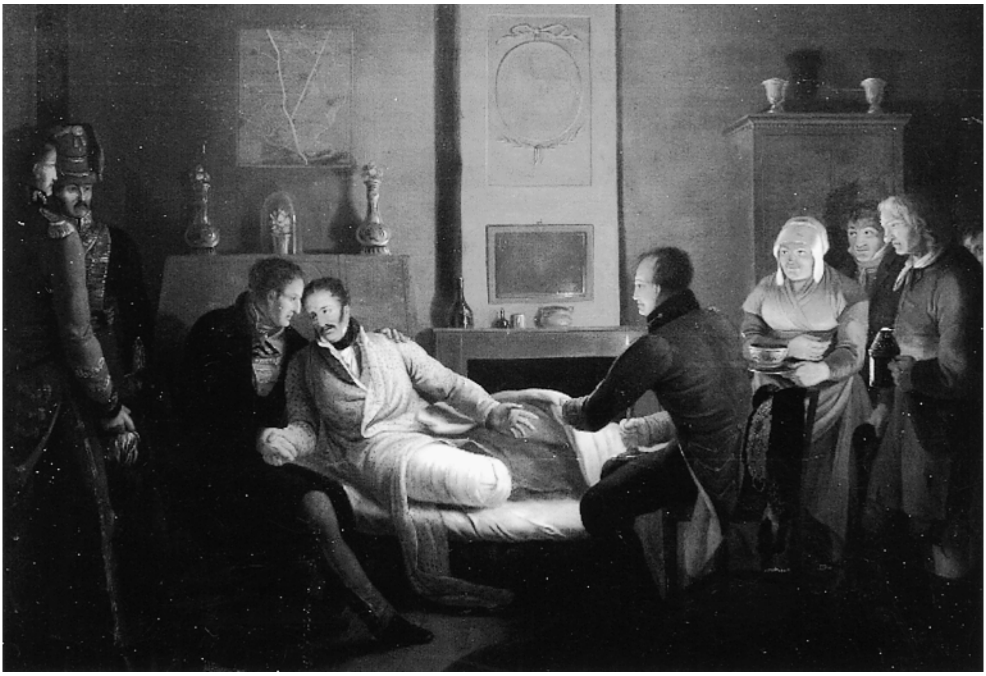

Fig. 5.4. Oil painting of a meeting between the Earl of Uxbridge (Anglesey) soon after his leg amputation and the Duke of Wellington, in a farmhouse near the battle site; it is considered the meeting is fictitious, as they were not good friends. (Painted by C.F. Coene and exhibited in Plas Newedd, Anglesey. © National Trust/Paul Kay, photographer.)

amputate relatively easy, as Heister had confirmed in the 18th century:

"In Wounds from large Guns, the Joint or Bone are frequently grievously shattered, or carried off; in this case it is far better to take off the Limb at once, than to spend a great deal of time in fruitless attempts at cure."[27]

One of the singular aspects of gunshot injuries at sea resulted from wooden splinters torn from the ship's timbers by cannon shot which then acted as lethal secondary missiles. When recommending immediate amputation for grossly compound wounds caused by bullets and shot, especially below the knee and shoulder,[28] Wiseman added a note on the perils of these wooden splinters:

"So also all those Fractures made by Splinters are exceedingly dangerous, they generally shattering the Bone to pieces; are subject to extraordinary Pain, Inflammation, Convulsions, and Death, unless immediate Remedy be had by removing those Bones, or by Amputation of the Member."[29]

However, Wiseman adds words of caution against over enthusiasm for amputation, stating:

"Amongst the Cruisers in private Fregats from Dunkirk it was complained, that their Chirurgeons were too active in amputating those fractured Members. As in truth there are such silly Brothers, who will brag of the many they have dismembered, and think that way to lie themselves into credit. But they that truly understand Amputation and their Trade, well know how villanous a thing it is to glory in such work."[29]

Recognising the need for radical amputation in the face of massively destructive and contaminated wounds was a step forward, assuming the victims survived to reach surgical facilities, but in actual practice before the later 19th century, this was not simple for several reasons. Firstly, adequate pain relief did not exist despite a need to divide healthy tissues in badly shocked patients; secondly, severe haemorrhage was difficult to control and counter, especially above the knee and elbow when the main arteries were damaged; and thirdly, complicating infection was poorly understood and lacked effective remedies, all problems examined in more detail in Chapters 7 and 8. Hence, amputation above the knee, through the muscular thigh, was a great risk and uncommonly reported before the later 17th century. However, in 1676, despite no new technical advance, Wiseman claimed to undertake above-knee amputations for complex gunshot injuries on battlefields and battleships, doubtless sustained by extensive experience, as his writings suggest:

". . . by good Bandages and Deligation of the Vessels, and when we cut above the Knee, by clapping Cauteries to the Vessels only; which sufficiently answers that Intention. Thus have I seen in my first Sea-voiages Amputations made above Knee, and afterwards practised them with great ease and safety."[30]

By bandages, Wiseman meant simple occlusive ribbons or other organic bindings around the limb, perhaps tightened by a stick to obstruct vessel flow, and by deligation, he meant individual vessel ligatures and yet, mostly, he relied on stypticks (caustic salts, turpentine) for smaller vessels and heated cauteries for all major vessels, provided nerves and other structures were not cauterised. These were risky options, above all demanding good illumination (preferably better than candlelight), accurate anatomical knowledge, and a suitably heated cautery to hand despite pouring rain on the battlefield or the pitching of a battleship in bad weather. Further, satisfactory initial coagulation of a major vessel might suddenly fail due to movement of the flimsy coagulum or as a result of wound infection, with catastrophic secondary haemorrhage. A more-reliable system was required, but its evolution proved slow and irregular.

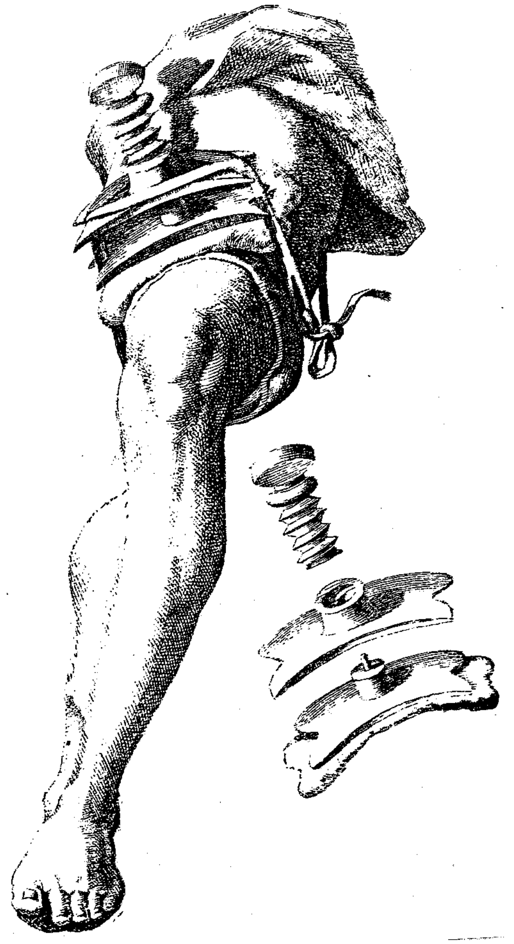

Fig. 5.5. Petit's screw tourniquet, wood and canvass applied to thigh; invented in 1718. (From Petit J-L. D'un nouvel instrument de chirurgie. *Hist Acad R Sci* 1718:199–202.[31])

Control of Haemorrhage and Infection

Petit's introduction of the screw tourniquet in 1718[31] (Fig. 5.5) was a major step forward in controlling bleeding from limbs before, during and after surgery. Unhappily, the problem of how best to secure divided arteries remained, for cautery had major drawbacks, yet the alternative of vessel ligatures also had penalties, for unabsorbable silk and wool acted as unsterile foreign bodies to cause infection. One common solution offered was to leave ligature ends long, protruding from the wound, to enable them to be teased out when it was considered the vessel was safely occluded (Fig. 5.6), although this was not easily determined. Towards the end of the 18th century, most surgeons abandoned heated cauteries and many decided to cut ligatures short so that these were buried, reckoning they would be discharged if infection supervened, a sequel which was by no means inevitable. More-positive progress was not made until prophylactic antisepsis became available after 1867,[32] for those who were enlightened and willing to change old habits. Resistance to Lister's regime was often bitter and bigoted as Terrillon observed, as late as 1892, when Deprés opened an abscess with a folding bistoury taken from his pocket and then asked for a drain:

"The nurse fetched one from a neighbouring ward. Deprés took the drain immersed in carbolic acid, put it on the floor, rolled it under his foot and then placed it in the wound."[33]

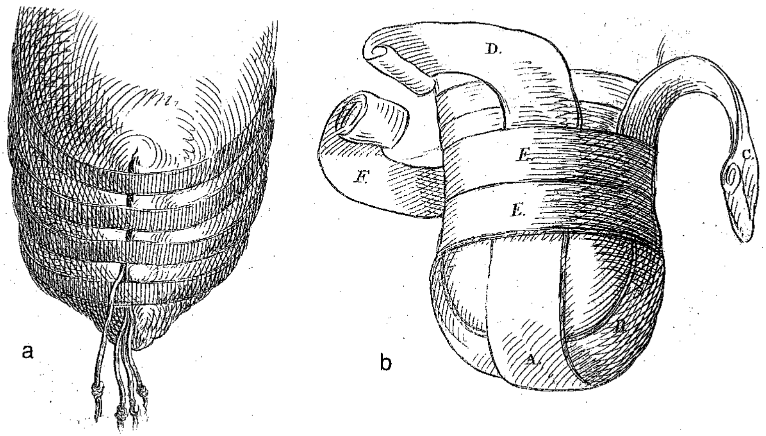

Fig. 5.6. a,b. Charles Bell's method of thigh stump dressing using strips of plaster to close wound, retaining long vessel ligatures to emerge through the wound and a Maltese-cross dressing and circular bandaging. (From Bell C. *A System of Operative Surgery*, vol 2. London: Longman: 1814:15–16.[45])

Yet by 1892, with the encouragement of Pasteur, surgeons were starting to operate aseptically by employing thermal sterilisation techniques which, added to chemical sterilisation of the patient's skin and surgeon's hands, ensured bolder and almost infection-free surgery.[34]

Logistical Factors

As suggested in the preceding chapter, the acceptance of immediate amputation for most compound fractures was strongly influenced by the opinions of military and naval surgeons who, having extensive experience of such injuries, were prepared to advise a similar approach in civilian life. However, not only were gunshot wounds contaminated with much foreign material and necrotic tissues, unlike most open fractures of civilian practice, but the particular circumstances of the battlefield also required consideration. As Petit observed, evacuation of soldiers from the field was often delayed and then followed by a long painful period of transport, with fractures poorly splinted, in a bone-shaking cart before reaching medical facilities. This transit was associated with continuing blood loss, painful movement of the fractures, often exposure to great heat or to great cold, all of which reduced the strength of the injured profoundly and hence their chances of surviving a delayed amputation. Petit and others believed early amputation on the field was essential.[35] Even the injured believed immediate operation was best, not least because their courage diminished with time, as Wiseman affirmed:

"And a Walloon earnestly begged of me to cut off his shattered Leg: which whilst I was doing, he cried, 'Depeche vous connous vendrone a terre mous bioran' (Hurry up, when we get ashore we'll have a drink). *Also others have urged me to dismember their shattered Lims at such a time, when the next day they have protest rather to die . . . Therefore you are to consider well the Member, and if you have no probable hope of Sanation, cut it off quickly, while the Soldier is heated and in mettle."*[36]

But often the numbers of wounded involved and the chaos of a major battle caused insurmountable obstacles to rapid evacuation, as experience confirmed at Waterloo after cessation of fighting on June 18, 1815. Among surgeons arriving from Britain to help, as soon as the slow communications of the time permitted, was Charles Bell 11 days after the battle, who noted that although the British wounded were badly off, the French wounded had hardly been evacuated and indeed many were to lie in the woods for a fortnight. In these circumstances, it is impossible to estimate the numbers dying without surgical assistance or who might have survived a timely amputation. Bell paid particular attention to the French, operating almost continuously for 3 days, and commented:

"While I amputated one man's thigh, there lay at one time thirteen, all beseeching to be taken next; one full of entreaty, one calling upon me to remember my promise to take him, another execrating."[37]

Professor Thomson, from Edinburgh, arrived in Brussels on July 8 and reported that surgeons on the field had been overwhelmed by numbers for it had taken several days to evacuate the 8,000 British injured to hospitals in Brussels and elsewhere. Three weeks after the battle, he found 2,500 wounded in Brussels and many others evacuated to Termonde and Anwterp. Thomson and a colleague took 12 days to make a full examination of the wounded in Brussels and noted many had fevers associated with the marshy countryside and also hospital gangrene.[38] Of 500 amputation cases, more than one-third took place before the onset of inflammation and progressed more favourably than the later amputations, recording a future plea for early amputation and more medical staff on the field, because of:

"The hurry, confusion, and uncertainty which occur during a battle, the multiplicity and variety of the cases which demand attention, and the shortness of the time which is left for deliberation in the period which intervenes between the infliction of the wound and the occurrence of inflammation and fever, . . ."[39]

Even with sufficient medical arrangements and staff, evacuation might take many days, as proved too often the case during the miserable trench warfare of World War I. Soldiers with open fractures of the femur were marooned in no-mans-land, often for many days, due to enemy fire, as only a stretcher party could extricate them, provided the bearers were not shot in the process. Too often infection and gangrene supervened before the victims reached surgical facilities, the death rate proving severe with or without amputation.[40] And although on wooden battleships sailors with gunshot wounds, especially of the lower limbs, were close to surgical assistance, they were reluctant to be put down into a dark airless hold for expectant treatment, conscious their bleeding wounds were liable to be nibbled by rats.[41] Many preferred an amputation stump which allowed more mobility than a painful open fracture which, at best, demanded many weeks of dressings confined to a bunk or hammock.

In the 17th century, major injuries of the upper thigh and hip region remained a problem as amputation at hip joint level was considered a step too far, due to the problem of securing major vessels in the groin. Ravaton reported that, in his experience, all men with gunshot injuries of the thigh with an open femoral fracture, when treated conservatively, eventually died. By contrast, gunshot fractures at other levels often did well if carefully managed. For this group of high thigh injuries with poor prognosis, he recommended amputation by disarticulation at the hip joint as the only possibility of saving life.[42] Unfortunately, it does not appear he was able to conduct such an operation, for he reported:

"I wished to do this major operation in 1743 on a gendarme of the Guard whose femur was fractured near the trochanter. I communicated my plan to several surgeons of merit, to have authority by their counsel and to be encouraged by their presence; some approved but others rejected my plan such that the patient died within a few days."[43]

Until the advent of helicopter evacuation, the reality for most military surgeons engaged in major conflicts was a constant struggle to treat the wounded against a background of constant shellfire, moving battle actions, long lines of communication, a shortage of personnel, drugs, dressings and splints, with poor hospital resources or even none at all.

Summary

Traumatic amputations were probably uncommon until heavy iron and steel weapons evolved, with fingers and hands especially vulnerable. Apart from axes, cold steel weapons proved incapable of amputations at higher levels. All changed dramatically in the 15th century when destructive gunshot wounding, associated with in-driven foreign material, often led to mortal sepsis. This battlefield enigma eventually stimulated elective amputation through sound flesh to save life and provide a healed stump. In parallel, methods of haemorrhage and infection control were addressed although not resolved before the 19th century. Doubts about boiling oil are expressed, and battlefield logistical problems are noted.

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6
Elective Amputation: Early Evolution to the End of the 17th Century

"Sometimes the extremities become gangrenous . . . you must cut off that limb as far as the disease has spread, so that the patient may escape death or greater affliction, greater than the loss of the limb."

Albucasis, c. A.D. 1000[1]

Gangrene and Pre-Renaissance Practice

Remembering the word "surgery" is derived from the Greek for "hand-work," it is probable that early surgical treatment for gangrenous limbs comprised the manual application of ointments, dressings and bandages to counter suppuration and unpleasant odour, in the hope mortified segments would detach themselves at the demarcation line with living tissues (Fig. 6.1) and induce spontaneous healing. That such gangrenous separations supervened is confirmed in the Hippocratic writings of the 4th century B.C.:

". . . even when a portion of the thigh comes away, or of the arm, both bones and flesh, but less so in this case; and when the forearm and leg drop off, the patients readily recover."[2]

In the 2nd century A.D., Galen also counselled an expectant approach. Even in 1363, Guy de Chauliac confessed, after detailing instructions on how to amputate for gangrene either at joint level or through bone, that he himself never amputated but advised scarification of dead skin followed by the application of arsenic to the mortified area, ensuring healthy tissue was defended against arsenical attack with suitable dressings and, finally, firm bandaging in anticipation of the gangrenous tissues falling away. He concluded:

". . . it is more honest for the physician that it falls spontaneously than to amputate it. For if one amputates there is always some rancour or regret, and thoughts by the patient that the limb might have survived."[3]

Indeed, until general anaesthesia was available, a conservative surgical approach was often favoured for gangrene; in 1824, Astley Cooper remarked:

"Nature adopts the very plan in her amputations which the surgeon pursues; the skin separates the longest, the muscles next, and then the tendons, together with the bones, which are left considerably shorter than the other parts . . . the bones become covered by skin, and the muscles surround the extremity of the bone."[4]

Other classical authors provided evidence of more-positive action with the removal of mortified digits and limbs at the demarcation line of dead and living tissues to counter unpleasant-smelling and death-threatening pathology. Celsus argued, in the 1st century A.D., that amputation for gangrene involved very great risk either from loss of blood or syncope, adding:

"It does not matter, however, whether the remedy is safe enough, since it is the only one. Therefore between the sound and 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 should 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 . . . and undercut . . . so that in that part also some bone is bared; the bone is then to be cut through with a small

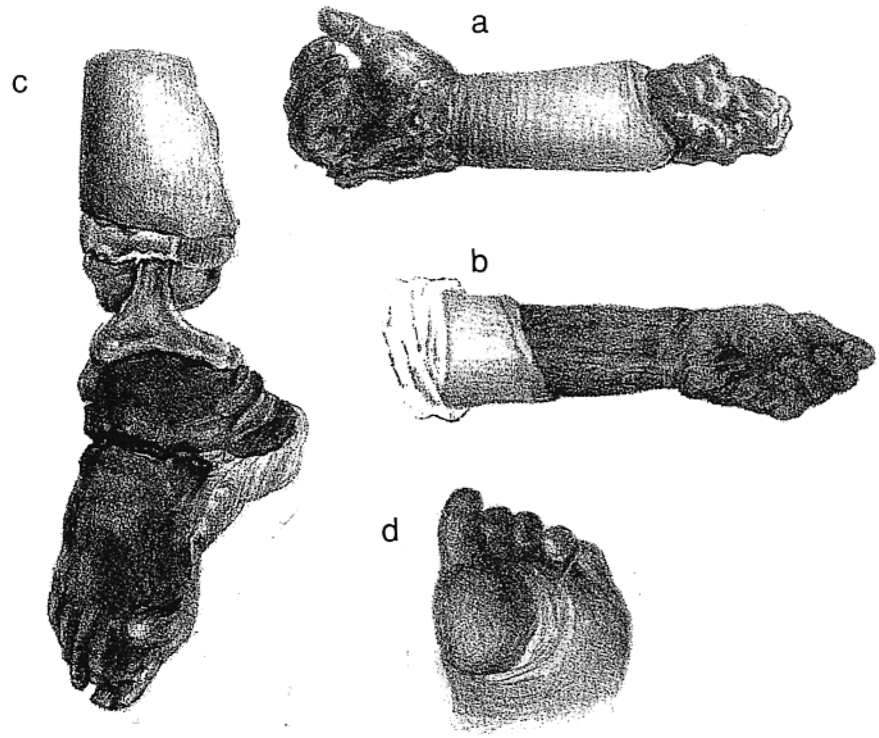

FIG. 6.1. Examples of gangrenous mortification. **a.** Hand after trauma and amputation through the forearm. **b.** Forearm with senile gangrene showing clear line of demarcation. **c.** Foot and ankle following cold exposure, showing final stages of spontaneous separation at the junction of dead and living tissues leading to amputation at a higher level. **d.** Part forefoot senile gangrene spreading to remainder of the foot. (From Spence J. *Lectures in Surgery*, vol 1. Edinburgh: Black, 1875: plate III.[53])

saw as near as possible to the sound flesh . . . and the skin drawn over it; . . . The part where the skin has not been brought over is to be covered with lint;"[5]

In this passage on amputation, Celsus did not mention vessels , nerves or the use of tourniquet or hot iron cautery, and it is concluded any division of sound flesh was superficial and limited to skin. However, in a chapter on wounds and haemorrhage, Celsus wrote vessels were to be tied in severe cases, retaining cautery as a last resort.[6] From this, Lister concluded Celsus would have adopted a similar approach to the haemorrhage of amputation,[7] an opinion shared by Wangensteen and Wangensteen.[8] When Celsus debated open fractures he stated those with flesh wounds involving the thigh and upper arm were grave injuries and observed:

". . . they are liable to more severe inflammations and also have a greater tendency to gangrene. And in the case of the thigh-bone, if the fragments have separated from one another, amputation is generally necessary The upper arm is also liable to this danger, but is more easily preserved."[9]

Celsus continued with a description of conservative management for long bone fractures, including reduction, medicated dressings, splintage, diet and general measures, but provided no details of an amputation technique. This author concludes any compound fracture requiring amputation had a grave prognosis being unstable, contaminated and complicated by extensive muscular and vascular damage, amounting to virtual traumatic amputations which were completed by minimal soft tissue severance and saw trimming of prominent bone. For many centuries before this, it is probable crushed, trailing and useless limbs were "amputated" in an act of instinctive common sense, sometimes by the patient. A 20th-century example is recounted by Duhamel during the 1914–1918 War:

"Auger was an engineering sapper. A shell had fractured his thigh and mangled his foot. As the foot was still con-

nected by a skin remnant, Auger took his pocket-knife and cut the foot free, saying to his comrades who had looked on in horror; 'Well comrades! Nothing much has been lost. Get me out of here.'"[10]

The distressing spectacle of acute traumatic amputations, domestic, battlefield or punitive in origin, must have encouraged the spontaneous application of coverings and, ultimately, medicated dressings to protect raw stumps, either undertaken by victims or their family. And in the case of transected fingers and toes, acceptable healing often followed, leading to recovery of adequate function, but for amputations above the hand and foot healing was more doubtful, and the best possible outcome often a thin painful scar fixed to bone, with poor residual function. As already observed, cultural and legal amputations recorded within historic times, at least for victims whose survival was anticipated, had their open stumps dressed to encourage healing and survival, perhaps to ensure their stigmatisation as permanent outcasts of society.

Fragmentary evidence from Archigenes, at the beginning of the 2nd century A.D., is more specific than Celsus and heralds a radical approach to amputation. He wrote:

"The operator must then tie or sew the vessels which pass to the parts; in certain cases a ligature is to be applied round the whole limb, cold water is to be poured upon it, and some are to be bled . . . a circular band is to be put round the limb, to draw up the skin with, and to direct the incision. After cutting down to the bone, the tendons are to be retracted, and the bone scraped and sawn. When much blood is discharged, red-hot irons are to be applied, and a double compress laid on . . ."[11]

This description suggests major blood vessels were exposed and tied as a preliminary step, presumably above the level of section. At the same time, the "ligature" applied round the limb indicated a form of tourniquet whilst cold water encouraged vessel constriction; and yet , he added, some were to be subjected to additional blood loss by venesection? Plainly, upward traction of the soft tissues assisted periosteal elevation and bone sawing, as high as possible above the soft tissue section, after which heated cautery was employed to bleeding points? If the details of these events and their sequence are not entirely clear, Archigenes confronted the dangers of haemorrhage rationally and offered several practical control measures which, for some commentators, is considered to be amputation through sound tissues above diseased or injured parts, even if he did not specify this operative technique unequivocally. Sadly, Archigenes added no explanatory case histories.

These instructions of Celsus and Archigenes were ignored or overlooked for many centuries, and it was not until the Renaissance before elective section, through sound tissues employing arterial ligature, returns to surgical texts. Hence, Paul of Aegineta in the 7th century A.D. limited comment to established gangrene, after the manner of Hippocrates and Galen, but was prepared to assist section at the line of demarcation. He wrote:

"Sometimes the extremities, such as a hand or foot, having mortified, so that the bones themselves are corrupted, either from having been fractured by some external means, or from having become putrid owing to some external cause, it is necessary to saw them off."[12]

Paul required heated cauteries and compresses to dry up discharge and to stimulate suppuration to obtain healing. From the 9th century A.D. onwards, Arabic authors also emphasised the application of cautery but, apart from Haly Abbas and Albucasis, were extremely conservative about amputation. Haly Abbas advised that less vascular tissues, such as the front of the leg and outer thigh, should be cut first, then bone sectioned before cutting the most vascular tissues last; this almost suggests the fashioning of soft tissue flaps to obtain easier stump cover, but this concept is not mentioned in his text.[13] Albucasis in his treatise on surgery and instruments, about 1000 A.D., not only recommended amputation for congenitally superfluous fingers and for gangrene but also to forestall death from spreading poison caused by:

". . . the bite of some dangerous reptile such as the marine scorpion, viper, or venemous spider, and so on. If the disease or bite be at the tip of the finger, cut off the finger, giving the disease no opportunity to spread to the rest of the hand. Similarly, if it attacks the hand, cut it off at the wrist . . . if it attacks the forearm, cut it off at the elbow through the joint itself. If the disease passes onward . . . by no means cut the shoulder, for that will be the death of the patient;"[14]

Albucasis described similar instructions for bites of the lower limb, emphasising that patients diseased above the knee should resign themselves to death for amputation was perilous above knee joint level. He applied ligatures [bandages] around the limb, both above and below the amputation site, to tense the soft tissues during section which were then protected by linen dressings to avoid saw injury; haemorrhage was controlled with cautery and styptic powders; vessel ligatures are not mentioned. Albucasis recounted the history of a patient which fails to shed light on his amputation technique and, paradoxically, underlined his obstinate refusal to assist, despite the presence of gangrene and the patient's pleadings for dismemberment of his foot, and later a hand, which, it is suggested, the patient undertook himself[15]; one is left wondering if Albucasis actually performed major amputations. Earlier, in ancient India, the threat of ascending complications and death from infected thorns embedded in hands and feet was recognised by Sushruta Samhita, for which he recommended amputations as high as the wrist and ankle.[15]

Reporting on surgery in Anglo-Saxon *Leech Books*, Payne submitted amputation was limited to gangrene when the blackened part had no feeling. Nevertheless, one contemporary practitioner recognised that cutting through healthy tissues promoted easier healing, for it was recorded:

"If thou must carve or cut off an unhealthy limb from an unhealthy body, then carve thou not it on the edge of the healthy body; but much more cut or carve on the whole or living body; so thou shalt better and readier cure it."[16]

On gangrene in the 13th century, Theodoric advised similarly:

". . . you should cut down to the healthy areas and leave no part of the putrid flesh, but take away some part of the live and healthy flesh. Indeed, you will effect a cure better and more quickly in this way."[17]

Theodoric also suggested pain relief during operative surgery by inhalation of a mixture of drugs, including opium, hyoscyamus, mandragora, and hemlock, by means of a soporific sponge. To revive the patient, another sponge soaked in vinegar was applied to the nostrils.[18] Later commentators stated this early form of anaesthesia had dubious efficacy, indeed was akin to poison for, sadly, patients often slept well enough but failed to wake up; use of "spongia somnifera" is not recorded beyond the medieval period.[19]

Between 1130 and 1247, decrees of the Catholic Church, especially that of Tours (1163), "*Ecclesia abhorret a sanguine*" (The church rejects bleeding), discredited surgery and surgeons, and excluded the contributions of interested priests and university trainees, to leave matters in the hands of empirics and barbers; patient care deteriorated and barber-surgery became limited, it is said, to minor wound-surgery and venesection. Medieval neglect of surgical management was characterised by delayed introduction of artificial limbs, already known to Herodotus and Pliny, according to Garrison who wrote:

"In the Middle Ages, there was an enormous loss of limbs due to the mutilating effect of anaesthetic leprosy and of ergotism, to wounds from cannon-shot (introduced at Crecy in 1346) and half-pound shot (Perugia, 1364), and to gruesome judicial punishments. The stumps were commonly bound up in splints. Crutches and wooden legs, afterwards so familiar in the works of Callot and Brueghel (fig. 12.1), are mentioned in the 'Acta Sanctorum' and other medieval chronicles and frequently appear in the sacred frescoes of the time. The iron hand is first seen in a picture of 1400."[20] (see Fig. 13.3).

Response to Gunshot Trauma

Evolution towards more-active surgery owes much to the inventions of printing and gunpowder. Despite the appearance of cannon and presumed gunshot wounds at Crecy in 1346, the first known surgical notice of these injuries in Europe is 1460, by Pfolspeundt, when he refers to methods of removing gunpowder from wounds without offering further management on the specific problems of these new injuries[21]; thus, he does not mention amputation. It was another German wound surgeon, Brunschwig of Strasbourg, who recorded the first detailed account of gunshot wounds in 1497; he believed these were poisoned by the powder and sometimes required amputation, haemorrhage being checked by applying hot iron cauteries or boiling oil to the vessels.[22] Finally, in 1517, the operation of elective leg amputation between ligatures was recorded in an illustration by Gersdorff, another "wound-surgeon" of Strasbourg (see Fig. 1.5), who believed gunshot injuries were poisoned and poured hot or warm oil into wounds, and who also employed constricting bands above and below amputation sites; he did not employ actual cautery, relying on styptics to arrest haemorrhage.[23] Nevertheless, Vigo, who wrote extensively on gunshot injuries in 1514, ignored these advances and returned to the practice of awaiting formation of a gangrenous demarcation line before conservative removal of mortified tissues.[24] Nevertheless, Vigo does mention treatment by immediate amputation for trauma. In 1545, Ryff published a revealing illustration of a leg amputation in progress, with a priest attending the patient, and details of instruments and dressings (see Fig. 9.1).

Franco recorded precise instructions for dismembering a leg or arm in his *Petit Traité* of 1556. He recommended the following: (i) ingestion by the patient of a mixture of syrups and herbs for several days both before and after surgery; (ii) attachment of the patient when lying on a bench; (iii) application of a tight ligature applied two or three fingers-breadths above the proposed incision, to control haemorrhage and cause numbness below; (iv) marking the proposed incision on the skin in ink; (v) use of a razor with the handle tied securely to prevent it buckling when cutting the flesh in one sweep down to bone; (vi) pulling on the soft tissues by means of the ligature to expose the bone as high as possible; (vii) section with a bow saw (Fig. 6.2); (viii) loosening the ligature to allow discharge of 'corrupted' blood; (ix) application of hot iron cauteries (fig. 6.2) to the flesh and bone to stop bleeding and 'cleanse' the tissues; (x) application of a linement to assuage pain; (xi) dressing with an emplaster; and (xii) a firm bandage left untouched for 2 or 3 days. Franco also mentioned as an alternative to the razor, a heated sickle-shaped knife (Fig. 6.2), with the object of cauterising haemorrhage during incision, as Croce also suggested.[25] Paré and Croce illustrated similar highly decorated bow saws, Croce adding a flat tenon saw (Figs. 6.3, 6.4). In 1551, Maggi demonstrated, experimentally, that gunshot wounds could be neither burned or poisoned by discharged gunpowder, and in 1560, Botallo emphasised the dangers of leaving foreign bodies and necrotic tissues if infection and amputation were to be avoided.[26] Gale, an experienced military surgeon, agreed in 1563 that wounds were not poisoned by gunpowder and, although he did not hesitate to amputate immediately for severely injured

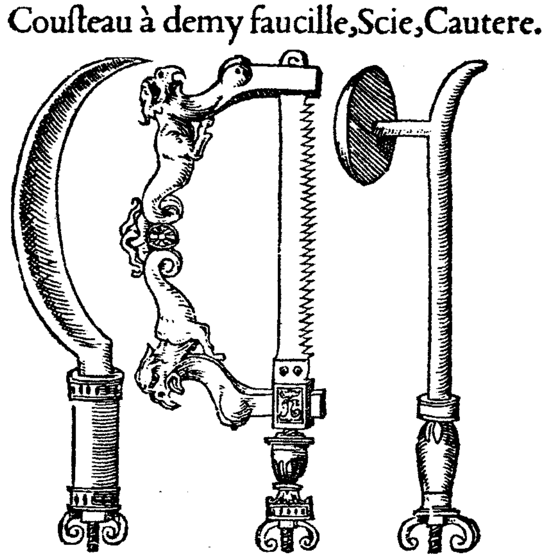

Fig. 6.2. Amputation half-sickle knife, saw and cautery iron, Franco, 1556. Note the exuberant decoration and uncomfortable handles which may have hindered expeditious action.[25]

limbs, he was prepared to dress lesser compound fractures in expectation of slow healing.[27] In 1563, Wurtz was very cautious about dismembering and claimed he was able to cure many crushed limbs and, even if they became putrid, he

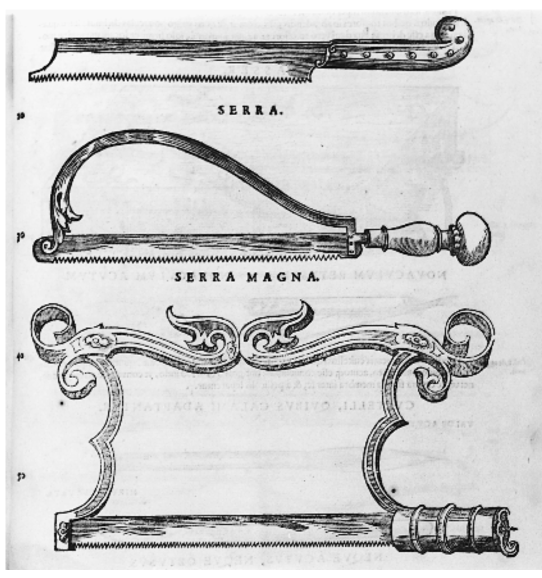

Fig. 6.3. Amputation saws including a tenon saw; note unnecessary overdecoration of the large saw. (From Croce JA, *Chirurgiae Libri Septem,* Venice: Zilettum, 1573.[54])

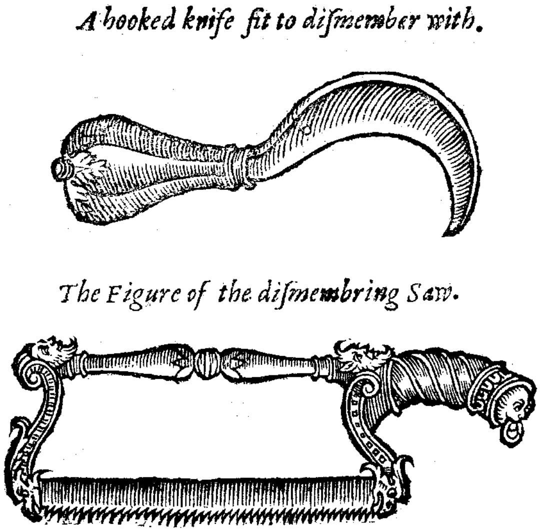

Fig. 6.4. Amputation sickle knife and bow saw with particularly ungainly handles. (From Paré A. London: Clark, 1678.[55])

advised waiting 10 days, despite the smell, before amputation.[28]

Meanwhile, in 1545, *La Méthode de Traicter les Playes Faictes par Hacquebutes et aultres bastons à feu* by Paré (1510–1590) challenged the uncertain, painful application of hot iron cauteries and inflammatory boiling oil to bleeding vessels, arguing that careful ligature of individual vessels was more rational and secure. He used a strangulating fillet or band above the amputation site to reduce bleeding, to induce distal numbness and to pull soft tissues as high as possible during bone sawing; he sectioned through sound tissues sufficient to ensure proper cover for below-knee stumps and to obtain a stump short enough for a kneeling prosthesis, even if this meant removing more tissue than was dictated by the pathology or trauma. Vessels were drawn out with his crow's-beak forceps and ligated with a double thread or, in the case of large arteries, a thread and needle was passed through adjacent skin, around the vessel and through skin again to be tightened over a linen pad to prevent skin necrosis (Fig. 6.5).[29] This latter system ensured secure anchorage of the ligature and also assisted its easy withdrawal if later infection supervened. Paré was one of the first to observe that long leg amputation stumps could prove a hindrance to walking on a kneeling peg-leg, forcing the patient to walk with three legs (that is, one leg and two crutches) instead of two. He cited the case of a military amputee demanding a second elective amputation to improve his mobility, as follows:

"For I so knew Captain Francis Clark, when as his foot was striken off with an iron bullet, shot forth of a man of War, and afterwards recovered and healed up, he was much troubled and wearied with the heavy and unprofitable burden of the rest of his leg, wherefore, though whole and sound, he caused the rest therof to be cut off, some five fingers bredth below his Knee; and verily he used it with much more ease and facility than before in performance of any motion."[30]

Clowes (1540–1604), experienced in both military and naval surgery, described one of the first above-knee amputations, for "grievous corruption" without applying vessel ligatures, relying entirely on restrictive powder and pressure bandaging. It can be assumed this corruption was gangrenous and the femoral artery occluded, otherwise his control of blood loss is remarkable, except he claimed to have a powerful powder secret to himself; such restrictive powders were unlikely to arrest major vessel haemorrhage. For those not in the secret, he advised "a bright cauterising iron." Clowes fully acknowledged reading both Paré's and Guillemeau's detailed accounts of ligation, yet never entertained this important advance, admitting: *"I never practised this order [method] by stitching the veins and arteries."*[31]

Lowe wrote in 1599, *"Where there is putrefaction . . . stay the flux of blood by Cauter actuals, and where there is no putrefaction . . . use the ligator."* This is one of the first references in English to application of arterial ligatures for amputation, probably because Lowe had worked in France for many years.[32]

At the end of the 16th and beginning of the 17th century, Fabry (Hildanus) made important original surgical contributions, illuminated by many case histories, including amputation techniques. He was among the first to perform above-knee amputation through healthy flesh and strongly advocated a red-hot knife to divide soft tissues and obtain occlusive coagulation of vessels at the same time[33]; however, critics said this latter technique was frustrating, as well as painful, for the knife became stuck to the tissues, rendering clean skin section difficult.[34] As we have noted (see

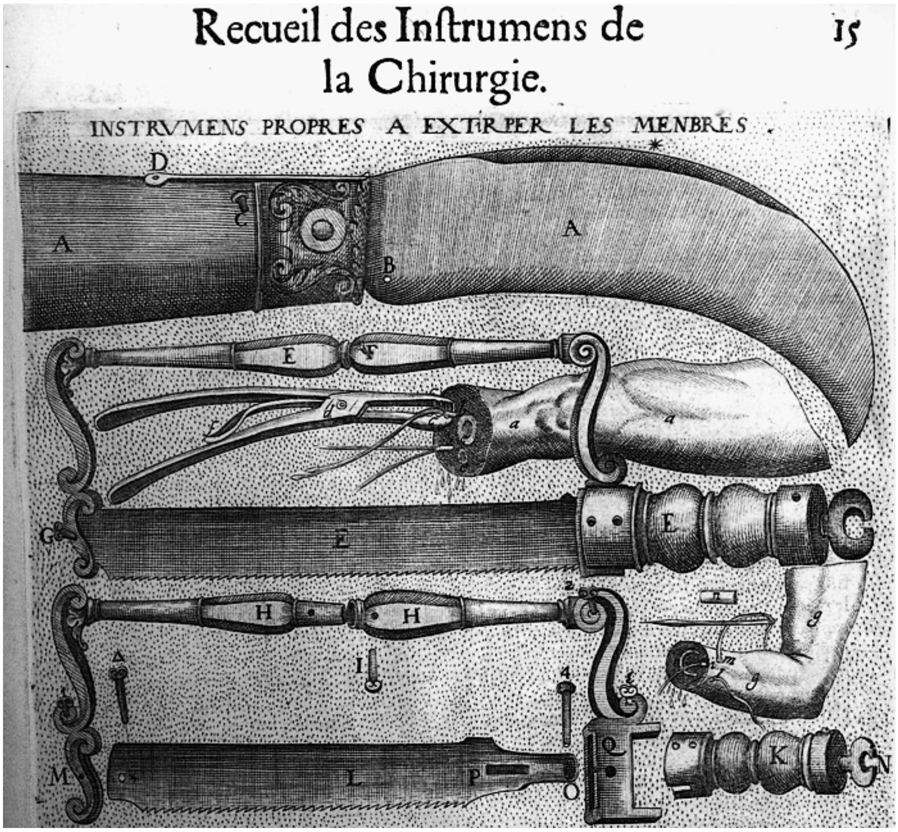

Fig. 6.5. "The correct instruments" for amputating limbs, showing concave knife, bow saw and also its constituent parts; additionally, vessel ligature (i) using a crow's-beak forceps and (ii) a method with a needle and thread anchoring the ligature through the skin to assist easier removal. (Attributable to Paré: Jacques Guillemeau, *La Chirurgie Francoise*, Paris: Gilles, 1594.[56])

Chapter 5), Fabry wrote against amputation of digits and the hand by means of a gouge or carpenter's chisel, and also disapproved of the use of large dismembering pincers or pliers (see Fig. 5.1), which he said lacerated nerves and tendons, and were much better reserved for cutting metal[35]; he expressed no sympathy whatsoever for cutting through mortified tissues and quoted a case seen in 1586:

"*. . . a robust young man from Savoy who developed gangrene of one leg upto garter level had, in order to save the knee, amputation at the demarcation line followed by diligent hot iron cauterisation of the stump: however he was tormented in vain, for gangrene had ascended much higher than was apparent from skin changes . . . one sees the same effect in apples and pears which very often have only a black mark on the skin yet are already totally rotten within;*"[36]

Fabry was among the earliest to insist that all amputations should take place through sound tissues well above disease level, that the limb should be tethered to a firm board to stop excessive movement by the patient, that the patient bled less if lying down, and that the bow saw was the best instrument for major bone sections, even if he had an unfortunate experience when his blade snapped before amputation was complete; as a result he insisted all amputation kits should carry a spare bow saw blade (Fig. 6.6). Curiously, Fabry favoured cautery and local astringents for haemorrhage control unless the patient was strong and lusty, when he recognised individual vessel ligatures were safer; to pick up vessels accurately and securely, he introduced special forceps with a locking mechanism on the handles (see Fig. 10.4), a precursor of the self-holding haemostat of the 19th century.

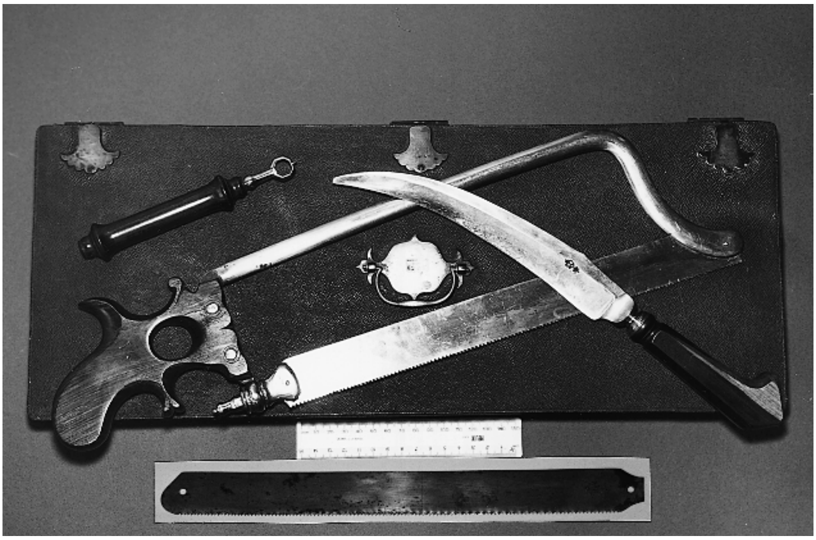

Fig. 6.6. Amputation box with concave knife, bow saw, spare blade and locking key to tighten saw blade, c. 1775; the knife and saw handle are typical English designs. Bow saws were shortly to be replaced in Britain by tenon saws. (From private collection.)

Although Woodall published extensive comments on amputation, most apply to the management of established gangrene of which he had comprehensive experience with patients in St. Bartholemew's Hospital, London. In his *The Surgeons Mate* of 1639, an attached publication entitled *A Treatise of Gangrena and Sphacelos; but Chiefly for the Amputating or Dismembring of any Member in the Mortified Part* (see Fig. 1.1) makes a strong case for section at the demarcation line or even through dead tissues but never living flesh, claiming good results. Indeed he produces some very early statistics in this field, affirming to have dismembered more than 100 legs and arms, in addition to many hands and fingers for sphacelos, that is, established mortification, over a period of some 24 years without a death due to blood loss. In addition, he suggested (in a convoluted way) that 16 of every 20 healed and left hospital.[37] However, the text indicates many of his patients were poor, especially children suffering from exposure and frostbite who, given warmth and food, might be expected to heal and be discharged from hospital. Further, unlike most practitioners Woodall had the luxury of hospital beds at his disposal, for stump healing after dismemberment was often lengthy, for example, four detailed observations required bed rest for 10 weeks, 3 months, 3 months, and 5 months, respectively, before cure.[38] Few patients throughout Europe would have had the benefit of such hospitalised care. Despite reluctance to endorse elective dismembering wholeheartedly, Woodall recorded full operative instructions for emergency amputation in his teaching manual for ship's surgeons, *The Surgions Mate* of 1617, including careful details and illustrations concerning the required instruments (Fig. 6.7), but unfortunately without case histories. He introduced the chapter on amputation through sound tissues as follows:

"Amputation or Dismembering is the most lamentable part of chirurgery, it were therefore the honour of a Surgeon never to use dismembering at all if it were possible for him to heale all hee undertooke; but necessitie hath no law: the Patient will declare in his naturall desire to live, the comfort that hee hath by it. Since therefore it is of necessary use, let the discreet Surgeon be ever prepared for it . . . If you be constrained to use your Saw, let first your Patient be well informed of the eminent(sic) danger of death by the use thereof; proscribe him no certainety of life, and let the worke bee done with his owne free will, and request: and not otherwise. Let him prepare his soule as a ready sacrifice to the Lord by earnest praiers, craving mercie and helpe unfainedly: and forget thou not also thy dutie in that kinde, to crave mercie and help from the Almighty, and that heartily. For it is no small presumption to Dismember the Image of God."[39]

For a below-knee amputation, Woodall relied on restrictive powders and tight bandaging to control haemorrhage although he admitted "some good men" use vessel ligatures after the manner of Paré. On the other hand, for above-knee amputa-

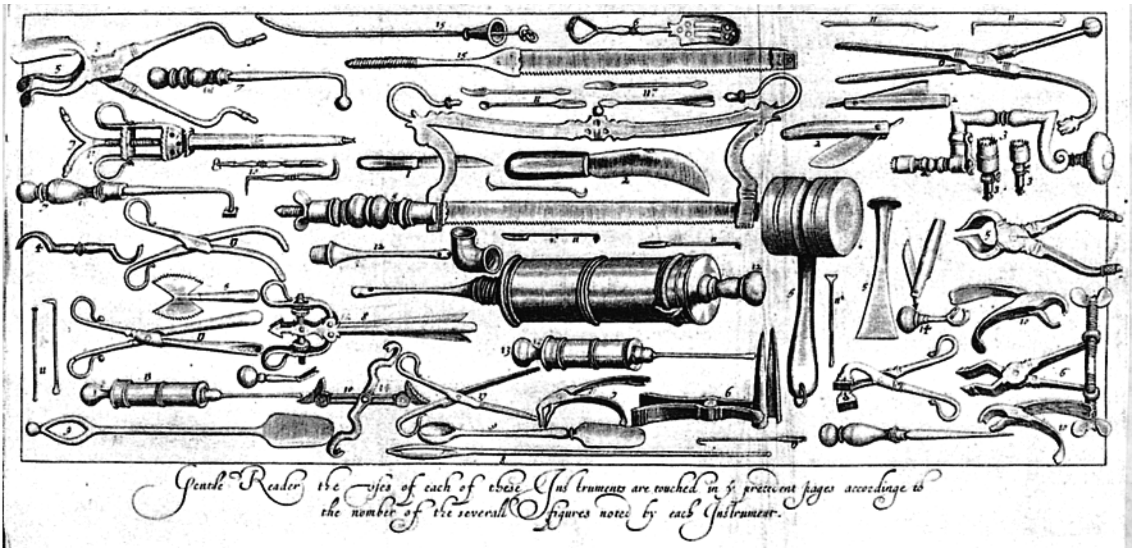

FIG. 6.7. Instruments recommended by Woodall for East India Company sea-surgeons' chests in 1617; note the massive decorative bow saw, chisel and mallet, clyster and urethral syringes, trepan, various bullet forceps, mouth gags and, at *bottom right*, dental forceps.[39]

tions he noted the great danger posed by veins and arteries which should be taken up with strong threads, although this undertaking was not easy and might have to be abandoned, to hope for the best![40] Woodall's conservative approach probably stemmed from his mainly civilian hospital-based experience, if we except a few months of military exposure in France, early in his career. Even his important book aimed at "young Sea-Surgions, imployed in the East-India Companies affaires" was mostly based on the log-books of the Company's experienced ships' surgeons, for Woodall never travelled outside Europe.

The outstanding *Armamentarium Chirurgicum* by Schultes, known as Scultetus, published posthumously, surveyed instrumentation and operative techniques, and was a pioneer in using illustrations to depict operative scenes in sequence yet, curiously, he overlooked major amputation procedures. Indeed, no major amputation saw is illustrated, normally a centre piece of many surgical treatises, although for one amputee Schultes described dismemberment through sound tissues, use of a "tourniquet," major artery ligation and lesser vessel cauterisation.[41] By contrast, he gave special place to hand and foot "guillotine" amputations for mortification, at the demarcation line, and pictured comprehensive instrumentation, including chisel, block and mallet (see Fig. 5.1) at a time when others had rejected such surgery as discreditable.

Wiseman wrote an influential surgical text in 1676, achieving five further editions after his death, illuminated by approximately 660 personal case histories which underline extensive experience in military, naval and civilian practice; a little earlier, only Fabry (Hildanus) had revealed such wide clinical exposure in his "six centuries" of observations. Wiseman's views on amputation for battle trauma are expressed thus:

". . . if it be done in the heat of Fight; for then, while they are surprized and as it were amazed with the Accident, the Lim is taken off much easier: and if it be the Arm, some of them will scarce be kept in the Hold while the Ship is close engaged in Fight . . . I cut off a man's Arm, and after he was laid down, the Fight growing hotter, he ran up, and helpt to traverse a Gun"[42]

However, not every soldier and sailor accepted amputation as Wiseman recorded,[43] although it made sense to dismember when the patient was buoyed up with adrenaline and the wound relatively pain free, provided no alternative course was evident, rather than amputate later when the wound was inflamed and tense and the patient feverish. Immediate lower limb amputations were also encouraged by injured sailors, to maintain independent mobility and prevent feared incarceration below decks, where injured limbs were exposed to nibbling by rats. Until the introduction of anaesthesia, most amputations were conducted with the patient seated but Wiseman was prepared to operate with the patient lying down; under battle conditions a seat might be difficult to obtain. He used a ligature (tourniquet) two fingers-breadths above section and criticised Woodall who relied on an assistant griping the thigh or leg to occlude vessels, a task which required a powerful grip that few could maintain throughout an operation. The ligature also numbed the skin and enabled the tissues to be pulled clear during bone section. Bleeding was stopped with button-shaped cauteries or by vessel ties, although he maintained that drawing out the vessels by forceps to place ties was:

" not a work to be done in the heat of Fight, nor without a clear day-light . . . it will be necessary to have your actual Cautery always ready, for that will secure the bleeding arteries in a moment, and fortifie the Part against future Putrefaction."[44]

In addition, Wiseman had strong faith in the "Royal Stiptick Water," a preparation prepared by Dr. Denis of Paris to arrest haemorrhage and the subject of a paper given to the Royal Society by Dr. Needham after testing by Wiseman.[45] Styptics were unlikely to seal large vessels such as the femoral and brachial arteries with any degree of safety, and Wiseman always kept iron cauteries handy.

Flap Amputations

A significant advance in technique was recorded by Yonge in 1679, in a letter added to his treatise in praise of turpentine as a wound dressing,[46] entitled *A new Way of Amputation, and a speedier convenient Method of curing Stumps, than that commonly practised*. This method aimed to heal stumps in 3 weeks, instead of many more weeks or months, by constructing a long flap of skin and fascia to cover bone ends, to accommodate a drain, and to allow insertion of four or five sutures without tension. Assuming no significant infection supervened, the bone stump did not project through the amputation wound, a common complication of earlier techniques. In recounting this, Yonge acknowledged his debt to *"a very ingenious surgical brother, Mr C. Lowdham of Exeter"* who, unfortunately, has left no personal record of this revolutionary operation.[47] Yonge cautioned against its use in the presence of inflammation, fistula formation or cancer and claimed the following advantages for major amputations, especially after trauma: healing was one-third or one-quarter the time of conventional procedures; skin ulceration and bone infection were uncommon; secondary haemorrhage was rare; the patient was subjected to less pain and hazard; the surgeon's costs for dressings and medicines was reduced; the healed stump did not break down at every slight rub or knock; and, finally, an artificial leg was readily tolerated.[48] Yonge provided no case observations although testifying confidence in and presumed experience of the new method. He did not indicate that flap amputations took somewhat longer to perform than circular operations, and therefore the patient's immediate agony was increased. Subsequently, no further evidence of this new technique is known before the confirmatory work of Verduin, a quarter of a century later.

Verduin published his new method of amputating in a Latin pamphlet of 1696,[49] translated by Vergniol, a refugee surgeon from France working in Amsterdam in 1697, as *Nouvelle Méthode pour Amputer les Membres* (see Fig. 1.3), that is, amputation by forming a soft tissue flap (Fig. 6.8); significantly, Vergniol had vivid experience of the method, having been subjected to a successful below-knee flap amputation when very ill from a suppurating shin, undertaken by Verduin himself.[50] Verduin acknowledged information from a former assistant who told him that a London surgeon (no name given) had amputated by the new method, and protested there must be a fault in the procedure as no other English surgeons had confirmed its utility; it seems clear he had not read Yonge's account. However, Verduin reported a much refined version of the technique, fully illustrated with instruments, newly devised equipment to ensure support and protection for the healing stump and a suitable prosthesis with an articulating knee joint (see Fig. 13.12). As a consequence, most European commentators gave Verduin undisputed credit for introducing flap amputation. Among his procedural refinements

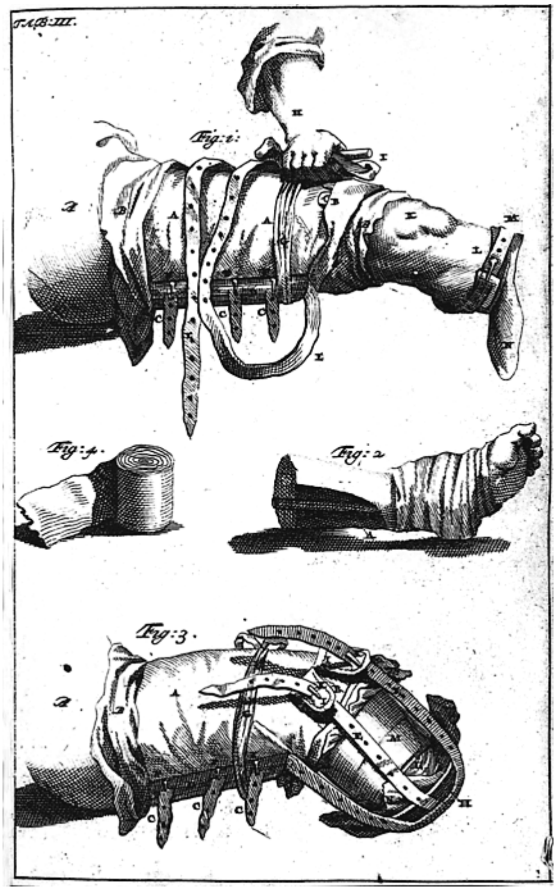

FIG. 6.8. *Fig. 1*, limb after below-knee amputation showing posterior flap hanging down and apparatus, applied before operation, to locate support for the flap (the hand is holding a twisting stick tourniquet to control bleeding); *Fig. 2*, amputated specimen; *Fig. 3*, flap supported by apparatus; *Fig. 4*, bandage to control the wound. (From Verduin PA. *Nouvelle Méthode pour Amputer les Membres* (translated by J. Vergniol). Amsterdam: Wolters, 1697.[49])

was a novel method of forming posterior calf flaps by transfixion, that is, penetrating by knife point in stabbing fashion, across the limb's diameter, close to the tibia and fibula, and cutting swiftly from within outwards and downwards to shape the flap. He used a curved knife which, it can be imagined, was less efficient than straight rapier-like blades employed for this technique in the 19th century (see Fig. 8.4); nevertheless, it was an advance which not only provided better cover for bone ends but, it has been shown, diminished pain when dividing soft tissues.[51] Verduin described no case observations, but it is apparent most amputations mentioned by him and a colleague were conducted for suppuration of the lower leg and foot, probably tuberculous in some instances and thus contrary to the advice of Yonge.

The soporifiic sponge and other prescriptions for dulling pain, apart from a dose of alcohol, disappeared from practice before the Renaissance and, as we shall discuss in Chapters 7 and 9, patients submitting to operations exercised remarkable stoicism and control without effective anaesthesia; this was illustrated by Ryder in the case of a boy who was only 9 years old, in Chapter 3. Another Ryder observation concerned a seaman whose foot was crushed severely by the truck of a recoiling gun; Ryder told him amputation was necessary:

"*. . . to which he readily agreed; so he hopp'd on one Leg to a Chest where sitting, I took it off, (he not expressing the least sign of pain or sorrow,) and afterwards when well, was by his Majesties favour made Cook of a Second Rate Ship.*"[52] (Frontispiece)

Summary

If surgical excision in the line of gangrenous demarcation hastened natural separation of mortified limbs and reduced suffering, it left a discharging wound which, at best, might heal only after several months to leave a fragile scar, prone to breakdown, and a stump often incapable of bearing an artificial limb. Later, more-aggressive removal of bone promoted closer apposition of skin margins which improved cicatrisation, yet these stumps remained fragile and often unsatisfactory for prosthetic fitting. In response to gunshot injuries, amputation through sound tissues, although more painful, was to produced healthier if slow healing. Eventually, flap amputations proved a key to better functional stumps, assuming the bone was not infected and discharged chronically, always a possibility before the chemical and thermal sterilisation techniques of the later 19th century.

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7
Elective Amputation: From the 18th Century to 1846

"The amputation of a limb is an operation terrible to bear, horrid to see, and must leave the person on whom it has been performed, in a mutilated and imperfect state; but still it is one of those which becomes, in certain circumstances, absolutely and indispensably necessary."

Pott, 1779[1]

In Chapter 6 we traced the introduction of elective amputation, hastened by revolutionary and destructive gunshot injuries, due principally to navy and army surgeons, and emphasised its haphazard and empirical evolution. From the 18th to 20th centuries, the contribution of military surgeons remained important but, concurrently, civilian practitioners, medical science and technology advanced more rational and humane solutions which escalated decisively during the late 19th and 20th centuries.

From the beginning of the 18th century until the discovery of general anaesthesia in 1846, patients continued to undergo amputation without satisfactory pain relief in what some have called the heroic era of surgery. If attempts to improve techniques took place, these were restricted by primitive surgical science based principally on detailed studies of anatomy, combined with gross pathology post mortem and simple chemistry. John Bell commented in 1801:

"Anatomy . . . is indeed the basis of medical education, the only one which will be acknowledged by any sensible and well informed man. Chemistry, physiology, pathology, all look back to the structure and functions of the human body, and twine themselves round this great trunk."[2]

As microscopes improved and pathological studies intensified, diagnosis became more accurate, resulting in improved operative techniques, equipment and instrumentation. If as a consequence advances were made to counter major haemorrhage and to improve the quality of amputation stumps, no permanent measures evolved to reduce the equally dangerous complication of lethal wound sepsis nor to abolish the pain of surgical operations. Of the positive contributions to amputation surgery, most involved new operative techniques devised by 18th-century surgeon-anatomists such as Dionis, Jean-Louis Petit, Heister, Cheselden, Le Dran, Benjamin Bell and Hey, whereas from midcentury agitation to change the timing of amputation or to avoid amputation became a particular debate of military surgeons such as Faure, Ravaton, Bilguer and Larrey. In addition, this period witnessed the first attempts to establish alternative operations to avoid the mutilation of amputation completely.

Controlling Haemorrhage

In 1708, Dionis rejuvenated Paré's work to prevent lethal haemorrhage by vessel ligation and strongly endorsed this over red-hot cauteries and astringents, which he considered not only more painful but more uncertain. He recalled the two methods proposed by Paré, either to isolate and pick up bleeding vessels accurately, for which Dionis advised the "crow's-beak" forceps, self-holding when closed by a spring or sliding ring, combined with a ligature beyond the forceps tip (Fig. 7.1) or,

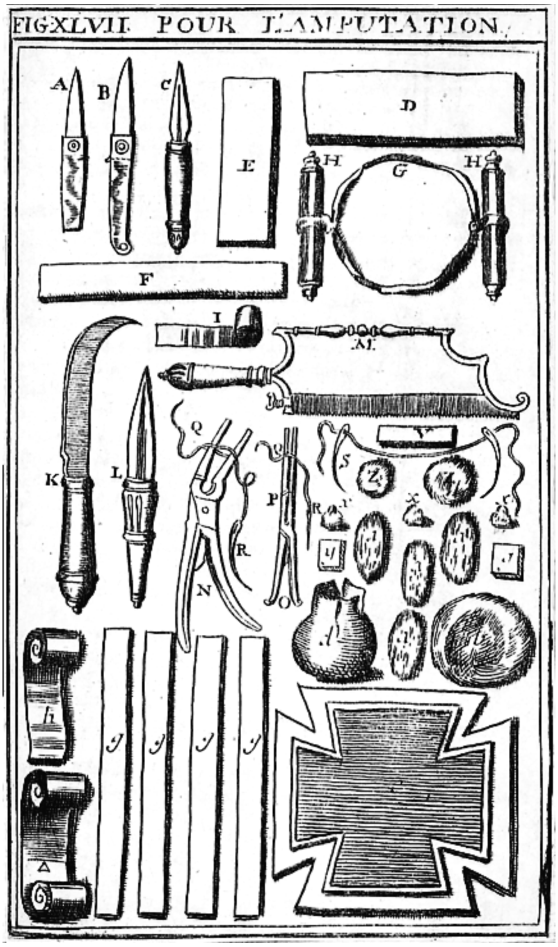

Fig. 7.1. Amputation equipment, Dionis, from 1708. *A, B, C, K, L,* various knives for small and large amputations; *H, G,* tourniquet with double twisting sticks; *M,* bow saw; *N, P, Q, R,* arterial forceps and ligatures; also various swabs and dressings. (From Dionis P. *Cours d'Opérations de Chirurgie.* Paris: d'Houry, 1750:744–745.[3])

alternatively, to thread needles at each end of a ligature, pass this around a vessel and then penetrate the adjacent skin to anchor the ligature over a small compress (see Fig. 6.5). Dionis found simple ligatures of the first method often failed being "loosened by arterial pulsation," and preferred the second ligature for its security and certainty, and also for ease of removal; before antiseptic practice, buried ligatures proved to be unsterile foreign bodies always prone to persistent infection and causing fresh bleeding.[3] Initially, surgeons were slow to discard cauteries and astringents but, by the end of the 18th century, most surgeons accepted vessel ligation as the only secure method of controlling haemorrhage of major vessels, including John Bell, who wrote against reliance on cautery (see Fig. 10.3) in 1801 as follows:

"Without reading the books of the old surgeons, it is not possible to imagine the horrors of the cautery, nor how much reason Paré had for upbrading the surgeons of his own time with their cruelties." and also, *"The horrors of the patient, his ungovernable cries, the hurry of the operator and his assistants, the sparkling of the irons, and the hissing of the blood against them, must have made terrible scenes, and surgery must in those days have been a horrid trade."*[4]

Bell was equally scathing of the application of caustics and corrosives to bleeding vessels, for they proved uncertain, dangerous and often deadly.

Before Petit introduced his revolutionary tourniquet in 1718, temporary control of major vessel bleeding at amputation was achieved by direct digital pressure on vessels or by means of a simple circumferential band around the limb, tightened by twisting a stick, the so-called Spanish windlass,[5] also mentioned in detail by Yonge in 1678.[6] Although some control was attainable by untwisting the stick to inspect bleeding points for ligature, the method remained clumsy and inefficient. Petit's invention was to control pressure by means of an integral wing-nut screw (see Fig. 5.5) which could be adjusted gently, up or down, ensuring safe visual evidence of bleeding, which could be stopped instantly by turning the screw.[7] Originally made of wood, the screw was soon replaced by an efficient brass model which dominated practice for more than two centuries, being still available during World War I. Heister, who wrote one of the most influential surgical works of the 18th century, having studied widely in Europe, described and illustrated Petit's tourniquet in detail, showing its application during amputation in the many editions and translations of his book (Fig. 7.2).

Le Dran, one of the first to analyse how best to disarticulate at the shoulder joint, ligatured the main vessels through an incision in the armpit before making the amputation.[8] Charles Bell agreed that this technique might be essential if the soft tissues and bones were damaged in the shoulder region, although when intact he

FIG. 7.2. Leg and arm amputations, dripping blood into large containers, with no obvious tourniquets; however, Petit's tourniquet is shown to *right*, and simple band tourniquets are seen in the leg drawings *above*. *Figs. 3, 4*, a guillotine amputation and use of the 'valet a patin' artery catch; *Figs. 5, 6, 7, 8*, Verduin's flap amputation including a healed stump which would be suitable for a kneeling peg-leg. (From Heister L, *A General System of Surgery*, London: Innys, 1743, plate 14.[68])

advocated thumb pressure by an assistant over the subclavian artery above the clavicle, until the humeral head was exposed when direct occlusion of the axillary artery with the surgeons' fingers was maintained against the humerus, until the divided artery was ligatured.[9]

Important anatomicropathological research by Jones, in 1805, recorded in his book *A Treatise on the Process Employed by Nature in Suppressing Haemorrhage from Divided and Punctured Arteries: and on the Use of the Ligature*, indicated that loosely applied ligatures which temporarily suppressed low-pressure bleeding failed to fracture the internal and middle coats of these vessels and often resulted in secondary haemorrhage as the blood pressure recovered; he stated many surgeons believed it was dangerous to ligature tightly and fracture these structures.[10] In fact, Jones proved by animal experiments that actual fracture of the inner coats was necessary to obtain secure adhesion of their surfaces, and it was this process which guaranteed permanent occlusion of arteries, assuming infection did not supervene. In parallel, he demonstrated the more elastic external coat did not fracture for its integrity was necessary to secure sound occlusion. He wrote:

". . . every operator should be acquainted with the force necessary to cut through the internal and middle coats of an artery: . . . this force is very slight, and the external coat of an artery is strong enough to allow the ligature to be tied tight, without it being cut through; . . . nor does there appear to be any reason for fear, that the external coat may ulcerate through before the internal coats have adhered, since we see from experiments, that their union is very soon effected."[11]

Jones also demonstrated that it was unnecessary to include soft tissues and nerves as anchors for a mass ligature of tape or other thick material, but to apply a single thread tightly and securely around the carefully isolated artery.

From the later 18th century, the hooklike tenaculum became a popular instrument for fixing a divided artery and pulling it clear of other tissues before ligature. Greater sophistication was provided by Assalini in 1812, when he devised a

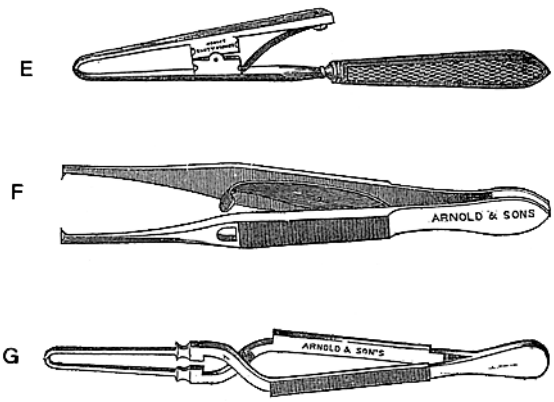

FIG. 7.3. Early 19th-century artery forceps. *E*, Assalini pivoting catch with self-holding spring; *F*, Liston's spring forceps with integral catch; *G*, cross-action spring forceps. (From Arnold's Instrument Catalogue, London: author, 1876.[69])

tenaculum artery forceps consisting of two limbs articulating by means of a pivot and self-holding by an integral spring (Fig. 7.3). By about 1830, the dissecting spring forceps was also adapted to self-hold by means of a variety of catch mechanisms, for the specific purpose of picking up arteries and other bleeding points accurately (Fig. 7.3). True crushing arterial haemostats were not devised until much later in the century.

Circular Operative Techniques

Early in the 18th century, an innovative amputation technique was introduced, the so-called circular or double incision, with the intention of promoting better stump healing (Fig. 7.4), although dispute surrounds its origin. Petit's posthumous surgical treatise, reprinted in 1783, claimed he was the first to incise the soft parts in two phases to gain adequate cover for the bone and sound healing[12]; Dieffenbach stated Petit introduced this double incision in 1718. On the other hand, Cheselden wrote in Gataker's translation and extension of Le Dran's treatise on surgical operations in 1749 that he suggested this method when still an apprentice, which Lister calculated must have been before 1711.[13] Cheselden wrote:

"The thing that led me to do this operation was what has too often happened, the necessity of cutting off the end of the stump a second time. This operation I proposed to my master, when I was his apprentice, but he treated it with neglect, though he lived afterwards to practise it, when he had seen me perform it in the same hospital."[14]

However, Louis in 1769 discovered whatever method was adopted to amputate through the thigh, including the circular approach, complications of an unhealed stump with protrusion of the femoral shaft (sugar-loaf deformity) often

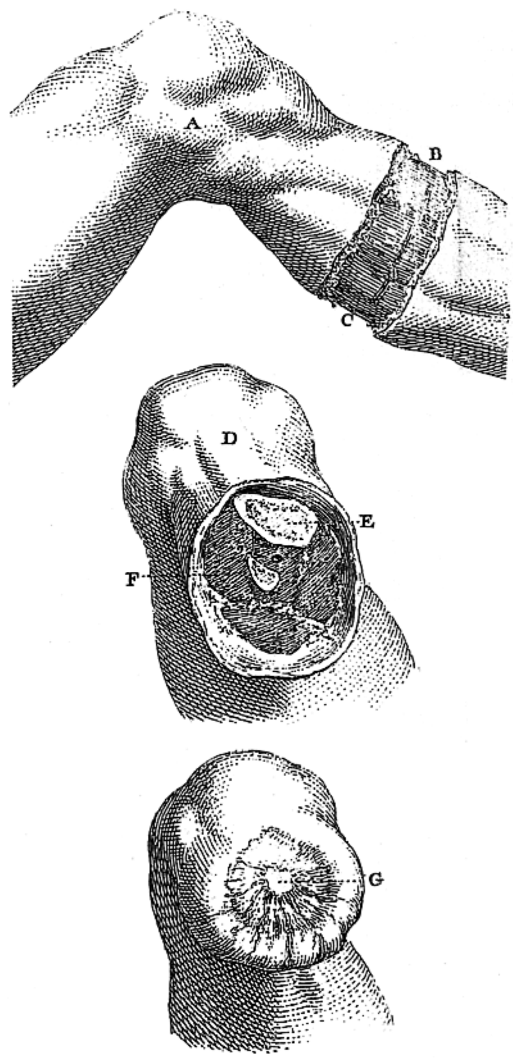

FIG. 7.4. Cheselden's double circular incision, suggested c. 1711, cutting muscles higher than skin; this was better than a simple guillotine section but slow to heal and, as *G* shows, producing a puckered fragile scar. (From Cheselden W. Observations by Mr. Cheselden. In: *The Operations of Surgery of Mons. Le Dran* (translation by Mr. Gataker). London: Clarke, 1768.[14])

necessitated a second "cutting," that is, bone section at a higher level. On anatomical grounds he considered the bandage or fillet usually tied between the tourniquet and the incision, to steady the soft tissues during incision, had the effect of preventing the large muscles of the thigh retracting and hence the femur was sawn through too low and too long. He advised, after the soft tissues were cut, all bandaging should be removed to allow maximal muscle retraction and a much higher section of the bone. Louis also observed the muscles posterior to the femur contracted much more than the anterior muscles attached intimately to bone, for which he made allowance in anticipation of preventing unpleasant "sugar-loaf" formation with bone protrusion.[15] Much later, Lister concluded this approach still left the bone covered by a thin scar, unsuitable for a prosthesis.[13] For thigh amputation, Alanson also modified this circular technique by a second incision through the muscles obliquely, attempting to release them from bone at a higher level than usual and form a cone-shaped stump cavity. He concluded, by this mode of "double incision," the wound:

". . . may in some degree be said to resemble a conical cavity, the apex of which, is the extremity of the bone; and the parts thus divided, are obviously the best calculated to prevent a sugar-loaf-stump."[16]

By contrast, for section through the shin, Alanson preferred the flap operation, as did his colleagues Lucas of Leeds and White of Manchester.[17]

For thigh amputation Gooch wrote in 1767:

"Surgeons have long complained of the great inconveniences attending a want of flesh, to cover the end of the bone in amputation above the knee, by which the cure is much retarded: and the stump being left in a conical form when cured, is more liable to external injuries ever after. In order to prevent these inconveniences many methods have been proposed and tried, which have not fully answered the end. In Pl. 14 is the figure of a retractor made of firm, strong leather which I invented and first used in 1739, and am convinced by repeated trials, it will effectually answer the purpose . . ."[18]

Benjamin Bell used a similar retractor and also paired metal retractors in 1787 (Fig. 7.5) and, similar to Gooch, reported acceptable healing but, it is probable, with less stump protection for a prosthesis than flap methods were to provide. Bell

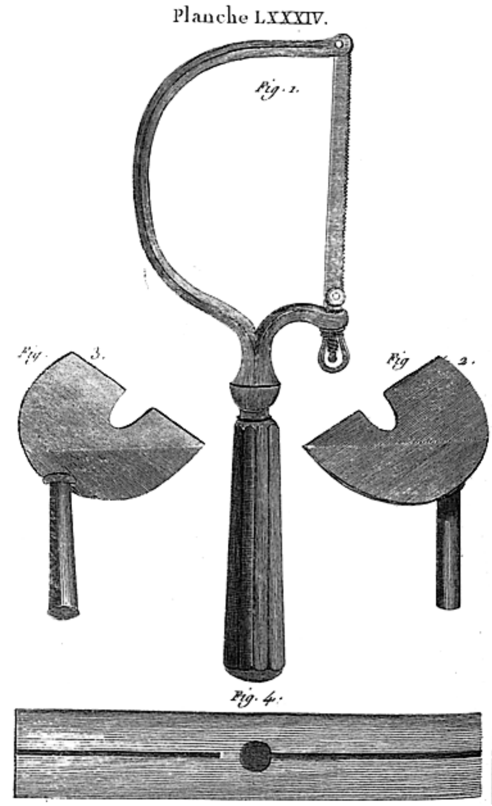

Fig. 7.5. *Fig. 1*, small bow saw for amputations of the hand and foot; *Figs. 2 and 3*, metal amputation retractors for shielding soft tissues of thigh and upper arm during sawing; *Fig. 4*, leather strip for assistant to fit over bone and retract soft tissues during sawing; recommended by Benjamin Bell, 1796. (From Bell B. *Cours Complet de Chirurgie Théorique et Pratique*, vol 6 (translated by E. Bosquillon). Paris: Barrois, 1796.[19])

maintained that Cheselden's circular incision applied to the thigh might take 3 to 6 months to heal whereas, since 1772, he had elaborated this method by additional detachment of muscles from the femur, for at least an inch, to obtain a higher bone section, improved soft tissue cover and thus healing in 3 weeks.[19] At this time, Bell claimed all techniques had improved so remarkably that 19 of every 20 amputations healed. Hey in 1803 approved of Bell's method for the thigh and upper arm, calling it the "triple incision." He explained:

"By a triple incision I mean, first, an incision through the integuments alone; secondly, an incision through all the muscles, made somewhat higher than that through the integuments; and thirdly, another incision through

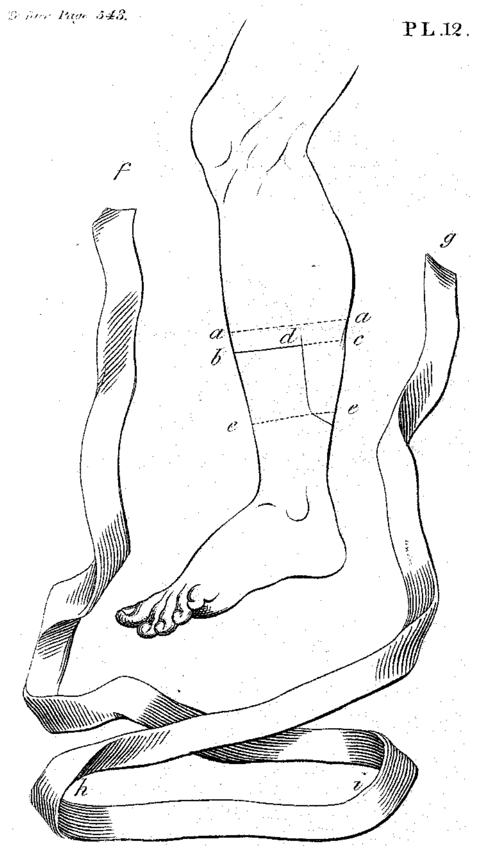

FIG. 7.6. Hey's method of calculating where to amputate through the shin, 1814; *a–a*, midpoint of shin for bone section; *b–d–e*, skin incisions, the flap being one-third of the circumference; *e–e*, guide to flap length; *f–g*, measuring tape. (From Hey W. *Practical Observations in Surgery, illustrated by cases.* London: Cadell, 1814.[20])

that part of the muscular flesh which adheres to the bone, made round that part of the bone where the saw is to be applied. When these incisions are made in their proper places, the integuments and muscles on the opposite sides will meet each other conveniently; and may be preserved in contact so as to produce a speedy healing of the wound . . ."[20]

Hey went on to explain how the exact location of incisions could be calculated in relation to differing diameters of limbs, although with respect to below-knee amputation, Hey recommended a posterior flap incision and, to estimate its length, he advised inking the skin after accurate measurements of limb circumferences, as opposed to diameters, using a marked tape or ribbon which, he stated, were sold in shops in small ivory cases.[21]

This is one of the earliest attempts to calculate soft tissue flap dimensions in proportion to the limb and mark them out on the skin before incision (Fig. 7.6).

Flap and Transfixion Amputations Resumed

Towards the end of the 17th century, when Yonge and Verduin described the formation of soft-tissue flaps, they anticipated below-knee stumps would heal more rapidly. In the early 18th century, Verduin's operative technique was supported enthusiastically by Garengeot with detailed illustrations including the transfixion technique demonstrated with his left thumb and fingers dangerously handling the blade point! (Fig. 7.7). O'Halloran also practised a flap technique in order, he claimed, to avoid infection by bandaging each flap separately for 12 days or so when contact between them was said to produce uneventful healing; on reviewing this unusual technique Alanson was sceptical.[17] It remained a general practice of most surgeons to adopt the circular incision of Cheselden for, until late in the !8th century, most major amputations took place at shin, thigh, upper arm or forearm levels where the circular incision was possible, even if healing was slow and might require excision of protruding bone. However, the adoption of bolder amputations at shoulder or hip levels, or through the hindfoot or ankle, inevitably involved the fashioning of flaps to cover the extensive soft tissue wounds produced, for it was plainly impossible for circular incisions at these challenging levels to be approximated without severe skin tension, often causing stumps to remain open wounds. Le Dran, who gave an early description of amputation at the shoulder joint in 1742, provided a clear description of the formation of flaps required to close the gap held open by the intact joint (glenoid) concavity.[8] About 1787, Chopart devised a disarticulation of the foot through the midtarsal joint, making use of a large flap of plantar skin and soft tissue to close the wound (see Fig. 11.1).[22]

The question of disarticulation at the hip was raised from time to time in the 18th century but rarely undertaken, usually leading to the patient's death. As Samuel Cooper wrote in 1822:

FIG. 7.7. Transfixion method of constructing below-knee posterior flap; the surgeon's left hand is steadying the blade somewhat dangerously, perhaps to ensure the flap is cut squarely in a downward direction. (From Garengeot RJ. *Traité des Opérations de Chirurgie*, vol 3, Paris: Cavelier, 1731:404.[70])

"The very idea of this formidable operation, for a long while, checked the hand even of the most ready advocate for the use of the amputating knife, and every mind shuddered at so extensive a mutilation. Still, it could not be denied that the chance of saving life occasionally depended upon a submission to the greatest temporary suffering, and that without the most cruel of sacrifices, the preservation of the patient was totally impossible."[23]

Cannonball destruction of the upper thigh was recognised as an indication for most of the earliest disarticulations although the mortality was high, almost certainly due to a shocked condition before operation and to an agonising ordeal for the conscious victims, not to speak of latent infection if patients survived long enough. In a memoir published in 1845, Cox described a successful case of disarticulation at the hip following chronic infection of a previous midthigh amputation and reviewed the known cases published in medical literature. Of a total of 84 patients, 26 were considered successful and 58 unsuccessful (69% mortality).[24] The majority had suffered gunshot injury in battle, until about 1820, when more civil cases were recorded, mostly with either malignant bone tumours or extensive chronic infection of the femur. Cox noted Blandin reported 3 cases in 1794 of which 2 survived, whereas of Larrey's 7 cases only 1 was successful, in 1812.[25] After the siege of Cuidad Roderigo, Spain, in 1814, Guthrie recorded a failure, but at the battle of Waterloo in 1815 he was able to report a successful case.[26] Most of these amputations made use of external and internal soft-tissue flaps to cover the joint cup (acetabulum), exposed after disarticulating the femoral head, but Cox employed anterior and posterior flaps (see Fig. 8.2). Even with general anaesthesia this major operation remained hazardous, lacking a remedy for traumatic shock, combined with difficulties in controlling postoperative bleeding and in preventing infection.

In 1815, Lisfranc introduced amputation of the foot through the tarsometatarsal joints, requiring the formation of flaps, the most important being the inferior flap with its weight-bearing skin (see Fig. 10.10).[27] Lisfranc's procedure was also important for introducing straight narrow knives to facilitate division of the small joints between the closely fitting bones of the foot, which also promoted the transfixion formation of large flaps (see Fig. 10.9).

A further soft-tissue flap modification was highlighted by Scoutetten, in 1827, termed by him "la methode ovulaire" or the elliptical incision for disarticulating operations.[28] Firstly he attributed this incision to Langenbeck for excision of metacarpals and metatarsals in 1807, then to Guthrie for his method of scapulohumeral amputation in 1815 and also to Abernethy for disarticulation at the hip joint. Scoutetten described elliptical incisions for the hip, shoulder and for the removal of fingers and toes only, which were then sutured in a straight line. In the case of the hand and foot, these incisions resemble what is now known as racquet incisions. As yet few surgeons practised flap procedures for amputations through the shin, thigh or arm, for most surgeons clung to the circular method or modifications of this. Even in 1837, Bourgery spoke for many who favoured the circular incision for thigh amputation, in the belief flaps produced large raw surfaces and thus were more likely to become infected than smaller wound surfaces based on circular techniques. Bourgery described many variations of the circular method, favouring B. Bell's triple incision. Bourgery advised that when flaps were made, those orientated laterally should be avoided in favour of anteroposterior flaps.[29] In the same year, Liston demonstrated in his book *Practical Surgery* the advantages of forming such flaps, with long slender knives, by limb transfixion in spearlike action, anterior and then posterior to the bone or bones of the limb to cut flaps from within outwards (see Fig. 8.4). He advised:

"Many amputations can be best performed by cutting from the centre to the surface of the limb, in others, part of the incisions may be made with advantage from without, and completed by cutting from within; others, again, may be performed very well, by cutting from the periphery towards the bone or joint. The incisions from within outwards, are more quickly performed, and give less pain then those in the opposite direction."[30]

Syme too believed these transfixion flaps caused less pain, mainly because the operation was much more rapidly performed.[31] Wangensteen and Wangensteen reported that flaps fashioned from within outwards were in fact less painful, proved by Lennander's research, when he operated under light or local anaesthesia in 1902.[32] Liston was the first surgeon in Britain to amputate a limb under ether anaesthesia in December 1846, when a man of 36 years ill with chronic, painful disease of a knee underwent above-knee amputation; although the patient felt no pain, Liston operated with his usual speed taking some 25 seconds (see Fig. 8.5), but the skin flaps were left unsutured until several hours later when bleeding had ceased; this was however painful for his patient. Subsequently the wound suppurated but the patient was discharged well 53 days later.[33] Thanks to anaesthesia, flap techniques were developed for most amputations with the exception of emergency amputations for mass battlefield casualties when it was considered circular incision and open drainage were more appropriate; indeed at the beginning of the 21st century, this method is still advised.

An important modification of below-knee amputation, making full use of a large soft-tissue flap, was introduced by Syme in 1842 for eradicating bovine tuberculosis of the subtaloid joint, that is, the foot joint immediately distal to the ankle.[34] Syme reasoned that if the thick skin of the heel region could be preserved then weight-bearing on the stump was a possibility and mutilation at a higher level would be avoided. His first patient presented with advanced disease producing discharge from the subtaloid joint, but responded well to excision of the foot and ankle malleoli, subsequently weight-bearing on the stump without difficulty (see Fig. 13.10). Syme's second case was a very ill university professor who underwent excision of the foot and also the articular surfaces of the ankle joint in 1843. Three years later, the patient wrote:

"I can lean the weight of my body on the naked stump without inconvenience; and, with a single stocking over it, am in the habit of walking through the house, when my boot is not at hand." Commenting on his boot he said: *"There are no straps or buckles, or steel supports of any kind, nor are they needed. From the bulbous form of the stump, and its circumference being considerably greater than that of the leg above it, the lacing of the upper leather completely suffices to hold the articial foot on. It would be impossible, indeed, to pull it off without loosening the lace or tearing the leather."*[35]

Symes' conservative amputation provided excellent function and, although often inappropriate in the presence of vascular disease, became established not only for foot joint infections but for mutilating injuries of the foot, proving an important amputation during World War II.[36] Despite its weight-bearing advantages, many limb-fitting surgeons claimed it was impracticable to provide prostheses, as noted in Chapter 13.

Military Surgeons Question Immediate Amputation

Petit's tourniquet emboldened surgeons, particularly in France, to amputate more readily, especially when operating without trained assistance.

Dionis' popular work on surgical operations emphasised the necessity of immediate amputation to save life, stating it was better to live with three limbs than to die with four.[37] In this he was supported by the equally influential Le Dran, also in Paris. Despite their teaching, the 18th century witnessed growing resistance to immediate amputation, led not by patients or society but by military surgeons who either totally opposed amputation for gunshot wounds to pursue more-conservative measures, assuming the patients survived or, alternatively, delayed amputation until their condition improved.

One of the fiercest opponents of amputation was Bilguer, a Prussian military surgeon with a large hospital at his disposal who treated survivors conservatively over many months or years, often to achieve wound healing but usually at the expense of fracture malunion and poor function. Unfortunately, Bilguer's diatribe on the inutility of amputation provided scanty clinical and statistical evidence to back his opinion that gangrene did not require amputation under his care. His regimen subjected gangrenous limbs to repeated linear incisions down to living tissues, followed by at least one daily (painful) dressing to encourage separation of dead tissues and prolonged gradual healing by granulation. If suppuration reached bone then he was prepared to amputate, but he does not tell us how many amputations were performed. In the five cases where healing is detailed, this took, 4, 8, 9, 10 and 24 months, respectively, mostly with the patient confined to bed.[38] He admitted:

". . . this method of curing limbs . . . is accompanied with a great deal of pain, with murmurs and impatience on the part of the sick; that it requires a very judicious surgeon, and gives him an abundance of trouble, care and anxiety; besides I do not pretend that every patient was saved by it."[39]

He stated that at one time he had 6618 wounded under his care of which 5557 were perfectly cured, 195 partially recovered for garrison duties, 213 were incapable of any work and 653 died. He noted all patients with gunshot wounds of the upper femur died, but otherwise we are left in the dark about the numbers and site of gunshot wounds treated expectantly. It is astonishing he denied amputation was necessary for gangrene, carious (tuberculous) joints and limb cancer, suggesting no other operative procedure, for he relied entirely on medication and local applications. In any event, few surgeons benefitted from Bilguer's exceptional hospital resources, especially when engaged on battlefields, whilst many patients did not have the courage to accept what was often painful treatment extending seemingly without end. Nonetheless, his *Dissertation on the Inutility of the Amputation of Limbs*, translated into English in 1764, began to raise doubts in some quarters and effect more-careful triage of the injured for amputation.

Earlier Faure, an army surgeon, had won an essay competition of the French Royal Academy of Surgery on the question of gunshot wounds complicated by fractures, which concluded delayed amputation was best, based on evidence accumulated at the battle of Fontenoy in 1745. Faure found only 30 to 40 men survived immediate amputation of 300, whereas all 10 soldiers who submitted to delayed amputation at 29 to 52 days survived. This essay was abstracted and commented on by Boucher,[40] who was another military surgeon at the battle of Fontenay. He reported the healing of 12 musket wounds associated with fractures which, in many circumstances he claimed, would have been subjected to immediate amputation, although he stated urgent amputation was always needed for severely traumatic cases due to cannonballs and grapeshot.[41] Later, Boucher modified this message to dispute Faure's dissertation, claiming that Faure's immediate amputations were not immediate enough whereas, at Fontenoy, Boucher saw 4 survivors of 9 emergency battlefield amputations, which justified his support of immediate operation.[40] Despite Boucher's somewhat confused reports, Thompson gave him credit for pointing out, more distinctly than preceding authors, three different clinical periods after gunshot wounds: firstly, before the onset of fever or deterioration of general condition, which period might last a few hours or a few days; secondly, the period of complications, which might last weeks if death did not supervene; and thirdly, a period when complications resolved or did not threaten the patient's general health. Boucher considered the first period the most advantageous for amputation, the second period extremely hazardous, and the third period propitious but less successful than the first period.[42]

Prominent injured surgeons who escaped amputation themselves also contributed to this debate. For example, Pott, a leading London surgeon who sustained a compound fracture of his shin in 1756, recommended for immediate amputation, was at the last minute managed conservatively with success.[43] Yet, Pott wrote forcibly against the thesis of Bilguer, saying:

"The writer, as well as the annotator [Tissot], *may have meant well; but certain I am, if their opinions were generally followed, mankind would be great sufferers."*[44]

Nonetheless, Bilguer's work encouraged doubters, such as John Hunter who was impressed with delayed treatment of several French wounded soldiers seen on Belle Isle, his only experience of gunshot injuries, after they had hidden and survived untreated for some days before capture. He wrote:

"The only thing that can be said in favour of amputation on the field of battle is, that the patient can be moved with more ease without a limb than a shattered one: . . . I say, that few did well who had their limbs cut off on the field of battle; while a much greater proportion have done well, in similar circumstances, who were allowed to go on till the first inflammation was over, and underwent amputation afterwards."[45]

When Larrey reviewed the timing of amputation for gunshot wounds, he concluded that when undertaken immediately for severe injuries, it often saved lives and, based on his experience in the Napoleonic wars, Guthrie, Britain's leading military surgeon, recommended immediate amputation for all compound fractures of the lower extremity but a less-radical approach for compound fractures of upper limbs.[46]

After the Napoleonic conflicts, Hennen came to similar conclusions and was particularly antagonistic to Bilguer's advice, observing:

"M. Bilguer inflicted a tenfold proportion of pain, and exposed his patients to an incalculably greater degree of danger than if he had removed their limbs at once. Fortunately for the contending armies of modern times, this specious inhumanity has now nearly passed away: surgeons no longer hesitate, and even patients appreciate their motives justly, and attribute the loss of limbs to the fire of the enemy rather than the incision knife of their friends."[47]

When reviewing the wounded in hospitals after Waterloo, Thomson was also critical of Bilguer's dissertation, noting that:

". . . [he] seems to have met but little difficulty in curing mortifications of the extremities; and it is equally difficult to reconcile the horror which Bilguer expresses at the slightest incision in amputation, with his recommendation of those free and extensive incisions which he practised in the treatment of mortification." And: *"The account which Bilguer has given of his practice, wants all that minuteness of detail which could give it interest or render it useful. With an appearance of accuracy as to the comparative number of those who died with and without amputation, he leaves us in complete ignorance of every circumstance upon which it is possible to found anything like a rational judgement, with regard to the advantages or disadvantages of his practice."*[48]

Alternative Procedures to Amputation

After Waterloo, Larrey, reduced in rank to become Honorary Surgeon to the Hospital of the Old Guard, treated 12 successive compound fractures with local dressings of styrax (benzoin), compresses of wine or vinegar and splinting; the dressings were changed only once or twice during wound healing.[49] Despite these successful conservative measures, avoiding amputation completely, these cases had no perceptible influence on wound care, despite Biencourt's claim in 1873 which concluded Larrey had changed the management of compound fractures radically.[50]

Wangensteen and Wangensteen also commented on the earlier excellent results of Bennion in dressing compound fracture wounds with tincture of benzoin. However, this information is only known through the conversation of an eyewitness, a Mr. Davies who told the surgeon Adams that, by comparison, other surgeons in the same area had poor results; Bennion published no account of his methods.[51] Bryant confirmed the efficacy of tincture of benzoin dressings in reducing the mortality of compound fractures in 1876,[52] having been preceded by Lister and others with more active remedies.

In this context, a much earlier report, by Crowther in 1802, of the healing of 28 consecutive compound fractures without an amputation is astounding.[53] Most of his patients sustained significant open wounds in mines, factories, and quarries around the manufacturing town of Halifax, elsewhere subject to routine amputation. Crowther applied dressings impregnated with wood tar to all compound fractures, a routine remedy handed down by his family for generations and found to avoid infection and gangrene. His two brothers, also in the practice, had similar experience over the same period, as each brother took their turn on call, although their patient numbers are not recorded. Later analysis showed that wood tar, obtained from beech wood, contained cresol, phenol and other related antiseptics. Sadly, this major advance in prophylactic care was not subject to further comment and appears to have been ignored beyond the innovators.

Ligation of major arteries to reduce enlarging aneurysm is first attributed to Antyllus in the 2nd century A.D. and, after a very long interval, to Anel in 1710, who ligatured a brachial artery proximal to, that is, above, the swelling. In 1785, proximal and distal ligatures of the femoral artery were undertaken by Desault, proving unsuccessful; Deschamps performed a similar procedure in 1799, with early death of the patient.[54] John Hunter, in addition to counselling an expectant policy for major compound fractures, also sought to avoid amputation for progressive popliteal aneurysm by proximal ligature of the femoral artery. His first patient in 1785 recovered to return to work, and his fourth patient in 1787 lived another 50 years, donating his limb for dissection and examination; this specimen is displayed in the Hunterian Museum of the Royal College of Surgeons of England.[55] High femoral aneurysms required ligation of the external iliac artery and was performed in 1796 by Abernethy, who divided the artery between ligatures with success; subsequently some patients developed ischaemia of the foot and lower leg and required amputation for this complication of an otherwise life-saving ligature.[56]

At this time another pioneering procedure to circumvent amputation was publicised when Park excised the diseased joint surfaces of a knee infected by tuberculosis, normally amputated for severe pain and gross infection. The patient, a sailor, underwent this novel operation in 1783 and subsequently the knee fused in a straight position, enabling him to return to sea. Park also excised an elbow joint and, expecting ankylosis, was surprised to see the patient recovered useful mobility and reasonable function.[57] Initially, joint excision made slow progress because of problems in determining what degree of disease was suitable, technical difficulties, especially in sawing bone close to the joint, and also because it was a longer and therefore more-painful procedure than amputation. However, once the chain saw had been designed and refined to pass behind joints,[58] resection became less traumatic whilst the introduction of anaesthesia ensured its future as a major reconstructive operation, culminating in the later 20th century by replacement of the excised articulations with artificial joint prostheses. In advocating joint resection, Park's cases were followed closely by Moreau's[59] and, in 1831, by Syme, who described 20 cases. There were similar sporadic reports until anaesthesia promoted this technique, stimulating major treatises by Culbertson and Ollier in the later 19th century.[60] When Syme made a plea for the efficacy of joint excision, he wrote:

"Owing to the improvements of modern surgery, more particularly in the treatment of aneurism, fractures, and necrosis, amputation of the extremities is now very seldom performed in civil practice, except in cases of disease or injury of the joints." And: *"The great recommendation of excision is, that it saves the patient's limb; and the benefits accruing to him from this are so important and conspicuous, that, unless the objections which can be urged against it should appear after mature consideration to be very serious indeed, we ought not to hesitate in giving it the preference."*[61]

Syme performed knee joint excision twice, in 1829 with success and in 1830 followed by death of the patient after 11 days. Whether Syme's experience was a factor or not, Butcher maintained knee excision faded from practice after 1830 until taken up again by Fergusson in 1850, to stimulate a steady stream of excisions, at least in Britain and Ireland. In 1855, Butcher reported that before 1830, 19 knee excisions had been performed worldwide, resulting in 11 deaths (68%) whereas, between 1850 and the end of 1854, 31 knee excisions were traced with 5 deaths (16%) and 1 failure (3%) leading to amputation, with 7 (23%) still under treatment. By 1850, general anaesthesia encouraged positive intervention and early complete excision, likely to improve results. He compared these figures with the results of thigh amputation for diseased knee joints, undertaken firstly at University College Hospital, London, reported by Erichsen, where of 34 amputations, 7 (20.5%) died and, secondly, in the Parisian hospitals, reported by Malgaigne, where of 153 amputations 92 (60%) died.[62]

Although the dilatation of missile tracks, to encourage drainage of blood and pus, goes back to at least Paré, this was often associated with tight wound packing which aggravated infective stasis as Belloste noted in 1696, thus precipitating desperate last-ditch attempts at amputation.[63] Apart from missile extraction, little change took place, and indeed surgeons such as John Hunter opposed interference with the wound as dangerous until Percy advised free incisions to relieve swelling, wound tension and its complications; Larrey also favoured what became known as debridement.[64] After visiting the military hospitals after Waterloo, Charles Bell made it clear any survivors with shattered upper limbs and infected wounds, especially after bullet wounds, faced protracted treatment or amputation, and were best dealt with by long incisions down to bone to open infected tissues and permit proper drainage. He wrote:

"*. . . make deep and long incision down to the fractured bone, pick away the loose pieces; let those which are long and adhering to the membranes remain till thrown off by the suppuration; dress the wound with lint dipped in oil, so that the lips of the incision do not contract, nor the matter and slough be in the slightest degree retained; lay the limb on a wooden or tin splint, and apply wet cloths to the whole extremity. That the cure will be slow must be a necessary consequence, but the evils already enumerated will be avoided, and instead of years of suffering in the state represented (plates VIII and IX)* (Fig. 7.8)*, or the loss of the arm, the patients will preserve a useful member.*" And also: "*The Russian soldiers in the hospitals around Paris at the end of the war, were treated in the manner I have describe, and their wounds, when compared to the state of the limbs of those who had been treated differently, proved in a very marked manner the superiority of the practice.*"[65]

Subsequently, incisions to drain dead and infected tissue met growing disapproval and in 1848, of 12 leading French surgeons debating the management of war wounds, only 1, a pioneer of the Napoleonic campaigns, believed in the merits of debridement. Of course it was true that, before antiseptic measures evolved, incisions with unsterile instruments and the application of unsterile dressings risked introducing bacterial contamination; the same could be said of missile extraction attempts which, nevertheless, met general acceptance.

Meanwhile, Brodie instituted a new method of treating chronic bone abscesses of the tibia which could be intensively painful, day and night, causing patients to demand amputation. In 1828

Fig. 7.8. Soldiers with infected bullet wounds after the Battle of Waterloo; on the *left* the inflammation is moderate but on the *right* advanced with much granulation tissue affecting the soldier's general condition; long drainage incisions were recommended, hopefully to avoid amputation. (From Bell C. *A System of Operative Surgery*, vol 2. London: Longman, 1814: plates VIII, IX.[65])

he reported that if the position of the abscess was carefully identified, the bone could be drilled and the abscess cavity opened with a small trephine to relieve the painful tension instantly, often promoting permanent cure.[66]

Technological and Peri-Operative Factors

The evolution of materials has had a profound effect on surgical instrument innovation, including the gradual refinement of amputation knives and saws, a subject examined in detail in Chapter 10. The production of crucible or cast steel in 1750, that is, steel of uniform mix without imperfections, initially for the manufacture of superior watch springs, eventually entered surgical instrument manufacture, and by the early 19th century, narrow, slimmer and sharper blades replaced the thick, heavy curved blades of the 18th century. Crucible steel also promoted manufacture of flat tenon saw blades, much less prone to breaking than narrow bow saw blades, and also produced quality spring forceps with sophisticated catches and slides to act as precise arterial forceps. In 1840, the Elkingtons discovered electrolytic silver plating of copper, which made the manufacture of solid silver probes and wound drainage tubes much cheaper.

In addition to new anatomical approaches and operative innovations, assisted by better instruments, a few surgeons attempted to improve amputation results by changing interoperative management and postoperative care. Alanson achieved acclaim for a consecutive series of 35 amputations performed without a death, in a city hospital, normally a source of high mortality, reported in 1782. In part, this was the result of careful use of the circular or double incision of the soft tissues, high bone section, skin approximation with adhesive tape to allow free drainage of the stump and careful bandaging but, more importantly, he devised a hygienic ward regimen. This system included isolation of surgical cases, frequent changes of bed-linen and patient's clothing, admission refusal for all ulcerated cases, isolation of gangrenous patients and, remarkably, oven-baking of clothes and linen of all infected cases.[67] Unfortunately, few surgeons proved capable of repeating his results, probably because of lack of strict ward discipline.

Summary

If, in this period, progress was accomplished in overcoming blood loss during major operations, life-threatening haemorrhage remained a constant phobia of postamputation surgery, especially above the elbow and knee, whilst measures to control stump infection made virtually no headway. Indeed, the fear of disabling and lethal sepsis with inability to relieve pain remained significant obstacles to major surgical procedures until the mid-19th century, when anaesthesia and chemical sterilisation introduced scientific surgery. In principle, amputation depended on mastery of anatomical detail, speed and improved instrumentation. For some, at this time, less crippling alternative procedures began to emerge.

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8
Elective Amputation: From 1846 to Recent Times

"... that, while the surgeon endeavours to avoid Scylla, he may not unwittingly run into Charybdis, mutilating a limb that might have been saved, and endangering life by the retention of one that should have been promptly amputated."

Gross, 1862[1]

"For it is not necessary ... that pus should be generated in wounds. No error can be greater than this."

Theodoric, c. 1267[2]

Revolutionary changes in the past 150 years have rendered operative surgery acceptable to patients, previously terrorised by pain, hazarded by blood loss and uncontrollable debilitating and lethal wound infections. At the same time, operative capabilities have spread an ever-widening net of endeavour to all parts of the body, from foetuses in utero to the elderly, severely injured and moribund, and although amputation remains a final solution for some, this now produces better functional stumps backed by increasingly sophisticated prostheses, often facilitating near-normal activity for amputees.

The Control of Pain

The acceptance of ether inhalation anaesthesia in 1846 is a watershed in the history of medicine, assuring patients the balm of pain relief and providing surgeons more time to perform operations accurately. Its success spread like wildfire, on a worldwide scale, in contrast to the halting application of antisepsis and asepsis, equally important to the development of safe surgery, to be debated later. No attempt is made to detail the development of general anaesthesia, a major subject in its own right, yet it is appropriate to discuss earlier attempts to relieve pain during major operative procedures including amputations.

Today's patients, familiar with aspirin and anaesthesia, have difficulty comprehending the acceptance of pain by our forbearers, especially in assenting to major operations such as lithotomy and amputation, even if we understand that patients were making a choice between impending death and possible survival. Doubtless there were many who could not countenance such operations and awaited inevitable death.[3] Nevertheless, our ancestors, and indeed some nonindustrialised societies today, appear to have resigned themselves to a life attended by pain and suffering, perhaps bolstered by a philosophy based on religious or tribal convictions. Meschig who observed trepanation, in 1980, without anaesthesia among certain tribes in Kenya for persistent headache, with locally made tools, extending over many hours, and often over many sessions, concluded:

"Africans are more capable of withstanding pain than Europeans, for they do not expect sympathy or pity from their fellows even if they complain."[4]

In Christian communities, many believed St. Paul's words in the Bible, literally:

"Beareth all things, believeth all things, hopeth all things, endureth all things."[5]

A late 18th-century manuscript described the reaction of Laura, a 9-year-old girl of an aristocratic family, who underwent thigh amputation for a painful tuberculous knee bearing this without a murmur, holding a bunch of flowers throughout, until the femoral artery was ligated when she cried "Oh!" She maintained two texts supported her ordeal: "*. . . through much tribulation you must enter into the Kingdom of Heaven*" and "*. . . if we suffer with Him we shall reign with Him.*" She also expressed great delight to think amputation took place on Maundy Thursday in Passion Week, by suffering thus to be tested like her Saviour.[6] And in 1844, Harriet Martineau when an invalid wrote on this theme, stating the:

"*. . . supposition—indispensable and, I believe, universal,—that pain is . . . ordained for, or instrumental to good.*" and acute pain can be: "*. . . vivifying and cheering.*"[7]

Knowledge of pain-relieving plant remedies has a long history; for example, the mandrake (mandragora bark in wine) was known to Dioscorides in the 1st century A.D. as safe in moderate doses "*. . . but being too much drunk, it drives out ye life.*"[8] Similar remedies and mind-blowing botanical drugs are still known among hunter-gatherer communities. By the 12th century A.D., a concoction of drugs was recommended as a soporific sponge by Michael Scott, who wrote:

"*Take of opium, mandragora and henbane, equal parts. Pound and mix them with water. When you want to saw or cut a man, dip a rag in this and put it to his nostrils; he will soon sleep so deep that you may do as you wish.*"[9]

Sadly, the patient often slept too well and perished. Hugh of Lucca's similar remedy was described by Theodoric as:

"*A decoction of opium, unripe mulberry, hyoscyamus, spurge flax, mandragora, hemlock, lapathum, ivy and lettuce seed, sponge soaked and dried, moistened with warm water and vapour inhaled by nostrils; resuscitation by another sponge dipped in fresh vinegar.*"[10]

Unfortunately, these remedies lacked accurate control of the dosages, for chemical assay did not exist until the 19th century. Further, many components were imported laboriously, especially to Northern European countries, leading to deterioration and possible adulteration of the products, or substitution, as Morson, a 19th-century authority on the manufacture of morphia from opium indicated; on purchasing opium cakes in the London docks, he took the precaution of thrusting a knife into them to exclude any substitution with wood.[11] Uncertainty about opium's efficacy condemned Horatio Nelson, whose right arm was amputated at Santa Cruz in 1797, to its prescription after his operation, not before (Fig. 8.1). His surgeon Thomas Eshelby reported:

"*Compound fracture of the right arm by a musket ball passing through a little above the elbow and artery divided. The arm was immediately amputated and opium afterwards given.*"[12]

However, Watt has reported that some 18th-century naval surgeons employed opium liberally, including preoperative use.[13]

Even so, other surgeons stated preoperative prescription, sufficient to allay pain, usually induced nausea and vomiting which interfered with operative procedures. Moore, a civilian surgeon claimed that for amputations:

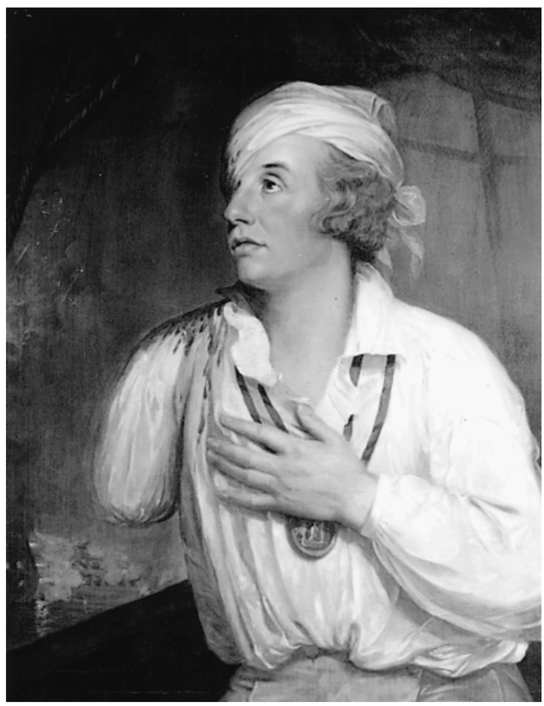

FIG. 8.1. Painting of Lord Nelson dressed after a scalp wound sustained at the Battle of the Nile, in 1798, also showing his right arm stump following injury at Teneriffe in 1795; blood has dripped from the scalp onto his right shoulder. (© National Maritime Museum, London, UK)

"The strongest dose we dare venture, has little or no effect in mitigating the sufferings of the patient during the operation."[14]

In the 20th century, the surgeon Wangensteen confirmed that, in addition, individual sensibility might vary considerably after a standard dose when he wrote:

"The senior author has seen a man of seventy-five remain in coma for four days after administration of one quarter grain (16 mg) of morphine."[15]

Alcohol is frequently mentioned in connection with amputations, opinions varying as to its object and any efficacy. Moyle, a naval surgeon when performing amputation on a sailor, wrote in 1693:

"*. . . give him a Spoonful of Cordial to cherish him . . .*" and also: "*. . . have a Cordial Bottle ready at hand to relieve men when they faint.*"[16]

In the Royal Navy, patients were often given a tot of rum and a piece of leather to bite on before an operation, suggesting the alcohol was to stiffen resolve rather than diminish pain. Dionis wrote in France that patients were much encouraged by half a glass of wine.[17] Alcohol may be better than nothing, especially when the British garrison at the siege of Lucknow in 1857 ran out of anaesthetic agents and were able to turn, apparently, to liberal stocks of champagne from the officer's mess. Cox mentions port wine for a disarticulation at the hip in 1842 (Fig. 8.2). Immediately after surgery he reported:

"*. . . and though the patient had drunk a full half pint of port wine, she was now in an extremely collapsed condition;*"[18]

Another recorded example concerned a successful Caesarian section in Uganda, witnessed in 1879 by Felkin, under banana wine inebriation.[19]

In 1363, Chauliac mentions bandages or fillets to arrest haemorrhage and for their numbing effect, sufficient to ameliorate the pain of amputation. Gersdorff's leg amputation (see Fig. 1.5) shows a length of cord binding above and a shorter length below the line of section but makes no mention of its numbing effect. In 1676, Wiseman considered a "ligature," that is, a bandage tourniquet, essential for major amputations and wrote:

The Compressor applied, the first incision with anterior flap.

FIG. 8.2. Disarticulation of the hip showing Signorigni compressor over the femoral artery and the formation of flaps by transfixion with a long, narrow, double-bladed knife, 1844. (From Cox WS. *A Memoir on Amputation of the Thigh at the Hip Joint*. London: Reeve, 1845.[18]) (See Fig. 9.4)

"*. . . by this ancient way of Ligature the Vessels are secured from Bleeding, the Member benummed, and the Flesh held steady, ready to receive the impression of your crooked Knife . . .*"[20]

An extension of this approach to numbing the operative site was discussed by Moore in 1784 when he introduced the application of specially constructed screw compressors (Fig. 8.3) to stupefy individual nerves. After trials these devices were abandoned as the numbness was variable and accompanied by severe and objectionable neuralgic pain. Following observations on shattered limbs exposed to freezing conditions during the French retreat from Moscow, deliberate refrigeration of limbs with ice was found to relieve pain during amputation. Unfortunately, sources of ice were not readily available until much later. By contrast, Cooper considered that warming and oiling the instruments would reduce pain.[21]

Attempts by Elliotson and others to interest the profession in the benefits of hypnosis in the 1840s, helpful to susceptible patients, fell on deaf and

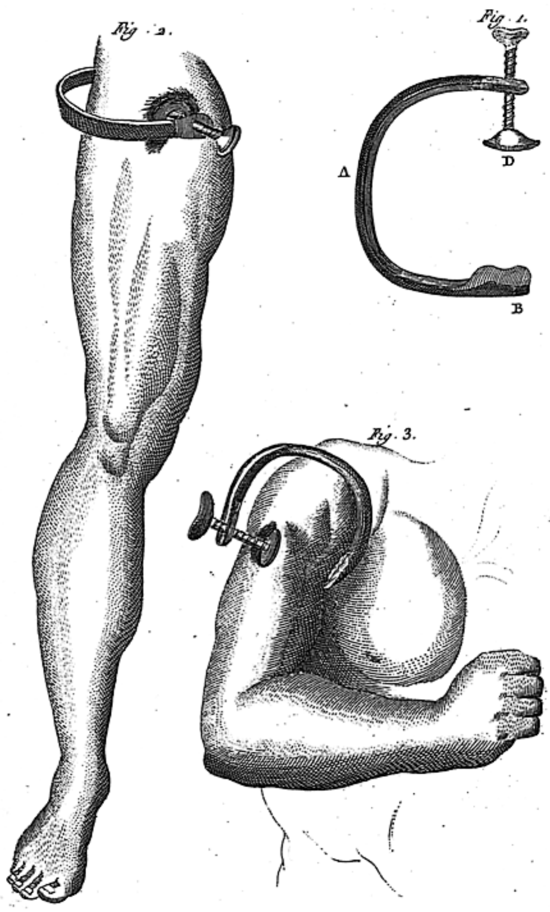

Fig. 8.3. Nerve compressor to induce loss of sensation; applications combining femoral and sciatic trunks, and combining cutaneous nerves of the arm with nerve trunks in the axilla. (From Moore J. *A Method of Preventing and Diminishing Pain in Several Operations of Surgery.* London: Cadell, 1784.[14])

derisory ears, being considered fakery by most practitioners. In India, Esdaile reported on his wide experience of hypnotic techniques at a native Indian hospital, having studied hypnosis already practised by the Hindu population. He performed over 950 operations, including amputations, relieved of pain, being endorsed by many European witnesses. His results arrived too late to influence surgeons in Britain for, very shortly after, ether anaesthesia was announced.[22] In practice, all that most surgeons offered was a speedy operation based on accurate anatomical knowledge. In 1822, Cooper believed:

"Modern practitioners have materially simplified all the chief operations of surgery, accomplished by better anatomical science, by devising less painful methods and by improving the construction of instruments."[21]

Commenting on hypnosis, Velpeau stated in 1840:

". . . these practices are a chimera, for it is better to have sharp scalpels, detailed knowledge and confidence, and the resignation of the patient; " adding: *"Immersing the instruments in hot water may reduce the pain."*[23]

Liston emphasised the importance of speed and wrote in 1838:

"The . . . parts should be divided by a single incision, rather than that the patient should be tormented . . . by a slow and tedious procedure, bit by bit." and for amputations he added: *". . . incisions from within outwards . . . give much less pain than those in the opposite direction."*[24] (Fig. 8.4).

We have mentioned (see Chapter 5) attempts at speedy amputation by axe, chisel and mallet, massive bone nippers and Fabry's "guillotine" of wooden timbers weighted with lead, usually ending with badly splintered bone, all of which were abandoned.

The timing of amputation was also considered important. Wiseman when employed in the Spanish navy complained that some colleagues undertook amputation too readily and unnecessarily, yet was convinced that immediate amputation for battle trauma was often best, and least painful when the victim was heated by the action, that is, full of adrenaline and endorphins. He commented:

"And then it must be done in its proper time, that is to say, suddenly upon receipt of the Wound, before the Patient's Spirits be over-heated either with Pain or Fever, etc." And: *"Therefore you are to consider well the Member, and if you have no probable hope of Sanation, cut it off quickly, while the Souldier is heated and in mettle."*[25]

Evidence of this "heating" is displayed by a seaman who, after arm amputation, was found by Wiseman helping to traverse a gun (see Chapter 6). On another occasion Wiseman was offered a drink by a sailor who pleaded for an immediate amputation.[25] Other military surgeons were also aware of this euphoric state exhibited by some but by no means all those severely injured.

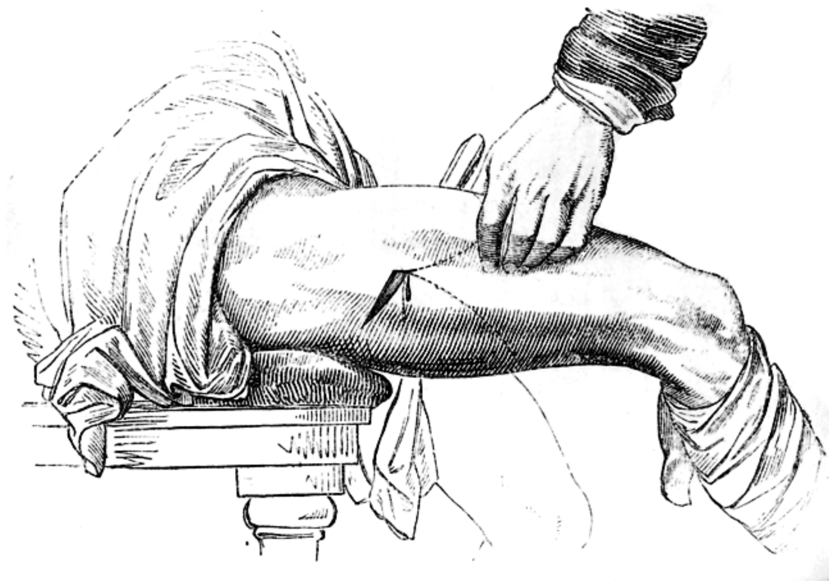

Fig. 8.4. Transfixion method of forming flaps for a midthigh amputation, Liston, 1837. (From Liston R. *Practical Surgery*, vol 7. London: Churchill, 1837.[24])

Yet beyond this state, evidence of remarkable self-control in accepting pain is reported as in the case of a boy aged 9 years who demanded thigh amputation to relieve his misery (see Chapter 3) and Thomas Main, a sailor at the battle of Trafalgar, having his arm amputated at the shoulder whilst he sang "Rule Britannia" *". . . with great composure, smiling and with a steady clear voice."*[26]

Even when anaesthesia was available, some patients were capable of submitting to major operations without its help. MacCormac related the story of an old French soldier injured at the battle of Sedan who underwent joint excisions of both a shoulder and an elbow, without anaesthesia, for he wished to monitor the operations and ensure amputation was not performed against his wishes.[27] During World War I, Leriche when asked to perform amputations on two Cossack soldiers, sent for his anaesthetist, only to be told by Russian colleagues that it was useless to give these soldiers anaesthesia for they felt no pain. With considerable repugnance, Leriche disarticulated three fingers and their metacarpals (half the hand) of one Cossack and the foot of the other:

"Neither one man nor the other showed the least tremor, but turned the hand or raised the leg when asked to do so, without showing even the slightest sign of momentary weakness, just as if under the most perfect local anaesthesia."[28]

Leriche pondered whether physical pain is influenced by a "mental factor," by energy or free will, either acting as a brake on the expression of pain or by actually diminishing painful perceptions. He emphasised further research was necessary, despite convictions that differences in racial and national responses existed, as in the case of the Cossacks, and that modern man's resolution had been weakened by familiarity with analgesics and anaesthetics.

After the first public demonstration of ether anaesthesia in the Massachusetts General Hospital on October 16, 1846, its use spread rapidly. Remarkably, Liston who was among the first to employ it in Britain on December 21, 1846, undertaking a midthigh amputation, still operated at breakneck speed to sever the limb in 25 seconds, by one account, or 28 seconds in another (Fig. 8.5); after wound suppuration the patient returned home 53 days later.[29] Such urgency increased surgical errors, but eventually the calm offered by freedom from the patient's screams and struggles ensured safer, more-deliberate work. Yet, a few established surgeons were reluctant to embrace anaesthesia, for example, in 1847 Professor John South, then aged 50 years, expressed reservations on the employment of ether, concluding:

". . . I have considerable doubt of the propriety of putting a patient into so unnatural a condition as results from

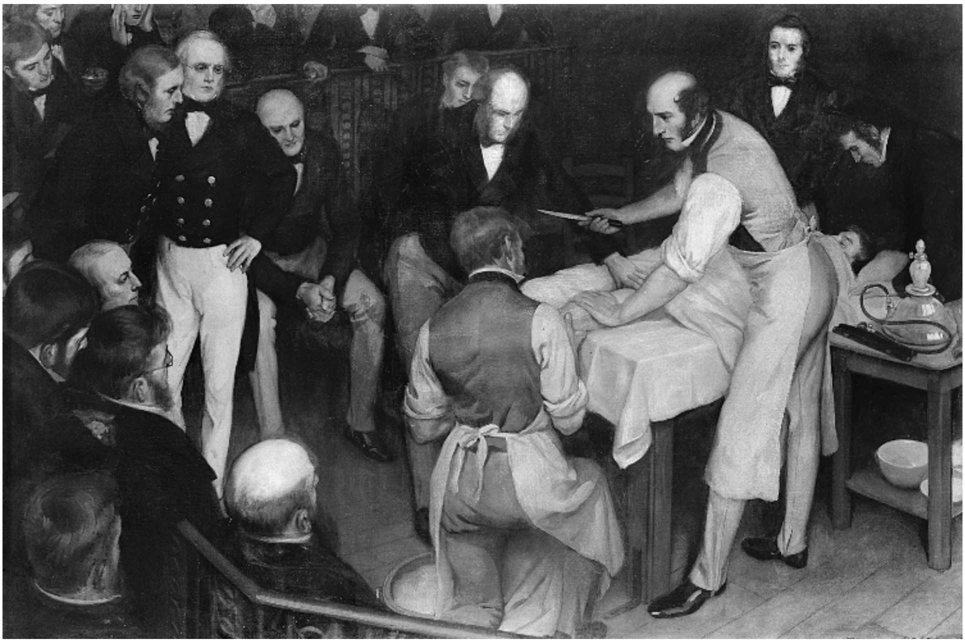

FIG. 8.5. Reconstructed painting of the first amputation performed in Britain under anaesthesia, December 1846, showing Robert Liston, Spencer Wells and Joseph Lister as a student; only Liston was definitely present. (Copyright Wellcome Trust Medical Photographic Library.)

inhaling ether, which seems scarcely different from severe intoxication, a state which no Surgeon would be desirous of having a patient who was about to be submitted to a serious operation."[30]

In January 1847, at the suggestion of David Waldie, James Simpson employed chloroform anaesthesia, and this and nitrous oxide gas were added to ether as potent pain-relieving agents.

The Control of Infection

Cleansing wounds with water, wine, balsams and other herbal lotions has a long history and is comprehensible with respect to fresh, dirty wounds which doubtless encouraged, long before any knowledge of the causes of putrefaction, instinctive distrust of obvious foreign material. Any effect of cleansing is uncertain for even macroscopically clean wounds became infected, and was accepted by many as inevitable and, indeed, a necessary requirement for healing and recovery, leading to the description "laudable pus."[31] Among those convinced that pus formation was not necessary for healing was Theodoric, who made his views clear in the 13th century, as the quotation heading this chapter demonstrates. Sadly, his proposition only became a reality post Lister, six centuries later. Meanwhile, surgeons continued to apply water dressings, dry lint, absorbent cotton wool or none at all, leaving the wound open to glaze over, assuming haemorrhage had been controlled, or various chemicals ad hoc, or cautery to cleanse wounds, doubtless being pleased if healing occurred without putrefaction. In Chapter 7 we noted the healing of Alanson's 35 consecutive amputations due to his isolation policy and open delayed wound closure, and also the avoidance of amputation by Crowther who applied dressings of wood tar (later shown to contain cresol and phenol) to 28 consecutive severe compound fractures. Yet these reports and the advice of Semmelweiss in 1847, who successfully prevented puerperal fever in obstetric wards by handscrubbing with soap and chlorine water, failed to alert any material change in surgical practices.

In 1834, Runge isolated carbolic acid (phenol), which was employed to sweeten dissecting rooms and to treat infected wounds. Both Lemaire and

Declat in Paris investigated the properties of phenol intensively and recommended its use for many infected conditions including suppurating wounds, disputing priority of application with Lister.[32] They and others demonstrated that phenol promoted the healing of putrefied wounds, sinuses and ulcers, yet they failed to initiate its prophylactic function. Lister in Glasgow, who experienced a depressing mortality rate of 45% for major amputations performed in his unit during 1864–1865, heard from a chemist colleague, Anderson, of Pasteur's experiments on fermentation and his proof against spontaneous generation, and wondered if something floating in the air was responsible for wound infections. Anderson, who knew that carbolic acid eliminated the odour of sewage, supplied Lister with a crude sample; in retrospect it is strange that Lister, apparently, had not heard of the investigations in this field of Lemaire, Declat and others. As pure phenol proved very irritating to wound tissues and his own hands, he changed to an oily solution of 5% phenol in 1865, which proved an efficient prophylactic against infection of fresh wounds.[33] In 1867 he described the successful management of 11 compound fractures treated with phenol dressings, without an amputation; at the same time he undertook 7 inevitable amputations for severe injury without a death.[34] As his system evolved, Lister performed elective surgery soaking the patient's skin, his hands, instruments and dressings, and from 1871 spraying the air around wounds, with phenol, to achieve a high ratio of wound healing without sepsis.[35] Amputation deaths of 45% before this regimen fell during the years 1867–1869 to 15%[36]; at the same time many patients with compound fractures, formerly candidates for amputation, healed without suppuration to preserve their limbs.

Many critics claimed failure to repeat Lister's results, almost certainly because they omitted to follow his precise instructions, and many were content to pursue old ways without attempting chemical antisepsis; if some immersed their instruments and dressings in phenol, they denied any relation to Listerism! Criticism by London practitioners was often damning and even when Lister became Professor of Surgery at King's College, London, in 1877, many students ignored his lectures and operating sessions initially. At a symposium conducted by William MacCormac in 1879, 14 well-known surgeons, all but 3 from London, debated antisepsis over two evening discussions. Five, all London surgeons, remained opposed to Listerism, 1 sat on the fence, but 8 supported antisepsis. A flavour of the opposition was expressed by Wood, a colleague of Lister at King's College Hospital, when he complained the hospital committee demanded personal funding to purchase antiseptic materials in his wards, adding:

"This was not unnatural, for my surgical colleagues, and notably Sir W. Fergusson, were of opinion (still shared by many) that the pure waters of Damascus were as good or better than all the carbolised waters of Israel for purifying influence."[37]

Schultze of Berlin, who visited Lister in 1874 and was converted to antisepsis, also visited many other medical centres in Britain and observed:

". . . in London Lister has few adherents. The principal surgeons have nothing to do with it, because they say they do not obtain from it any better results, and, speaking generally, the whole affair is too complicated for them. Precise objections you do not hear; the details of practice are usually unknown to them."[38]

In Paris too there was much opposition and even callous demonstrations in front of students. As late as 1892, Terrillon reported Dépres opening an abscess with a folding bistoury and then asking for a drain:

"The nurse fetched one from a neighbouring ward. Depres took the drain immersed in phenol, put it on the floor, rolled it under his foot and then placed it in the wound."[39]

Considerable opposition was also expressed in America where little notice was taken of antiseptic surgery until Lister spoke at the International Medical Congress, Philadelphia, in 1876. Thereafter, acceptance was slow and, as Watson's quotation in Chapter Ionpage 8 indicates, opposition or indifference was still common in 1883. Fortunately, Lister's pupils, house surgeons and many impartial visitors witnessed the remarkable changes indisputably linked to Lister's practice to disseminate his views. Important foreign visitors who supported Listerian antisepsis included Saxtorph of Copenhagen, Lucas-Championniere of Paris and Reyher of Dorpat; Lucas-Championniere was to write the first book on antiseptic surgery in 1876[40] and Reyher, serving in the Russian army during the Russo-Turkish war, was the first to demonstrate that antiseptic management was possible during battle conditions, reversing sepsis from 62.9% to 10.5%.[41] It was principally German surgeons who embraced Lister's practice with energy and scientific thoroughness to demonstrate its superiority over other regimens, usually without visiting him, by simply digesting his publications. In 1872, Volkmann of Halle, faced with many cases of pyaemia and erysipelas after elective operations, instituted Listerian practice as an experiment and was amazed at the transformation of his wards, to become *"Lister's most devoted disciple."*[42] Similarly, Nussbaum of Munich, who had experienced a hospital gangrene rate of 80% in 1872, was amazed to find this drop to zero.[43]

Pasteur stated in 1874:

"If I had the honour of being a surgeon, I would never introduce into a human body an instrument that had not been passed through boiling water and better that a flame, just before an operation, and rapidly cooled."[44]

He amplified this in 1878, recommending careful hand-washing and flaming, the use of dressings subjected to heat at 130°–150°C and water to 110°–120°C. Regrettably, surgeons were extremely slow to seize on these revolutionary instructions, although it is believed Macewen in Glasgow began to boil his instruments in a fish-kettle during the late 1870s.[45] Primed with the science of bacteriology and knowledge of Pasteur and Koch's laboratory autoclaves, surgical heat sterilisation emerged in France and Germany between 1883 and 1893.

Neuber of Kiel was probably the first to autoclave operating gowns in 1883 and then to advocate sterile caps and rubber shoes in 1886.[46] By 1887, Tripier of Lyon was autoclaving wound dressings and perhaps instruments.[47] Redard in Paris, having shown that simple boiling did not always sterilise the inside of tubular instruments and needles, commenced autoclaving instruments and dressings before 1888[48] (Fig. 8.6E). Von Bergmann of Berlin claimed in 1890 that for 2 years he had operated with autoclaved swabs and sutures, and boiled instruments, continuing to employ antiseptics for the patient's skin, his hands and for catgut.[49] This aseptic scheme, clarified by von Bergmann's assistant Schimmelbusch, in his monograph of 1892, reported a range of autoclaves and boilers, special drums for autoclaving linen, swabs, dressings and sutures, and also novel glass and metal operating furniture[50] (see Fig. 8.6F), constituting the basis of modern surgical practice.

In the 20th century, bacteriological knowledge, chemotherapy, antibiotics and ventilated clean-air operating theatres have all diminished the risks of infection, although modern management has induced a growing problem with drug-resistant organisms. Reduced bone and joint infection rates, after operations in specially ventilated clean air enclosures, confirm Lister's suspicions about organisms floating in the air, although he was persuaded to abandon his phenol spray in 1887.

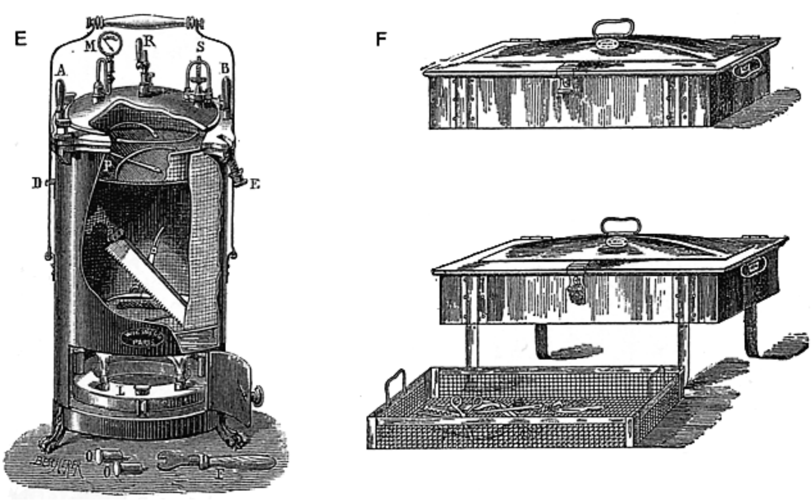

Fig. 8.6. *E*, Redard's autoclave for sterilising instruments, 1888[48]; *F*, Schimmelbusch's portable boiler, packed and opened to show legs beneath which heat was applied, and also the removable tray for instruments, 1893.[50]

Critics still diminish Lister's contribution, believing that heat sterilisation is the keystone of modern surgery, overlooking that the patient's skin, the surgeon's hands and many instruments such as endoscopes cannot be submitted to heat sterilisation, whilst the march of resistant bacteria often relates to poor observance of simple Listerian prophylaxis. Inescapably, operative surgery's struggle against infection continues, dependant on both rigorous aseptic and antiseptic measures.

Amputation During Warfare

After the battles of the Napoleonic era, Europe experienced a lull for several decades until broken by the Crimean campaign, followed by the Franco-Prussian and other European Wars, and also the American Civil War, culminating in the savage 20th-century disasters of the two World Wars. If battlefields accelerated the number of amputations, this was accompanied by growing numbers of major industrial accidents, rapid transport injuries and rampant joint tuberculosis to test civilian surgeons similarly.

During the Crimean War (1854–1856), France, Turkey and Britain fought Russia, unprepared for the diseases which killed most soldiers and also frostbite, caused by severe winters, and hence a source of amputations. The British made some use of chloroform while the French employed it widely, although the crowded hospitals were overwhelmed by hospital gangrene, eventually diminished by Florence Nightingale's regime. French surgeons achieved some success with dressings of ferric chloride, and also cautery.[51] Due to hospital infection, Scrive advised immediate amputations, noting however that of 9 disarticulations at the hip, all died. Of 4698 amputations by the French, 27% died, but Scrive does not indicate what percentage of 1512 thigh amputations (32% of the total) or 912 leg amputations (19.5% of the total) were mortal.[52] British amputation mortality ranged from 0.5% to 1.8% for fingers and the forearm, from 22.9% to 27.2% for the arm and shoulder, and from 50% to 86.8% above the knee.[53]

The American Civil War of 1861–1865 produced huge numbers of casualties and many amputations, those undertaken by the Union army being meticulously recorded in six substantial volumes. Again the use of general anaesthesia was available but antisepsis remained primitive; Wangensteen draws attention to some control of hospital gangrene by a few officers, employing bromine, turpentine and nitric acid, respectively.[54] However, Keen observed:

"We used only the ordinary marine or toilet sponges. After an operation they were washed in ordinary water to cleanse them of blood and pus, and were used in subsequent operations. . . . If one fell on the floor it was squeezed two or three times in ordinary water and used at once! . . . Practically every serious wound was bathed in pus, many times abscesses followed, or erysipelas, or blood poisoning, or hospital gangrene, or lockjaw."[55]

The overall mortality rate of 29,980 amputations performed by the Union army was 26.3%, ranging from 2.9% for fingers and hand, to 5.7% for toes and feet, to 33.2% for shin amputation, to 54.2% for thigh amputation and to 83.3% for hip disarticulation. It is estimated the Confederate Army sustained 25,000 amputations.[56]

The siege of Paris during the Franco-Prussian War of 1870–1871 is notorious for deprivation, famine and a high mortality after amputation. Although many wounds were treated conservatively, the mortality after expectant treatment, by excision or by amputation was equally severe. The French surgeon, Nelaton, performed 70 amputations resulting in 70 deaths, and other surgeons in Paris had similar experience. Lister wrote a paper on antiseptic management expressly to help military surgeons in this conflict, without serious response.[35] In the fighting outside Paris, Lucas-Championniere, who as we have observed keenly supported Listerian antisepsis, was prevented by his chief from bringing carbolic acid to his field hospital where patients were dying from septic conditions, and it was taken back unopened to Paris.[57] However, despite the appalling mortality from wounds, volunteers such as Sims from America and MacCormac from Britain were able to perform some antiseptic surgery.

World War I introduced trench warfare on an unprecedented scale, precipitating massive artillery bombardments, resulting in 77% of all gunshot wounds being caused by shell fragments,[58] a complete reversal of the predominance of bullet wounds typical of former wars. Shell fragment wounds were often multiple, causing ragged destruction of soft tissues and underlying bone, as well as retention of the metal fragment or fragments with contaminated in-driven clothing remnants. A further common aggravating factor stemmed from delay in evacuating the injured from flooded and muddy terrain, and particularly from dangerous no-mans-land, before definitive surgical treatment could begin in a Casualty Clearing Station some 25 miles or so behind the front line. This delay was most significant for gunshot wounds of the thigh with open femoral fractures, for evacuation on a stretcher was the only method of transport from no-mans-land where stretcher bearers often became casualties in attempting evacuation.[59] Compound fractures of the femur had a depressing reputation, and the number who died before evacuation remains unknown. Of those rescued, Hurley and Weedon recorded an average delay in reaching their surgical station of 3 to 4 days, often with gas gangrene, and that within 48 hours of reception 38% were dead despite treatment.[60] Such victims were usually candidates for amputation and before blood transfusion and the Thomas splint became mandatory, the mortality remained high; in addition there were no antibiotics. In one analysis of 144,264 British troops with upper or lower limb injuries, 4,236 (2.9%) underwent amputation, of which 75 (6.5%) upper and 344 (11.15%) lower limb amputations died.[61] American statistics for 4,057,101 soldiers who fought in World War I indicate that 4,403 underwent major amputations. Of the 60 million combatants of all nations, 7 million were killed, 19 million were wounded and half a million underwent amputations.[62] One benefit stimulated by these large numbers of amputees was an obligation to improve prosthetic services (see Chapter 13).

World War II revealed another type of war with large numbers of civilians directly involved, especially subject to heavy aerial bombardment, and with military battles proving largely mobile contests, involving heavy armaments due to tanks, planes and sophisticated artillery; shell wounds were common except in jungle warfare. Civilians and others trapped in collapsed buildings often sustained crush injuries of their limbs and died of renal failure due to damaged muscle producing metabolites blocking kidney function,[63] even if amputation was performed. Early evacuation,

Table 8.1. Military statistics during recent wars.

War	Wound mortality	Amputation rate
American Civil	13.3%	Not known
WW I	8.0%	2.0%
WW II	4.5%	5.3%
Korea	2.5%	13.0%
Vietnam	1.8%	13.5%

Source: From Refs. 56, 58.

good splintage, transfusion of plasma or blood, occasional arterial repair and the availability of penicillin late in the war often saved limbs from amputation. However, the severity of tissue damage by landmines and the more destructive power of weaponry generally often made conservative measures unavailing, to produce an incidence of amputation at 5.3% which overtook the 2% of World War I.[64] Commenting on major conflicts involving American forces, Aldea and Shaw demonstrated that from the American Civil War to the Vietnam War, overall wound mortality dropped from 13.3% to 1.8% whilst paradoxically the amputation rate increased from a low figure to 13.5% (Table 8.1), suggesting firstly, that weaponry had become more destructive with time and secondly, that improved evacuation methods and basic wound care enabled victims formerly destined to die to be saved by amputation.

Amputation During Civil Life

In contrast to battlefield indications centred on gunshot injury, and ignoring occasional gunshot wounds due to hunting and shooting accidents, civil indications for amputation were linked to diseased joints, leg ulceration and to industrial and traffic injuries. In the 19th century, not many lived long enough to develop degenerative arterial disease, unlike the aging population of the 20th century, especially those over 70 years of age whose failing circulation dominates current indications for amputation in civil life. Diabetes mellitus is a potential source of gangrene, but an association between the two does not appear to have been made until the mid-19th century (see Chapter 2), and without insulin it is doubtful whether amputation was feasible.

At the beginning of the 19th century, scrophulous joints due to bovine tuberculosis, the "white swelling" or "tumor albus," were common and, in Britain at least, proved a frequent indication for amputation, to rid patients of painful swollen joints which eventually ulcerated to form permanent sinuses and secondarily infected bone, associated with spread elsewhere and death. That amputation could resolve both local and more general spread seems to have taken place, according to Lloyd who described two amputees as follows:

"The first case is a little boy, about eight years old, who had a scrophulous affection of his knee joint, who was terribly reduced, and who had symptoms of mesenteric disease, and yet perfectly recovered after the limb was removed. The next is the case of a little boy, eleven years of age, whose limb was amputated on account of scrophulous disease of the tarsus and metatarsus, who perfectly recovered, although he was so ill before hand, from the irritation of the foot, that it was debated whether the operation would give a chance of recovery."[65]

Many however were not considered suitable for surgery or died after amputation. As noted in Chapter 7, the alternative operation of joint excision was essayed in the late 18th century by Park and Moreau, taken up in the early 19th century by Syme and a few others, but was not established generally until after ether anaesthesia became available.[66] Subsequently, most joints were excised, including the hip and, as a result of Lister's enterprise, the wrist to save the hand.[67] Towards the end of the 19th century, the development of efficient splintage, for example, by Hugh Owen Thomas,[68] and adequate provision of long-stay beds in sanatoria reduced operative solutions even further. As the Industrial Revolution and factories motivated by machinery developed, increasing numbers of trapped limbs, especially involving children, and particularly the hand and arm necessitated amputation. Legs were frequently run over by wagons, coaches and railway stock as the latter burgeoned after 1840. Eventually, legislation reduced work-related injuries but other high-velocity accidents proliferated as bicycles, motorcycles, motor vehicles and eventually aeroplanes added their toll.

Warfare and scientific advances in the 20th century have added blood transfusion, resuscitation techniques, arterial reconstruction, skin and bone grafting, and antibiotics to the surgical arsenal, resulting in the reconstruction of injured limbs previously subject to amputation. As we discuss in Chapters 12 and 13, some believe the pendulum has swung too far towards prolonged programmes of repair when modern amputation techniques and prostheses may provide better function.

Summary

Amputees before anaesthesia recorded amazing examples of sangfroid during surgery, including that of children, often buttressed by strong religious convictions. Others admitted to real pain and terror. In 1846, general anaesthesia not only relieved patients but gave surgeons time to operate more accurately and also pursue alternative operations which avoided amputation. Despite this miraculous advance, surgery remained hazarded by lethal wound infections until prophylactic chemical sterilisation commenced in 1867, to be further reinforced by thermal sterilisation about 1890. Sadly, the 20th century saw warfare on an unprecedented scale, stimulating, however, splintage systems, transfusion, antibiotics, evacuation methods, arterial repair and intensive patient care. Many severe limb injuries are now remediable, although there are limits to the pursuit of reconstruction.

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9 Interpretations of Amputation by Society, Patients and Surgeons

"Medicine, magic and religion are abstract terms, each of which connotes a large group of social processes, processes by means of which mankind has come to regulate his behaviour towards the world around him."

Rivers, 1924[1]

". . . it is no small presumption to Dismember the Image of God."

Woodall, 1617[2]

". . . amputation should be performed only under circumstances when no other means will avail. The difficulties in determining these circumstances are often very great, and sufficient to perplex even the most experienced practitioner."

Fergusson, 1852[3]

From time immemorial, accidental severance has proved a "fait accompli," an immediate reality for unfortunate victims who, deprived of choice, are subjected to instantaneous loss when a limb is savaged by a crocodile, alligator or shark, struck by a cannonball, transected by railway wagon wheels, obliterated by a landmine (see Fig. 1.7) or wrenched off by entrapment in powered machinery. The immediacy and speed of these injuries diminished the apprehension and protracted pain associated with elective amputations before anaesthesia and, in minor cases at least, the suddenness of accidental section sometimes obscured instant recognition of an injury. Thus, a coal miner who lost a fingertip in a machine only became aware of his amputation when a companion fainted at the sight of blood, was concussed, and had to be assisted to the surface by the amputee. Survivors of such mutilations usually require treatment to assist sound healing of the open stump, at which stage the patient has a choice for or against further action dependant on societal and personal factors. Any deliberate act of amputation, surgically performed or otherwise, relates to a variety of considerations determined by the victim or patient, their surgeon or surgeons, or by the attitude of the society to which they belong, but usually to a combination of these determinants of which society, through time-honoured rituals, religious convictions or scientific knowledge, may prove the most important. Indeed, unless society approves, elective amputation will be forbidden, irrespective of surgical advice, or even the patient's desire to avoid death.

Society

We have argued (see Chapter 2) that various societies recognised and accepted nonsurgical amputees long before surgical amputation was considered or attempted, although not all societies have undertaken amputation, as Harley indicated when studying the Mano tribe in remote Liberia:

". . . surgery is limited to bone-setting, blood-letting by shallow incisions, circumcision and scarification by tribal marks on the skin . . . instruments are ordinary household utensils . . ."[4]

Similarly in 1877, Gordon observed:

". . . among the Burmese the surgeon, even in the oldest and lowest acceptance of the word, does not exist, and there is not the faintest knowledge of anatomy . . . They use no knife or instrument of any kind."[5]

We assume Gordon was recording his experience in the remoter areas of Burma and not in major cities. Whether these societies undertook ritual or punitive amputations is not stated although, as suggested earlier, some knowledge of the physical imperfections of accidental amputations must have been acquired, if only at a digital level. It may be surviving amputees were found alien to some societies and rapidly dispatched, as probably happened to crippled members of hunter-gatherer communities or nomadic tribes, when no longer able to keep up with their fellows or fulfil a positive role in a harshly competitive environment. Within historic times, we have considered evidence that weak or crippled infants were judged useless to the Spartan state and thrown into a ditch (see Chapter 1). Such attitudes doubtless applied to congenital amputees but we cannot be sure how surviving amputees after trauma or disease were viewed, especially if previously contributing positively to their tribe or family group, particularly if a community leader or chieftain. Even societies that refused amputation entirely might accept accidental loss, as Daniell discovered when visiting Old Callebar in the Bight of Biafra (now Calabar, Nigeria) in 1849:

"The people of this town manifest the most decided aversion to the performance of any surgical operation, and so strong is their abhorrence of amputation, that they would rather suffer death than any loss of an extremity. When, however, any portion of the limb has been taken off, either by alligator or ground-shark, they check the haemorrhage by applying a hot piece of iron, which has sometimes been of permanent benefit."[6]

It may be that peoples dependant on gruelling and continuous work to subsist knew instinctively that amputation would restrict efforts to support themselves, rendering them a serious drain on others. In 2005, the massive earthquake centred on Kashmir highlighted the position of isolated mountain people, especially in Pakistan, dependant on their own resources and hard physical labour for survival. Commenting on much delayed treatment, due to communication difficulties, of those injured with grossly infected wounds in need of amputation a newspaper report stated:

"Pakistan is a country without a safety welfare net, and in its remote northern villages physical disability is often a worse fate than death. For poor subsistence farmers scraping a living from the harsh mountains, a dependant who cannot work is seen as a huge liability." To emphasise this, a husband said of his injured wife, a candidate for amputation: *"I will not permit this. I will let her die than allow cutting her arm. She would not be able to work anyway."*[7]

Ultimately, it is apparent amputees were accepted by many societies, possibly promoted by their survival after accidental loss, or punitive and legal severance ordered by the self-same societies, to designate community outcasts as prisoners, slaves, trespassers or criminals, or participants in tribal rituals, and also as a warning or reminder to others. In these latter cases, victims were denied choices either for or against loss of their limbs or digits, as society monopolised all decision powers impelled by punitive, ritualistic or religious convictions; moreover, those who performed the actual punishment and severance, as pseudo-surgeons, also had no choice but to obey higher authority. Such profound societal convictions continue in some Islamic states where Sharia law punishes thieves and prisoners by amputations, although often these are now undertaken under anaesthesia by trained surgeons, as described in Chapter 4 when, in 1999, a prisoner of war of the Taleban underwent hand and foot amputations by a surgical team before a large crowd in a football stadium. In contrast, the same Muslim states often forbid elective surgical amputation for injury or disease, believing this renders the human frame imperfect for burial and precludes its ascent to Paradise. Even in the presence of mangled lower limbs following antipersonnel mine explosions, Coupland, working for the International Red Cross, confirmed in 1992 that Muslim religious practices to avoid surgical amputation have to be respected.[8] Also in the 20th century, Hilton-Simpson noted Berber tribesmen isolated in the Atlas Mountains of Algeria frequently undertook skull trephination, yet never surgical amputation which was completely taboo; indeed, Hilton-Simpson recorded the enormous pleasure of Berber practitioners when compound limb fractures healed after many months of expectant treatment and after discharging much dead bone to leave a short, weak, barely functioning limb.[9] Yet, lacking knowledge of antiseptic and aseptic surgical techniques, this was doubtless the safest course, at least for the surgeon, although elsewhere modern amputation techniques would have provided sound working stumps and satisfactory prostheses with a more-certain return to early activity and employment.

Of the many ritual amputations recorded (see Chapter 4), most concern the fingers of females, principally in Africa, North and South America, India and New Guinea. It can be supposed adults assigned this mutilation had little choice in the matter but at least understood long-established tribal magic and custom in acquiescing to their loss, unlike the small girls of the Dugum Dani tribe of New Guinea subjected to finger amputations with a stone adze, without anaesthesia, in 1961, whose state of mind is difficult to imagine, even if told their sacrifice was to placate the ghost of a blood-related tribesman killed in battle (see Fig. 4.2). One must emphasise such guillotine amputations healed very slowly and often badly because of bone infection and necrosis leaving poor fragile scars, and yet, such sacrifices were frequently multiple over a period of time, resulting in the loss of several or even all fingers. The rationale for finger amputations included the following: to indicate a sign of mourning, to secure an eventual peaceful death, to prevent further deaths when these were numerous in a family, to avert serious illness, to indicate a widow's second marriage, to facilitate the making of fishing nets by removing the ring fingers, to celebrate the achievement of manhood, or to indicate a self-inflicted penitence towards a hierarchy such as a gangster mafia, or to participate in a religious act, a political protest or an insurance scam.

In those societies eventually accepting elective surgery, most prominently in Renaissance Europe, the debate surrounding intervention or not was essentially between patient and surgeon, although their communication involved inevitable overtones of religious, cultural and traditional attitudes, influenced by Catholic Church decrees rejecting deliberate operation and bleeding which prevented instructed priests from contributing to medical and surgical care as hitherto. And in Europe, the earliest accounts of elective amputation all expressed the need for patients or surgeons, but usually both, to pray or go to church for confession before the operation.

Thus, Von Gersdorff counselled in 1517:

"If the limb must be cut off, and nothing else will help, . . . you should advise the patient above all to go to confession. and receive the Holy Sacrement on the day before you amputate. And if the surgeon hears Mass before operation, God will favor his work."[10]

Von Gersdorff's illustration of an amputation scene (see Fig. 1.5) shows a spectator who has a dressing on his left hand suggesting amputations of his fingers, but who is wearing the emblem of a cross at his neck, emphasising the importance of religion to Gersdorff. Ryff's illustration of about 1545 (Fig. 9.1) is even more explicit, picturing a priest, prayer book in hand administering to the patient during surgery. In 1596, Clowes reminded his surgical readers that when performing amputation:

". . . through the assistance of almightie God, you shall luckily accomplish this worke, by your good industry and diligence," And their patients: *". . . have ministered unto them some good exhortation concerning patience in adversitie, to be made by the minister or preacher. And you shall likewise advertise the friends of the patient, that the worke which you go about is great, and not without danger of death."*[11]

Here Clowes reminds us that operative death could be attributed by society to the surgeon, irrespective of the patient's original condition, and hence it was essential to warn the relatives. Whether legal actions or sanctions followed at this time is not clear, but at least a surgeon's reputation and capability would be suspect. No evidence indicates that surgeons faced the penalty of losing a hand for their operative failure, as noted when we discussed the Code of Laws established by Hammurabi in ancient Babylon (see Chapter 4). However, Kirk hints at a society's retribution when composing a medical report on the Kingdom of Shoa, Abyssinia, in 1843. When asked for his opinion on a boy with a grossly ulcerated tibia and an ununited compound fracture near the knee joint, he told an officer of the King's household that amputation offered the only chance of saving his life, to which the horrified official replied:

"If you succeed you will get no credit by it, people will say it was the will of God; if the boy dies, they will say you killed him and you will have much trouble."[12]

In the 20th and 21st centuries, surgeons found guilty of operative negligence by society (their

FIG. 9.1. Amputation scene showing patient supported by a priest, his surgeon and apprentice, by Walther Ryff, 1545. "Tourniquets" appear to be applied above and below the amputation site, and two knives, a bow saw, needle and thread, sponge and dressings are seen. (From Gurlt E. *Geschichte der Chirurgie*, vol 3, Berlin, Hirschwald, 1898:49.[40])

peers and the courts) lose their status and employment but not their lives. Patients are now well protected by society and its legal systems, which enable examination of the facts through a succession of court appeals if necessary.

In addition, society also had cultural restraints associated with ancient astrological superstitions, as Woodall indicated in 1617 when speaking of amputation and the necessary instruments (Fig. 9.2).

"All these necessaries as is said made ready to the worke, in the name of the Almighty, the sharpe instruments being as neere as you can hidden from the eyes of the patient. . . . This worke of dismembering is best to be done in the morning, doe it not willingly the signe being in the place, neither the day of the full moone, . . ."[13]

Woodall suggested a practical note by operating in the morning during daylight, still available in the afternoon when complications might supervene. On the other hand, amputations after severe trauma required immediate action, irrespective of the quality of the light or the phase of the moon. Towards the middle of the 17th century, admonitions advising patient and surgeon to pray or confess, or to adhere to astrological directions, disappeared from European surgical texts.

Earlier discussion has noted that not all societies countenance elective amputation, including those in Saudi Arabia, parts of Nigeria and Afghanistan when under the Taleban (see Chapter 4) who are guided by Sharia law, a code for human existence, including daily prayers, fasting and donations to the poor, but also a code dictating physical punishment for crimes including flogging, stoning and amputation. Yet, the same societies forbid or disapprove of amputation for medical reasons, believing it an interference with the wholeness of the human corpus, precluding ascent to Paradise. Coincidentally, in some Islamic countries practising legal amputations, many innocent victims have been seriously injured in recent years by antipersonnel mines, designed to blow off the foot, posing difficult choices for

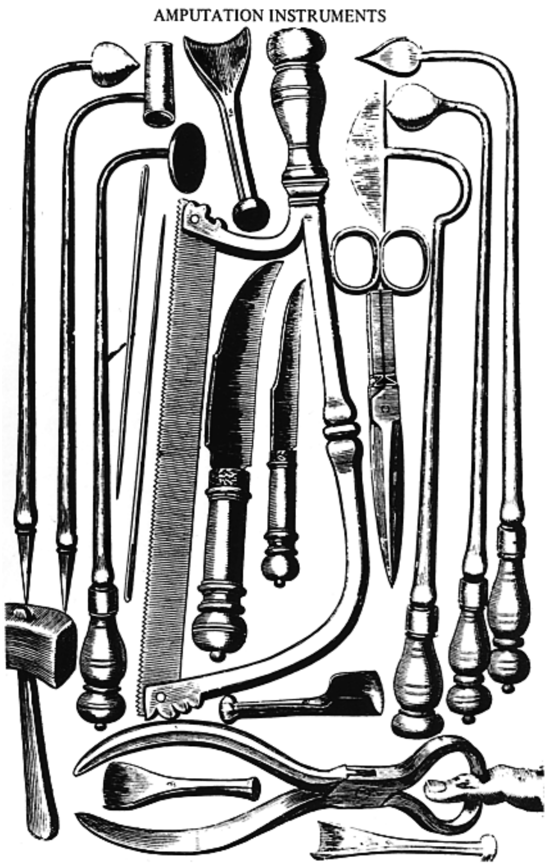

Fig. 9.2. Amputation instruments from 1639; these are of relatively simple construction, including a very modern form of scissors. Woodall offers a wide range of cauteries and chisels with a mallet. (From Woodall J, *The Surgeon's Mate*, London: Bourne, 1639.[41])

patients and relatives, especially the parents of maimed children. Even so, as Coupland stated, Sharia views must be accommodated.[8]

Despite a general acceptance of amputees into the community, they, as do other handicapped citizens, often met and continue to meet bias and misguided intolerance, as Thomas and Haddan reminded us in 1945:

"The amputee often experiences great anxiety as to this attitude towards his disfiguring handicap and usually dreads the ordeal of returning home and having to face family and friends. The malevolent influence of the unreasoning prejudice of society towards a physical defect is well known and must be faced realistically and with courage by the amputee . . . Not pity, but a sympathetic understanding and helpfulness are what is desired. Assistance should be rendered only when requested, the amputee being given every opportunity to be as independent as possible . . ."[14]

For lesser amputations of fingers and toes, toleration by the community is more evident, and indeed such amputees may lead a normal existence without apparent physical handicap, especially if only a single digit has been lost, for adaptation and reeducation of the hand may be remarkable, as a colleague's history confirms. He lost his left index finger in an accident at the age of 4 and subsequently played the piano, passing the Teacher's Certificate at the Royal Academy of Music, and later became a consultant orthopaedic surgeon performing major operations demanding bimanual skill and control until normal retirement; he has observed his left middle finger is thicker than on the right, although he is right-handed.[15]

Patients

The victims of congenital deficiencies, acute accidental limb severance and of punitive, legal and many ritual amputations have no opportunity to express their wishes in the matter, in contrast to the majority of patients faced with less concrete situations where there is opportunity to debate their future with surgeons, relatives and friends. By contrast, victims who are trapped alone and without communication or aid have to make a choice for or against amputation without advice, relying only on their knowledge and a veneer of traditions inherent to their own society. The trapped victim in extremis and desirous of survival who performs an amputation acts as both patient and surgeon. Repugnant as such actions appear to the average citizen, the instinct to survive remains powerful despite self-inflicted excruciating pain and uncertain immediate complications. Such self-amputations have been reported with some regularity in the press, proving less rare than may be imagined (see Chapter 3).

In somewhat similar frame of mind and desperation, we note injured or diseased patients who clamoured for a surgeon, demanding or indeed insisting on immediate limb amputation. In particular, from close observation of wounded comrades, many soldiers and sailors recognised no other course was possible and moreover were aware that delayed amputation was more painful. Wiseman emphasised these points, about 1658, as follows:

". . . a Walloon earnestly begged me to cut off his shattered Leg: which whilst I was doing, he cried, 'Hurry up when we're back on land we'll have a drink'. Also others have urged me to dismember their shattered Lims at such a time, when the next day they have profest rather to die. . . . Therefore you are to consider well the Member, and if you have no probable hope of Sanation, cut it off quickly, while the Souldier is heated and in mettle. But if there be hopes of Cure, proceed rationally to a right and methodical Healing of such Wounds: it being more for your Credit to save one Member than to cut off many."[16]

Another sailor's sangfroid is recorded by Ryder in 1685:

". . . upon the Recoil of a Gun the Truck ran over his Foot, breaking in pieces all the Bones of the Metatarsus: perceiving his Foot very much tumefied and discoloured above the Ankle, I made deep Incisions on the Tarsus, and Metatarsus, which he felt not; I told him there was a necessity to take off his Leg, to which he readily agreed; so he hopp'd on one Leg to a Chest where sitting I took it off, (he not expressing the least sign of pain or sorrow."[17]

"Heated and in mettle" is a 17th-century description of the body's immediate response to injury when boosted by high adrenaline levels, bolstering a courageous acceptance of surgery but which diminished as levels returned to normal and as the wound began to swell and inflame. Earlier we noted the elated sailor who sang "Rule Britannia" during his amputation.[18]

For more-chronic conditions such as dry gangrene and persistent fracture non-union with chronic pain, purulent discharge, loss of weight, sleeplessness and immobility, it is apparent courage of a different kind is manifest. We have already recorded the remarkable determination of a boy, aged about 9, with severe chronic leg complications after crushing by a cartwheel a year previously. Reduced to a skeleton with 11 discharging fistulae and his health fading fast, he insisted on removal of his useless limb, saying to the surgeon:

". . . he knew he should be well, if I would cut off his Thigh: and that if I would lend him a Knife, he would cut it off himself; . . ."[19]

He remained remarkably composed throughout a successful amputation. In drawing attention to the incredible cooperation of some children faced with major operations without anaesthesia, Stanley quoted an observation recorded in 1819. A 7-year-old boy with a diseased knee joint came under the care of Abernethy, a London surgeon, who said:

"I suppose, my little fellow that you would not mind having this knee removed, which pained you so much and made you very ill?" The boy replied, *"Oh no, for mammy has told me that I ought."*[20]

During the amputation, the boy remained quiet and displayed neither hesitation nor opposition. Here perhaps the influence and encouragement of the parent were paramount. At the other end of the age range, Sir James Lowther, aged 77 years in 1750, asked for a below-knee amputation for gout complicated by infection and bone necrosis in the foot after years of misery, which he:

". . . submitted to with his own peculiar calmness and resolution without the least tendency to faint under the operation . . ."[21]

He lived for another 5 years and wore a below-knee prosthesis. In general terms such patients have reached the end of their tether, perhaps realising that anything would be better than the unremitting pain, persistent discharge, rotten odour, immobilisation, general fever, loss of appetite and weight, and an instinctive recognition that death approached relentlessly. In 1706, Edward Thwaites, who became Professor of Greek at Oxford, consulted Charles Bernard, surgeon in London, with a constantly painful tuberculous knee (the King's Evil), and when the surgeon demurred amputation, Thwaites said:

"I came to London on purpose to have my leg cut and off it shall go: and if you will not do it, lend me your tools and I will do it myself."

It is reported he would not suffer himself to be tied down and during the whole operation made no sound. He recovered to die 5 years later when the disease spread to his lungs.[22] This is not to imagine that every patient had the courage to hazard the uncertainties of a major operation before the days of safe surgery. However, those surviving were often relieved. Also in the 18th century, Petit recounted the case of a boy who had been ill with caries of a leg and infected fistulae keeping him awake for 2 months; the night of the amputation he slept soundly and this continued till after his stump healed.[23]

The rapid progression of infected gangrene from the foot or hand towards the trunk was another reason for patients to demand immediate amputation. For dry or slowly established gangrene, the prospect of living with a black, functionless, foul-smelling limb into an uncertain future gave time for reflection, yet also proved a persuasive reason for accepting amputation. Similarly, the relentless growth of a tumour, especially if hindering mobility and work, has persuaded patients to ask for surgical excision or in extreme cases acceptance of limb sacrifice, even in the absence of pain as recounted by Peirce in 1737. A farmer's son, aged 25 years, complained of a swelling which enlarged over 8 years, ultimately preventing him working from the time *"of Hay-Harvest 1735"* (Fig. 9.3). It is clear the size and weight of what was probably a cartilaginous tumour near the right knee would have prevented a normal gait, or even a comfortable sitting or sleeping posture, and its continuing growth presented a frightening prospect for the patient. Peirce states the lower thigh stump healed but does not tell us whether the patient had an artificial leg or resumed work.[24]

A more urgent demand for amputation relates to the victim's entrapment in a dangerous environment with poor resources, as applied to the rescue of a Colonel of the Gurkha Rifles trapped by his arm in a crashed helicopter leaking oil from an overheated engine, in a remote area of the Malaysian jungle in 1964. A medical officer in the helicopter was unharmed although he carried no anaesthetic or surgical equipment. The victim, suspended by his crushed arm, and the surgeon had to be supported amidst the wreckage by a colleague whilst a difficult amputation lasting an hour was undertaken using a pair of socks as a tourniquet, a clasp knife, a bayonet and a fishing line for ligatures. As another example of sangfroid in extremis, the Colonel remained conscious and silent throughout, acknowledging the powerful effect of peer pressure in stating:

> *"I sensed that the Gurkha soldiers of B Company were now grouped around the wreckage. Bravest of the brave, how often had I seen their courage when wounded in battle. Now I had to try to live up to their standards, to show I was worthy to be one of their officers."*

A successful operation enabled him to continue his career and become a Brigadier-General.[25]

Sometimes patients initiate an amputation following dissatisfaction with a badly healed and painful compound fracture, or a painful and recurrently infected amputation stump, or a stump too long for an efficient prosthesis. An example of this, reported in the press in 2004, concerned a Royal Marine officer whose severe leg injury in a climbing accident eventually healed,

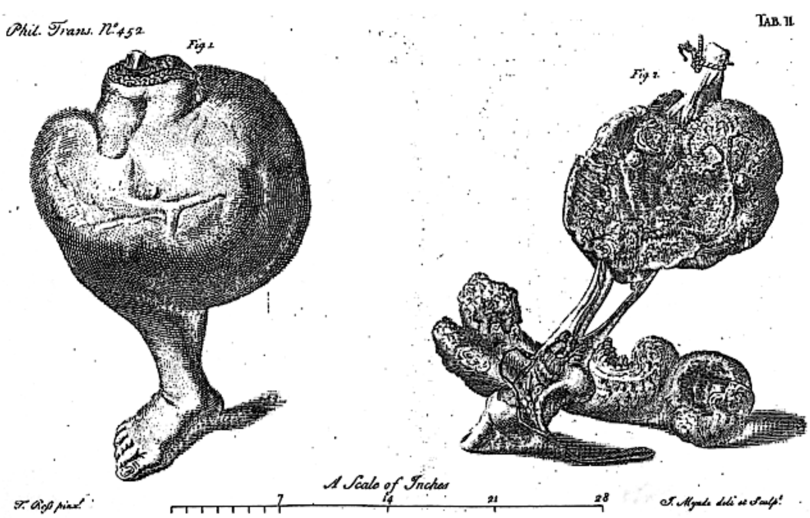

Fig. 9.3. Engraving of massive upper tibial tumour with its bony and cartilaginous skeleton, excised in 1736 by Jeremiah Peirce; he stated the amputated specimen weighed 69 pounds.[24]

leaving him with poor function and a threat of retirement. He perceived a sophisticated artificial limb would improve his capacity and after surgery and rehabilitation was permitted to remain in the service fully active and, indeed, was enabled to join a polar expedition.[26] In the 16th century, Paré left the following account of reamputation of an overlong stump incompatible with the prostheses then available:

"For I so knew Captain Francis Clark, when his foot was srticken off with an iron bullet, shot forth of a man of War, and afterwards recovered and healed up, he was much troubled and wearied with the heavy and unprofitable burden of the rest of his leg, wherefore, though whole and sound, he caused the rest thereof to be cut off, some five fingers bredth below his Knee; and verily he used it with much more ease and facility than before in performance of any motion."[27]

Cox wrote a complete monograph in 1845 concerning a woman of 23 years who asked for reamputation, after suffering for 14 years from an infected stump following an above-knee amputation for a diseased left knee joint. She submitted to amputation through the hip joint in 1844, shortly before general anaesthesia was available; Cox reported she drank half a bottle of port wine, although it is not clear whether this was before or after the operation, and subsequently survived with a well-healed stump (Fig. 9.4).[28]

For many patients faced with an acute injury operation was totally unacceptable, perhaps more often than we can estimate, as such case observations of refusal are rarely described. However, for most patients matters were less clear cut, as their decision for or against amputation was not heightened by the acute shock of an injury or by chronic illness and relentless bodily sapping misery, but by less precipitate symptoms, for example, the gunshot wound treated conservatively until infection gradually spread or the chronic bone ulcer which dripped with pus and interfered with normal activity but was not life threatening. In these circumstances the debate between patient, surgeon and relatives might occupy days or weeks and, before general anaesthesia, persuaded many patients to refuse amputation and to live on in hope of recovery, however slim.

Wiseman described the instantaneous reaction of a soldier who received a musket ball injury of the elbow joint at the battle of Worcester in 1651; the humerus, radius and olecranon bones were all shattered and, at that time, open joint injuries were considered a clear indication for amputation. Wiseman commented:

"Upon sight whereof I called Will. Clarke (now a Chirurgeon at Bridgnorth) and other Servants about me, to cut off the Arm, and the while I endeavoured to encourage

Fig. 9.4. Elizabeth Powis, aged 24 years, showing healed scar after hip disarticulation in 1844 for a painful unhealed stump following above-knee amputation when aged 9 years, probably for tuberculosis.[28] (See Fig. 8.2)

the Souldier to endure it. In answer thereto he only cried, Give me drink, and I will die. They did give him drink, and he made good his promise, and died soon after; yet had no other Wound than that. By which may be perceived the danger in delaying this work to the next day, when the aforesaid Accidents have kept them watching all night, and totally debilitated their Spirits."[16]

Duhamel highlighted the more-laboured quandary of a soldier in World War I who was struck in both knees by a grenade and required immediate amputation of one leg for massive injuries. The other less traumatised leg was treated conservatively for some weeks, but gradually chronic infection spread and his general condition deteriorated, for which a second amputation was advised. At first the soldier refused to consider this advice, despairing of a future without legs, work, marriage and children until, eventually, Duhamel convinced him independence was possible with artificial legs, and he was rescued by a second dismemberment above the knee. Both stumps healed and eventually he coped with prostheses, became a tax inspector, was married and had children.[29] Before the days of anaesthetics and antibiotics, it was even more daunting for patients with an inflamed wound who underwent an amputation which proved insufficient to cure their condition and were then advised to undergo further amputations at higher levels to avert spreading infection. Wheeler recounts this experience of a nurse working in a hospital attached to his Regiment, in the War of the Spanish Peninsula, in 1814 as follows:

". . . she pricked her finger with a pin left in one of the bandages, caught the infection, her finger was first amputated, then her hand, the sluff appeared again in the stump, she refused to undergo another operation, the consequence was she soon died."[30]

Beyond the decision to accept an amputation and its associated threats of immediate complications, the patient also had to accept, if all went well, inevitable deformity and disability, as manifest sources of future anxiety and misgivings. Even in the 21st century, as the Waterford Disability Network affirmed:

"Many people who have suffered the loss of a limb will go through a period of intense emotional turmoil and grief: they will suffer anger, depression and disbelief. Ongoing support from family, friends and medical professionals is vital, and rehabilitation has to include both the physical and emotional needs of the person."[31]

On a different note, some Muslim patients preserve their amputated limbs or limb remnants to be buried with them after death so they can go to Paradise whole. And on a related note, the preserved limb has been retained, in one instance at least, for public inspection and the victim's repeated pilgrimage, as the case of General Sickles reveals. Injured while on horseback at the battle of Gettysburg, his shin being shattered by a cannonball, he was evacuated with a saddle-strap tourniquet, smoking a cigar and drinking brandy. After a low-thigh amputation, the specimen was preserved and sent to the Army Medical Museum for display (Fig. 9.5). On recovery and retirement, Sickles preferred a pair of crutches to a prosthesis, and was in the habit of visiting the Museum regularly to view his loss (Fig. 9.6), often bringing

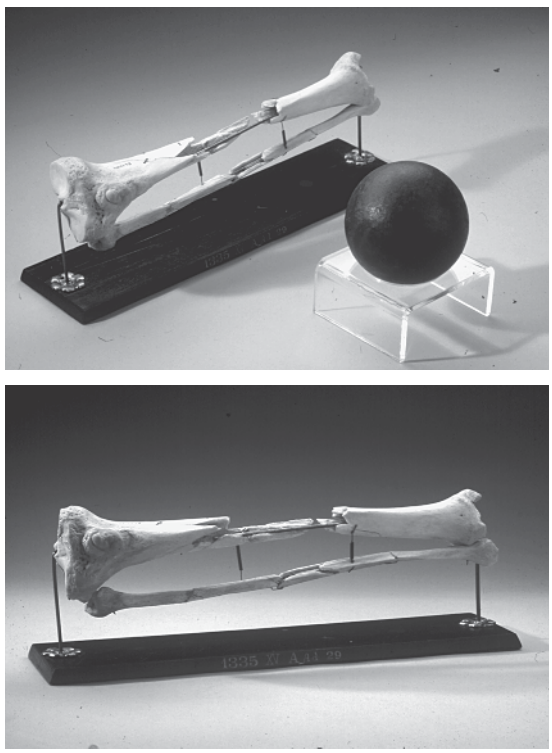

Fig. 9.5. Tibia and fibula of General Sickles amputated for injury by cannonball at the Battle of Gettysburg in 1863, demonstrating massive bone loss below the knee and an appropriate cannonball. (With permission of the National Museum of Health and Medicine, Washington, DC.)

Fig. 9.6. Engraving of General Sickles with an above-knee amputation, on crutches, examining his shattered leg on public display in the Armed Services Medical Museum.[32] (With permission of the National Museum of Health and Medicine, Washington, DC.)

friends with him to admire the leg. Mark Twain, who was a neighbour, commented:

"... the General valued his lost leg away above the one that is left. I am perfectly sure that if he had to part with either of them, he would part with the one he has got."[32]

Surgeons

We have argued that early societies probably rejected amputees and, until the latter were accepted by their fellows, no elective surgical amputation was possible. Once amputees were accommodated by society, study of the indications for and how to perform an amputation were possible. Unfortunately, before the introduction of gunpowder and the severe trauma of compound gunshot wounds, no case evidence has been found to support earlier operations designed to achieve a healed stump capable of tolerating a prosthesis. During the 15th century, gunshot wounds of the limbs became increasingly common and, at first, created uncertainty among military surgeons due to ensuing complications such as gangrene and ascending infection, followed by death of the victim, in contrast to more-familiar and less destructive arrow wounds. Certain surgeons considered gunshot wounds were poisoned by the explosive powder, which was believed to blacken the wound margins, and suggested hot oil lavage as a countermeasure. With experience it was realised, firstly, the blackening was due to contusion of the soft tissues and, secondly, other factors were more important, particularly disruption of the main arteries to a limb and the inflammatory effect of in-driven and contaminated clothing, armour and other foreign bodies accompanying the passage of the missile. Paré, one of the first to recognise this, advised at the first dressing:

"The wound must forthwih be inlarged, unless the condition of the part resist, that so there may be free passage forth, both for the Sanies or matter, also for such things as are sarced (sic), *or otherwise, contained therein; such as are pieces of their Cloaths, Bombast, Linnen, Paper, pieces of Mail, or Armour, Bullets, Hail-shot, splinters, of Bones, bruised Flesh, and the like, all which must be plucked forth with as much celerity and gentleness as may be."*[33]

However, if the limb was shattered and its blood supply compromised, or if it was impossible to clear the debris, often difficult when, for example, coins in a soldier's pocket were fragmented by the missile and driven deep into the wound, then it was recognised amputation through sound tissues above the wound was a means of preventing serious complications and the patient's death. This important realisation changed the management of gunshot wounds dramatically and proved a significant surgical breakthrough, ushering in elective amputation as an increasingly acceptable procedure, even in the days before anaesthesia and asepsis. However, for most surgeons a major limb amputation posed a number of difficult dilemmas:

i. What were the precise factors determining which injured patients required amputation and which could be treated expectantly?
ii. When was the best time to undertake amputation?

iii. At what level should amputation take place?
iv. What assistance, equipment and instrumentation were appropriate?
v. How was the patient's pain to be managed?
vi. How was the inevitable bleeding to be controlled?
vii. How was the stump to be dressed and infection avoided?

And later, if the patient survived:

viii. Would the stump be suitable for an artificial limb and what was available?

Many of these issues are discussed in earlier or later chapters and do not receive further attention here. However, questions i, ii and iii merit consideration now as they are influenced, in part at least, by the patient in preliminary discussions with their surgeon.

As the quotation from Fergusson at the head of this chapter suggests, surgeons faced with an injured patient were often perplexed in determining the best course of action, summed up by Gross, as already noted, in observing it was possible to mutilate a limb that might have been saved and endanger life by retaining one which should have been amputated. On battlefields and battleships, these issues appeared to have been more clearly defined and amputation performed more readily because of the press of numbers and difficulties in evacuating men with agonising wounds due to inefficient splintage and lack of transport. Further, men under military discipline and exposed to peer pressure were more likely to acquiesce to surgical advice, particularly if virtually immobilised by pain and shock and knowing an arm amputee could walk on his own or with a comrade, and a leg amputee might manage crutches or be evacuated on horseback. This experience of military conditions influenced civil practice, especially after warring periods ceased and military surgeons returned home in large numbers. Certainly there was a period in the 17th and early 18th centuries when practically all civilian compound fractures were subjected to amputation, even when not associated with the foreign bodies of gunshot wounds. However, as already emphasised, Bilguer, John Hunter and others with military experience began to question such management, and indeed Bilguer claimed amputation was rarely indicated.[34] This movement encouraged more-conservative treatment, the practice of delayed amputation and, in civil practice particularly, a growing interest in seeking less destructive operations especially for joint disease and limb aneurysms (see Chapter 7).

During the Napoleonic campaigns, there was reversion to immediate amputation, whenever possible, on the part of military surgeons such as Larrey, Percy, Guthrie and Hennen, doubtless related to encounter with vast numbers of wounded, difficulties in their evacuation and a lack of sufficient hospital facilities. Where evacuation to a hospital took place, a waiting policy was possible yet fraught with uncertainty, as in the case of Corporal Wheeler shot at the Battle of the Nivelle in 1813. He received penetrating bullet wounds close to both ankles and was conveyed by mule and also by a cart to St. Jean de Luz for hospital treatment. The left leg settled but the right continued to discharge and he was evacuated by boat to convalesce at St. Andia near Spain where unhappily, some 6 months after injury, the wound deteriorated and formed an abscess which was opened; he was sent to the incurable ward at Funterrabia. He wrote:

"My wound continued to get worse, I had every attendance that could possibly be given and all the remedies applied to prevent mortification, at length my leg and thigh was reduced so small that I could span it with my hand, but the wounded part and foot were swollen to an enormous size, and the wound was as large over as a tea saucer. It was at length agreed to amputate my leg, this I joyfully agreed to being heartily tired of such a frightful troublesome member. Twice were I removed to the surgery to undergo the operation but each time the little Spanish Doctor, who had charge of me, overruled it and I was taken back to my bed, I understood my Doctor wished to try something else, then if that failed the leg was to come off."

Eventually, the doctor applied *"something like pepper and salt mixed"* from a bottle and the wound was bound up for several days.

"My wound now was changed from a nasty sickly white-brown colour to a bright read (sic). *He* (the doctor) *capered about like a mad fellow, called the other doctors who all seemed surprised, he put some more stuff out of the bottle on the spots and the next morning I was removed down stairs This was on the 9th inst.* (9th June, 1814). *Since then my wound improves surprisingly."*[35]

Twelve months later, as Sergeant Wheeler, he fought at the Battle of Waterloo. It was subsequent to the chaos of Waterloo that more-conservative measures were forced on surgeons, simply because thousands of casualties could not be treated for many days; among survivors evacuated from the field, delayed amputations were performed although the results, for example, Charles Bell's patients, proved poor.[36]

Until general anaesthesia was established, all the surgeon could offer the patient was a speedy operation dependant on his anatomical knowledge. Small advantages were gained after 1718 with the efficient screw tourniquet of Petit, which encouraged accurate haemorrhage control by ligature, as opposed to uncertain cautery, and later in the century with the use of fine crucible-steel knives permitting the formation of rapidly shaped soft tissue flaps. Acceptance of new concepts including anaesthesia was sometimes obtuse as the deplorable remarks of Sir John Hall, Principal Medical Officer in the Crimean War indicate, despite the availability of ether and chloroform which he considered dangerous:

"However barbarous it may appear, the smart of the knife is a powerful stimulus, and it is much better to hear a man howl lustily, than to see him sink silently into his grave."[37]

With the introduction of antiseptic wound practice, the problems of operative pain, haemorrhage and infection were virtually solved, except that many surgeons clung to old ways and refused to accept chemical sterilisation with antiseptics, or practised a partial regimen incorporating some elements, or failed to follow Lister's exacting instructions. As Watson's quotation in Chapter 1 reveals, conservative surgeons rejected Lister's prophylactic system in their ignorance, by thanking God they had neither witnessed its application nor employed it.[38] If society was regulated by traditional concepts, then many surgeons were in a similar boat, unwilling to change direction, despite exposure to scientific reasoning. However, the addition of thermal sterilisation in the late 1880s, combined with clear demonstrations of specific pathogenic bacteria in wounds, quickly broke down remaining resistance to scientific prophylaxis, which continues as the basis of surgical practice in 2005.

Anaesthesia liberated patients from painful experienced during wound exploration by providing time for surgeons to remove foreign bodies and debride damaged tissues thoroughly and, hence, diminishing the need to amputate precipitately. At the same time longer alternative procedures were encouraged to avoid amputation as a solution, especially the reconstruction of damaged arteries. Unhappily, the American Civil War, and the two Great Wars, amongst many other conflicts, have been associated with ever more destructive weaponry (see Chapter 8) and amputation remains a necessary option. In 20th-century civil life, an aging population has added an increasing burden of deficient vascular problems which, too, may require amputation as a life-saving measure. Since World War I and especially World War II, surgeons have worked more closely in cooperation with limb fitters and manufacturers, after recognising their former levels of amputation might not be appropriate to the prostheses available. In major British institutions operative surgeons, specialist limb-fitting surgeons, craftsmen and manufacturers cooperate to the mutual benefit of the amputee who, ideally, receives the most efficient prosthesis for their amputation. In recent years, this teamwork has been extended to harness the expertise of muscle and nerve physiologists, materials scientists and electronic engineers to provide remarkably efficient limbs which often mask a patient's disability entirely.

If these advances have made the surgeon's work easier, there is still the often-difficult task of knowing when to amputate and where to amputate, factors which depend on experience. It is now possible to reimplant limbs if the detached portion is not too traumatised, although such surgery requires time for bones to heal and even longer for nerves to recover, partially at best, after many months or even years. It may be prudent to consider an efficient amputation and prosthesis with a quick return to activity than embark on a prolonged and uncertain period of reconstruction. As a sceptical surgeon entitled a lecture in 1994, "Limb salvage versus amputation: technique over reason?"[39]

Summary

It is postulated that mankind's acceptance of amputees is necessary before elective surgical amputations are undertaken. Even so, some societies do not countenance elective surgery, usually for religious reasons, despite the presence of amputees of congenital, traumatic and punitive or legal origin sanctioned by the same societies. Hence, the wish of a patient to live with three limbs than to die with four, even with the acquiescence of a surgeon, carries no weight unless supported by their communities.

Before anaesthesia, painful amputation was often endured stoically, paradoxically bolstered by intense religious conviction. For the surgeon, the former dilemmas concerning if, when and where to amputate, and how to alleviate pain, prevent haemorrhage and infection, have diminished by utilising modern supportive measures. Limb reimplantation is now possible, although not always successful.

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10
Surgical Instrumentation and Equipment

". . . it is very fit and needfull for the Surgion to have at the least two incision knives, one greater, one lesse, and that he keepe them sharpe and cleane; but let them not be so thinne grownde in the edge as the Rasor, for then they will deceive the workeman . . ."

Woodall, 1617[1]

"If used sensibly, the tourniquet is a safe instrument. Most of the few complications seen with its use are preventable."

Klenerman, 2003[2]

Instruments designed specifically for elective amputation are not essential, provided suitable alternatives are found in urgent circumstances. Several published accounts confirm any sharp knives and saws, often borrowed from the kitchen or a craftsman, proved expedient in skilled or even unskilled hands as the following observation reveals. In a report by Treves, a passenger with a crushed arm on a sailing ship rounding Cape Horn in 1886 underwent an above-elbow amputation, performed by the second mate and the ship's carpenter without operative experience, anaesthesia or surgical equipment, yet a successful outcome:

"The instruments were provided by the carpenter, and consisted of a shoe knife, a saw, and a sail needle. The patient's wife furnished a sewing needle and some silk."[3]

Nonetheless, such improvisation would have benefited from orthodox surgical experience and instruments.

Early operative techniques of elective amputation were dominated by two immediate priorities, firstly, how to restrict a patient's pain to the minimum and, secondly, how to prevent death from blood loss. Before general anaesthesia, pain-relieving measures were generally ineffective because of profound uncertainties in administering safe doses of soporifics and opiates, although alcohol sometimes bolstered morale. Other measures included the application of tight bandages, later termed tourniquets, to numb tissues below the bandaging and also specific attempts to paralyse individual nerves to the limbs by applying compressors, as suggested by Moore in 1784.[4] Moore's scheme required placing the compressor head accurately on the sciatic nerve or femoral nerve, or both together (see Fig. 8.3), without obstructing adjacent veins or arteries, and maintaining compression for up to an hour before sensory loss below was effective. In practice, this proved extremely difficult if not dangerous and also a painful experience for the patient, leading to abandonment of the method. Sadly, only hypnosis offered a possibility of relief before general anaesthesia (see Chapter 8).

For too long the only significant measure available, in the quest to diminish pain, was the surgeon's operative speed endeavouring to diminish the patient's sufferance to as brief a period possible, by employing accurate anatomical knowledge, an economical technique and the most efficient instruments available. Hence, dependant on existent technology, soft-tissue incision knives were long, strong and sharp, yet not too keen to be blunted by the edge turning, as Woodall hints in the foregoing quotation (see Fig. 9.2). Similarly, bone saws needed to be long and thin, their teeth carefully set and manufactured of suitably tempered steel to avoid blade fracture, a complication of bow saws in particular, sometimes caused by sudden movement of the patient at critical moments.

Irrespective of the keenness of cutting instruments, until adequate measures to control haemorrhage were introduced, elective amputation was rarely hazarded by Graeco-Roman and medieval authors, as noted in Chapter 5. In practice, it was not until the complications of gunshot injuries stimulated a change of attitudes that effective tourniquets, heated cautery and vessel ligatures evolved to control blood loss, enabling major operations to acquire a more-predictable outcome and readier acceptance by patients who, in extremis, chose amputation.

Bandages and Tourniquets

Firm compressive bandaging of wounds probably stimulated the concept of controlling bleeding with bandages (also termed ligatures) above and below a wound or a site chosen for amputation. In the 2nd century A.D., Heliodorus advised compressing the vessels as far as possible with a bandage above the amputation site.[5] Albucasis said tight ligatures (bandages) should be applied above and below the site, enabling an assistant to exert soft-tissue traction during surgery.[6] In 1364, Guy de Chauliac also recommended bandages above and below the operative site,[7] and in 1517 Gersdorff confirmed this procedure in the earliest known illustration of an amputation (see Fig. 1.5). In the early 17th century, Fabry specified a constricting ligature made from a woman's hair ribbon[8] and Wiseman mentioned using a *"red ribbon"* almost certainly made of silk which he kept wrapped around his case of lancets.[9] At some stage, a stick was introduced to tighten simple bandages by twisting, the so-called Spanish windlass, a system previously employed to tighten the cordage on wagons; no precise date of introduction is known. It is claimed that Morel, a surgeon at the siege of Besancon in 1674, improved the simple bandage-stick tourniquet by introducing a pad stuffed with hair to overlie the major limb vessels and then passed the bandage through a piece of leather which supported a twisting stick.[10] In an emergency anything to hand, including a weapon, might substitute for a stick (Fig. 10.1).

In 1718, Petit devised the screw tourniquet (see Fig. 5.5),[11] a major step forward in design, permitting the operator to control bandage pressure by minor adjustments of the screw and also reduce pressure to view arterial bleeding points and secure them again, without the delay of bandage release and reapplication, as was necessary with earlier tourniquets. If left in position too long, as sometimes happened, tourniquets produced permanent ischaemia and gangrene (see Fig. 4.6b). Derivatives of Petit's tourniquet were constructed to control vessels in the lower abdomen and pelvis for hip disarticulation but, proving uncertain and hazardous, were finally abandoned (Fig. 10.2).

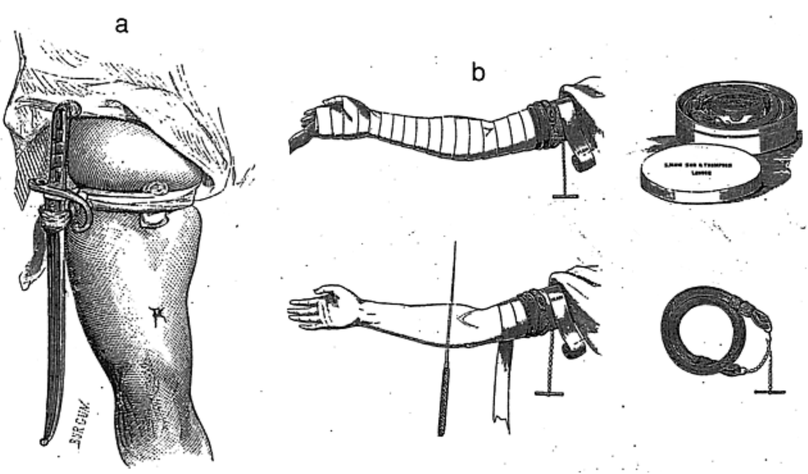

Fig. 10.1. a. Improvised tourniquet with sabre, cravat and handkerchief. (From Malgaigne J-F, *Manuel de Médicine Opératoire*, vol 1, Paris: Germar Baillière, 1874, fig. 42.[65]) **b.** Esmarch's elastic bandaging to exsanguinate the arm followed by his tourniquet seen *lower right*. (From Maw, Son & Thompson's *Instrument Catalogue*, London, author, 1882.[66])

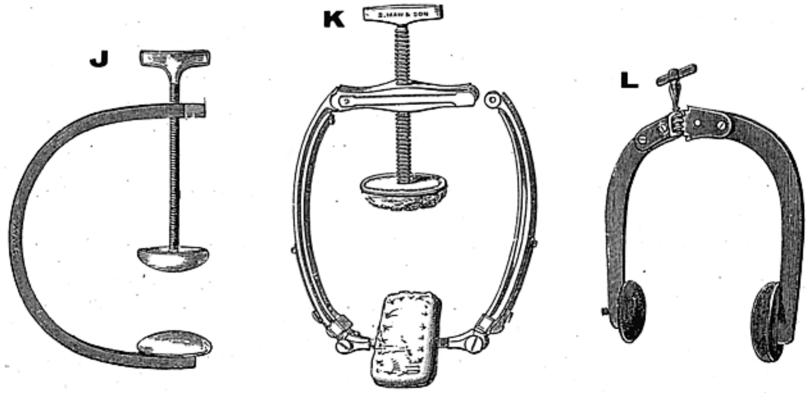

FIG. 10.2. Limb root tourniquets: J. Lister's abdominal for aorta during hip disarticulation; K. Skey's for femoral and axillary arteries; L. Signorigni's for femoral and axillary arteries. (From Maw, Son & Thompson's *Instrument Catalogue*, London: author, 1882.[66])

In 1873, Esmarch began to exsanguinate limbs, before amputation, by winding up a bandage from the toes or fingers, to be removed following application of a rubber tube tourniquet at the root of the limb.[12] In 1879, Lister advised elevation of the foot or hand for 2 minutes, using gravity as a simple method of exsanguinating limbs, followed by an Esmarch elastic tourniquet at the root of the limb.[13] Langenbeck is credited with replacing Esmarch's simple exsanguinating bandage and his tube tourniquet with flat elastic rubber bandages, which are now known as Esmarch's bandages (see Fig. 10.1). These methods of exsanguination continue although tourniquets are now based on an inflatable rubber bag, derived from the sphygmomanometer, and linked to a gauge enabling precise pressures to be applied, a system attributable to Cushing in 1904.[14] However, it remains difficult to apply a tourniquet at the groin or axilla, and these high amputations demand careful dissection and haemostasis by open vessel ligature.

Actual Heated Cautery

The application of heat by iron cauteries is noted by Hippocrates, principally as a method of counter-irritation against internal diseases, or to dry up ulcers and wet gangrene, to destroy tumours and to treat haemorrhoids; he does not describe heat coagulation of bleeding vessels. Celsus in the 1st century A.D.[15] and Archigenes in the 2nd century A.D.[16] give early references to the application of heated cauteries to control haemorrhage; this is mentioned again by Paul in the 7th century A.D.[17] and by Albucasis in the 10th century.[18] Thereafter cautery is the mainstay of controlling severe haemorrhage until Pare revived vessel occlusion by ligature in the 16th century, as discussed in Chapter 5. Even so, red-hot iron cauteries continued to be applied by some surgeons until the late 19th century.

Iron cauteries from the Roman period are rare survivals, usually corroded and fragmentary, offering little information on the structure of cauteries before the 7th century A.D. when Paul described a variety of forms, each for specific treatment indications, mostly for counter-irritation of internal diseases but also for amputation due to gangrene of the hand and foot, when he advised: "*. . . apply red-hot irons to the vessels to stop the haemorrhage.*"[17] Albucasis illustrated more than a dozen forms of cautery for disease, and for arterial haemorrhage he wrote:

"*. . . put in the fire several olivary cauterie, small and large, and blow them to make them very hot. Then take one, small or large according to the size of the wound and the site of the opening of the artery, and bring the cautery right down on the artery . . .*"[18]

Subsequently olivary-headed cauteries are frequently mentioned (Fig. 10.3a) as a correct shape for sealing the mouths of arteries. Yet, cautery was not infallible, especially for larger arteries. Yonge[19] and John Bell[20] both observed that if the cautery iron was too hot, the scar stuck to the iron or the scar loosened and dropped off; if the instrument was not hot enough, no adequate scar formed and repeated applications might be needed. In addition, the furnishing of a suitably heated cautery at a critical moment also posed practical problems,

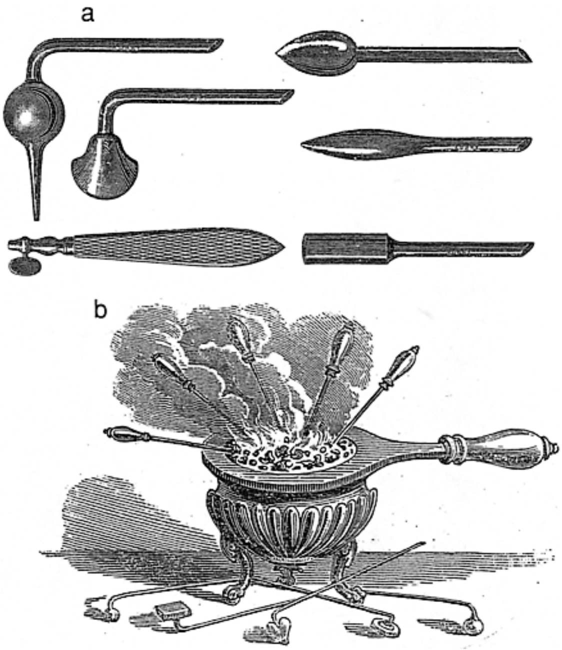

FIG. 10.3. a. Selection of cautery heads for fitting into ebony handle; two olivary heads are seen on the *right*. (From Aubry's *Instrument Catalogue*, Paris: author, 1900.[67]) **b.** Brazier for heating 18th-century style cauteries with fixed wooden handles. Most of the cauteries seen *below* were for drying up gangrene and ulcers. (From Bell J. *The Principles of Surgery*, vol 1. Edinburgh: Cadell, 1801:149.[20])

especially on a rain-swept battlefield or a ship in severe weather (Fig. 10.3). Bell concluded dismissively in 1801:

". . . the horrors of the patient, and his ungovernable cries, the hurry of the operator and assistants, the sparkling of the irons, and hissing of the blood against them, must have made terrible scenes, and surgery must in those dark days have been a terrible trade."[21]

This drama of heat cauterisation, hideous for both patient and surgeon, encouraged the application of potential cautery, that is, the use of styptics, astringents and caustics and, unfortunately, poisonous agents such as arsenic and corrosive sublimate. Combined with local pressure these applications often succeeded initially but, sadly, were often followed by tissue necrosis, infection, ulceration and secondary haemorrhage and even death from poisoning.

Following abandonment of red-hot iron cauteries, the efficacy of thermal haemostasis was not overlooked and, assisted by general anaesthesia, new sources of heat were explored. In 1854, Middledorpf discovered galvanocautery[22] and, in 1876, Paquelin devised thermocautery,[23] both extremely efficient for small vessel occlusion. In 1907–1908, Doyen introduced an electrocoagulation machine[24] and Nagelschmidt coined the term "surgical diathermy" for small vessel coagulation.[25] In 1928, Cushing and Bovie devised a diathermy machine offering a choice of coagulating or cutting current.[26] Today, at the beginning of the 21st century, coagulation methods continue to evolve utilising electrohaemostatic scalpels, laser beams and ultrasonic energy.

Instrumental Vessel Occlusion and Ligatures

Ligation of major vessels was advised by Celsus,[15] Archigenes[27] and Galen[28] and, later, by Albucasis if cautery failed, although he expressed reservations about ligatures which, at that time, were not absorbable and often provoked secondary infection and haemorrhage.[18] No further reference to ligation is observed before Paré questioned heat cauterisation in the 16th century, suggesting ligation was more secure and humane. Paré drew out vessels with crow's-beak forceps and tied double threads or used a needle to secure ligatures through adjacent skin over linen packs (see Fig. 6.5), enabling him to cut out ligatures after vessels had thrombosed to avoid persistent infection. Few followed his advice, some fearing tight ligatures would divide arteries, others stating it was impossible to draw out vessels during the turmoil of a battle, or without clear daylight that was often lacking at the end of a day's fighting or in the cockpit of a warship.[29] However, the alternative of cautery also remained unreliable and painful, especially when adjacent nerves were cauterised in error. By the end of the 18th century, surgeons with sound anatomical knowledge agreed that drawing the vessel clear and ligating securely was the best solution, especially if ligatures were left long enough to emerge through the wound, for careful extraction when occlusion was considered secure (see Fig. 5.6).

Although larger cut vessels could be picked up with fingers, isolation with instruments had more practical application. In the 17th century, Fabry (Hildanus) described a pivoting forceps with a rack on one handle and a hinging catch on the other (Fig. 10.4A), an early self-holding clamp for vessel occlusion. In the 18th century, Heister and Garangeot illustrated a "valet a patin" forceps with a self-holding spring; the incentric pivot ensured the jaws were opened by pressure on the handles against the spring's resistance (Fig. 10.4B). However, neither of these concepts prospered widely.

From the late 18th century, it was common for vessels to be transfixed by sharp hooks and drawn out for ligature. Charles Bell considered the tenaculum hook to be the best instrument for this purpose. Nevertheless, hooks and particularly forceps might also pick up nerves, as indeed happened to Horatio Nelson in 1797 when his right arm was amputated, leading to subsequent nerve irritation in the stump by a tenacious ligature (Fig. 8.1). A novel self-holding instrument, devised by Assalini in 1812, was based on a two-limbed tenaculum articulating via an incentric pivot, controlled by a spring; thumb pressure on one handle opened the jaws whilst the spring kept them closed firmly on tissue taken in their sharp extremities (see Fig. 7.3). It became popular in Britain and remained part of the armamentarium until late in the 19th century as did spring forceps, controlled by a variety of catches, to act as arterial clips or clamps (Fig. 7.3), usually one to an amputation box. These instruments were far removed from later haemostatic (vessel-crushing) forceps for their power of grip was low and widely variable, as recent estimates have shown.[30] Nevertheless, for a time both forms of arterial forceps were in use.

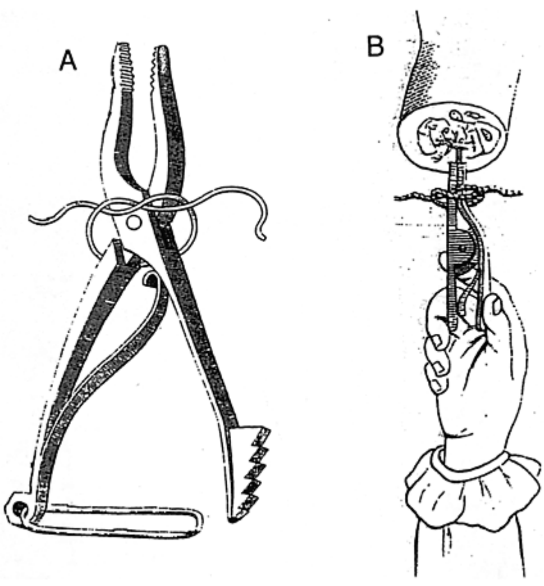

Fig. 10.4. A. Arterial forceps with spring resistance, hinging catch and ligature. (From Fabry de Hilden, *Observations Chirurgiques* 1669.[8]) **B.** Arterial forceps, "valet a patin" type with incentric pivot, spring resistance and ligature. (From Heister L. *A General System of Surgery*, vol 1. London: Innys, 1743.[40])

Haemostatic Artery Forceps

After 1847, general anaesthesia liberated patients from the pain of amputation, affording additional operative time for surgeons to combat haemorrhage carefully, enabling small vessels as well as large to be located and ligated. Nonetheless, the threat of infected ligatures and secondary haemorrhage persisted until antiseptic and aseptic techniques were established. In the meantime, the concept of haemostatic closure of vessels evolved, following research by Jones proving all except major vessels could be crushed safely in the jaws of powerful forceps, to cause adherence of their walls, maintained after forceps removal, and thus effect complete permanent vessel occlusion without sutures or heat, as discussed in Chapter 7.

Webber's arterial forceps, introduced in 1853, was shown to rupture the inner arterial coat but preserve the outer, resulting in self-adhesion of the latter. The strongly toothed jaws meshed accurately but the instrument was not self-holding, which may account for its failure to be more widely used. In 1879, Wells acknowledged the historical importance of Webber's forceps,[31] by which time other self-holding forceps were available. The key to efficient locking and simple release is attributable to the talented instrument maker Charrière who, in 1858, devised a rack and catch closure (Fig. 10.5B), conveniently situated between the handles and manipulated unimanually by digits located in the terminal bows of the handles. Despite this, Charrière preferred his earlier invention, the pin and hole closure (Fig. 10.5A), which dominated manufacture for a time. Koeberlé, who employed a pin and hole closure for his artery

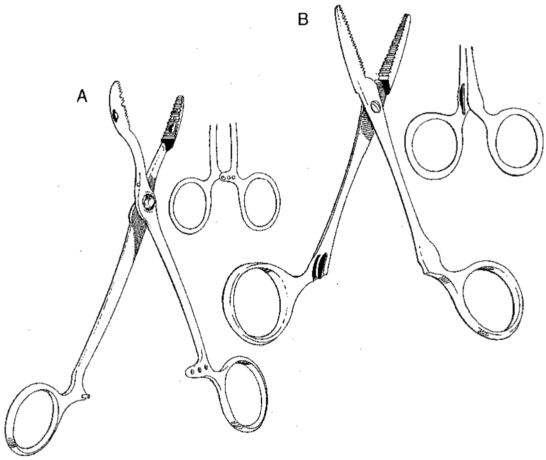

FIG. 10.5. A. Pivoting arterial forceps controlled by pin and hole catch, Koeberle type, c. 1877. **B.** Pivoting arterial forceps controlled by rack and catch, Spencer Wells type, c. 1879. (Drawn by Frances Lambert.)

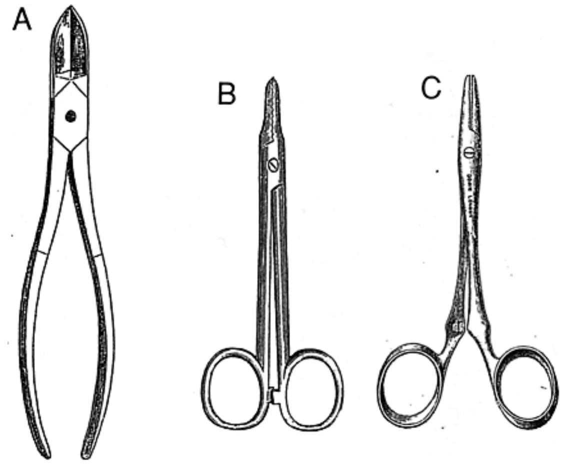

FIG. 10.6. A. Liston's bone-cutting forceps. **B.** First version of Spencer Wells artery forceps. **C.** Definitive version of Spencer Wells artery forceps. (From Krohne & Sesemann, *Instrument* Catalogue London: author, 1878,[68] and Down Bros., *Instrument Catalogue*, London: author, 1889.[69])

forceps to exert *"haemostasis by excessive compression"* in 1865, made the pin oblique to render closure easier; in the author's experience one-handed manipulation of pin and hole closure is awkward and often becomes a two-handed manoeuvre. To demonstrate his concept, Koeberlé left his forceps in position for 2 days after a Caesarian section, removing it successfully without ligature.[32] He was attacked fiercely by Péan, and his pupils, Deny and Exchaquet, for suggesting he had introduced compression haemostasis,[33] whilst Wells calculated Koeberlé's second pin and hole closure exerted a trivial 3.25 pounds pressure.[31] At this time, many minds concentrated on the advantages of forcipressure and unravelling the priority of individual claims is not easy. Koeberlé did not publish his work until 1877; meanwhile Deny and Exchaquet claimed, in 1875, that Péan had employed forcipressure forceps for several years and no longer applied ligatures in any operation.[34] From 1868, Péan utilised the easily applied rack-catch of Charrière which heralded the artery forceps of modern surgery, still in use at the beginning of the 21st century. Meanwhile, Mathieu's instrument catalogue of 1864 featured the rack-catch for both a dressing forceps and a needle-holder.[35] In 1879, Wells claimed that he had preceded Koeberlé and Péan by many years in employing forcipressure[31]; this is true only if we believe Wells' cross-action bull-dog clips achieved the same power as haemostats. Wells did not employ his well-known arterial haemostat before 1874[36] (Fig. 10.6B,C), although he improved Péan's forceps by introducing extremely powerful rack positions and also measured their compressive powers accurately, for the first time (Table 10.1). MacCormac illustrated the use of both spring and rack arterial forceps at an amputation (Fig. 10.7). Since then, rack forceps have multiplied to dominate the operating table, with many variations of

TABLE 10.1. Pressure exerted by forceps jaws, gripping leather 1 mm thick.

Arterial forceps	1st catch (lbs)	2nd catch (lbs)
Koeberle	—	3.25
Pean	8	12
Wells (old)	22.5	—
Wells (new)	12	22.5

Source: Wells TS. Remarks on forcipressure and the use of pressure forceps in surgery. Br Med J 1879;1:926–929.

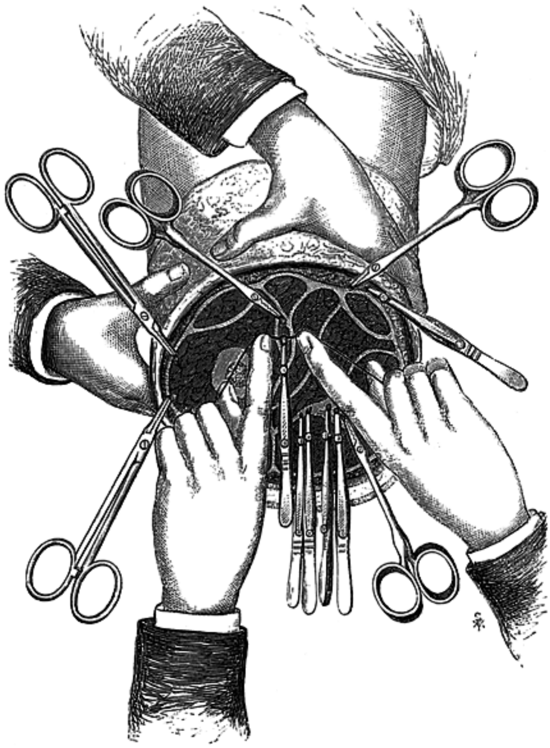

Fig. 10.7. Thigh amputation demonstrating use of spring and pivoting artery forceps to control bleeding vessels, some of which are ligated; those clamped by pivoting haemostats were often occluded by pressure alone. (From MacCormac W, *Surgical Operations*, Part II, London: Stritk Elder, 1889, fig. 106.[70])

dimension, jaw shape, degrees of curvature and number of catches, all described as haemostatic artery forceps, and each specified by one or more of a bewildering echelon of surgeons' names.

Large and Small Knives

Before the 16th century, amputation knives described in texts are either not illustrated, defectively illustrated, or do not survive in collections and hence remain structurally obscure. Subsequently, illustrated or surviving amputation knives are either large or small, the former for dividing the major soft tissues and the latter for penetrating soft tissues in difficult areas, especially between the tibia and fibula of the shin, and between the radius and ulna of the forearm; in Britain, small knives with two-edged blades were often termed "catlins" or "catlings," a term which has not been explained but may be related to "cutting."

Gersdorff's amputation scene of 1517 (see Fig. 1.5) and Ryff's of 1545 (see Fig. 9.1) illustrated a single relatively short, straight and strong knife, presumably for undertaking all soft-tissue dissection. By 1545, however, Paré figured a "hooked" amputation knife, that is, of sickle shape with a concave cutting edge (see Fig. 6.4), believed to be applied more rapidly to the convex surface of limbs; that is, a longer section was cut in one sweep of the blade in the technique of guillotine dismembering. Franco, in 1556, also recommended the "culter falcato," or hooked knife (see Fig. 6.2) and, as we shall see, the sickle shape persisted in some hands until the 19th century, although with diminishing degrees of curvature as knives became ever straighter. In the writer's view, sickle-shaped blades, appropriate for guillotine procedures, became recognised as inappropriate for undertaking flap amputations (see Fig. 6.8) which stimulated the rehabilitation of straight knives.

By contrast, Croce employed a large convex-edged blade in 1573, as did Fabry (Hildanus) in 1646, who also illustrated a smaller concave knife in 1646 (Fig. 10.8); in practice, convex blades remained a minority choice. Among those employing concave edges were Woodall, initially

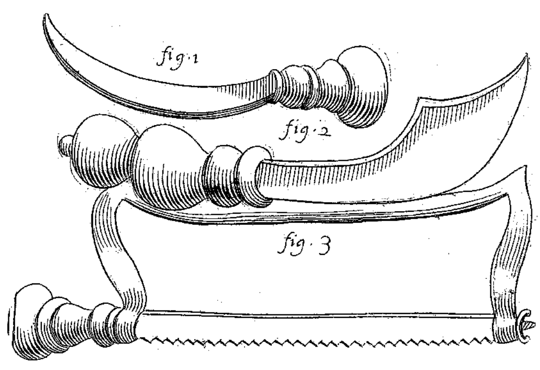

Fig. 10.8. Amputation Instruments, 17th century. *fig. 1*, concave knife; *fig. 2*, massive convex bladed knife; *fig. 3*, bow saw of unusually simple design. (From Fabri de Hilden G. *Observations Chirurgiques*. Geneva: Chouet, 1669.[8])

in 1617 (see Fig. 6.7) and again in 1639 with a reduced degree of concavity (see Fig. 9.2), Scultetus in 1653, Verduin in 1697, Purmannus in 1706,[37] Garengeot in 1727,[38] Sharp in 1739[39] and Petit in a posthumous work of 1783. In 1743, Heister also featured a large concave knife yet, exhibited alongside this: "*. . . a small-sized straight Scalpel, more commodius for dividing the Skin and Flesh in Amputations than the large crooked one . . .*",[40] a first criticism of concave-edged knives traced by the writer. Heister offered no explanation for displaying the concave knife in his important textbook. Possibly he comforted those apprentices whose masters still favoured such knives. By the later 18th century, English amputation knives, as represented in museums, retained a moderate concave edge (see Fig. 6.6) and, despite the introduction of long straight narrow blades with slight convex extremities, most English amputation boxes retained one knife displaying minor degrees of concavity until the late 19th century, often with a slight notch on the back and a round blunt termination, described by Brambilla as the "cultrum angli," the English knife (Fig. 10.9). It is understood these shadowy analogues of the original sickle knives were believed to facilitate rapid guillotine amputations, especially under battlefield conditions.

As early as 1588, Clowes illustrated straight-edged folding or clasp knives for amputation, a century before the introduction of flap procedures; he offered no explanation for selecting this form of knife. Straight blades did not become evident again until 1772 when Perret advertised both concave- and straight-edged knives, indicating the latter were necessary for flap amputations[41]; Brambilla offered a similar choice in 1782.[42] Alanson, who published a remarkably successful series of amputations, advised in 1782:

"*. . . operate with a lesser knife, than that used in common amputations; a catlin of modest size answers the purpose very well, is more handy, cuts with either edge as the turn of the hand directs, and acts more under the immediate view of the eye than a larger knife.*"[43]

Benjamin Bell also advised a strong straight-edged knife in 1788. By the 19th century, most amputation knives became essentially straight

Fig. 10.9. Selection of knives, 18th to 20th centuries. From *top:* concave blade with notch on back, the "cultrum angli"; long transfixion double-edged blade; convex blade of Liston type; slightly concave blade, the final form of the "cultrum angli" of the late 19th century; all-metal knife with convex blade of early 20th century; all-metal scalpel of mid-20th century, perfectly adequate for all amputations under full anaesthesia. (From Private Collection.)

edged but also much longer and slimmer, technically possible thanks to the availability of cast or crucible steel (see Fig. 10.9). This process produced a blade of uniform structure and hence stronger than earlier shear steel blades which had to be thick to resist breakage. At the same time the transfixion method of amputation was reintroduced, a method benefiting from narrow blades inserted like a lance (see Figs. 8.2, 8.4); these also furthered the technique of foot amputation by disarticulation through the complex of tarsal joints, as suggested by Lisfranc[44] (Fig. 10.10). The length of lancelike knives varied to match the diameter of the limb or digit undergoing amputation with choices between 4 inches and 13 inches overall, the longest having a 9-inch blade for hip disarticulation (see Fig. 10.9). Often called Liston's knives, they were sharpened on the back of their tips to act as periosteal elevators and were narrow enough to pass between leg and forearm bones, rendering catlins obsolete.

With the establishment of thermal sterilisation techniques after 1890, all-metal knives became obligatory and, about the same time, knives longer than 11 inches overall disappeared from instrument catalogues. After World War I, surgeons performing nonurgent amputations found simple dissecting scalpels equally effective and less unwieldy in achieving healthy flaps for primary healing and functional stumps. This choice was facilitated by utilising disposable scalpel blades, from about 1920, to provide a choice of sizes and blade edges instantly sharp. However, for emergency amputations, especially under war conditions, long knives continued to be used for rapid guillotine procedures. At the end of the 20th century, British armed services still retained 10-inch Liston knives in emergency surgical kits, although their frequency of use is believed to be virtually nil.[45] In practice, small interchangeable, disposable scalpel blades are employed, especially for the slow methodical surgery needed to

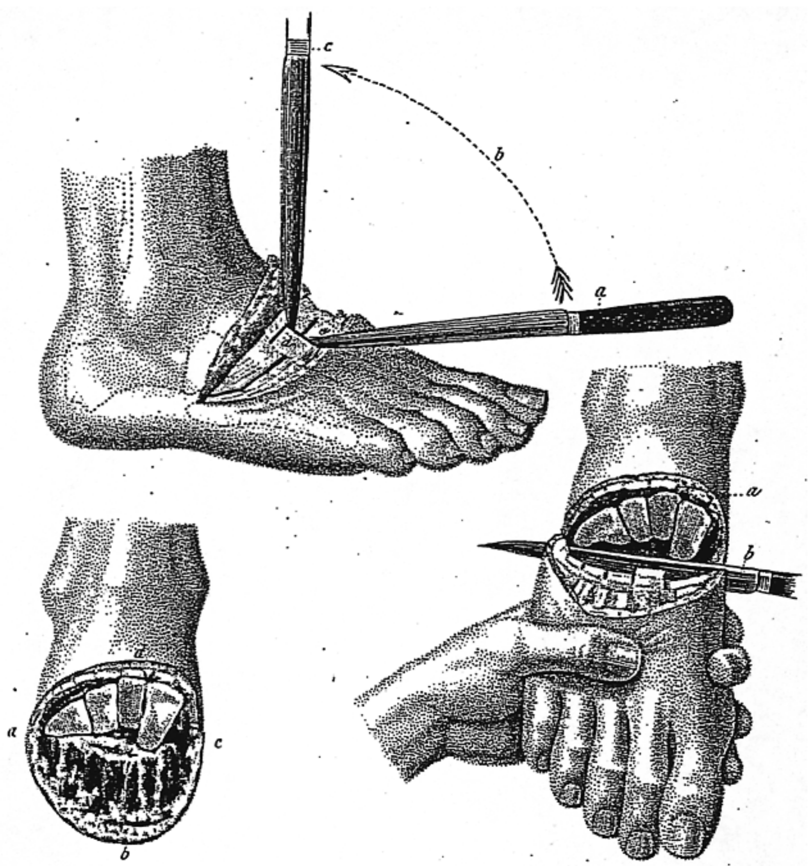

Fig. 10.10. Operative diagram of Lisfranc's tarsometatarsal disarticulation of the foot with plantar flap; his long narrow knives were introduced, c. 1815, to facilitate dissection between the tightly arranged joints of the midfoot. (From Bernard C, Huette C, *Precis Iconographique de Medecine Operatoire*, Paris: Mequignon-Marvis, 1845, plate 24.[71])

preserve tissues after traumatic mangling of the foot and lower leg by destructive antipersonnel mines, as Coupland's experience demonstrated (see Fig. 1.7).[46] Today, the long knives of the past, intended to shorten the patient's agony, epitomize grisly memorials to horrific and hasty dismembering before anaesthesia.

Unusual Blades

Cautery-Knives

Croce and Fabry appear to be alone in suggesting amputation with heated blades, termed cautery-knives. Fabry stated this method reduced soft-tissue bleeding and also caused muscles and nerves to contract well clear of contact with the saw cut.[47] Wiseman found heated blades stuck to the tissues, causing delay in their efficient manipulation, and abandoned them[48]; no other authors supporting heated blades have been traced.

Swords, Chisels and Guillotines

Legal and punitive amputations performed with swords or axes may have stimulated surgeons to operate in this way. According to Harley, the Masai tribe in Kenya amputated for severe compound fractures very deftly, by means of a long sword on a block.[49] Woodall, one of the first to mention special chisels and mallets (see Fig. 9.2) for instantaneous amputation, restricted this application to fingers and toes. He and others noted that chisel amputations at higher levels resulted in splintering of bone and frequently incomplete division of soft tissues, particularly tendons and nerves,[50] resulting in more than one blow before completion. Fabry considered this a cruel method, unworthy of a rational surgeon, yet he recommended a guillotine machine for the same purpose, consisting of two large blades set in timbers weighted with lead, basing his favorable opinion on a report by Master Cognomine but without supportive case histories (see Chapter 8).[51] However, Purmannus, one of the last authors to illustrate chisels for digital amputations, in 1706, also recorded witness accounts of two double-bladed machine guillotine sections through the shin which ended badly, concluding it was much better to amputate in the ancient way with knife and saw.[52] As also noted in Chapter 8, Mayor raised the possibility of instantaneous cutting, termed by him "tachytomie," yet offered no practical solution.[53]

Bone-Cutting Forceps

Woodall advised *"dismembering nippers or cutters,"* a form of large pliers with transverse linear blades, for rapid amputation of fingers and toes. Scultetus suggested even larger cutters for amputations as high as wrist and ankle level, almost certainly needing two-handed strength to achieve this (see Fig. 5.1). Garengeot said cutting pliers were best for trimming diseased or fractured bone, and implied the power to amputate through sound flesh and bone was beyond even the strongest surgeon.[54] In any event, difficulties in obtaining sound stump healing lead to abandonment of dismembering with nippers by the early 18th century. Their successor, Liston's bone forceps made of superior cast steel (see Fig. 10.6A), remains in use at the beginning of the 21st century.

Hand Saws

It is likely that the earliest saws for elective amputation were borrowed from butchers, carpenters and other craftsmen; those pictured by Brunschwig in 1497 (see Fig. 5.2) and Gersdorff in 1517 (see Fig. 1.5) certainly suggest affinity with butcher's hacksaws. However, Ryff's of 1545 has decorative features on the handle and also has a blade tension adjustment screw (see Fig. 9.1), suggesting manufacture specifically for surgery. Franco (Fig. 6.2), Pare (Fig. 6.4) and Croce (Fig. 6.3) illustrated even more decoration, so elaborate that their finials possibly interfered with expeditious amputation. Indeed, Solingen pleaded in 1684 for simply constructed instruments, indicating that decorative extras snagged on tissues, that highly worked handles proved uncomfortable to hold and both obstructed rapid surgical technique.[55] During the 16th century, amputation saws increased in length and in weight, perhaps to speed up their sawing action, or to accommodate a strong wide blade and therefore reduce the possibility of blade fracture if the patient struggled. This complication prompted prudent surgeons to carry spare blades, although as we noted earlier, Fabry (Hildanus) was found wanting on one occasion.

The writer has been unable to find a surgical saw for measurement older than a decorative saw, now in the Musée d'Histoire de la Médicine, Paris, identical with an illustration in Woodall's *Surgions Mate* of 1617 (see Fig. 6.7); it is a massive 67 cm long, weighs 1.85 kg and has the mark of Hobbs of London. Another bow saw of similar style, considered to be of the same period, was estimated to be 62 cm in length.[56] Selected bow or frame saws from the 18th to 20th centuries measured by the writer indicate that saws of the Woodall era were the largest made and thereafter they diminished gradually in length (see Fig. 6.6). Dionis commented on saws in 1708:

"The saw . . . is an instrument common to surgeons and several tradesmen; however that of the surgeon is always made by the best cutlers, superior to the others by its neatness and finish . . . it should be small and light, in order to manipulate it with more freedom, and have a handle which provides a very firm hold."[57]

Desault's bow saw of 1790 is 50 cm long; French saws of the 19th century diminish to 34 cm and in the early 20th century to 30 cm. Short saws for minor digital amputations are excluded from the foregoing discussion.

Amputation saws evolved radically in the later 18th century with the manufacture of wide flat, or tenon saws which became dominant in Britain in the 19th century (Fig. 10.11), although little mentioned in Europe, despite illustration by Petit in Paris in 1774 and by Brambilla in Vienna in 1782, although both also featured bow saws. When Benjamin Bell figured amputation instruments in 1788 and Savigny produced his instrument catalogue in 1798, only tenon saws were displayed. Tenon saws also reached America yet made no headway in continental Europe. These differences may relate to the ready availability crucible steel from Sheffield, whose uniform quality promoted the manufacture of wide, thin saw blades, reinforced along their backs to reduce buckling during use. Surgical tenon saws were less inclined to snag and splinter bone, and hence cut more smoothly than narrow bow saw blades and did not snap during operations. In Britain, major amputation saws of tenon pattern remain in instrument catalogues of the 21st century, yet for metacarpal and digital amputations, small bow saws are recommended whereas, perversely, small flat saws with mobile backs are advertised in France for digital

FIG. 10.11. Selection of tenon amputation saws, 19th to 20th centuries. From *top:* Weiss's notched blade or self-clearing saw with strengthened back and English handle; standard tenon saw with backing and commonly found English handle; Army pattern all-metal saw with mobile back and another English handle form, fenestrated to reduce weight. (From Private Collection.)

amputations. Despite this, individual exceptions existed, dependant on surgeons' preferences. Farabeuf concluded in 1885:

"It is not the fashion in France to employ wide saw with mobile backs, so solid and easy to control: we prefer frame saws. In my view it's a pity. However we can adapt a frame saw to use narrow blades with fine teeth; that's its advantage. But sometimes blades snap and one should not operate without having at least one spare. Remember the story of Fabricius Hildanus who broke a saw operating in the country and was obliged to send several leagues away to find another. In a similar situation it would be better to borrow a saw from a neighbouring butcher or workman."[58]

Nineteenth-century American publications offered a selection of bow and tenon saws, probably influenced by German, French and British imports, with surgeons' choices dependant on their training. However, during the American Civil War, the tenon saw became more popular, and in 1866 Gross wrote:

"Every amputating case contains a large saw, resembling a common dove-tail saw of the cabinet-maker. The adjoining sketch (see Fig. 10.11) *represents the form of instrument which I am in the habit of using . . . The teeth are large but sharp, and set cross-wise on the edge, that the instrument may not hang or hitch as it works its way through the bone."*[59]

The large teeth of Gross's saw were advertised by Weiss before 1831 to self-clear bone debris and prevent the teeth binding but, by the end of the 19th century, Weiss's teeth were no longer a considered requirement, being replaced by double rows of teeth and also improved teeth setting, allied to better-quality steels. In addition, blade backs were made thinner than their cutting edges to improve clearance.

Other Saws

Bow saws were devised with angulating blades, principally for the resection of joints, but Farabeuf and other French surgeons adapted this for amputation to produce a rounded bone end. The bimanual chain saw, also introduced for joint resection, was adapted by Tyrrell, who asserted in 1825:

"In amputating part of a metacarpal or metatarsal bone, I always use a chain saw, which I find much more convenient than the common metacarpal saw, being employed with greater facility and cutting more rapidly."[60]

No other supporting accounts have been found. Similarly the Gigli wire saw, successor to the chain saw, was recommended by Coupland in 1992 to produce a bevelled bone section when tidying the shattered stumps of antipersonnel mine injuries.[61] At the end of the 19th century, manual rotary saws were mechanised by electricity and in the 20th century by compressed air; no evidence has been found to indicate these fast rotating saws were wielded for amputation. Later, oscillating and reciprocating actions were introduced and these safer modalities may have been utilized for amputation but, again, no accounts have been traced.

Miscellaneous Equipment

Retractors

Traction, employing either bare hands, a simple split sheet or towel to pull on the soft tissues directly, enabled assistants to retract them and gain better skin cover by dividing bone as high as possible. For gunshot destruction of an elbow joint, Wiseman wrote:

". . . Mr M(urray) drew up the Skin and Musculous Flesh of the Arm towards his Shoulder, whilst I made a strong Bandage some three or four inches breadth above the affected Part. Then with a good Knife I cut off the Flesh by a quick turn of my hand, Mr Murry pulling up the Flesh whilst I bared the Bones."[62]

Later, specifically made leather and metal retractors were substituted by some surgeons (see Fig. 7.5), although critics said metal retractors were painful and only served to lengthen the operation. Matters eased for circular or guillotine amputations when the divided skin was rolled or pulled upwards, to permit oblique section of the muscles which were then retracted to bare the bone (see Fig. 7.4). Flap formation, especially transfixion flaps, improved bone cover significantly whilst anaesthesia promoted the pain-free use of hooks and hand retractors to guarantee healthy functional stumps, always dependant on the skill of the surgeon.

Tables and Chairs

Franco advised that amputation patients should be lying on and attached to a bench. Many however recommended amputation with the

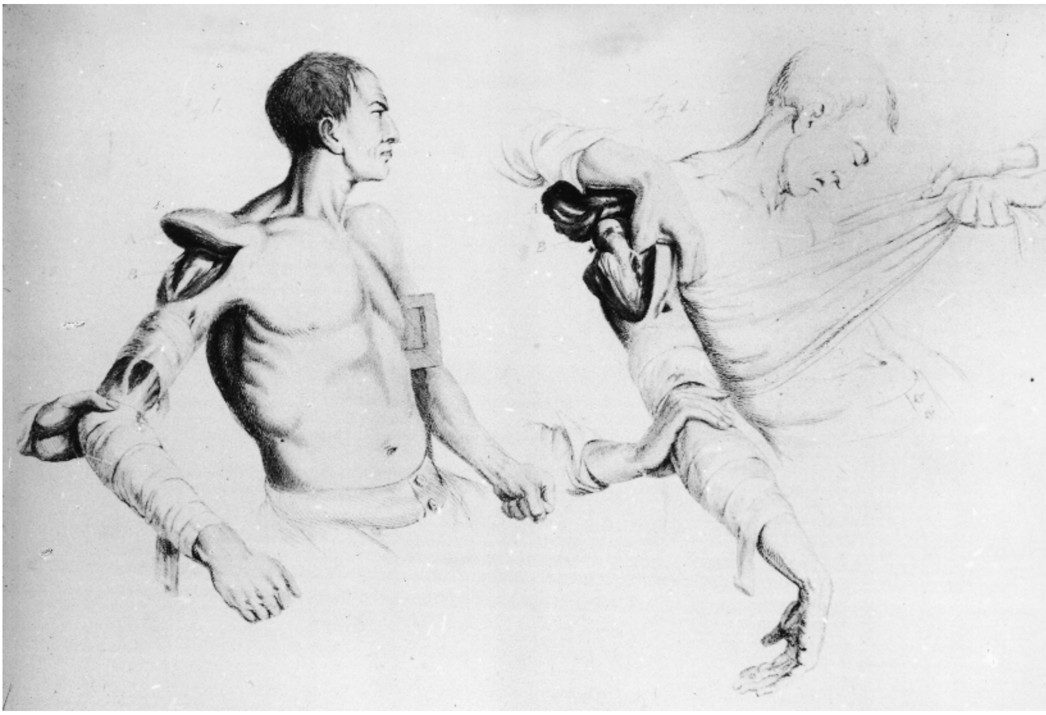

Fig. 10.12. Disarticulation at the shoulder with patient seated and alert initially, but in the second drawing he has fainted and would need the support of the towel held by an assistant. (From Bell C, *Illustrations of the Great Operations of Surgery*, London: Longman, 1821.[72])

patient seated, and indeed this remained standard practice until patients were anaesthetised. Why sitting was considered best is not fully explained although some surgeons considered this provided better operative access; in addition, yet unremarked by surgeons, patients fainted more readily in this position, briefly easing their agony. Wiseman stated injured sailors sit or lie and indicated suitable seating might be unavailable during a sea-fight.[63] Sharp appears to be a lone voice in questioning the practice of operating on seated patients in civil practice. He wrote in 1739:

"Lay your Patient on a Table two Foot six Inches high, which is much better than a low Seat,, both for securing him steady and giving yourself the advantage of operating without stooping, which is not only painful but inconvenient . . ."[64]

Why Sharp's advice received no immediate support is not explained in contemporary publications, despite the need for patients to lie for thigh amputations and hip disarticulations, to ensure operative access at these levels. This particular posture was demanded by the large numbers of knee and thigh wounds during the Napoleonic wars, often performed on the ground during battles. However, for upper limb amputations the chair remained a popular choice; in the aftermath of Waterloo, Charles Bell performed shoulder disarticulation with his patient seated; his drawing indicates the patient fainted during the procedure, the only illustration traced to show the effects of sitting upright during major surgery (Fig. 10.12).

Summary

Knives for soft tissues and saws for bone are the indispensable instruments for operative dismemberment. Initially borrowed from domestic and craft sources, they evolved forms specific to surgical needs, after gunshot injuries precipitated life-saving amputation. Curved knives with concave blade edges were advised for circular amputations, giving way to straight knives with slightly convex edges for flap amputations, still a preferred procedure. Bow or frame saws, large and heavy at the beginning of the 17th century, have diminished in size ever since. Wide tenon saws displaced bow saws at the end of the 18th century in Britain, and later in America, but not in continental Europe. Equipment and instruments to control haemorrhage were stimulated by amputation procedures. Before general anaesthesia, most dismembering was undertaken with the patient seated. Assisted by anaesthesia, instruments became smaller and more accurate.

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11
Indications, Timing and Procedures

"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."

Vitali, 1986[1]

"Owing to the improvements of modern surgery, more particularly in the treatment of aneurism, fractures, and necrosis, amputation of the extremities is now very seldom performed in civil practice, except in cases of diseases and injury of the joints."

Syme, 1831[2]

Written evidence to determine, from the surgeon's point of view, when to operate and what technique will answer the patient's problem, is the only information debated in many surgical publications on amputation. Indeed, historically, the literature appraising various levels and modifications of upper and lower limb removal, from the finger- and toe tip to the trunk, is immense and can only receive an outline survey in this chapter.

Before addressing purely surgical indications, nonsurgical reasons mentioned in previous chapters are summarised. Ritual, punitive and legal amputations performed without surgical indication lack the victim's consent, as do traumatic amputations caused by massive gunshot injury (see Fig. 5.3), transection by wagon or train wheels and bites by sharks or crocodiles, although for these victims surgical assistance is usually sought to tidy the wound and fashion a suitable stump for a prosthesis. Near-traumatic amputations with distal limb deprivation of vascular and nerve supplies, perhaps attached by a few tendons and a section of skin, also fall into the latter category; those surviving traumatic limb avulsion are similarly placed. Gangrenous limbs, frostbitten toes and feet, and gangrene caused by ergot poisoning when the limb or digits separated spontaneously usually needed surgical assistance to achieve a satisfactory stump for prosthetic purposes, depending on the expertise available. In the days before anaesthesia and antiseptic surgery, many victims did not receive help or preferred to avoid surgical intervention.

Large chisels struck with a mallet or pincer-cutters to amputate fingers, toes, hands and even attempts at higher levels produced guillotine amputations which healed badly, being akin to section at the demarcation line of gangrenous limbs. Trapped victims in extremis without assistance, obliged to undertake their own amputation, are also a special category who, when finally rescued, need surgical intervention to repair and improve what maybe an unsatisfactory amputation from the surgical aspect. In addition, there is a group of patients who insist on amputation, even without anaesthesia, usually because of chronic pain or debilitating infection, despite advice informing them of insufficient disability for the surgical risks involved, or that they were too ill, or had evidence of disease elsewhere; despite this a number achieved their aim as Velpeau relates in a chapter on indications in 1840. He reported:

"In 1821, a robust man came to the Hospital of St Louis, apparently in vigorous health, determined to have an above knee amputation for an ankylosed knee which required him to walk with a crutch. After remonstrating

with him in every way, and having painted a dark picture of the dangers to be faced, M. Richerand finished by agreeing to his insistence; the amputation was simple enough; no local accident followed; but a fever which soon developed nevertheless ended in death on the fifth day."[3]

Velpeau described two similar cases, one requiring a below-knee and the other a finger amputation, both ending in death. However, Watson, commenting on Velpeau's deductions in 1885, maintained such cases were no more likely to experience complications than surgically approved amputations and surgery could be justified by assessing carefully the merits of each patient. Fortunately, Watson was able to avoid operative infection as a committed adherent of prophylactic Listerian antisepsis.[4] As far back as 1000 A.D. a patient pleaded with Albucasis for amputation, in this instance refused by the surgeon, but then performed by the patient.[5] In addition amputees dissatisfied with a painful or unsatisfactory stump have insisted on revision procedures, as discussed in Chapter 9.

Surgical Indications

Any listing of surgical indications must recognise many factors have changed and are changing with time, as new knowledge and techniques evolve. As Syme pointed out in the quotation heading this chapter, several conditions formerly subjected to routine amputation were already circumvented by alternative procedures introduced in the late 18th century, although these prospered fully only after anaesthesia was established. The indications below refer to conditions which posed or pose questions demanding surgical opinion and debate, for amputation is rarely self-evident to patients.

Congenital Abnormality

Grossly deficient or deformed lower limbs are sometimes removed to provide suitable stumps for rapid mobilisation with a prosthesis rather than a series of reconstructive operations, extending over many years, which in any event may require a supporting orthosis. Thus, in the 19th century persistent club feet were sometimes amputated,[6] although most are now corrected by reconstructive operations, leaving only occasional skeletally defective cases for inevitable ablation (see Fig. 2.1). Supernumerary toes and fingers need removal but generally amputations of the upper limb are best avoided, as any residual power can be harnessed to activate an artificial arm.

Crushing Injuries and Compound Fractures

Amputation was commonly indicated for crushing injuries often associated with vascular interruption and severe soft-tissue damage leading to gangrene, and for open fractures which more often than not became infected and might also have vascular problems and become gangrenous. Open wounds with tissue damage can be contaminated with tetanus and gas gangrene organisms, and before modern treatments, amputation was often a last desperate remedy. Today such limbs can be decompressed and drained, undergo arterial reconstruction and debridement, and receive prophylactic immunotherapy and/or chemotherapy, as well as undergo internal or external fracture fixation. Amputation remains the only course for grossly damaged limbs.

Gunshot Wounds

As emphasised previously, these malevolent injuries precipitated the introduction of elective amputation, in recognition that missiles carried in foreign material causing infection, gangrene and death. Military surgeons promulgated immediate amputation until Bilguer and others in the 18th century suggested avoidance of amputation or delayed amputation if the limb was not viable (see Chapter 5). Although this moderated precipitate surgery, especially in civil hospitals, perversely the number of battlefield amputations increased with time, as the escalating destructiveness of missiles defeated attempts at limb reconstruction. A noteworthy feature of modern antipersonnel mines is the deliberate obliteration of the foot and lower leg (see Fig. 1.7).

Vascular Failure

Frostbite resulting from intense vessel spasm may cause gangrenous loss, especially of fingers and toes, even in the healthy. Until late in the 18th century, enlarging aneurysms, associated with injury by venesection when an artery was wounded or caused by syphilitic damage, were considered indications for amputation above the aneurysm. Increasingly significant today is vascular occlusion of sclerotic arteries affecting the elderly, especially in long-lived Western societies where it is the commonest indication for amputation despite other measures, including arterial reconstruction. The same societies are affected by a rising incidence of diabetes mellitus which damages arteries and peripheral nerves, the latter causing sensory impairment to touch and pain, exposing the feet to unnoticed injury and infection which then complicates diabetic management. Restoring insulin levels helps, but infected bone ulcers and narrowed vessels may precipitate local excisions of the foot or, in severe cases, major lower limb amputations.

Joint Injury and Disease

Joint injuries were common indications for amputation before Park, Moreau, Syme, Fergusson and others developed knee and elbow excision (see Chapter 7) especially for caries, that is, bovine tuberculosis, which spread from joint synovium to bone, causing painful joint destruction. Later, wrist excision to avoid hand amputation for caries was introduced by Lister. In the 20th century, joint infection and destruction was managed by chemotherapy and joint fusion to avoid amputation. Open damage to joints, especially caused by gunshot injury and even minor penetrating injuries, frequently became infected, necessitating amputation before antiseptic and aseptic measures. At the beginning of the 21st century, surgical reconstructive techniques also include joint excision and replacement by artificial joints.

Severe Chronic Leg Ulceration

Discharging ulceration of the lower leg and foot was commonly the result of imperfectly healed open and infected fractures, or a sequel to acute osteomyelitis, or infected varicose ulceration, all probably aggravated by dietary factors. During World War II, prisoners in Japanese war camps developed tropical ulceration, associated with vitamin deficiencies, often eroding the shin bone and necessitating life-saving amputation as a final resort.[7]

Benign and Malignant Tumours

Before the introduction of anaesthesia, tumours of bone or other limb tissues often presented late, by which time they were massive in size and an obvious burden to victims, both physically and mentally. When malignant, the presence of secondary deposits would have contraindicated amputation. However, for presumed benign tumours, a few heroic amputations without anaesthesia have been recorded, including a huge cartilaginous leg tumour in 1737 (see Chapter 9; Fig 9.3) and a similar femoral tumour in 1816, said to be consequent to a fracture (see Fig. 2.5) but more probably the cause of the fracture. In recent times, benign tumours are unlikely to reach similar size and are excised locally with skeletal fixation if required. Malignant tumours were often subject to amputation until the 1970s when radical excision, combined with implanted prostheses for defects and chemotherapy, improved results significantly, making amputation a much rarer indication.[8]

Severe Pain

Unremitting pain, especially bone pain curtailing sleep and daily activities, was a source of pleading on the part of patients,. When chronic bone infection finds no external outlet, it remains encapsulated in a thickly walled abscess cavity under tension , the so-called abscess of Brodie, who discovered, if the site could be located accurately, trephining into the cavity decompressed tension and pain dramatically, making amputation unnecessary.[9]

Neurological Deficits

In addition to diabetic neuropathy, absent sensory feeling in the feet and hands may result from leprosy, or from nerve interruptions at a higher level, or from hereditary sensory neuropathy. Lack of feeling often results in minor injuries being overlooked until secondary infection is established, leading to bone involvement that necessitates amputation of toes and fingers. After complete brachial plexus injury, frequently caused by motorcycle accidents, the resultant muscle paralysis produces a flail arm which may simply dangle uselessly. An effective solution is to amputate through the upper arm and arthrodese the shoulder joint, enabling the trunk muscles to control an artificial hand and arm.[10]

Entrapment

Limbs trapped by machinery, a vehicle crash, or by falling masonry as after bombing or an earthquake, may require sacrifice of the trapped limb to save life, even if the limb is still viable. For example, after an earthquake, extrication without the trapped limb often takes precedence over attempted rescue with the limb, to prevent further building collapse. Similar urgency applied to the rescue of an Army colonel trapped by his arm in a crashed helicopter leaking oil from an overheated engine (see Chapter 9).

Timing

Determination of a precise indication to amputate also involves selection of a suitable time to amputate. Immediate amputation would be self-evident for most trapped victims and was also the rule in the early centuries of gunshot wounding, especially during the heat of battle. In the 18th century, Bilguer maintained he amputated rarely for gunshot wounds, recommending conservative care, fortunately having at his disposal hundreds of hospital beds.[11] Others suggested delay to assess the victim's progress and, hence, possibly save a limb which otherwise would be amputated.

Delay might mean as soon as "shock" settled and haemorrhage control was achieved or, alternatively, at some days or even weeks distant when local infection had settled, assuming the patient survived. Unfortunately, the latter methods were often completely impractical when massive numbers of wounded presented, as for example during the major battles of the Napoleonic era, the American Civil War, and especially those wounded by invasive shrapnel and shell fragments which dominated World War I battles and some of those of World War II. Delays were certainly common during these conflicts, often up to a week, as a consequence of physical problems in evacuating the wounded, especially from no-mans-land, to surgical facilities.[12] Since World War II more rapid transport systems, particularly the use of helicopters, and basic protective inoculations, antibiotics and modern resuscitation methods combined with arterial reconstruction and skin and bone grafting have saved many limbs formerly amputated.

For many conditions in civil life, a more-measured approach is possible, so that patients are carefully assessed, in particular, the elderly with arterial deficiencies, gangrene, infections or diabetes, or for others, often younger, with malignant lesions to consider secondary deposits and conduct surgery under the best possible circumstances.

Surgical Levels and Procedures

Ad Hoc Amputations

Before the development of elective amputation in response to gunshot trauma, little evidence is available to indicate whether amputation levels were rationalised with a view to fitting a prosthesis. For traumatic loss by animal bite, military action or legal section, surgical treatment was unable to influence the level, as was the case of incomplete amputation, although surgery might improve skin cover. For well-established gangrene, spontaneous separation of the mortified segment was possible as Hippocrates indicated and as Guy de Chauliac believed was best, to prevent the surgeon being accused of interference if the patient died, a situation Astley Cooper accepted as late as 1824 (see Chapter 6). When caused by ergot poisoning, spontaneous separation took place readily at the line of demarcation between dead and living tissues. For those patients anxious to rid themselves of an offensive and dead appendage, surgeons also took the same route, gradually easing the dead tissues clear, applying hot iron cauteries to dry up discharge and if necessary cutting or trimming protuberant bone. Lacking choice in determining an amputation level rendered consideration of a functional stump and a prosthesis quite remote. In any event, prostheses were relatively primitive until at least the 16th century and often lower limb survivors simply used crutches or, if a bilateral amputee, a cart as depicted in the paintings of Bosch and Brueghel (see Figs. 2.4, 12.1). A modified procedure was proposed by Ab Aquapendente to solve the three common problems of arresting gangrene, controlling haemorrhage and preventing pain, by removing dead tissues to within an inch of the demarcation line and then applying heated cauteries to dry up the remaining collar of gangrene, which he maintained dropped away in 3 or at the most 4 days[13]; no case histories or results are mentioned.

In World War I, it was the advice of the official memorandum for British Army medical officers treating gas gangrene (see Fig. 2.2) at Casualty Clearing Stations to perform rapid circular amputations through the gangrenous area making use of any fracture to determine the level of section, secure bleeding points, leaving the wound open to drain, in anticipation that the remaining gangrenous tissues would be decompressed and recovery might follow.[14] On survival and further evacuation, a formal amputation at a site of election was performed. With respect to the upper limb, it is assumed preservation of all living tissues was practised in recognition that any residual function was a bonus, particularly before artificial arms with dynamic function evolved. Rescue from entrapment preserves as much of the surviving limb as possible, especially when victims are obliged to undertake their own surgery, lacking knowledge of recommended amputation levels.

Early Elective Amputations

For gangrene, Celsus advised cutting between the sound and diseased part, but not through a joint, and Albucasis was prepared to amputate hands and feet but warned that amputation was perilous above the knee (see Chapter 6). One of the first to consider measured operative stumps of the lower limb, with a view to subsequent function with a prosthesis, was Paré who wrote when considering a gangrenous foot:

"Wherefore you shall cut off as little as that which is sound as you possibly can; yet so that you rather cut away that which is quick, than leave behind anything that is perished . . . For if you take these two things into your consideration they will induce you, in this propounded case and example, to cut off the Leg, some five fingers bredth under the Knee. For so the Patient may more fully use the rest of his Leg with less trouble, that is, he may the better go on a wooden leg; for otherwise, if according to the common Rules of Art, you cut it off close to that which is perished, the Patient will be forced with trouble to use three legs [one good leg and two crutches] *instead of two."*[15]

Basic Elective Procedures and Flaps

In this section we note, briefly, basic elective amputations and tissue flaps described in surgical literature (see Chapter 7 for more detailed discussion) and, in subsequent sections, we examine amputations and disarticulations specific to the upper and lower limbs, respectively. At this stage of our narrative, it should be apparent that three fundamental forms of elective amputation are practised: firstly, guillotine amputations with an axe or chisel, although equally well performed with knife and saw; secondly, circular amputation when the skin and subcutaneous tissues are incised in guillotine fashion but muscles and bone are cut at higher levels; and thirdly, flap amputation when various forms of soft-tissue flap are constructed allowing the muscles and bone to be cut significantly higher and cover the bone without tension, to enhance primary healing and create a comfortable stump. Flaps vary in size and shape and may be unequal in length with one large enough to cover the stump and reach the smaller one, or equal in length, or racquet shaped, or circular or square shaped, or based anteroposterior to the limb, or based laterally, or based obliquely. Flaps were also designed to use gravity to cover stumps, or to have a good blood supply, or to place weight-bearing skin over the stump.

Formal Lower Limb Procedures

Toe Amputation and Disarticulation

Until the 18th century, removal of toes for gangrene, frostbite, infection or congenital deformities was performed by rapid guillotine methods. Flap formation, as by racquet incision, designed to promote sound healing, appeared in the late 18th century and remains a standard procedure, especially for disarticulation at the metatarsophalangeal joint. Disarticulation of all the toes was described in 1960 as the "Pobble operation" after Edward Lear's verse:

"It's a fact the whole world knows, That Pobbles are happier without their toes."[16]

Recommended for severe toe clawing combined with metatarsal head callosities, good results were reported[17] although, in the author's experience, balance is disturbed and metatarsal heads can remain painful. Disarticulation of the great toe has proved a source of debate because of its importance in contributing to power and stability of the foot. In the 18th century, Le Dran advised amputation through the first metatarsal neck but, in the 19th century, Dupuyren found this no advantage whilst Blandin strongly recommended disarticulation.[18] This became the rule in the absence of metatarsal disease.

Metatarsal Amputation

Guillotine amputations by chisel were still recommended by Scultetus in 1655 but caused ragged division of skin and tendons with uncertain healing. By 1739, Sharp advised metatarsal division with a small bow saw, presumably after suitable skin-saving dissection. Hancock claimed that Turner was one of the first to perform proximal amputation of all the metatarsals with a saw, in 1787, for a massive tumour of the second metatarsal overlying the whole metatarsus.[19]

Tarsometatarsal Disarticulation

Disarticulation of the accessible first metatarsal with its toe is pictured in Bell's *Illustrations of the Great Operations of Surgery* in 1821, but for intermediate metatarsals he found it a struggle to open the tarsometatarsal joints and advised bony division with a small trephine. In 1827, Scoutetten, employing his "ovular" or elliptical skin incision, a form of racquet, was able to remove intermediate metatarsals whole by dividing the basal ligaments with a fine bistoury.[20]

Total excision of all metatarsals and their toes was recorded by Hey on a patient with caries of the metatarsals in 1799, introducing a long plantar flap:

"I then separated with scalpel the four smaller metatarsal bones, at their junction with the tarsus; which was easily effected, as the joints lie in a straight line across the foot. The projecting part of the first cuneiform bone . . . I was obliged to divide with a saw."

This approach healed well but the power of the intact tendo Achilles, unapposed by the divided dorsal tendons, produced an equinus (downward) position of the foot, although Hey did not comment on this.[21] This method has been confused with Lisfranc's operation, popularised by French authors who, erroneously, claimed Hey did not supply precise details of his operation. It is also suggested that Hey's operation was different because he also sawed through the base of the second metatarsal, leaving it in situ.[22] Lisfranc described disarticulation of all the metatarsals in 1815, leaving the cuneiforms intact, by using his long double-edged knives to divide joint ligaments without sawing (see Fig. 10.10); Hey's contribution was not acknowledged. Lisfranc stated the base of the second metatarsal should never be left in situ although he was not against trimming the medial cuneiform to obtain skin cover, that is, Hey's procedure.[23] As the incidence of tuberculosis of the foot joints diminished, these operations became rarely indicated. If performed for trauma today, the dorsiflexor tendons should be anchored to balance tendo Achilles power.

Midtarsal Disarticulation

Disarticulation of the forefoot from the midfoot, through the talonavicular and calcaneocuboid joints, was performed by Chopart before 1792, preserving the talus in the ankle mortise and the calcaneum[24] (Fig. 11.1). Originally performed with a long plantar flap, other approaches attempted equal dorsal and plantar flaps championed by Chelius, the medioplantar flap by Sedillot and the dorsal flap by Baudens.[25] These operations are modified by preserving the navicular and/or cuboid, often by mistake, the foot assuming an equinus position unless measures are taken to oppose the intact tendo Achilles by attaching the dorsiflexor tendons. In recommending his own amputation, Syme remained partisan to Chopart's

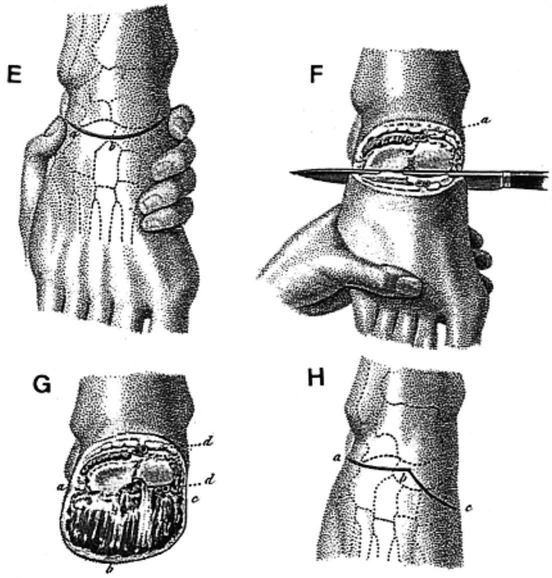

Fig. 11.1. *E, F, G.* Operative diagram of Chopart's midtarsal disarticulation with plantar flap. *H.* Sedillott's slightly modified approach. (From Bernard C, Huette C, *Précis Iconographique de Médecine Opératoire,* Paris, Mequignon-Maris, 1854, plate 25.[9])

classical disarticulation when possible, claiming none of his patients developed an equinus deformity.[26] Others disagreed and abandoned this and also Lisfranc's amputation, although reappraisal by Millstein et al. in 1988 suggested Lisfranc and Chopart amputations for trauma were better long term than more-distal amputations, that is, with a longer foot often with a troublesome scar. Nevertheless, more than 50% of their Chopart operations were revised to a Syme's or below-knee amputation.[27]

Subtalar Disarticulation and Transtalar Amputation

Hancock stated subtalar disarticulation was suggested by Lignerolles, first performed by Textor in 1841 and promulgated by Malgaine in 1846 (Fig. 11.2).[28] Lateral, medial, posterolateral and posterior flaps were attempted to ameliorate results but retention of the talus proved troublesome, usually causing an equinus attitude and pressure of the talar head against foot prostheses. In 1864, Hancock excised the talar head and applied a sliver of cancellous calcaneum (see Fig. 11.2, D), after the manner of Pirigov. Suitable indications for subtalar disarticulation were uncommon and results often unsatisfactory. Nevertheless, in 1921, Farabeuf devoted a complete chapter to this procedure, noting every conceivable form of skin flap which made little difference to an unsatisfactory outcome.[29] On the basis of extensive surgical experience in World War I, Elmslie wrote in 1924:

> "*Subastragaloid* [subtalar] *amputation consists in a disarticulation of the foot . . . being covered by an internal plantar flap. This amputation is rarely possible, and leaves a stump which is less satisfactory than that of Syme's amputation.*"[30]

These procedures are now of historic interest only.

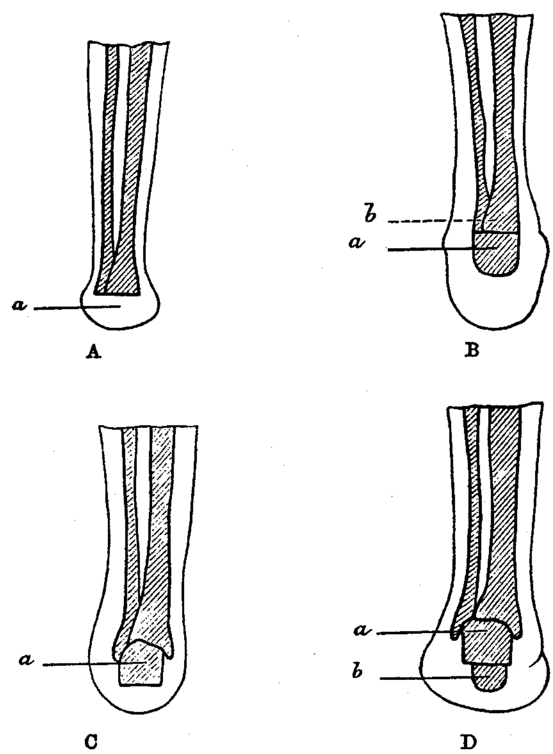

Fig. 11.2. Sagittal sections of lower shin and foot to show hindfoot amputations. **A.** Syme's stump removing foot, malleoli and thin section of tibia. **B.** Pirigov's stump is similar but retains the calcaneal tuberosity applied to cut tibial surface. **C.** Lignerolle's stump retaining talus and ankle joint. **D.** Hancock's stump retaining body of talus and calcaneal tuberosity. (From Kirkup J. Foot amputations: (2) Hindfoot. *Foot* 1994;4:117–119.[28])

Ankle Disarticulation and Tibiotalar Amputation

Removal of the foot by disarticulation through the ankle joint was undertaken sporadically before the 19th century. In 1796, Bell noted the projecting malleoli of the tibia and fibula made it difficult to obtain adequate skin cover and, even when healed, the long stump proved difficult to fit with a suitable prosthesis, and formal below-knee amputation was advised.[31] Farabeuf maintained that Baudens rehabilitated ankle disarticulation in 1841 and, although he did not remove tibial articular cartilage and fashioned an anterior flap unsuitable for weight transmission, Farabeuf thought Baudens should share honours with Syme for this innovation.[32] If Baudens' technique failed to find a permanent place in the armamentarium, Syme's ankle disarticulation retained adherents (see Fig. 11.2, A) and, at the end of the 20th century, has achieved widespread support assisted by new prosthetic technology.

When bone and joint tuberculosis was common, Syme noted the subtaloid joint was often involved, for which in 1831 he advised below-knee amputation at or below the middle of the tibia, not an ideal stump for a prosthesis. Although a protagonist of joint excision whenever possible, he considered talocalcaneal excision uncertain and hence developed amputation at the ankle joint, reporting in 1843 on a patient with tuberculosis:

"As the disease extended beyond the limits of Chopart's operation, it would have been necessary, in accordance with ordinary practice, to remove the leg below the knee, but as the ankle seemed sound, I resolved to perform disarticulation there . . . the disarticulation being then readily completed, the malleolar projections were removed by means of cutting pliers."[26]

The thick skin under the heel was carefully repositioned under the ankle stump and in due course the patient did well, walking long distances, presumably with a high boot (see Fig. 13.10); additionally, it was possible to walk on the naked stump, a considerable advantage about the house. Syme's amputation was performed sporadically, becoming popular in Scotland and Canada but neglected in England on the grounds it was difficult to fit a prosthesis. During World War II, it came back into prominence and in 1956 Harris, in a wide-ranging survey, emphasised the importance of precise technique, noting the importance of cutting the plantar flap without disturbing the cellular weight-bearing elastic adipose tissue in the heel, of careful section of the ankle surface and malleoli to be parallel to the ground when standing, of removing minimal bone to present the largest bony surface for weight-bearing, and of precise suturing of the flap supported initially by adhesive strapping.[33] Recently, Syme's popularity has been boosted with a light plastic prosthesis into which the stump is introduced from the back or side.

Pirigov approved of Syme's amputation but proposed an osteoplastic modification in 1858 to minimise the shortening and to stabilise the heel pad. He preserved the posterior bone of the calcaneum with its tendo Achilles attachment, to be applied to the cut surface of the tibia with a view to osseous union[34] (see Fig. 11.2, B). It was not always easy to turn the osteoplastic flap through 90° without further shortening of the tibia, which diminished the area of cancellous bony contact and also lost length; union between tibia and calcaneum often failed and if the calcaneum was diseased, Pirigov's operation was not possible. However, Hancock stated sloughing of the heel flap was less evident than after Syme's operation. Pasquier and Le Fort proposed horizontal section of the calcaneum at the superior limit of the tendo Achilles insertion, thus leaving more than half the calcaneum to be applied to the tibia which had to be further shortened; this required a healthy calcaneum.[35] This procedure never attracted adherents although it was revived in 1939 by Boyd, a good result depending on sound tibiocalcaneal arthrodesis.[36]

Tibial (Below-Knee) Amputation

Tibial or below-knee amputation was the first amputation to be estimated in terms of its stump length, the so-called site of election, to accommodate the only satisfactory prosthesis available, that is, a peg-leg on which the amputee kneeled; if too much tibial length was conserved, this projected prominently and uncomfortably backwards (see Figs. 2.4 and 12.1). As noted earlier in this chapter, Pare determined the level of section accurately, recommending tibial division five fingers-breadths below knee joint level, at a time when many authors failed to be precise. On the other hand, later surgeons suggested a variety of tibial lengths. Consideration of French authors alone demonstrates that De La Charriere advised four fingers-breadths below the knee joint in 1692,[37] Garangeot six in 1731,[38] Sedillot both four and five fingers below the tibial tuberosity in 1839,[39] Velpeau two or three fingers below the tuberosity in 1840,[40] and Farabeuf five fingers below the joint or at least 10 cm of tibia in the late 19th century.[41] In contrast, some believed amputation should be as low as possible to save life for, in the days before antiseptic surgery, mortality increased in proportion as the level of section approached the trunk. In the 17th century, Solingen argued for amputation just above the level of pathology provided a sound scar was obtained and was supported by Dionis at the beginning of the 18th century.[42] In 1768, Ravaton who had extensive military experience strongly endorsed this view, quoting an injured soldier's history of amputation just above the ankle, illustrated with the prosthesis which enabled him to return to army duties (Fig. 11.3).[43] B. Bell, also partisan to low tibial section, calculated, from his experience, in 1796 , that healing after high tibial section by a circular incision rarely took less than 10 to 12 weeks, and by equal flap incision 4 or 5 months, whereas section just above the ankle healed in 2 or 3 weeks; maintaining the reduced diameter and muscle exposure diminished complications.[44] In the later 19th and early 20th centuries, Farabeuf also considered amputation below the point of election was justified if the scar was not terminal and quoted the operations of Hey and Teale as examples.[45] When possible, Hey amputated through the middle third of the tibia, publishing very precise instructions for calculating his incisions (see Fig. 7.6) to cover the stump with sound tissues, employing a posterior flap held in position with adhesive plaster. In 1858, Teale favoured section at the junction of the lower and middle thirds of the tibia using a long anterior rectangular flap and short posterior flap, the long flap being calculated to form a perfect square which, under gravity, covered the stump fully and encouraged union to the short flap (Fig. 11.4). Of 28 such amputations, he recorded 1 death but only 10 were noted to wear a prosthesis, distributing weight equally

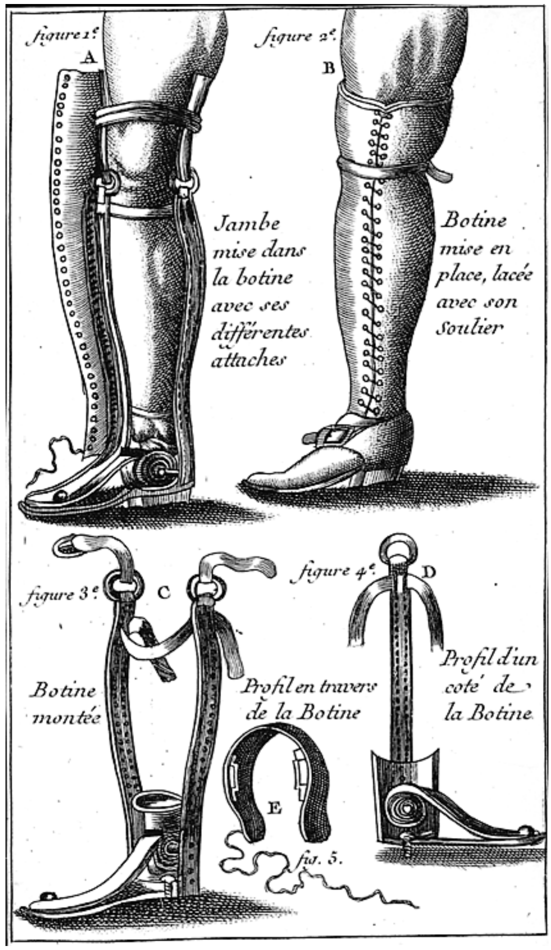

FIG. 11.3. Foot disarticulation by Ravaton and his boot designed to permit weight-bearing and provide some spring to the prosthetic foot. (From Ravaton Mons. *Chirurgie d'Armée.* Paris: Didot, 1768, pl. 5.[43])

between the stump and the upper shin. Teale stated:

"The character of the stumps obtained by this method of operating may now be considered. Their chief peculiarity consists in their having a soft mass of tissues, devoid of large nerves, moveable over the sawn end of the bone, which enables them to bear pressure on their extremity. In proof of this the following table may be referred to, as it contains the result of all the cases . . . in which artificial limbs have been used."[46]

Utilising antiseptic prophylaxis and anaesthesia, Watson observed in 1885 that complete wound drainage and complete and continuous

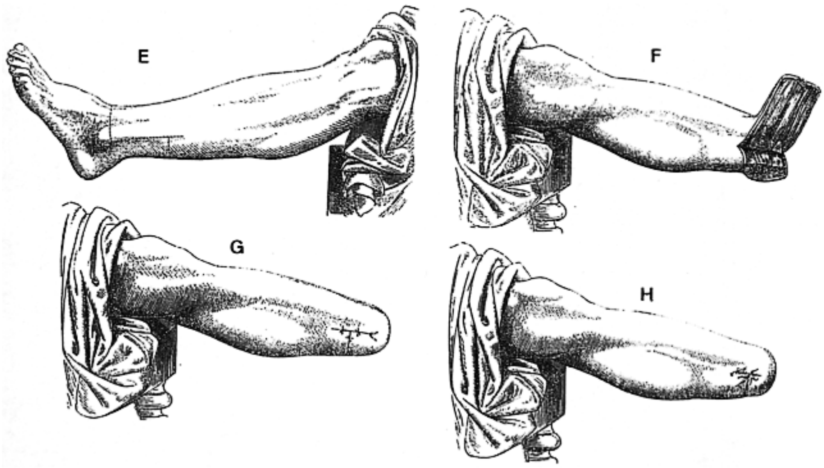

Fig. 11.4. *E, F, G, H.* Teale's long anterior and short posterior flap amputation of lower tibia, aimed to produce a healed scar and good soft tissue stump cover, 1858. (From Teale TP. *On Amputation by a Large and a Short Rectangular Flap.* London: Churchill, 1858.[46])

approximation of the wound surfaces now ensured sound healing, and he recommended amputation at any level through the shin. He remarked:

"In the performance of amputation of the leg, the older surgeons commonly removed the limb a few inches below the knee at a site designated by them as the point of election; but modern surgeons are less inclined to operate in this locality, and some even regard it as a suitable point for rejection."[47]

The difference of opinions on below-knee levels of amputation continued until the 20th century when views hardened in favour of section in the upper part of the shin. Elmslie after World War I experience considered amputations through the lower shin produced stumps with congested skin circulation which easily ulcerated; he also said the term "seat of election" should be abolished as it was associated with kneeling prostheses which had become obsolete and, in any event, protracted kneeling produced degenerative changes in the knee.[48] Broca and Ducroquet considered there was a case for those engaged in agriculture to have both a kneeling "poor man's peg" advantageous for heavy work and an alternative leg bucket with thigh corset worn intermittently to preserve the knee joint.[49] Both Little[50] and Elmslie,[51] working at Roehampton where vast numbers of gunshot amputees from World War I were rehabilitated, advised tibial stumps 7 inches as ideal, but said as little as 1.5 inches was possible for knee control. By 1942, with World War II in progress, Langdale-Kelham and Perkins recommended a tibial stump of 5.5 inches which allowed for reamputation if the scar was unsatisfactory, their ideal "site of election" being 4 inches, whilst 3 inches was the minimum for a below-knee limb. They dismissed out of hand lower amputation levels through the tibia, including Syme's.[52] From Roehampton in 1986, Vitali et al., doubtless swayed by an elderly population, were also firmly against any tibial stump longer than 6 inches (15 cm), pointing out the poor skin of long stumps and their diminished capacity for significant end-bearing pressure unless the stump was closed by a periosteo-osteo-myoplastic procedure.[53]

Knee Disarticulation and Supracondylar (Low Femoral) Amputation

Disarticulation at the knee received little recognition before Fabry's brief mention in the 17th century[54] and Petit's more positive recommendation in the 18th century when he quoted a successful case history.[55] Commenting on its negligence in the 19th century, Velpeau described 14 disarticulations of which 13 healed and most walked with a prosthesis.[56] Eventually it was judged a rapid, atraumatic procedure for the very ill, associated with a bonus of minimal muscle and no bone damage, which diminished haemorrhage and postoperative infection.[57] However, the large mass of the condyles and patella made skin cover problematic although, when healed satisfactorily, the stump became weight-bearing and suitable for a working prosthesis. If improved somewhat by fashioning lateral flaps, as directed by Smith,[58] to form a scar between the condyles, nevertheless many practitioners removed part or all of the condyles and/or the patella to reduce skin tension and diminish the bulky stump. In 1857, Gritti proposed section of the femur immediately above the condyles and application of the patella, excised of its cartilage, to the femur as a weight-bearing stump.[59] Stokes modified this in 1870 by removing more of the femur to diminish tension and improve sound bony fusion with the patella.[60] The Gritti–Stokes amputation achieved some popularity although the patella sometimes lost its position and weight-bearing potential. To address this problem, Farabeuf detailed Sabanejeff's procedure which preserved an oblique slice of tibia with attached patellar tendon and reduced patella, yet expressed no opinion on its efficacy.[61] At the end of the 20th century, Vitali et al. state knee disarticulation has been found very suitable for elderly patients with ischaemic limbs, because it preserved proprioception, assisting the seated posture and weight-bearing potential; also its bulbous shape aids the retention of prostheses and promotes resumption of some independent walking, even without prostheses.[62]

Femoral (Above-Knee) Amputation

In contrast to the long debate on levels of below-knee amputation, the site of bone section for above-knee amputation has excited minimal discussion. Long recognised as carrying greater risks to life from haemorrhage and infection, which escalated as femoral division approached the hip, most authors amputated at the lowest point possible, in relation to the pathology, but have varied in their approach to techniques and the formation of flaps (Fig. 11.5). Circular, equal anteroposterior, or lateral, or unequal flaps have all had supporters who have borne in mind the considerable musculature of the thigh and differences in power between divided groups of extensors versus flexors and abductors versus adductors.

As already observed, few surgeons risked above-knee amputation until the 17th century when military and naval surgeons faced with escalating gunshot trauma accepted this challenge, helped by better tourniquets and precise occlusion of arterial vessels, initially with heated cauteries, replaced by ligatures in the 18th century. Results also improved when the circular incision was replaced by the double incision of Petit and Cheselden, and again by the triple incision of B. Bell (see Chapter 7). In the early 19th century, military surgeons were often faced with ragged, irregular wounds which obliged the formation of a flap from surviving sound tissues and, in due course, this experience supported elective formation of flaps, especially for the muscular upper thigh[63]; such flaps were already in use for below-knee section and were unavoidable for hip disarticulation (see Fig. 8.2). Unfortunately, the fashioning of flaps took longer than circular incisions, exposing the patient to more pain, and delaying its full acceptance despite improved healing rates. Vermale proposed lateral flaps in the mid-18th century but they never became popular as the scar tended to become adherent in the midline. The employment of crucible steel to manufacture instruments in the late 18th century, enabled long narrow knives to be fabricated free of any danger of snapping. Introduced by Lisfranc for foot amputations (see Fig 10.10), Liston seized on their use for thigh amputation, cutting equal anteroposterior flaps by transfixion (see Fig. 8.4), to maintain incision from within outwards was not only rapid but less painful than other methods.[64] However, Spence, who reviewed Liston's stumps, noted scar adherence to the bone and recommended a longer anterior flap to protect the bone.[65] Despite this, many surgeons, especially on the battlefield and for acute civil trauma, continued circular amputations, even in recent wars as a rapid emergency operation, enabling revision later if required.

At low levels in the femur and also for knee disarticulation, Carden described the single long anterior flap which, assisted by gravity, cicatrised away from the bone end to cover the stump with skin accustomed to weight-bearing (Fig. 11.6); of 31 amputations over 10 years there were 10 deaths, a satisfactory result before antiseptic surgery.[66] When Lister's antisepsis was correctly applied and, especially, when thermal sterilisation procedures were adopted, the old fears of protracted healing and sepsis diminished dramatically, producing better stumps. Unfortunately, in the muddy trench conditions of World War I, many compound fractures became septic due to severely

Fig. 11.5. Amputation of thigh by "un tour de maitre" (circular incision), c. 1860. It is not clear whether the patient is anaesthetised, nor can a tourniquet be seen; remarkably the operators are wearing aprons to protect their day clothes. (From Malgaigne JF. *Manuel de Médicine Opératoire*, vol 1. Paris: Germer Baillière, 1874, fig. 235.[78])

delayed treatment,[12] resulting in poor scars among survivors, many of whom were seen by Little who concluded the ideal amputation had a long anterior flap and a scar behind the bone, although some apparently bad scars were compatible with good locomotion. He found, irrespective of the scar, when adductor and flexor muscles had retracted, loss of control resulted with bunching of these muscles to make prosthetic fitting difficult. However, examination of 500 thigh amputations for end-bearing clearly indicated that lower-third stumps were much superior, hence the longer the stump the better; he considered the best site was 3 or 4 inches above the knee joint and 5 inches from the hip the minimum.[67] During World War II, Langdale-Kelham and Perkins' sites of election were 10 inches from the top of the great trochanter, up to 12 inches being better and 6 inches the minimum for retaining an above-knee limb; 4 inches was ideal for a tilting table, the prosthesis for disarticulation of the hip.

In 1986, Vitali et al. said above-knee amputations referred to the Limb Fitting Centre, Roehampton, were often badly executed due to failure in attaching divided muscles to the stump area. They recommended equal anteroposterior flaps, high clean section of nerves, closure of the femur with a periosteal flap and careful suturing of opposed muscle groups over the bone to produce a more-physiological stump; ideally, bone section was 14 cm (5.5 inches) above the knee joint.[68]

Disarticulation of the Hip

According to Velpeau, this severe operation was first performed successfully by Perault in 1774 on a patient whose thigh was crushed between a wall and a wagon leading to gangrene; he subsequently worked as a cook.[69] Velpeau catalogued the early cases before 1840, including some for carious hips, but the mortality was considerable. Larrey undertook several disarticulations for gunshot injury in Egypt and in Russia with some survivors. Without anaesthesia and haemorrhage control other than finger pressure by assistants, it remained a last desperate resort, demanding great courage on the part of patients and also surgeons; we noted in Chapter 9 a successful hip disarticulation for a failed thigh amputation in 1844 (see Fig. 9.4). Aided by anaesthesia, disarticulation became more acceptable and vigorous attempts were made to control haemorrhage by occluding the aorta or iliac vessels with special tourniquets, as discussed in Chapter 10 (see Fig. 10.2); various flap techniques have been used including the long posterior flap of Kelly.[70] Now, many original indications have disappeared and, if required today, there is the assistance of blood transfusion and other resuscitative measures.

Hindquarter Amputation

Complete ablation of the lower limb with attached hemipelvis, or most of the hemipelvis, was a heroic procedure before accurate monitoring systems and transfusion developed. According to Peltier, Girard performed it successfully in 1894,[71] although it was Gordon-Taylor who perfected the procedure between 1922 and 1950, reporting 50 amputations at one hospital in 1952. The majority of these were for bone and soft tissue sarcomas of the hip region, with an immediate overall mortality of 22%, diminishing in the later cases; 10 patients survived 5 years.[72]

Formal Upper Limb Procedures

Amputations of the hand, arm and shoulder have not yielded as many eponymous procedures as described in the lower limb for, it is generally agreed, conservation of surviving tissues is the main objective, irrespective of length, provided remnants have normal sensation; even part of a thumb and one finger may have better function than a complete artificial hand. In addition, upper limb amputations prove less shocking to the system and heal better than the lower limb. Lister, commenting on the arm's better blood supply, wrote in 1883:

"Thus, it is a more serious thing to amputate a toe than a finger, and to take away the arm at the shoulder joint is a much safer proceeding than to cut off a leg below the knee, even though a larger wound would be inflicted, and a larger portion of the body removed, in the former case than in the latter. The more advanced in life the patient is, the more do these differences show themselves."[73]

Arm stumps transmit movement as opposed to leg stumps which support body weight against gravity before initiating locomotion, yet the upper limb activity is much more complex, functioning in space rather than the fixity of ground contact.

Early surgical writers such as Pare and Wiseman mention arm amputations without indicating sites of election, although Fabry (Hildanus) noted a patient with a gangrenous arm after venesection, presumably at the elbow followed by infection, whom he amputated at the level of the axilla.[74] It is only in the 18th century that levels become more specific.

Finger and Hand Amputations and Disarticulations

Conservation of surviving fingers and part hands must have been an objective within historic times, but little is recorded before Woodall illustrated curved chisels, a mallet and a pair of cutters or nippers removing a finger through a phalanx in 1639 (see Fig. 9.2) and Scultetus illustrated similar instruments for removing a hand in 1653 (see Fig. 5.1). Such guillotine sections would have healed slowly and with sensitive terminal scars at best. In 1731, Garengeot criticised these methods of "the Ancients," especially for fearing to amputate through the interphalangeal joints, and described two incisions over the lateral aspects of a finger joined by a circular incision to form flaps and cover bone ends including articular cartilage.[75] Sharp also advised amputation through finger joints, for preference by circular incision beyond the joint.[76] In 1814, C. Bell found a simple circular incision satisfactory for disarticulating fingers.[77] Malgaigne considered section through a phalanx was necessary to save length whenever possible, and formed a semilunar palmar flap based on the ovular incision of Scouttten which he extended dorsally to create the racket incision, claiming its introduction in 1837.[78] Subsequently, the racket incision became popular especially for preserving palmar and plantar skin, thus reducing pressure on the scar. Preservation of the proximal phalanx only was found awkward due to loss of flexor power and, for the index and little fingers, when anaesthesia was available, the phalanx and its metacarpal were removed for cosmetic reasons. Vitali et al. state that one and a half digits are necessary for useful function, although for the middle and ring fingers even a short stump has some functional value and, cosmetically, can be hidden when the hand is half closed.[79] Retention of the thumb or part of the thumb is of considerable value, although severe crush or gunshot injury of the hand may necessitate its loss or even disarticulation at the wrist.

Disarticulation at the Wrist and Forearm Amputation

Wrist disarticulation was considered an acceptable procedure, especially for those who could not afford a prosthesis, as forearm rotation was preserved and, if the carpus was retained, it possessed some carrying capacity. In 1866, Gross expressed its virtues forcibly as follows:

"Disarticulation at the wrist should always be preferred to amputation of the forearm whenever it is practicable, inasmuch as the mutilated extremity affords a much longer lever which afterwards may be used with great advantage for various purposes, at the same time that it is more easily adapted to an artificial hand. I have repeatedly seen persons who, after this operation, enjoyed an amount of action in the limb that was truly astonishing, and who expressed very great satisfaction at having so good a weapon of defence in accidental pugilistic encounters, the long stump enabling them to deal a most powerful blow."[80]

Malgaigne also preferred wrist disarticulation to forearm amputation which had a mortality of some 30% in Parisian hospitals, whereas by 1874 he experienced 16 radiocarpal disarticulations without a death.[81] In 1900, Bryant reported a mortality rate of 8% for civil disarticulations, a possibility of chilblains in the stump and difficulty in fitting an appropriate prosthesis.[82] This contrary opinion hardened during World War I, especially in Britain, due to difficulties in siting an artificial wrist, causing the arm to be longer than its fellow.[83] During World War II, similar criticism was voiced noting the impossibility of accommodating forearm rotation in a prosthesis and the stump's vulnerability to chilblains.[84] However, by 1986, Vitali et al. were able to report that recent prostheses had overcome these problems and wrist disarticulation was no longer deplored.[85]

Early forearm amputations were performed, generally, as low as possible, and this approach was still counselled in the 19th century by Gross and Malgaine. However, Petit, somewhat a lone voice in 1783, believed cutting through tendons near the wrist encouraged infection and he preferred cutting muscle bellies in the upper third.[86] Bryant, who preferred forearm amputation to wrist disarticulation, does not state any specific bone length although he preserved the supinator muscle insertion, that is, the upper third of the radius; he reported a mortality of 15%.[82] Gross reported good function of forearm stumps as short as 2 inches from the elbow.[87] Once again World War I experience induced changes and amputation at any level had to be accepted. In World War II, the site of election for forearm amputation was designated 7 inches from the olecranon and at least 4 inches to control a below-elbow limb. In 1986, Vitali et al.

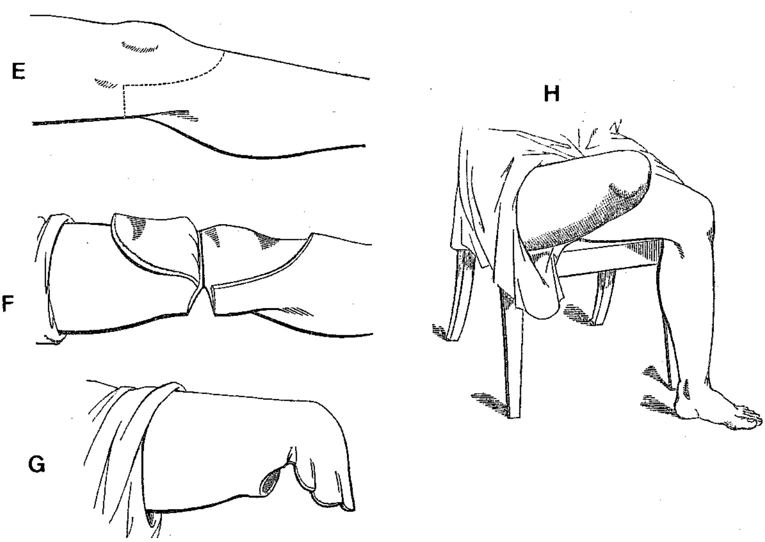

Fig. 11.6. *E, F, G, H.* Carden's single anterior flap amputation of the lower thigh to improve stump healing and produce a scar offset from weight-bearing pressure, 1864. (From Carden HD. *On Amputation by a Single Flap.* London: Richards, 1864.[66])

recommended an ideal length of 17 cm (6.75 inches) from the elbow tip.

Elbow Disarticulation and Upper Arm Amputation

Paré undertook a disarticulation of the elbow, but according to Malgaigne this technique remained forgotten until the 19th century when it was resuscitated by Dupuytren who claimed 10 or 12 successful disarticulations. However, Malgaigne noted the statistics of Salleron who had 5 deaths of 26 disarticulations.[88] Gross strongly supported disarticulation as a safe easy operation which, generally, healed promptly, leaving a useful stump.[89] Farabeuf's enthusiasm for this procedure was associated with detailed descriptions of operating by both circular and elliptical incisions, by both anterior and lateral flaps and by four other routes![90] However, it remained a rare operation, Little reporting 7 of 1000 mainly military amputations, as compared with 175 upper arm amputations. In 1942, Langdale-Kelham and Perkins found elbow stumps very difficult to fit with a working prosthesis and Thomas and Haddan concurred, stating it was the clumsiest of all arm prostheses.[91] Vitali confirmed this view, recommending an above-elbow amputation.

Wiseman and other early surgical authors performed upper arm amputations but no specified levels are noted. Lord Nelson underwent humeral section for a gunshot wound of the elbow joint in 1798, apparently just above the level of compound bone injury, and subsequently coped without a prosthesis. Larrey, Guthrie and other military surgeons amputating the upper arm do not specify a particular level, except that Larrey advised that for high sections, a small remnant of humerus should not be retained, for complete shoulder disarticulation was required. This view was opposed by Sabatier and Guthrie who believed the remnant was not prone to deformity, preserved the shoulder outline and stabilised a prosthesis.[92] A circular incision was recommended for amputation through the lower arm and flap incisions for the upper arm. Elmslie said amputation could be performed at any level through the humerus, leaving 1 inch at the shoulder if possible. Langdale-Kelham and Perkins recommended an ideal stump of 8 inches measured from the acromium and at least 4 or 5 inches if an above-elbow limb prosthesis was to be worn. Vitali et al. said the ideal section was 10 cm (4 inches) above the elbow joint, using anterior and posterior flaps, and suturing the elbow flexors to the triceps expansion.

Disarticulation at the Shoulder

This major operation developed in the 18th century, promoted by detailed anatomical knowledge, including initial compression of the subclavian artery against the first rib, and acceptance of ligatures for major arterial bleeding, achieving great popularity during the Napoleonic wars. According to Ledran, his father performed the first disarticulation before 1731, for a patient with caries involving the humeral neck, achieving a successful outcome.[93] French surgeons promoted many methods of performing this operation, confirming a need to vary approaches, dictated by individual pathology and in particular the state of skin flaps after gunshot injury. Indeed, scrutiny of Velpeau's 1840 survey reveals an astonishing list of 33 reported procedures employing circular, flap and elliptical incisions, including his own three variations of the latter.[94] Larrey is famous for claiming 90 cures of 100 disarticulations using a racquet incision, although Malgaigne was sceptical in view of personal statistics and experience in the Crimean War when mortality in the French army was 52.7% and in the British 33.3%; in the American Civil War, the mortality was 39.2%.[95] Farabeuf apologised for a "historical atlas" of diverse shoulder disarticulation techniques occupying 24 pages, to which he added 28 illustrations of variant incisions![96] This extraordinary ingenuity reflects an obsessive interest in a major procedure which demanded precise anatomical knowledge, providing satisfaction to many surgeons. Gross observed:

"Amputation at the shoulder joint is one of the most easy operations in surgery. Richerand long ago remarked that it might be performed with the same celerity with which an adroit carver separates the wing of a partridge, and nothing is more true, although I have occasionally seen a case in which the surgeon consumed time enough not only to cut up the whole bird, but also to devour it."[97]

In 1900, Bryant confined himself to four methods including Larrey's racquet approach and reported a mortality of 25% to 38% for gunshot wounds.[98] Removal of the humeral head left an unsightly and often uncomfortable prominence of the acromion, and after World War I experience Elmslie advised saving the humeral head if not damaged; this was also the message from World War II. Vitali et al. confirmed the problems of fitting prostheses and recommended part-excision of a prominent acromion.[99]

Forequarter Amputation

Resection of the arm with attached scapula and clavicle was first performed by Surgeon Cuming in the Royal Naval Hospital at Antigua in 1808 on a sailor hit in the shoulder by a cannon ball; he made a good recovery.[100] Velpeau remarked that pull-off injuries of the arm (see Chapter 3) and shoulder disarticulations combined with part of the scapula, followed by healing, may have encouraged such surgery. and by 1840 he was able to report several cases, mainly for malignant disease.[101] Surprisingly, Malgaigne and Farabeuf have nothing to say on the subject. Gross reported a few more cases but had no personal experience. In 1900, Bryant considered the operation tedious, attended by great loss of blood and difficulty in obtaining flaps to close the wound in malignant cases; for 51 recorded forequarter amputations, he said the mortality was 25%.[102] In Little's analysis of 1000 consecutive amputees from World War I, only 1 underwent forequarter resection. Thomas and Haddan commented on its significant disfigurement and difficulty in fitting a prosthesis which has no function, although by restoring shoulder symmetry the patient's morale is boosted.[103] In 1986, Vitali et al. commented that it was rarely performed, mainly for malignant tumours around the shoulder joint, and recommended Littlewood's posterior approach but gave no reference.[104]

Summary

In contrast to ritual, punitive and traumatic amputations, most elective procedures are subjected to debate between patient and surgeon, although many indications are compelling for reasons of congenital deformity, severe injury, gangrene, chronic bone and joint infections, and tumours and also for victims of entrapment. Since the late 18th century, many former indications are nullified by reconstructive procedures, a process which continues. If timing an amputation was a major dilemma before anaesthesia and safe surgical management, today, at least, death from haemorrhage and infection are remote whilst sound stump healing and excellent prostheses are anticipated. As is evident, variations in stump flaps and bone section levels or joint disarticulation are numerous and have spawned a bewildering range of techniques, especially for the lower limb. An attempt has been made to condense these developments in historical sequence.

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12
Stumps: Reattachment, Management, Complications, Revision and Care for Limb-Fitting

"*. . . high inflammation, large suppuration, exfoliation of the bone, a tedious cure, and in the thigh particularly, retraction of the muscles, and a sugar-loaf stump, or an incurable wound, was generally the consequence of the common mode of amputation;*"

Alanson, 1782[1]

"*Amputation is the beginning not the end of treatment.*"

Watson-Jones, 1945[2]

Nonsurgical amputations by accidental dismemberment, by ritual, punitive and legal sanctions or those performed in extremis by the trapped victim are usually guillotine divisions of each tissue at the same level. Assuming victims survive and no surgical revision follows, healing is tardy, producing fragile scars, often with bone protruding as the muscles retract, and hence unsatisfactory stumps for prosthetic fitting. Severe frostbite, gangrene caused by vascular failure, infection, diabetes, ergot and other toxins, without surgical revision, generally produce similar stumps after tediously slow spontaneous partition at the demarcation line (Fig. 12.1). Separation at the junction of gangrenous and living tissues was also assisted by surgical division of exposed bone as described by Woodall in 1639, when at least one of his patients was given an artificial leg for loss just below the knee, presumably a kneeling peg-leg. Of three other gangrenous separations assisted by Woodall, no suturing or bandaging to promote stump healing was possible, yet he recorded closures between 3 and 5 months later.[3]

Limb Reattachment

Reattachment or replantation of traumatically severed limbs, developed over the last half-century, is most favourably performed with a clean division of structures, that is, a guillotine section causing minimal damage to the stump and detached limb. Perhaps the concept of reattachment crossed the minds of earlier practitioners long before the necessary technology evolved; in Chapter 3 we noted a young boy who, in all innocence, urged the surgeon to put his leg back before confessing the accident to his mother. Closely parallel is the medieval legend of the patron saints of surgery St. Cosmos and St. Damian, frequently painted as "The Miracle of the Black Leg," revealing their prodigious operation of amputating the painful cancerous leg of a Christian followed by its immediate replacement with an allograft leg taken from a Moor who had just died (Fig. 12.2).[4] However, the first major reattachment of modern surgery was performed by Malt and McKhann of the Massachusetts General Hospital in 1962 when a 12-year-old boy severed his right arm near the shoulder in a train accident. After 8 hours of surgery, bone continuity and the blood supply were reestablished and subsequently nerves and

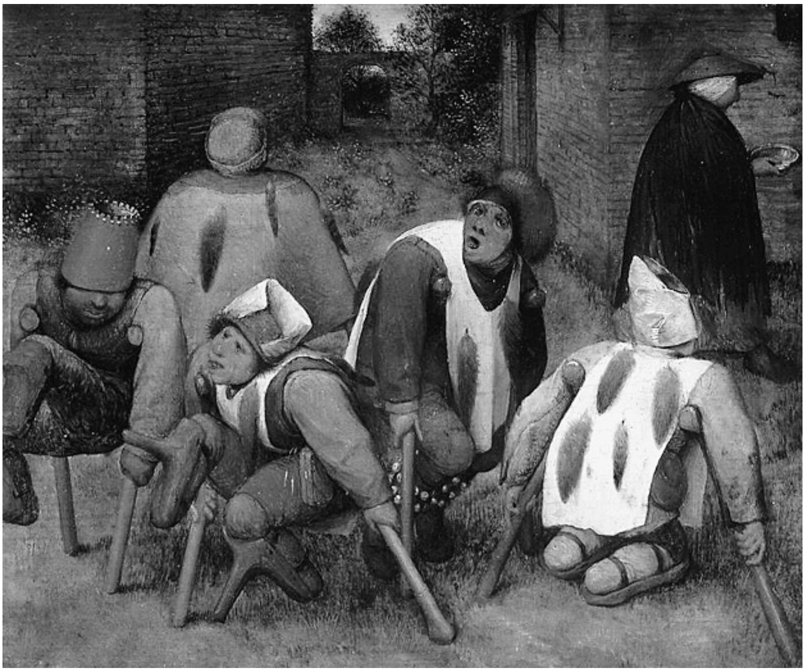

Fig. 12.1. Painting of a group of young men suffering from ergot-induced bilateral amputations, using kneeling prostheses and crutches, by Pieter Brueghel (1525–1569). (Permission of Norman Publishing.)

tendons were connected, enabling the boy to resume baseball and later drive a heavy lorry.[5] Since then, surgical teams have been established worldwide to undertake reattachment (replantation), including all fingers of a hand, when the residual tissues are suitable. Recovery after such operations is prolonged and useful nerve function is particularly difficult to achieve, although younger patients do better (see Fig. 13.17). Unless these traumatic amputations involve a precise guillotine section, attempts can be disappointing and precipitate a succession of operations with very little gain, resulting in a functionless or poorly functioning limb ending in amputation, causing some to describe such surgery as "technique over reason." Often there is no choice but amputation, for example, when a limb has been disposed of by a shark or severely traumatised by a machine, as happened recently when a worker fell into an industrial shredder and lost both arms.[6] More commonly, doubt arises with limbs still attached but severely crushed, associated with compound fractures, severed blood supply and, possibly, divided nerves and tendons. Helfet et al. studied the dilemma, salvage versus amputation in the lower limb, in 1990, and proposed a Mangled Extremity Severity Score to discriminate between these two surgical options. Points were given in relation to the trauma energy involved, to the degree of shock and to the ischaemic state, enabling them to make satisfactory decisions, although not all amputations were immediate.[7]

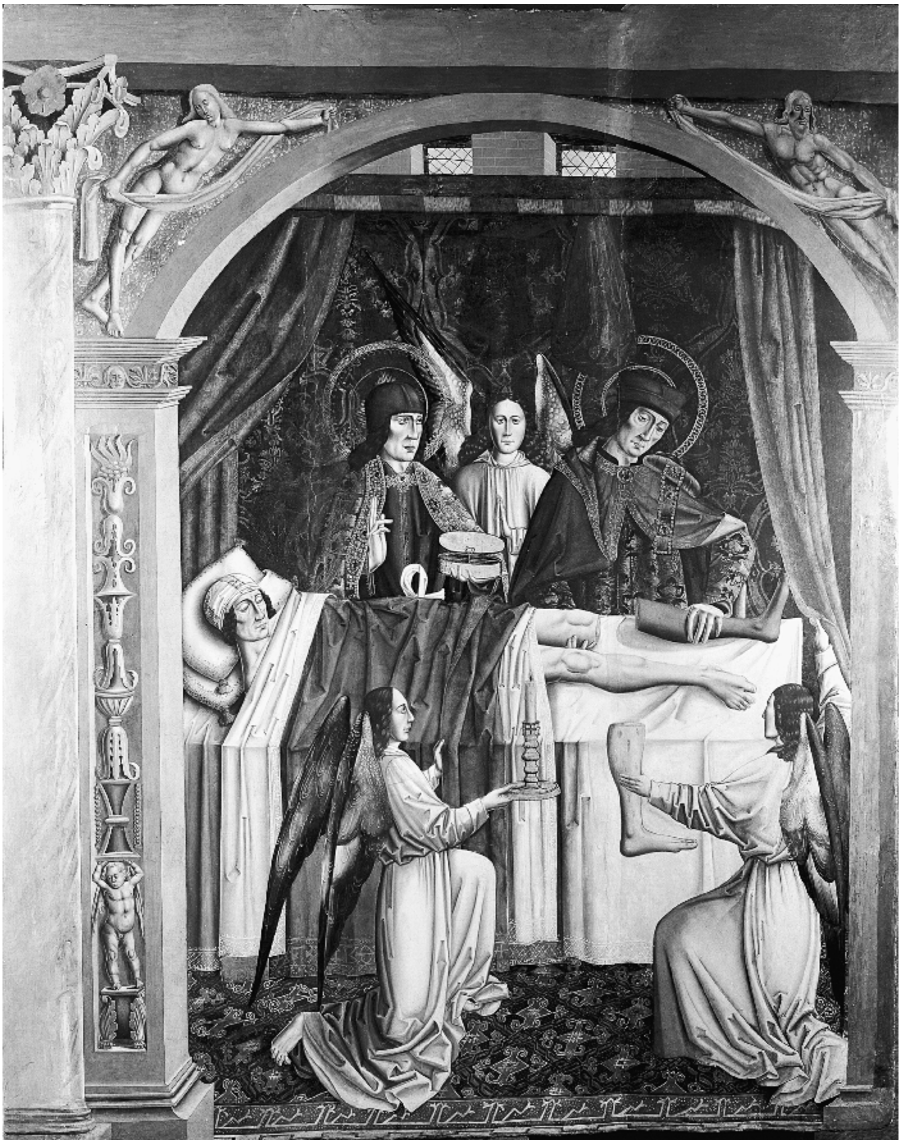

Fig. 12.2. Painting of St. Cosmos and St. Damien performing a miraculous implantation of a Negro's leg to replace the patient's amputated white leg, seen in the foreground, 1495. (Copyright Wellcome Trust Medical Library.)

Surgical Stump Management

For surgical guillotine amputation, it was accepted practice to spiral a bandage around the stump, from the root of the limb towards the wound, to manipulate the skin and soft tissues over the bone end to promote healing, although this was often imperfect. Despite the slow healing of guillotine section, this form of amputation is still advised, especially as an emergency on the battlefield or, similarly, to save a trapped victim in a dangerous situation, although today the section is revised surgically. Commonly undertaken for gas gangrene during World War I, the wound was unsutured to allow maximal drainage of purulent discharge and gas and to prevent wound tension. Huggins, who had charge of nearly 2000 amputees from the Flanders battlefields at the Pavilion

Hospital, Brighton, admitted 2 months to 2 years after amputation, recommended stump traction with weights via a pulley (Fig. 12.3) and stated:

"Unhealed stumps are, as a rule, the result of the so-called guillotine amputations. . . . or one in which the flaps have not been stitched up, should be treated with continuous skin extension from the earliest possible moment until healed or operated again; continuous extension will almost cover a guillotine stump in a few weeks."[8]

Probably this solution was successful because most of his amputees were young men with good skin and tissue circulation; older patients, especially with vascular deficiency, would require great care to prevent skin damage by adhesive plaster extension. In 1872, Bryant had recommended traction for any stump showing signs of wound retraction, applying weight indirectly to a perforated zinc splint which was bound firmly to the bandaged stump.[9]

Cheselden, who claimed to improve guillotine amputations by a double incision, that is, cutting the muscles higher than the skin, nevertheless expected imperfect healing of a below-knee stump as his drawing demonstrated (see Fig. 7.4). Le Dran, who amputated by this method, stated the stump took 2 or 3 months to heal, depending on the size of the limb, for which reason flap methods were proposed.[10] B. Bell, commenting on Cheselden's double incision, observed transverse thigh amputations took at least 3 or 4 months, or even 5 or 6 months, to heal whereas flap closure of stumps healed, in the absence of infection, in 2 or 3 weeks.[11] Alanson, who sectioned skin, muscles and bone at different levels applied adhesive strips and a roller bandage of swan-skin flannel, later changed to fine Welsh flannel, which Alanson claimed supported the skin firmly without hazarding its circulation[12]; after a month most stumps were healed or had minor sinuses which ultimately closed.[13]

Earlier, Pare approximated the lips of amputation wounds with four sutures to reduce exposure to the air, not aiming to unite completely; indeed, this was impossible for, if attempted, the sutures would cut out.[14] Wiseman was insistent on a single stitch of strong brown thread, inserted half an inch from the wound edges, and covered by medicated dressings, an ox bladder and a bandage starting on the stump and, contrary to later authors, rolled upwards; the stitch was removed on the third day.[15] Sharp was not confident in bandaging alone and recommended two cross-stitches at right angles to each other, made up of 8 coarse silk threads on a seton needle, doubling to 16 on insertion, three-quarters of an inch from the wound edges, and tied in a "bow-knot," to assist easy release for undue tension or to secure a bleeding vessel. He reported in 1750:

". . . the Stitches wear thro' the Skin and Flesh in twelve or fourteen days; but this is done so gradually, that it causes very little Pain or Inflammation . . . they consequently come off with the Dressings, yet by this Time the Skin and Muscles are fixed . . ."[16]

However, stitches were often extremely painful to insert, particularly on coarse seton needles, and closure retarded the drainage of residual blood and inflammatory discharge, hence encouraging deep infection. In the later 18th and early 19th centuries, establishment of the triple circular and the flap incisions permitted loose approximation of stump edges, sometimes relying on adhesive strips, and bandaging but sometimes a combination of a few sutures and adhesive strips.[17] In 1814, C. Bell illustrated adhesive strip closure of stumps to which an additional Maltese-cross bandage was

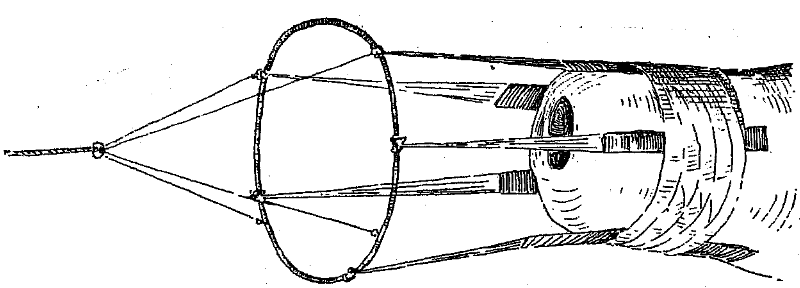

FIG. 12.3. Unhealed femoral stump after guillotine section, undergoing adhesive plaster traction to mobilise skin and encourage wound closure. (From Hull A, *Surgery in War*, London: Churchill, 1918, fig. 100.[46])

applied, followed by a conventional encircling bandage (see Fig. 5.6). In the mid-19th century, many surgeons followed Dupuytren's advice to leave wounds completely open for several hours so as to sponge the raw surfaces with cold water, thus visualising and controlling postoperative haemorrhage rapidly, before dressing and bandaging rendered this more difficult. This management allowed the wound surfaces to "glaze over," said to assist adherence when eventually bandaged. In complete contrast, Lister's antiseptic regimen promoted confidence in immediate wound closure, in anticipation of primary healing without infection, provided Lister's additional advice of inserting temporary drains was followed. In 1885, Watson listed methods of stump dressing in detail, noting Guerin's massive cotton-wadding dressing, O'Halloran's open method which separated the flaps for about 12 days, the completely open method associated with long flaps and phenol irrigations, Callender's modified antiseptic treatment, Markoe's through drainage also applying phenol, Gamgee's dry and infrequent dressing, Hewson's earth treatment, water dressings and, finally, his recommended alternative of a full antiseptic scheme as introduced by Lister for amputation stumps.[18] Aseptic sterilisation practices further advanced primary stump healing but did not excuse or correct unsatisfactory initial surgery which remained a source of stump complications.

Early Stump Complications

Immediate complications of haemorrhage, infection, gangrene, septicaemia and death have been noted in earlier chapters. Older writers also comment on postoperative spasms of the stump which, in 1822, S. Cooper stated can cause painful agony, with contractions of stump muscles precipitating bony protrusion and, also, generating more widespread muscle spasms, leading occasionally to death[19]; he does not mention tetanic spasms which could be mortal. Velpeau confirmed local spasms in 1832, even present before the stump was dressed, usually responding to binding stumps firmly to the mattress and by patients taking opium.[20] Conceivably, some spasms were caused by accidental inclusion of nerves in vascular ligatures?

Late Stump Complications and Revision

Following surgery, amputation stumps may prove suitable for provision of satisfactory prostheses, or may not, because of a variety of established conditions. Earlier authors were especially concerned about continued suppuration, failure to heal, "sugar-loaf" formation with bone protrusion, painful scars and overlong below-knee stumps which prevented efficient use of a kneeling peg-leg. Poor or failed healing necessitated permanent bandaging to protect fragile tissues from further damage and also to absorb chronic discharge, a common picture demonstrated in Bosch's drawings of below-knee amputees (see Fig. 2.4). Bone protrusion was diminished by sawing off the excess, leaving a bony ulcer which might exfoliate spontaneously leaving, at best, an indurated and sensitive scar. Before anaesthesia, a few resolute patients insisted on or accepted reamputation, an operation particularly undertaken for the overlong stump; the risks were great, mainly from infection, and not all survived (see Chapter 6).

It must be remembered that even a soundly healed stump changes in contour and size during the first few months after surgery and also that stump complications have changed in the last two centuries in response to an aging population, to new surgical techniques and to artificial limb innovations. Complications observed by a variety of authors selectively follow, recognising these are noted in publications principally from the late 18th century onwards. Alanson's list for 1782 is recorded in the quotation heading this chapter, emphasising the significance of absent bacteriological knowledge at that time.

Velpeau listed postoperative complications as follows:

i. Cone formation (sugar-loaf) of the stump, which was rare thanks to improved circular incisions and primary wound healing, but still provoked by suppuration.

ii. Exfoliation of bone ends, which often took 3 or 4 months to necrose and discharge naturally or with surgical assistance; this was long regarded as inevitable, perhaps induced by heated cauterisation or caustic remedies formerly in vogue.

iii. Hospital gangrene, a frequent and perilous infection which might necessitate amputation at a higher level.

iv. Swelling of the stump, sometimes associated with erysipelas infection, likely when primary healing was attempted, for it was rare with delayed healing methods. Treatment necessitated opening the stump wound, applying leeches or, most efficaciously, making multiple and deep incisions. On survival, further treatment included reamputation; Gourand reported 10 such operations between 1814 and 1815 with 9 cures.

v. Phlebitis with suppuration carried a high mortality and was associated with infection of the bony medullary cavities propagating infection to the heart.

vi. Cystitis mainly in lower limb amputees who often needed catheterisation.[21]

In 1839, Sédillot listed a similar series of complications, adding tetanus as a particular problem among military amputees. He also studied the anatomy of stumps during their early years of formation, distinguishing those which healed primarily, with a linear, lightly puckered scar and those healing secondarily, with a more irregular scar attached to bone. Stump dissection demonstrated that muscle tissues were largely absorbed, the principal vessels were converted to fibrous tissue, nerve ends were enlarged and bone ends presented no evidence of a medullary canal, which closed over with dense fibrous tissue. Sedillot suggested extensive examination of postmortem stumps would prove informative. He noted many amputees gained weight and advised dieting and regular venesection.[22] Liston did not list stump complications in 1837 but discussed reamputation for inconvenient length, tenderness, prominent bone ends, infection, ulceration and nerve adhesions. In most cases he advised a simple filleting out of 2 or 3 inches of bone and, if necessary, shortening of nerve trunks.[23] Chelius found similar stump complications in 1847, noting severe problems induced by infection and also torpid patients who showed insufficiency of inflammation with a flabby wound not inclined to heal, for which local aromatic remedies and poultices were recommended.[24]

In 1872, Bryant considered most through-femoral and -humeral stumps became conical with time as a result of muscle wasting whereas this was rare when double bones of the forearm and shin were divided or after elbow and knee joint disarticulation. He said conical formation in childhood was inevitable, especially below the knee where normal bone growth, due to the upper tibial epiphysis, might require shortening on more than one occasion; this also involved the humerus

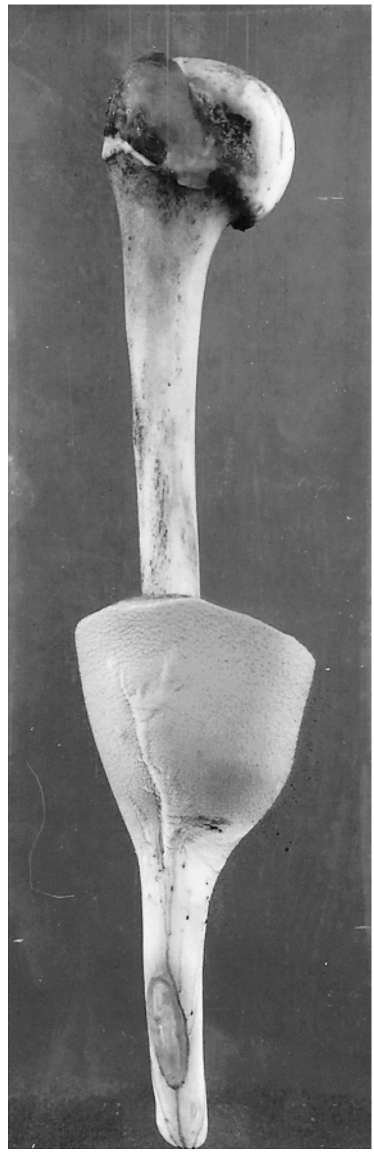

FIG. 12.4. Disarticulated humerus excised for natural bony overgrowth of an above-elbow stump, for a compound fracture sustained by a boy of 6 years run over by a heavy wagon; the protrusion of the humerus is marked with formation of a bone ulcer. The second operation took place when he was 15 years old; specimen was deposited in 1897. (With permission of the Royal College of Surgeons of England.)

(Fig. 12.4). Painful stumps caused by neuroma formation were cured by nerve excision (see Fig. 12.4), although extreme pain caused by hyperaesthesia was resistant to operation but might benefit from local belladonna, opium or stramonium.[25] Watson's chapter on stump classification proves disappointing, merely calling stumps good, bad or indifferent, and noting conical and infected stumps, exostosis formation and rare bowing or twisting of juvenile bones.[26] Huggins, on the basis of extensive experience of military amputees from World War I, was very critical of guillotine amputations which often needed reamputation but warned it was prudent to delay further surgery until 6 months after septic stumps settled, when he advised an oblique rather than a transverse guillotine reamputation.[27]

Little's practical handbook, as he modestly subtitled his book of 1922, was based on extensive experience of World War I amputees. He instituted accurate measurement of stump lengths and also a study to estimate normal bone lengths of 100 men with their heights for comparative purposes. Little cited the following complications as sources of common delay in fitting:

i. Sinus formation due to bony sequestrum formation, the persistence of missile fragments or unabsorbed ligatures such as silk, all of which demanded exploration.

ii. Painful nerves or tenderness caused by to inflammation, especially bulbous formation of divided nerves trapped in scar tissue, more troublesome in the upper limb. Persistence of pain after 3 months required high division of bulbous nerves (Fig. 12.5), then crushing followed by the injection of absolute alcohol, although he admitted some patients did not respond to these measures. He mentioned causalgia, but does not enlarge on its management, and also jactitating stumps which on the slightest pressure induced clonic spasms of the stump, often difficult to treat.

iii. Unsound scars, usually associated with suppuration and failed primary union, especially after gas gangrene when no flaps were made, leading to heavy scarring adherent to bone. Although unfit to bear weight, many such stumps could be fitted with a prosthesis, but the remainder needed scar excision or, as a last resort, reamputation. If skin and bone were short, up to 10 pounds weight extension via adhesive strapping

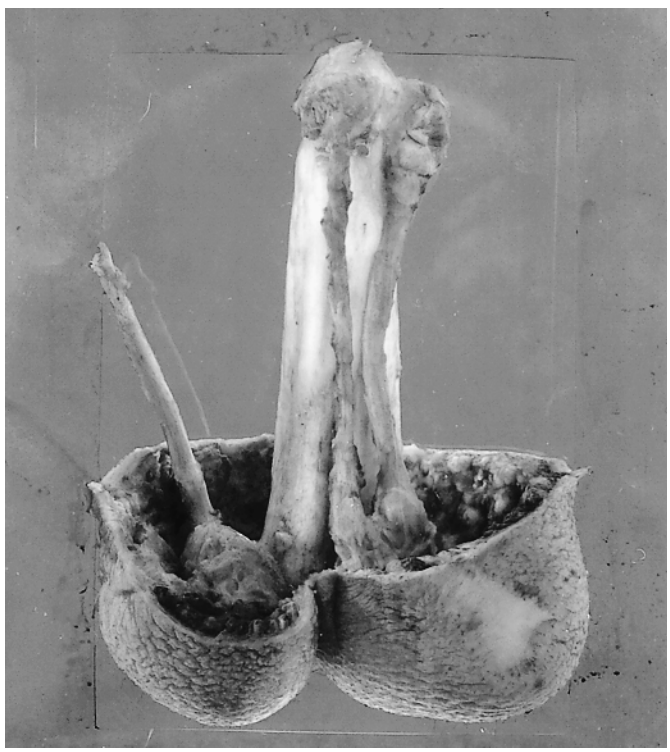

Fig. 12.5. Excised above-elbow stump for persistent pain caused by adherence of bone and nerves to scar; the humerus has been shortened with the ulnar, median and radial nerves which are seen to terminate in large neuromata in the scar tissue. Deposited in 1949. (With permission of the Royal College of Surgeons of England.)

was applied for some weeks (see Fig. 12.3); with upper limb extension the patient could be ambulatory. For below-knee stumps, complete excision of the fibular shaft sometimes provided adequate skin cover.

iv. Contractures in the neighbourhood of joints above amputations were a serious drawback. Stiff shoulders hampered the action of prostheses for above-elbow sections markedly but a stiff elbow was less troublesome for below-elbow sections. Most serious was the stiff hip with flexion and/or abduction contractures, commonly seen with short thigh stumps which, nevertheless, might be fitted with a prosthesis without treatment. For long thigh stumps, strenuous physiotherapy was recommended or, if necessary, surgical excision of contractures or, as a last resort, excision arthroplasty of the hip joint. He stated only 30° of knee flexion is necessary for a walking prosthesis although at least 90° is required to sit comfortably.[28]

In an addendum, Little illustrated radiographic features of stumps from a collection of 116 prints which he donated to the Royal College of Surgeons of England, some showing spur formation that caused no symptoms and were associated with good stump function whereas good radiographs might hide painful stumps.[29]

Largely based on World War II experience, Thomas and Haddan attributed most stump difficulties to the following:

"1. Faults in the stump itself, due to improper operative technic, infection, or improper preparation of the stump for the prosthesis. 2. Poor stump hygiene, with resulting skin irritation or infection. 3. Faulty fitting of the prosthesis. (This, though most often blamed, is probably the least frequent of all causes.)"[30]

Detailed complications were as follows:

i. Persistent tenderness after fitting a prosthesis caused by low-grade infection, vascular disturbances, adherent scar and irritable neuroma; painful neuromata were not so common as generally thought, but if pain was suspected and abolished by local anaesthetic infiltration, nerve resection was indicated.

ii. Phantom pain and causalgia, noting that all amputees experienced sensations relating to ablated anatomy, usually not disturbing and persisting briefly. Commoner in the upper than lower limb, the severity was related to amount of sepsis experienced in the stump. Sensations of warmth, itching, burning, throbbing, piercing, cramping, sticking and of the limb being crushed or torn were described although, fortunately, intractable pain in the phantom was rare. They added psychic factors played a role in susceptible individuals and noted Leriche and Livingstone's investigation of the part played by the autonomic nervous system and the help given to some cases by injection of sympathetic ganglia. Their review of the literature confirmed cure was difficult. If local anaesthesia of paravertebral ganglia was effective, repeat injections or ganglionectomy was justified, and for the extremely introspective patient, frontal lobotomy was a possibility. Initial pain due to sepsis, tight bandaging, insufficient sedation and painful dressing changes indicated probable factors that should be avoided.

iii. Ulceration, associated with an overlong stump, especially below the knee; venous stagnation and swelling was more marked in those with peripheral vascular disease. Sinus formation was usually the result of osteomyelitis, and X-rays might confirm bony sequestra for removal.

iv. Bursal formation often developed over bony points subject to friction by a socket and required adjustment of the prosthesis.

v. Skin irritation, furunculosis, infected sebaceous cysts and eczematous dermatitis were associated with lack of stump hygiene or a poorly fitting socket.[31]

Gillis developed extensive expertise in managing painful stumps, devoting a chapter to this in 1954, and suggested the following factors, including a growing trend by several authors to implicate prostheses in the 20th century.

i. Local stump pathology of skin, fat and fascia, muscle, nerve, vessels or bone.
ii. Pain associated with artificial limbs caused by poor fit, faulty alignment, poor supporting appendages and controls.
iii. In the lower limb, remote causes due to lumbar disc prolapse, spinal arthritis or hip or knee arthritis, possibly on the good side.
iv. Central causes, producing phantom and perhaps causalgia.

v. Psychogenic of economic, emotional, hysterical or, rarely, self-inflicted origin.[32]

Gillis discussed these in more detail and illustrated problems with X-rays and excised stump pathology, many of which excisions are now exhibited in the Anatomico-Pathological Museum of the Royal College of Surgeons in London (see Fig. 12.5). In 1957, Gillis provided an analysis of 2000 consecutive surgical procedures performed at Roehampton, the national centre for amputation management. Of these, 738 (36.9%) were primary amputations, 926 (46.15%) were reamputations and 339 (16.95%) were lesser operations on the stump, including scar, nerve, ulcer, bursa and tumour excisions, sequestrectomy and bone excisions, draining of abscesses, sympathectomies for pain, and secondary suturing. Of the 2000 procedures, 1262 were performed for pathological conditions of the stump, that is, 63.1% of all operations.[33] In the 1963 edition of *Campbell's Operative Orthopaedics*, Slocum provided an exhaustive and practical analysis of stump complications, including a list of causes and specific treatments. There were 12 main complications and 34 causes, mostly related to primary surgical imperfections, for none were attributed to an ill-fitting prosthesis[34]; recent editions of *Campbell's Operative Orthopaedics* no longer include this classification.

In 1986, Vitali et al. did not discuss what they termed short-term stump pathology, as this either resolved or progressed to reamputaton, being more concerned with long-term pathology, which was listed under three headings:

i. Preamputation pathology, firstly with respect to the skin especially when vascular deficient, scarred after compound fractures, anaesthetic due to neurological factors or ulcerated and affected by chilblains, and the effect of adjacent flail, unstable, restricted or ankylosed joints.

ii. Postamputation pathology, with reference to the skin and scar, muscles and nerves, along the lines noted by previous authors.

iii. Stump pathology initiated by unsatisfactory prosthetic fitting, including dermoid cysts, eczema, problems caused by the amputee gaining weight to alter forces between stump and prosthesis, and prosthetic misalignment.

Each amputation site was reviewed for specific surgical and prosthetic pathology.[35]

In contrast to the problems of bone protrusion and "sugar-loaf" formation, stumps can be too short for adequate fitting of prostheses and may require reamputation at a higher level or, possibly, lengthening the shortened bone as described in 1990. Eldridge, Armstrong and Krajbich were able to lengthen a tibial stump from 7 to 11.5 cm using the Ilizarov circular distraction frame on an 18-year-old man who had sustained a traumatic amputation close to the knee as a 5-year-old. As bone lengthening proceeded to a tibial length of 15 cm, they encountered bone penetration of the overlying skin with infection and eventually had to sacrifice 3.5 cm of gain, followed by skin grafting. For future stump lengthening, they concluded prior skin reconstruction was essential.[36]

Cineplastic Revision

To improve the function of upper limb stumps, skin-covered tubes, rings and hooks were constructed to contain exteriorised working muscles and tendons, first by Ceci in 1896, at the direction of Vanghetti, and continued by other Italian and also German surgeons; Sauerbruch reported 1500 cases in 1920. In the United States and UK, this form of plastic reconstruction was found less successful and rarely undertaken after World War I.[37] An alternative procedure, the Krukenburg conversion, proved more practical, especially for double forearm and blind amputees, involving separation of the radial and ulnar stumps to form active pincers. This technique required mobilisation of the radius to "pinch" the stable ulna, both covered with skin and moving tendons appropriately.[38] Due to the unappealing aesthetic result, it did not prove popular in Westernised societies[39] but for poorer societies, without sophisticated hand prostheses, it has proved valuable especially for bilateral amputees whose livelihood depends on manual labour.[40]

Stump Preparation for a Prosthesis

Before the 20th century, very little is recorded on stump care with the object of moulding the tissues, strengthening stump muscle control, preventing contractures and certainly not immediate mobilisation with a temporary prosthesis or pylon. Understandably, before anaesthesia, antisepsis and asepsis, efforts were concentrated on preserving the amputee's life, threatened daily by serious hazards of haemorrhage and sepsis, perhaps for months after surgery, and on attempting to ensure a satisfactory scar despite prolonged healing. While it was recognised a sound stump underwent a process of reduction in girth over many months, methods of bandaging to assist this process are very much a 20th-century observation. However, Bigg, a medically qualified limb-fitter, wrote in 1885 that stumps enlarged immediately after operation and, when healed, gradually shrank over 10 to 15 months, or even 2 years, observing it was important to tell the patient of these changes for he had experience of amputees becoming disheartened and abandoning their loose prosthesis without seeking guidance. This consideration did not mean fitting should be delayed, provided alterations were made for shrinkage, by additional stump socks or changing the socket.[41]

The chaotic experience precipitated by vast numbers of amputees from the battlefields eventually promoted positive preparation of stumps before fitting artificial limbs. Due to delayed healing many military amputees arrived for consideration of prostheses months after injury with weakly controlled stumps and deformities resulting from joint contractures above the amputation site, making prosthetic fitting less than ideal. After World War I experience, Elmslie made a plea for early immediate bandaging and massage to encourage stump shrinkage, and especially active exercises to prevent joint contractures in the lower limb, to produce a strong and efficient stump capable of maximal benefit from a prosthesis; bandaging was unnecessary for the upper limb. At the earliest opportunity, often after 3 weeks, walking was instigated in temporary prostheses made from plaster of Paris, cut-down crutch sticks and webbing harness (Fig. 12.6); the plaster cast was changed for stump shrinkage before achieving its final form and a permanent limb.[42]

At the end of World War II, Thomas and Haddan discussed stump preparation in great detail, emphasising the need to shrink the stump to a conical shape by bandaging, to exercise the stump muscles and thereby encourage patients

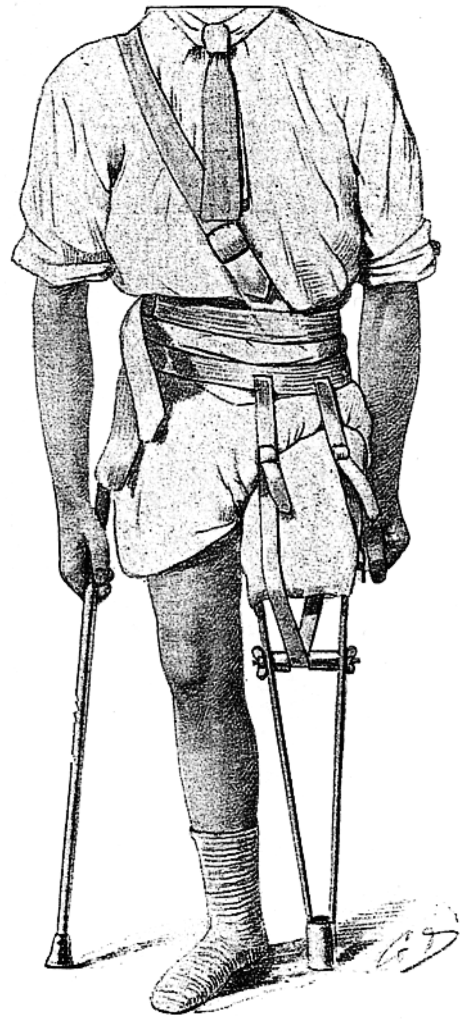

Fig. 12.6. Elmslie's temporary prosthesis for thigh amputee, to encourage early mobilisation. A plaster of Paris "bucket" surrounds the stump and incorporates a cut-down crutch and webbing holding the bucket to the trunk; on the intact side, a walking stick is attached to the webbing, 1924. (From Elmslie RC. Amputations. In: Carson HW (editor) *Modern Operative Surgery*, vol 1. London: Cassel, 1924: fig. 66.[42])

who were too often neglected between amputation and limb-fitting. They doubted whether massage or tapping the stump to toughen it was of value, unlike muscle activity against resistance, contrast bathing and the whirlpool bath for low-grade stump inflammation. Early introduction to a temporary peg-leg prosthesis or pylon was considered by the U.S. Army and Navy to be the most effective means of conditioning lower limb stumps and also of encouraging the patient psychologically. Thomas and Haddan, however, believed this was unnecessary in civilian practice, for a permanent limb could be fitted within a few weeks, and shrinkage countered by adding stump socks, and making a new socket if required, only needed for some 25% of amputees in the United States. Stump hygiene was vital by daily washing and change of socks, by exposure to fresh air as much as possible, by reducing friction and by using talcum or lanolin for dry skin.[43]

Vitali et al. encouraged the patient to look at and handle the stump and, supervised by a physiotherapist for lower limb amputees, to move up and down the bed, perform stump exercises, to dress normally and learn a transfer routine from bed to wheelchair. They claimed stump bandaging could be dangerous and was unnecessary, maintaining that oedema was controlled by using a bed board at all times, by posture and exercises and by mobilising with a pneumatic postamputation mobility aid, consisting of an inflated bag over the dressed stump, encased by a metal frame to take partial weight, and walking between parallel bars or with crutches.[44] Use of this aid began between 5 and 10 days postamputation, principally to control stump oedema and to gain confidence and balance by upright mobilisation. Vitali et al. claimed 10 years experience of this aid without any untoward effect on stumps, although it was inapplicable to bilateral amputees. In addition, they boosted healing of lower limb stumps in a controlled environment treatment unit, delivering warm sterile air to undressed wounds in a clear plastic bag, at alternating pressures. They were not keen on immediate postoperative pylons over plaster of Paris casts but recommended a temporary prosthesis at 3 weeks and early mobilisation in hospital.[45]

Summary

Before anaesthesia, stumps were hurriedly made, were prone to secondary haemorrhage and usually became infected to some degree, producing long-term problems for amputees who survived. Anaesthesia provide0d more time to fashion better-covered stumps and control haemorrhage, but infection remained a bugbear until antiseptic and aseptic techniques were accepted. Even so, the exigencies of warfare on a gigantic scale revealed many complications associated with stump care. Further, in civil practice, most amputations were undertaken by surgeons who lacked sufficient experience to appreciate the needs of the stump in relation to available prostheses. Only since World War II have amputees benefitted from a multidisciplinary team approach to stump management, from preoperation until satisfactory prosthetic fitting.

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13
Artificial Limbs and Rehabilitation

With Contributions by Kingsley Robinson, MS, FRCS

"Amputation for injury or disease of the extremities has been practised for many centuries, and no doubt dates from pre-historic times. Some forms of prosthetic appliances have probably been used for nearly as long."

Little, 1922[1]

"The availability of new materials for the design and fabrication of artificial limbs often has an influence on surgery."

Murdoch and Wilson, 1996[2]

When Murdoch surveyed amputation literature in 1970, he concluded many more articles, monographs and books had been written on surgical techniques than on prosthetic solutions to limb loss.[3] This idea was certainly true before the 20th century, whereas since World War I much has been published on research into and the development of artificial limbs, even if we exclude the many individual limb-makers catalogues. Simply considering books and manuals, principally in English, on the subjects of amputation and artificial limbs since 1918 reveals significant numbers are devoted exclusively to artificial limbs, limb-fitting and amputee rehabilitation, whilst many others combine these topics with operative surgical techniques, often illuminated by contributing authors from many specialities; very few address amputation surgery in isolation.[4]

During the latter half of the 19th century and especially the 20th century, expertise in artificial limb design, fitting and manufacture has advanced considerably to achieve ever more effective functional and aesthetic prostheses, whereas amputation techniques have changed little except to be performed more circumspectly in response to the assistance of anaesthesia and the safety of operative sterilisation techniques. Significant prosthetic advances were stimulated by the vast numbers of amputees resulting from the two World Wars, and any changes in surgical techniques were small, often initiated by observations of limb-fitters and -makers, limb-fitting surgeons and the complaints of individual patients.

Review of early developments in this field must be imperfect for, as Little's quotation above indicates, artificial substitutes for limbs have a long and unrecorded history and only at the Renaissance does more precise information emerge. As we approach the present, there is an acceleration of discoveries determined by considered responses to stump problems, to the suggestions of amputees themselves, improved manufacturing methods, the discovery of new materials, the participation of bioengineers and, almost at the last hurdle, the casual yet eventual willing participation of operating surgeons. Today, it is accepted that an amputee's problems are reviewed by a team of closely cooperative professionals to achieve the best solution for each victim's disability. In the past 50 years, prosthetic technological changes have been significant and frequent, creating a science-based and expanding speciality.

Early History to the End of the 18th Century

Reported and Illustrated Prostheses

We have already commented on the apparent escape of Hegesistratus from imprisonment in the 5th century B.C. (see Chapter 4), who in the process lost or removed his chained and perhaps gangrenous foot which he replaced with a wooden substitute of unknown construction.[1] If limb substitutes were introduced for prehistoric amputees, it seems probable most efforts were concentrated on crippling lower limb loss, as unilateral upper limb amputations were generally accommodated by opposite upper limb function. Single-handed survival proved easier than single-footed survival, especially for hunter-gatherer and cave-dwelling communities whose lower limb mobility was essential in a harshly competitive environment. However, the Roman General Marcus Sergius, who lost his right hand during the Second Punic War (218–201 B.C.), had an iron hand constructed which, it is said, he wielded with great dexterity in battle.[5] This device was an expensive rarity and even lower limb substitutes would have been uncommon at this time, for foot and leg amputees usually adjusted to the assistance of sticks or primitive crutches. In Epstein's survey of the history of the crutch, he noted examples in ancient Egyptian carvings and paintings and on Greek vases, but little else until the Middle Ages when peg-legs are pictured by artists such as Bruegel and Calot, and Bosch, whose studies of the 15th century also demonstrate crutches (see Fig. 2.4).[6] Padula and Friedmann believed punitive amputations of the Moche culture, c. 600–300 B.C. in Peru, depicted by archaeological finds of ceramic bottles, exhibit cup-shaped prostheses used for walking (fig. 4.5).[7] In the case of ankle disarticulation it is conceivable that weight-bearing took place, but probably these cups were to protect stump scars, almost certainly fragile after punitive guillotine section. Commenting on the early dearth of prosthetic information, Garrison wrote:

"A striking illustration of the medieval neglect of surgery is to be found in the late appearance of artificial limbs. . . ."[8]

In the later 19th century, when prostheses were more sophisticated, General Sickles, wounded and amputated at the Battle of Gettysburg, preferred crutches to an artificial leg (see Fig. 9.6).[9] Indeed crutches were often preferred as the only solution when a stump was painful, discharging or ill adapted for the prostheses available, particularly before revision surgery of stumps was secure against infection and further failure.

Woodall reported, in 1639, that he had received accounts of amputees in the East Indies who used bamboo prostheses cushioning the stump with straw, or perhaps to cushion the bent knee resting on a bamboo peg-leg, for kneeling skin was adapted for weight bearing.[10] At some stage wooden peg-legs became standard for below-knee amputations, provided soft tissues over the kneeling area of the upper tibia were preserved, as was often the case (see Fig. 2.4). Earlier, Paré illustrated simple peg-legs for "poor men" but also a more-complex prosthesis incorporating an adjustable thigh socket, mobile knee and ankle joints which could be locked, the whole being armour plated, presumably for a knight on horseback (Fig. 13.1).

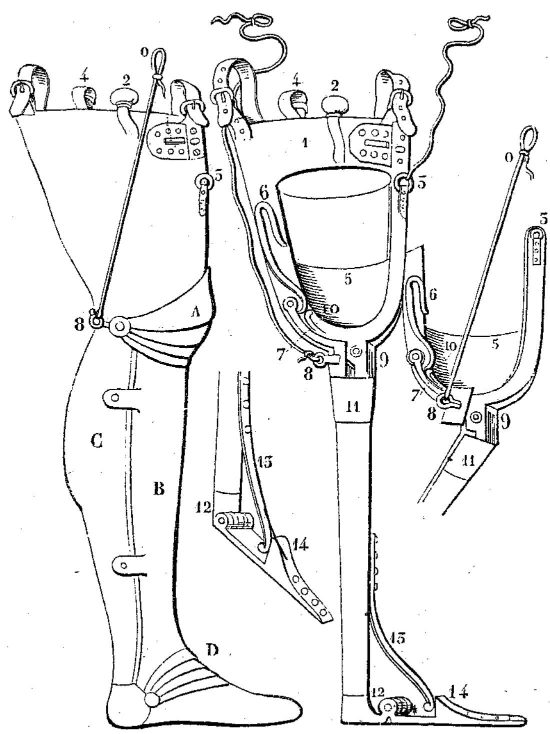

FIG. 13.1. Paré's sophisticated above-knee prosthesis of iron and steel, armoured for a knight on horseback and, probably, too heavy for weight-bearing locomotion, especially with the knee locked in extension. (From Paré A, *Les Oeuvres*, Paris: Buon, 1575.[51])

He also illustrated metal artificial hands with moveable joints which were manipulated by actions of the good hand and, as Little suggested, probably efficient enough to hold a horse's bridle and, as with armoured leg prostheses, to disguise the knight's fallibility under battle conditions and persuade the enemy of normality.[11] Generally, elaborate prostheses at this time were limited to amputees with significant financial resources to pay an expert armourer for suitable steel, whereas the peg-leg could be made up by a wood-turner or carpenter or even by patients at relatively little cost.

During the Civil War in Britain, the Hospital of the Savoy in London treated amputee soldiers whose prosthetic requirements survive in credit bills submitted by William Bradley, hospital carpenter, indicating he supplied wooden legs and their attachments, made repairs, and provided crutches of various lengths. On May 15, 1654, he charged £2 9s. for supplying a pair of legs with straps and buckles for Thomas Swaine, adjusting the wooden legs of seven residents and supplying two pins for a wooden leg. On June 21, 1654, he charged 10s. for a wooden leg with materials for Thomas Harrison and the same for Joe Wilson, plus various pins and an iron swivel for four other men, totalling £1 7s. 1d. Gruber von Arni, who extracted these details, also wrote:

"The prosthetic limb supplied on the 3rd August 1657 to George Matheson who had suffered an above knee amputation was described as 'a new artificial leg' with a leather box, plated all over with iron, complete with swivels and pins and cost £3 3s 11d. On 12th February, 1654, a soldier named Fisher was provided with a wooden hand costing 5s." (From Bills in the National Archives at Kew.)[12]

The mention of swivels and pins suggests more-sophisticated prostheses than a simple peg-leg with kneeling platform, and it is noteworthy one above-knee amputee was given an artificial leg with attachments incorporating a mobile knee joint. Unfortunately, no actual prosthesis, diagram or painting of this period has come to the author's attention.

Earlier we noted sailors with a peg-leg were reemployed as ships' cooks, as in the case of a sailor whose foot was crushed by a gun-truck, described by Moyle in 1674[13] (see frontispiece).

Surviving Historical Prostheses

An Egyptian mummy buried in 1550–700 B.C. was found with a wooden toe substitute for an absent or amputated great toe, probably a ceremonial addition after death, for even today a working prosthesis at this level is unnecessary provided the victim retains functioning lesser toes and wears a firm-soled shoe, although the power of running would be impaired. Another mummy, of the Ptolemaic period, had been fitted with a symbolic artificial arm after a forearm amputation, said to ensure the victim was given a new limb in the afterlife.[14] One of the earliest major artificial limbs to survive, dated by adjacent pottery finds to about 300 B.C., was destroyed by fire-bombing of the Museum of the Royal College of Surgeons, London, in 1942 (Fig. 13.2). This lower limb artefact, discovered in a cave near Capua, Italy, was associated with a skeleton lacking bone consistent

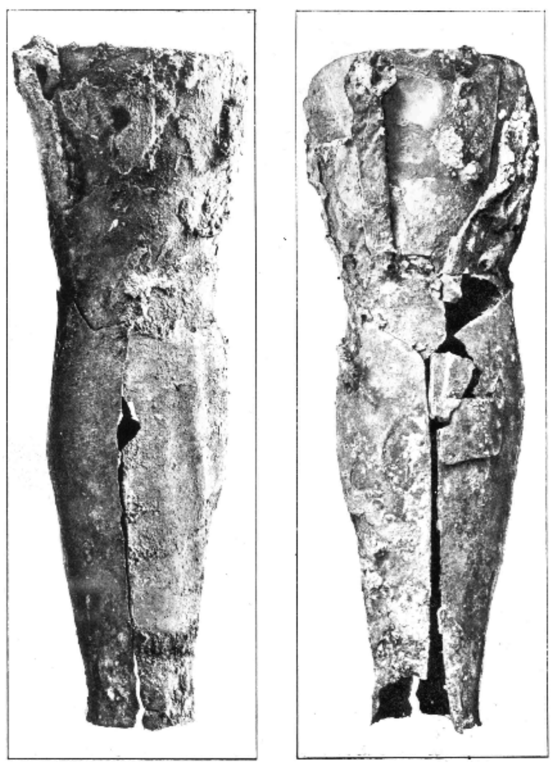

Fig. 13.2. Imperfect Roman bronze and wooden prosthesis for an amputation near the right knee, c. 300 **B.C.**, found with a skeleton near Capua, Italy, but destroyed by fire bombing in London in 1942. The skeleton bore a waist band of sheet bronze edged with small rivets, possibly to support the prosthesis.[15] (With permission of the Royal College of Surgeons, London.)

Fig. 13.3. Iron and steel prostheses of the 15th to 16th centuries. The hand has an immobile thumb, which could be opposed to the mobile fingers by applying the sound hand, and was probably designed to hold the reins whilst horse-riding but otherwise had limited function; the leg is fenestrated for lightness but has a short thigh section with a fixed knee in 30l′ of flexion, emphasising its use on horseback and total unsuitability for walking.[16] (With permission of Stibbert Museum, Florence, Italy.)

with the length of the bronze and wooden prosthesis, suggesting an amputation through or near the knee.[15]

In 1930, Putti reviewed surviving historic artificial limbs of the 15th and 16th centuries, made of iron or steel, deposited in the Stibbert Collection, Florence, and observed three artificial hands, two artificial arms and two artificial legs (Fig. 13.3). Of the two lower limb prostheses, neither was for walking, one being adapted for horseback exclusively, with the knee piece permanently flexed, and the other constructed to hide a deformity. Each hand had fixed thumb pieces with mobile fingers, all flexing on the same axis, to lock in opposition when grasping objects.[16] Thomas and Haddan agreed with Little's conclusion that armoured military horsemen replaced limbs to conceal their disability when facing an enemy.[17] Nevertheless, some warriors desired functional limbs to assist aggressive actions, and sophisticated examples were produced at the Renaissance by skilled metal craftsmen, especially in Germany and Italy. An outstanding example of this craftsmanship is seen in the surviving prosthetic hand of Goetz von Berlichingen, dated 1509, with articulating and locking fingers, capable of grasping a sword which, it is claimed, enabled von Berlichingen to achieve a harder sword-stroke than with its natural predecessor (Fig. 13.4).[1] Another artificial arm found in a tomb of an Alsatian who died in 1564 had movable wrist and elbow joints, as well as fingers adjusted and set by use of the good hand.[18] In the Science Museum, London, five artificial limbs are believed to originate from the 16th to 18th centuries; four are forearms with

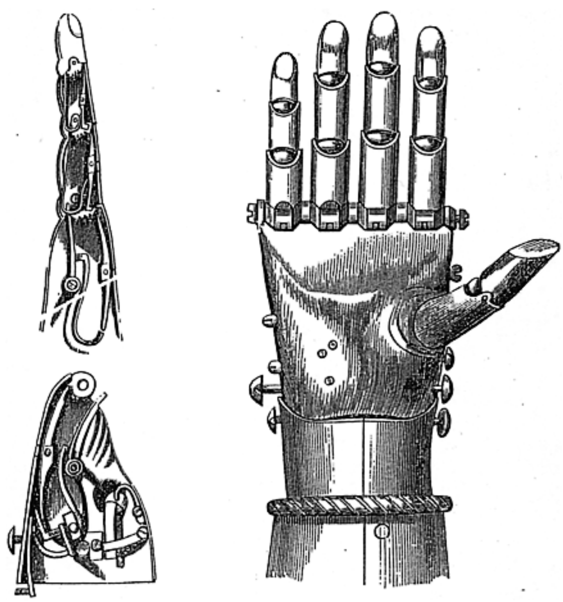

Fig. 13.4. Prosthetic hand of Goetz von Berlichingen, c. 1509, with moveable thumb and fingers, controlled by the sound hand, said to have been used to grasp and wield a sword in battle. (From Watson AB. *A Treatise on Amputations of the Extremities and Their Complications.* Philadelphia: Blakiston, 1885: figs. 140–142.[4])

hands and the fifth is an arm with forearm and hand. All are made of iron or steel, and there are no lower limb prostheses.[19]

Observations in several museums demonstrate that surviving prostheses made before the 19th century are fabricated in ferrous metal mostly for the upper limb. Paradoxically, lower limb amputations are far more numerous than upper limb amputations, both in the past as now, and thus more artificial legs were manufactured. However, artificial legs were made of wood and leather for lightness to facilitate movement, and also for cheapness, metal being too heavy and too expensive except for knights on horseback. Hence, metal limbs are preserved whereas, it is assumed, organic materials have decayed to destruction, leaving a gap in museum artefacts. In the later 18th century, some wooden prostheses made a "clapping" sound as the ankle stops struck against each other during weight-bearing and were known as "clapper legs."

Developments in the 19th Century

The Napoleonic wars resulted in a flood of amputees, proving a stimulus to more sophisticated and functional prostheses, at least for the wealthy. Thus, the Earl of Uxbridge, later Marquess of Anglesey, whose right leg was amputated above the knee at the Battle of Waterloo (see Fig. 5.4), was in a position to criticise his initial "clapper leg" and to commission an improvement from Potts, a leading London limb-maker, at his own expense. The resultant prosthesis evolved with knee and ankle movements coordinated, employing interconnecting catgut tendons, so that knee flexion produced synchronous ankle dorsiflexion (Fig. 13.5). In addition, its manufacture in

A

B

Fig. 13.5. a. Marquess of Anglesey's leg made by Potts of London, c. 1820. This light limb in wood also coordinated ankle and knee movements, proving a successful solution for above-knee amputees over many years. This prosthesis is exhibited in Plas Newedd, Anglesey. (© National Trust.) **b.** Anglesey's leg to show internal construction including cords to connect joint movements. (From Little EM. *Artificial Limbs and Amputation Stumps: A Practical Handbook*. London: Lewis, 1922: fig. 185.[1])

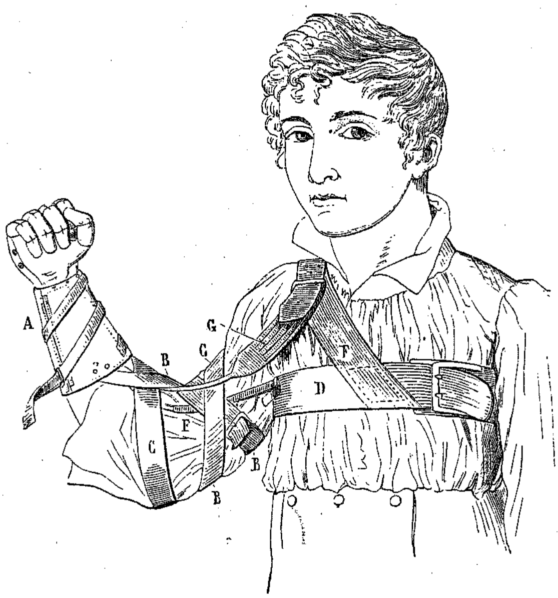

FIG. 13.6. Bailiff's prosthesis for forearm amputation, the first to utilise the trunk muscles to open an artificial hand otherwise kept closed by springs, 1818. (From Watson AB. *A Treatise on Amputations of the Extremities and Their Complications.* Philadelphia: Blakiston, 1885: fig. 159.[4])

hollowed-out wood created a light prosthesis, much appreciated by wearers, leading to its adoption as a standard leg in the United Kingdom and America for many years.[20]

An important advance introduced at this time by Bailiff, a Berlin dental surgeon, involved harnessing the muscle power of the trunk and shoulder girdle to motivate finger flexion and extension of forearm prostheses, a mechanism which has persisted to the end of the 20th century (Fig. 13.6). The same mechanism was applied to above-elbow prostheses by Von Peterssen, a Dutch sculptor, in 1844, who extended catgut cords from behind the sound shoulder into the artificial upper arm segment, to the elbow and finally into the forearm segment. Other cords extended the fingers by elbow extension and shoulder abduction whilst the fingers were automatically flexed by springs.[21] Similar arm prostheses were improved in 1867 by the Comte de Beaufort, who made particular efforts to ensure these were supplied to the poor, although he warned that limitations of function at the expense of power were inevitable, stating:

"Certain combinations may be made in order to vary the workings of the fingers, so as to produce diverse movements of the wrist and forearm in imitation of nature; but to overcome these difficulties it is necessary to use artifices which weakens the means of action and necessitates great expenditure of force. The marvellous, moreover, can only be obtained at the price of certain sacrifices."[22]

Others tried to manufacture hands with normal function but, for most manual trades and crafts, simple working arms with devices such as hooks were significantly more practical for power activities, especially for lifting. Bigg displayed several of these for soldiers after the Crimean War (Fig. 13.7); provision of working hands was usually accompanied by a nonfunctioning dress hand for social occasions. However, until the 20th century the function of many artificial hands and arms depended on the normal limb and especially the power of the good hand to change hooks and other tools.

In 1846, Palmer of Philadelphia's leg was claimed a great improvement over the Anglesey leg, having a spring in the foot to impart lifelike firmness to the step. It was awarded first prize at the International Exhibition of 1851 in London.[23] This design was followed by the Bly's anatomical leg, patented in 1858, which incorporated an ivory ball in a vulcanised rubber socket to provide

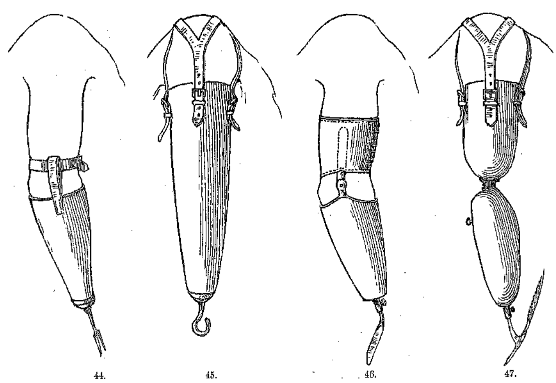

FIG. 13.7. British Army regulation devices for forearm and arm amputees, established after the Crimean War: *44.*, fork; *45.*, hook; *46.*, knife; *47.*, quill pen. These components were changed and attached by the sound hand. (From Bigg H, *Artificial Limbs and Amputations*, 1885.[30])

polycentric ankle motion (Fig. 13.8), an advance which Bly claimed to be:

"*. . . the most complete and successful invention ever attained in artificial limbs.*" Yet he hinted at limitations, adding: "*Though the perfection of my anatomical leg is truly wonderful, I do not want every awkward, big-fatted or gamble-shanked person who always strided or shuffled along in a slouching manner with both his natural legs, to think that one of these must necessarily transform him or his movements into specimens of symmetry, neatness and beauty as if by magic—as Cinderella's frogs were turned into sprightly coachmen.*"[24]

In addition, Bly introduced a mechanism representing the cruciate ligaments to give the knee natural action and diminishing shock to the stump when weight-bearing. A cheaper and simpler device, introduced by de Beaufort, eliminated true ankle motion, substituting a short rocker made of wood and cork for both below- and above-knee amputees; his knee joint was only flexed when sitting[25] (Fig. 13.9). The concept of a suction socket for above-knee prostheses was developed by Parmalee in 1863, to which he added a polycentric knee and a multiarticulated foot.[26] Despite these advances, many leg prostheses remained basic and virtually unchanged for centuries, especially for amputee soldiers supplied from official British Government sources as late as 1885 (Fig. 13.10). Offered from stock without individual measurements in the pursuit of economy and durability, they were not approved by Bigg, although he admitted the results were "*generally pretty fairly good.*"[27] Even in 1914, kneeling prostheses were still commonplace although, in France at least, more sophisticated with a choice of fixed or mobile knees during weight-bearing (Fig. 13.11).

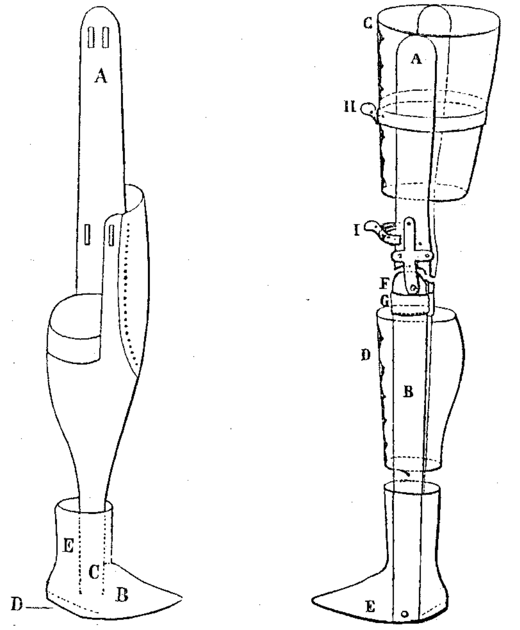

FIG. 13.9. Cheap Beaufort legs made of wood, cork and leather, with short rocker feet without ankle joints: *left*, a kneeling prosthesis for below-knee amputees; *right*, a prosthesis for above-knee amputees, the knee only flexing on sitting, c. 1867. (From Little EM. *Artificial Limbs and Amputation Stumps: A Practical Handbook.* London: Lewis, 1922: figs. 14, 15.[1])

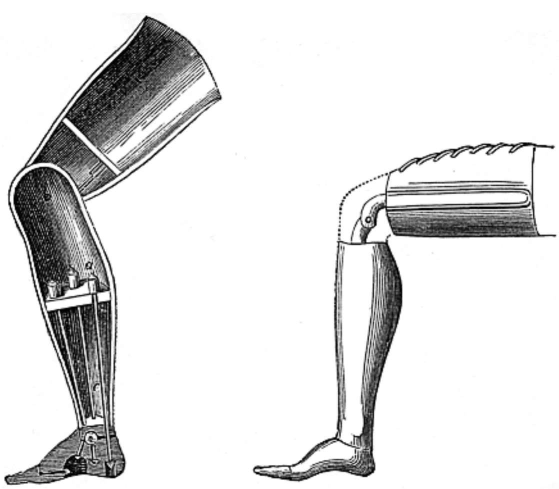

FIG. 13.8. Section of Bly's above-knee leg of 1858 with improved ankle control centred on a glass or ivory ball, resting in a rubber bed, controlled by cords; *right*, the Bly below-knee leg. (From Watson AB. *A Treatise on Amputations of the Extremities and Their Complications.* Philadelphia: Blakiston, 1885: figs. 205, 206.[4])

The numerous amputees resulting from the American Civil War had stimulated the activity of highly competitive limb-makers in the United States, including D.W. Kolbe of Philadelphia (founded c. 1849), A.A. Marks of New York (c. 1853), J.E. Hanger of Philadelphia (c. 1861), B.W. Jewett of Washington (c. 1865) and R. Clement of Philadelphia (c. 1868). Increasingly intensive competition resulted in dominance by Marks and Hanger; Marks introduced a resilient rubber foot which eliminated Bly's complicated ankle joint

Fig. 13.10. Royal Hospital pensioner, Chelsea, with regulation box kneeling peg for a left below-knee amputation and a regulation boot for a right Syme's amputation, c. 1885. (From Bigg H, *Artificial Limbs and Amputations*, 1885, fig. 41.[30])

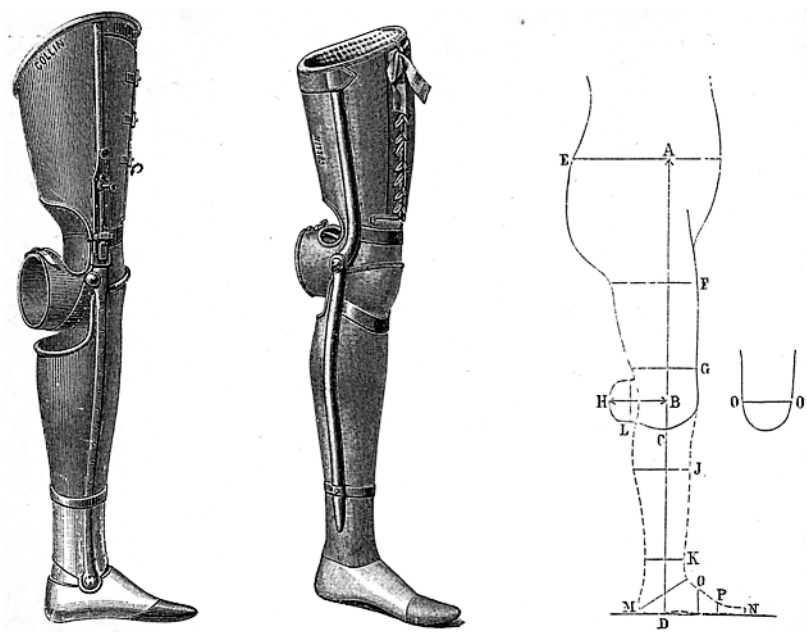

Fig. 13.11. Sophisticated kneeling prostheses, c. 1914: *left*, knee fixed when walking; *centre*, knee free to move when walking, both flexed on sitting; to *right*, diagram of measurements for fitting. (From Collin's *Catalogue d'Instruments*, Paris: Chez Collin, 1914, figs. 2090–2092.[52])

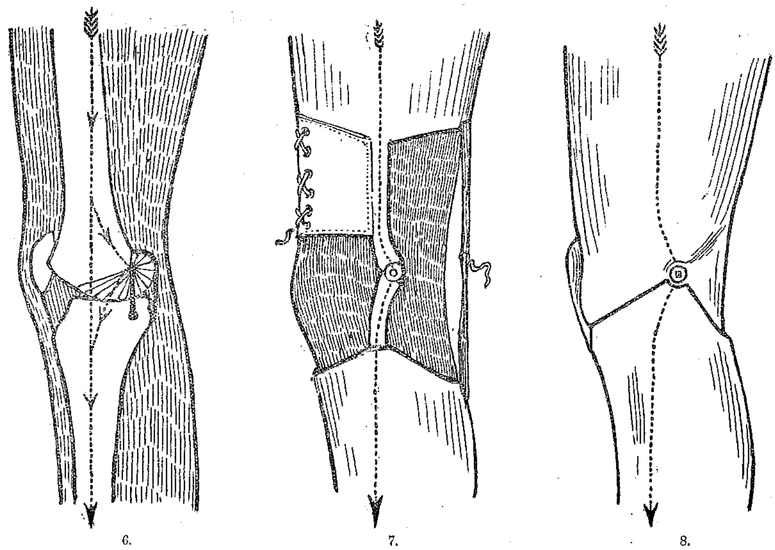

Fig. 13.12. Bigg's explanation of knee locking mechanism: *6.*, anatomical section showing axis posterior to weight-bearing line; *7.*, prosthetic arrangement for below-knee amputee; *8.*, for above-knee amputee. (From Bigg H, *Artificial Limbs and Amputations*, London: author, 1885, figs. 6–8.[20])

and Hanger introduced and popularised wooden sockets for stumps.[28] Thomas and Haddan commented:

"A review of all the available literature describing prostheses made during the latter half of the nineteenth century indicates that many of the limb-makers wore artificial limbs themselves, and while many of them actually thought they had achieved the maximum improvement in artificial limbs, newcomers were constantly announcing something better. Admittedly, many of the claims for their products were ridiculously extravagant; nevertheless a great development in artificial limbs in the United States was made during this period."[29]

However, it was Bigg in London who pointed out the significance of alignment, in 1885, especially in placing the axis of knee joint prostheses posterior to the knee centre to approximate to normal knee movement (Fig. 13.12).[30]

Developments in the 20th Century

Most sockets were made of block leather tightened by lacing or carved in wood until Marcel Desoutter, an above-knee amputee as a result of an aeroplane accident, was stimulated to manufacture, in cooperation with his brother Charles, an aeronautical engineer, a lighter prosthesis of sheet aluminium in 1912, the first successful light metal prosthesis (Fig. 13.13).[31] This design was followed by the Hanger aluminium limb for above-knee prostheses, leading to their almost universal adoption in Britain by the mid-20th century. For above-knee amputees, Desoutter introduced limb suspension with a freely mobile pelvic joint superior to previous suspension from the shoulder. Hanger's similar pelvic suspension depended on active movement of the stump to introduce more-positive control than was possible by shoulder suspension alone. Pelvic suspension also led to modern knee control mechanisms including the knee brake which improved efficiency and grace in walking for above-knee amputees.

World War I proved a turning point in the provision of improved artificial limbs, free of charge, for the vast numbers of young military amputees hoping to return to employment despite mutilating war injuries. Before this war, Little concluded that amputations were comparatively rare operations in Britain, quoting figures at one London hospital in 1913, where of 5483 major operations performed only 34 were amputations. By contrast, as a result of World War I, official British statistics recorded 41,300 surviving military amputees of which 72.5% involved the lower extremity.[32] Of these, 24,000 attended Queen Mary's Hospital, Roehampton, which became a national centre for prosthetic provision and continues in the 21st century; smaller centres were established elsewhere in Britain. This vast volume of work finally drew together limb-fitters who cooperated with each other and, more importantly, compelled surgeons to consider the opinions and expertise of limb-fitters and limb-makers to the benefit of patients' interests rather than their own narrow focus on surgical detail. Similar cooperation was achieved in the United States where Thomas and Haddan stated that before World War I:

". . . the limbmakers in this country, as in all others, were an unorganised group of rugged individuals, each going his own way, rarely speaking to his competitor, and much less consulting with him. There was little or no cooperation between the limbmakers and surgeons . . ."[33]

In October 1917, the Surgeon-General of the U.S. Army issued an invitation to all limb-makers to meet in Washington and discuss the problems of supplying prostheses to war veterans. Thomas and Haddan believed this meeting contributed more to the development of prosthetic science than any preceding event, laying foundation to the Association of Limb Manufacturers of America, with increased cooperation and research between limb-makers, brace-makers and surgeons to the mutual benefit of amputees. This collaboration strengthened in World War II when, in 1944, the National Research Council of Canada hosted an international conference on amputation and artificial limbs, attended by representatives of many allied nations, with far-reaching scientific results as well as stimulating agencies to provide prostheses for those unable to purchase them.[33] In the United Kingdom, the formation of the National Health Service in 1946 also ensured a completely free service of prosthetic provision and of any revision surgery. In 1953, Gillis calculated that of Britain's 35,343 amputees due to war injuries, 23,740 (67%) were from World War I or before and 11,945 (33%) from World War II, including civilians.[34] He commented:

"The making of artificial limbs has a long history, most of it, unfortunately, very scantily recorded . . . there is no doubt that the improvement in limb-fitting and limb-making which has been the feature of the last 50 years has been due to the close integration of surgical and mechanical skill. This is not to say there is room for complacency. There is still much to be learned and much to be done."[35]

Vitali et al. observed that since World War II a scientific and technological explosion had taken place, leading to major changes in prosthetic design throughout the world, owing much to the introduction of plastics enabling accurate reproduction of sockets made from these light materials. They added:

"The Committee on Prostheses, Braces and Technical Aids of the International Society for the Welfare of Cripples (later to become the International Society of Prosthetics and Orthotics), together with the International Association of Orthotists and Prosthetists, have promoted the speedy exchange of information internationally. As a result surgeons and therapists are better informed and the modern prosthetist is not just craft-trained at the bench but technically trained, using techniques and devices from many countries."[36]

They also noted that until about 1960 most artificial limbs were exoskeletal, that is, hollowed to receive the stump with an external body shape which also bore weight in the case of the leg or the forces of arm movement, fundamentally little changed for centuries. Since 1960, most limbs have become endoskeletal with a central post for weight-bearing or arm actions, combined with a cosmetic cover of light material such as plastic, carbon fibre and composite materials (Figs. 13.14 and 13.15) and, in some instances, the use of pneumatic (gas) and electric control devices. At the same time, stimulated by these evolving prosthetic advances, amputation procedures have been revised or old procedures have been reintroduced. Thus, ankle and knee joint disarticulations, previously disapproved by prosthetists for difficulty in fitting, are now endorsed thanks to the use of lateral skin flaps, modern prosthetic materials and a four-bar linkage knee joint. For above-knee amputation, the long posterior skin flap of Verduin, first introduced in 1695 (see Chapter 6), is now back in favour, as is the reattachment of muscles over the bone end to improve the stump's power and also its vascularity.

Since the 1960s, the advantage of patellar tendon-bearing sockets for below-knee amputations has resulted in the abandonment of thigh corsets and, after hip disarticulation the introduc-

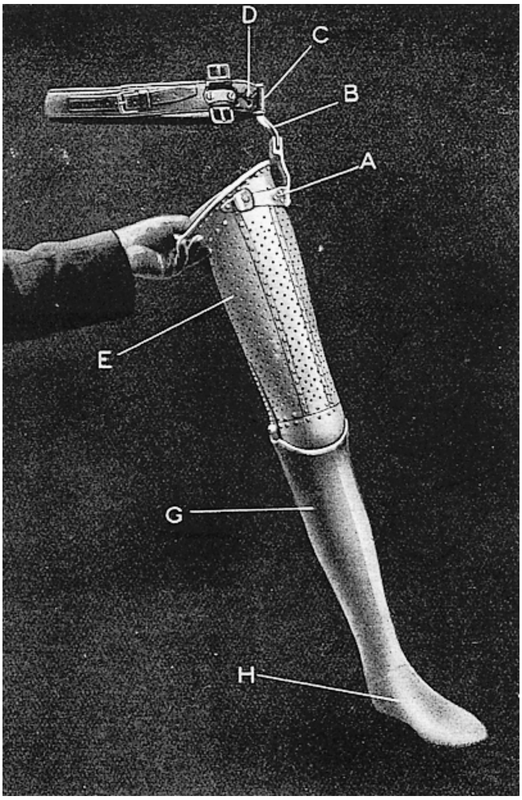

Fig. 13.13. Desoutter light aluminium prosthesis for short thigh stumps with pelvic supporting band and, originally, a fixed ankle but later given some movement with rubber buffers, c. 1912. (From Little EM. *Artificial Limbs and Amputation Stumps: A Practical Handbook.* London: Lewis, 1922: fig. 217.[1])

tion of weight-bearing on the ischium, with a socket embracing the whole pelvis, has removed the need for massive body harnesses. With respect to artificial arms, Vitalli et al., in 1986, considered recent improvements were minor although socket fitting had improved with electric and myoelectric controls which, nevertheless, were still in their infancy whilst further work, to improve sensory feedback as well as mechanics, was much needed.[37] They concluded:

"Amputation, in which speed and skill used to be a matter of pride, had come to be regarded by many surgeons as a sign of failure and a last resort to be avoided if possible. Now most amputations are by surgeons who use amputations as the treatment of choice when it is indicated, representing a major change of attitude towards the procedure." And: *"The science and art of amputation and prosthetics have changed and are continuing to change. There is reason to believe that the future will see further advances leading to changes in amputation surgery, socket configuration and controls."*[38]

A decade later, Murdoch and Wilson claimed their book *Amputation: Surgical Practice and Patient Management* was firmly focussed on the operating surgeon, yet it also illuminated the latest research and expectations of artificial limbs. Drawing together the experience of some 35 authors of many disciplines, from Europe, the United States and Canada, they insisted no surgeon should amputate without a full understanding of the biomechanical and prosthetic factors consequent to his surgery.[39] In a brief historical introduction, emphasising the important stimulus of World War II and its war veterans in the United States, they praised the work of the Committee on Prosthetics Research and Development of the National Academy of Science who had formed teams of orthopaedic surgeons, engineers and prosthetists in various parts of the country and in Canada, assigning each with specific tasks to improve the life quality of amputees. The Committee urged:

"Surgical techniques were considered as much a part of the programme as development of devices because it was soon realised that the function of the prosthesis could be no better than the function provided by the stump."[40]

In 1963, Weiss of Poland described methods of measuring the effects of myoplastic surgery for revised stumps and, incidentally, drew attention to walking mobilisation of patients the day after surgery, using rigid dressings and temporary pylons. As a consequence, myoplasty and osteoplasty were given greater worldwide significance in managing peripheral vascular problems, enabling both the knee to be saved more frequently and early mobilisation encouraged, all of which resulted in a complete reversal of the former ratio of three above-knee amputations for one below-knee amputation in the United States by the early 1970s. At the same time, encouraged by the work of Brand with leprosy patients, foot infections were treated more conservatively, preserving all practical length, applying rigid dressings and prescribing special shoes.[41] Further progress related to Syme's

Fig 13.14. Sprinting amputee on Otto Bock design leg, after knee disarticulation. (Copyright of Dorset Orthopaedic Co. Ltd.)

ankle disarticulation which had fallen out of favour in many countries, but not in the United States, Canada or Scotland, largely because of ungainly prostheses for stumps considered too long for an ankle joint, despite their capacity to weight-bear. By employing new plastic laminates, prostheses developed in the United States and Canada became lighter, stronger and greatly improved in appearance, with the result that Syme's amputation has become more widely undertaken. Knee disarticulation has followed a similar course, being revived by replicating knee movements with the innovative Orthopaedic Hospital, Copenhagen (OHC) prosthesis which places the centre of knee rotation into the shank of the prosthetic limb, hence eliminating the former bulky "outside" knee joint. As a result, both knee disarticulation and low femoral amputations are more acceptable and, moreover, the longer stump provides stronger and more efficient movement control than the shorter conventional mid-femoral section.[41]

Despite evident progress in the 1980s, The International Society for Prosthetics and Orthotics complained many improved techniques were still woefully lacking in even sophisticated surgical circles, as Murdoch and Wilson explained in 1996:

". . . most of the amputations are done by surgeons as a life-saving measure, who see only a few patients a year, have little contact with prosthetists and do not realize the importance of the stump as an organ of locomotion and its relation to the ability of the amputee to obtain maximum use of the prosthesis."[41]

Despite these comments, supraspecialisation continues to flourish, and it is likely more amputations in the future will be conducted by surgeons trained in the biomechanics of prosthetic design. Further, academic research by biomedical engineers employing gait analysis, load measurements and computer-aided design have contributed new concepts and more-efficient prostheses, whilst amputees themselves are more informed and capable of pressing for personal solutions to particular problems. Growing involvement of the disabled in sports activities and particularly the stimulus of the Para-Olympic Games have created active, competitive amputees who participate in athletic events, seeking the most efficient prosthesis available for successful competition. Today, microprocessors in the Otto Bock 'C' Leg can monitor and control artificial knee movements 50 times a second, enabling the stability and swing action to adapt in response to weight-bearing activity (Fig. 13.15). Amputee sprinters have achieved remarkable times with such prostheses specifically adapted for running (Fig. 13.14) but need another prosthesis for normal walking activity and yet another adaptation for cycling. With respect to hand prostheses, sensory feedback has always proved elusive but ongoing research, in various centres, expresses hope of achieving a robotic hand with sensors stimulating nerves in the stump to elicit sensory motor control of the prosthesis.

FIG. 13.15. Otto Bock leg mechanism. (Copyright Otto Bock UK.)

Developments in the 21 Century

Prosthetic advances continue in various fields with energy-storing spring feet, multiaxial ankles, silicon sleeves with ratchet peg attachments, improved suction sockets, knee mechanisms controlled by computer, gas or hydraulic power, and electric battery-powered hands, wrists and elbows. In particular, the concept of attaching prostheses directly to the bone of the stump is receiving significant attention, especially for transfemoral and upper limb amputees, and ultimately perhaps for application after hip disarticulation and hemipelvectomy. Until 1959 when

FIG. 13.16. Osseointegration 5 years after installation of the left femur implant and connecting abutment; the prosthesis is an Otto Bock 3R 80 and the drum-shaped component is the Integrum Rotasafe, a fail-safe device to prevent accidental trauma; the key operates the attachment clamp. (Courtesy of Kingsley Robinson.)

Fig. 13.17. Reimplantation of a severed hand 1 year after operation. (Courtesy of Kingsley Robinson.)

Branemark confirmed a secure bond between commercially pure titanium and living bone of the jaw,[42] all attempts to attach prostheses had failed because of infection. Consequent to the success of titanium-anchored dental prostheses, a system to place implants in stump bone was tested. After initial titanium peg insertions, a period of 6 months healing was allowed before the stump scar was penetrated by a connecting implant to which a prosthesis was bolted.[43] This system, termed osseointegration, proved satisfactory and although infections were encountered, most responded to antibiotics. More than 70 amputees have been treated in Sweden, 15 in Roehampton, London (Fig. 13.16) and 2 in Melbourne.

The improvement in the quality of life of successful osseointegration volunteers is dramatic. Arm amputees develop accurate myoelectric control and leg amputees, mostly transfemoral, no longer have ischial pressure or sores and abscesses in the groin, previously necessitating periods on crutches or in a wheelchair. Osseointegration has great potential and could become the technique of choice at primary amputation. However, the junction between titanium and the skin remains a potential site of infection, and its control depends on effective antibiotics.[44] (See Addendum)

What is the future? Whilst the transplantation of hands has been performed successfully (Fig. 13.17), the long period necessary for extensive nerve regeneration has limited the outcome of lower limb implantation and transplantation. Will the miracle of St. Cosmos and St. Damien (see Fig. 12.2) actually be achieved, perhaps? Meanwhile, skeletally attached prostheses will prove acceptable to amputees who cannot tolerate sockets.

Rehabilitation

In the sense of a positive programme to assist patients recovering from an injury or a major operation, rehabilitation is essentially a 20th-century concept, spurred on by World War I and its vast numbers of disabled who wished to resume employment despite residual physical defects. Before the 19th century little information is available although, as we have remarked, amputee cooks were often engaged on ships, however, as far as is known, without any rehabilitation programme. In 1885, Bigg gave advice on learning to walk with an artificial leg, enumerating actions which might take some weeks to acquire perfectly, using crutches and sticks initially, one assumes under guidance of the limb-fitter. He deplored use of a peg-leg as this introduced a stumping gait which is difficult to correct when a superior artificial leg is supplied.[45] In the 19th century, many limb-makers were amputees themselves who were well placed, in the absence of any specialist, to educate new patients.

In 1922, Little also made the point that, to obtain the best results, the efforts of the patient must be supervised and intelligently guided by instructors who were similarly mutilated, as was the practice in France. Little wrote a chapter on what he termed reeducation, consisting either of physiotherapy or actual work, preferring to institute the latter at the earliest possible moment, and, best of all, work at the victim's former trade. However, his workshop training for arm loss was restricted to woodwork, digging, loading and wheeling a barrow, and using a sledgehammer, whereas for lower limb amputees training involved walking with a "rough" prosthesis, between two rails and observing their progression in a mirror under supervision of a limb-fitter. When their limb was approved, the amputee was further instructed by noncommissioned officers who had lost limbs. Little noted that 60% to 70% of French war wounded formerly worked in agriculture and that great efforts were made to return most amputees back to the land with strong peg-legs and split hooks for their upper limbs.[46] However, Broca and Ducroquet stated not all was satisfactory in France for reeducation was better arranged in Belgium and Austria where soldiers were not discharged from workshops before training was complete, although it has to be remembered the French casualty numbers were enormous. Broca and Ducroquet also emphasised that intelligence and determination were important factors in retraining, usually obligatory for upper limb loss, whereas lower limb loss enabled some standing and most sitting occupations to be evaluated.[47]

In 1945, Thomas and Haddan emphasised the emotional shock of amputation, worse for an upper than lower limb, and noted this was less for patients with chronic disease who in fact might welcome loss of a painful, gangrenous or incapacitating limb. Before operation careful explanation and encouragement were required, although a future dependant on a prosthesis needed frank discussion and, if possible, this should include consultation with a limb-maker. Early postoperative mobilisation and patient independence were essential, preferably in the company of other recovering amputees, and they recommended the U.S. Army's Reconditioning Program divided into physical, educational, occupational and recreational phases, also paying attention to the attitudes of the amputee's family and community, their surgeon and limb-maker, and to the value of voluntary and government agencies for the physically handicapped.[48] When Eisma discussed the principles and philosophy of rehabilitation for amputees in 1996, he divided them into preoperative care and postoperative management. Before surgery, the patient's locomotor system and psychological condition needed evaluation whilst free discussion of the amputation level and expectations of a prosthesis were essential. During stump healing, the locomotor system needed exercise training whilst the activities of daily living were initiated, psychological support was given and provision of a satisfactory prosthesis ensured.[49]

Restoration of function and employment are now an essential part of a programme in which the operation of amputation forms but part of the whole. Many reports confirm extraordinary recoveries of activity after limb-fitting; for example, during World War II, the RAF fighter pilot Douglas Bader resumed flying after bilateral leg amputations and then survived as a prisoner of war. More recently, many amputees have participated in the Para-Olympic Games or run a marathon whilst soldiers have returned to military duties in war zones. A newspaper headline in 2005 announced:

"Bionic US troops go back to war: Amputees returning to frontline duty can outrun the rest of the regiment on their high-tech legs."[50]

In fact, the American officer involved in this account, aged 33 years, had lost a foot and did not claim to outrun all his men. Nevertheless, positive personalities combined with modern high-quality prostheses have achieved remarkable recoveries, indebted partly, at least, to enterprising rehabilitation programmes.

Summary

Until the 16th century, concepts of artificial limbs are based on uncertain written evidence and on artistic representations. In general, arm amputees accepted a single-handed existence and leg amputees crutches or a peg-leg if their knee was intact. Museums contain more surviving iron hands than legs, all designed exclusively for amputee knights riding to combat and to hide their weakness. By contrast, functional legs in wood and leather have not survived much before the 19th century when significant improvements in construction and function materialised with articulating ankles, knees and hands motivated by shoulder girdle muscles. In the 20th century, particularly following the two World Wars, greater cooperation between prosthetists and surgeons

combined with the expertise of engineers and material scientists ensured important advances in design. Today, sophisticated new limbs, improved rehabilitation and the potential of implanting prostheses directly in bone offer prospects of near-normal function for many amputees, unimaginable half a century ago.

Addendum

During final evaluation of this book, news emerged of a possible solution to infection at the junction between osseointegrated titanium implants and cutaneous tissues. By studying how the antlers of deer grow through overlying skin, it was observed the bone structure at the skin margin was porous into which the living dermis penetrated. For some osseointegrated amputees, the introduction of a metal flange perforated with small holes and in contact with the bone extremity where the titanium implant exits has resulted in protective skin growing around the metal. This new technique of Intraosseous Transcutaneous Amputation Prosthesis (ITAP) is encouraging but remains under trial by scientists and surgeons in London.[53]

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