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Amputation revisited

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Introduction

This lecture was created to honour our founder President Knud Jansen. In New York the Knud Jansen lecture was presented by Charles Radcliffe (1977) and in Bologna by Ernst Marquardt (1980; 1981). The author is very conscious of the honour paid to him and of the distinguished company he joins.

Knud was a fine surgeon and a great teacher. Moreover, with his vast knowledge of the literature always presented his material against a historical backcloth. It is therefore, the author's intention to present the subject of amputation surgery in the same way under the following headings:

Epidemiology
Amputation levels
Pre-operative phase
Anaesthesia
Amputation procedure
Stump environment
Individual amputations
Rehabilitation and prosthetic fitting

Epidemiology

In ancient times, so far as can be seen from archaeological remains and such pictures that exist, amputation was usually the result of unspecified gangrene or trauma. It might have been accidental or from fighting, was occasionally associated with practices in magic, with ritual sacrifice or with punishment: indeed, to this day in some parts of the world the ablation of one or both hands is still used as a punishment for theft. In the Middle Ages huge numbers of amputations were performed, largely because of the invention of the cannon used first at Crecy, 1346 and the half pound gunshot at Perugia, 1364. At the same time Hansen's disease, i.e. leprosy was endemic and responsible for large numbers of amputations. The fungus ergot found in rye and therefore in rye bread caused epidemics of poisoning due to the alkaloid mix of LSD as a hallucinogen and ergotamine as a vaso-constrictor. Many died, 40,000 in the South of France in 994, many presumably died happy, but not a few survived with gangrenous limbs. When potatoes and wheat replaced rye, the epidemics diminished—the last major outbreak being in Russia in 1929 and the last minor in Pont St. Espirit in France in 1951 when four people died.

In the nineteenth century because of the urban disease of hospital sepsis, amputation became one of the most commonly performed operations.

Today the causal conditions for amputations vary considerably from one part of the world to another; surprisingly in countries such as Nigeria and Zambia the motor car is probably the commonest cause of amputation. Leprosy still features in some of parts of the world as it did in the Middle Ages and is responsible for a number of amputations.

However, in Northern Europe, the picture is quite clear, 85-86% of primary amputation resulting directly from vascular disease whether it is atherosclerosis, diabetes or a combination of both. The other causal conditions such as trauma, tumour, congenital deficiency and the rest constitute no more than 15%.

Most of the amputations performed in Europe and North America are because of vascular disease and the patients are elderly with multiple handicaps. For a variety of reasons it is only in the last few years that a large proportion of these patients have been successfully rehabilitated. One of the main reasons for this success has been the ability to ally the clinical signs to increasingly accurate methods of ancillary investigation. Holstein (1982) has shown that by employing skin perfusion pressure measurements it is possible to predict wound healing in over 90% of cases, taking a level of 30 mm Hg as the main guideline. Equally good results have been reported using Doppler ultrasound and thermography.

Where diabetes is a feature even more knee joints can be saved. Indeed, Syme's amputations and partial foot procedures become possible. A number of feet can be saved entirely from any amputating procedure by careful surgery, excision of dead tissue, opening up of infected areas and by careful application of pressure dressings.

In trauma the long established principles hold in this group, namely to conserve all viable tissue. The judgement as to whether tissue is viable or not may be difficult, but one should err on the side of conservation. Wounds should be closed when feasible. If the tissue is doubtfully viable then open flaps should be used. Stump reconstruction can be performed later if required especially in view of a long life expectancy. Philosophically the situation here is decidedly different from that of an elderly patient with vascular disease and a short expectation of life.

Osteosarcoma is perhaps a good model for considering the management of tumours. Until a few years ago amputation was commonly performed, usually between the ages of 10 to 20 years and with a 5-year survival rate of no more than 20%. The place of radiotherapy has waxed and waned and the situation has become even more complicated with a range of chemotherapeutic agents. The reports by Jaffe (1972) and Jaffe and Watt (1976) on the use of high dose methotrexate with citrovorum factor and other agents have stimulated many workers in the use of these agents and has increased hopes that there will be decided improvements in survival rates. However, an enlarged experience is required before secure judgements can be made about the situation and large scale projects such as the United Kingdom Medical Research Council trial presently in progress are to be commended. Such information as there is suggests that amputation will continue to have a principal place in the management of these malignant tumours. Equally there is evidence that chemotherapy permits amputations through the affected bone provided the amputation site is some 10cm above the most proximal area of bone reaction as seen on the bone scan. An increasing number of reports indicate, at least in the soft tissue sarcomas of the extremities, that radical local re-section and internal prosthetic replacements may obviate the need for limb amputation.

Children with congenital limb deficiencies were shunned from society in the past. Today society is more caring about these children, but the incidence is particularly rare in the experience of any one surgeon and in the author's view the management of these cases is best

undertaken by those with an accumulated experience. The distillation of these larger experiences will become easier now with the International Society for Prosthetics and Orthotics system of nomenclature and classification (Kay, 1974) reaching the stage of a draft standard for the International Standards Organisation. Two points can perhaps be made. The consensus view that congenital absence of fibula is best treated by ablation of the foot at 10 months is largely confirmed by the experience of Westin et al, (1976). As for the many other deformities discovered at birth the surgeon must take more care and seek such advices as he can before proceeding to ablation of any part of an already deformed limb.
Patients presenting with limb discrepancy, paralysis and deformity derived from a broad group of disease and disability categories provide very difficult decisions as amputation, if used, is not a life saving procedure. Very careful analysis is required and very often amputation is performed in conjunction with osteotomies, joint replacement and the like.

Amputation levels
The ancients performed their amputations below, at, or just above the level of the gangrene, wherever that may be. A huge variety of procedures are listed in the literature but the most significant contributions were made by Ambroise Pare (1564, 1951) in the sixteenth century. He was the first surgeon to choose an amputation site well above the gangrenous area and specifically at a level which he considered to be suitable for fitting with a prosthesis.
Today we should concern ourselves not only with the pathology but with the anatomy at the proposed level of section along with the management of the tissues at that particular level. Equally we should consider what protheses are available.
Finally we should not forget the very personal factors such as age, sex and occupation. For example, care is required in considering the use of knee disarticulation and Syme's procedures in the young woman because of the bulbous nature of the stumps. Proper consideration of all these factors will point the surgeon to the most appropriate procedure depending on the circumstances.

Pre-operative phase
In the preparation of the patient for amputation history reveals a variety of different approaches. About A..D. 25 Celsus (1938) suggested that "the surgeon should have an intrepid mind, devoid of all tenderness and pity and entirely deaf to the shrieks and outcries of the suffering patient".
In the fourteenth century Guy de Chaulac, for his time a very sophisticated and sensitive man, recommended that "the surgeon be well educated, skilled ready and courteous; let him be bold in most things that are safe, fearful of those that are dangerous, avoiding all evil methods and practises; let him be tender with the sick, honourable to men of his profession, wise in his predictions, chaste, sober, pitiful, merciful, not covetous or extortionate but rather let him take his wages in moderation according to his work and the wealth of his patient".
A book called the Surgions Mate (Woodall, 1617), much valued by the military surgeon, commends the following—"Let first your patient be well informed, prescribe him no certainty of life—with his own free will and request and not otherwise—let him prepare his soul by earnest prayer" and recommends also that the surgeon seek mercy and help as "it is no small presumption to dismember the image of God".
It is, of course, our duty today whenever possible to explain the nature of the proposed operation, the various events attendant to it and finally the procedure itself. We should explain the phantom phenomenon but not indulge in a discussion on phantom pain, explain when pain is likely to be felt and what will be done about it, what the rehabilitation

programme will be and something about the prosthesis. It is very often useful for a patient to talk to an amputee who has gone through the various events described.

Anaesthesia

We know from the Talmud (1938) and contemporary Arab writings that patients were given potions to induce sleep and reduce pain; Theodoric in the thirteenth century recommended the use of a sopoforic sponge employing opium and mandrake (Taylor, 1933). As ever, the lessons of the past were forgotten and we find a respected German surgeon called Heister in 1718 recommending that six assistants be used to hold and keep the patient quiet while the amputation was being performed

There can be no doubt that the use of general anaesthesia as advocated by Morton (1847) (ether), Wells (1847) (nitrous oxide) and, of course, Simpson (1847) (chloroform) in Edinburgh, revolutionized all surgery. Modern anaesthesia has even permitted advances in the ancient and humbling operation of amputation. It is our practice to use spinal anaesthesia; ensuring no pain for 1-2 hours hence less confusion, fewer problems with hypotension (unilateral), fewer chest complaints and, in diabetes, liquids and a light diet can be given much sooner.

Amputation procedure

Developments in amputation surgery have inevitably been bound up with other developments, such as anaesthesia. In its absence, speed of operation was absolutely essential as embodied in the "tour de maitre" using one sweep of the knife to cut through all the soft tissues. Liston of Edinburgh and London, mentor and later implacable enemy of James Syme, was an expert. Another charismatic figure of not so long ago, Sir Reginald Watson-Jones, when demonstrating this technique, used one of the knives from the Royal College of Surgeons and in his enthusiasm almost committed a self-amputation. At any rate he was taken limping from the lecture hall bleeding profusely and with a monstrous laceration through an elegantly tailored trouser leg of the best cloth.

Other technical innovations played their part, for example the invention of the rubber bandage by Esmarch in 1873 and, of course the development of a variety of surgical instruments.

During the Greek period from 400 B.C. amputation was carried out through gangrenous tissues and in many cases secondary removal of necrotic bone was required. Celsus (1938), in about A.D. 25 employed circular cuts through the leg down to bone. The skin was drawn proximally first, then the soft tissues retracted and divided and finally the bone cut. He made a particular point of using a rasp to smooth off rough bone margins—almost 2000 years later this fundamental element of amputation appears to have been forgotten by some surgeons. The tissues were then allowed to come down to cover the stump of the bone.

The next significant contribution was from Leonides about A.D. 200 (Taylor, 1933). He employed a simple circular incision cutting the soft parts where there were no large vessels. The muscle and skin were retracted upwards with a linen cloth and the bone severed. The remainder of the tissues including the blood vessels, were then divided with a cautery.

There followed a number of modifications through the centuries relating mainly to the treatment of bleeding or its prevention, using constricting bandaging. The most notable contribution of all came from Ambroise Paré (1564, 1951) that French military surgeon of great experience, humanity and innovation. He retracted the skin upwards using a tight haemostatic bandage above the operation site.

He then employed a circular incision of the soft parts down to bone, ensuring there was enough soft tissue to cover the bone end. He divided the bone with a saw but only after the periosteum had been stripped upwards. The vessels were secured with his crow's beak forceps and ligated. The wound edges were approximated with four loosely placed sutures. It is to be regretted that for several hundred years most of his techniques and devices, based on what was undoubtedly the largest single surgical experience in Europe, were forgotten.
The next significant advance related to the use of flaps to ensure coverage of the bone. Lowdham of Oxford employed a single flap, cutting from within out after severing the bone, and 100 years later in 1768, Ravaton employed a double flap (Taylor, 1933). In the eighteenth and early nineteenth century there was a reversion to former practices.
By this time in urban hospitals sepsis was rampant. Compound fractures of the femur proved fatal in 80% of cases; and, in those of the tibia, in 50%. Speed was of the essence and the "tour de maitre" became an absolute requirement in the practice of the great surgeons of the day.
Lister's use of antisepsis and modern aseptic techniques have paved the way for modern practice which is based on principles of tissue management.
The management of skin is basic to the success of any amputation. The higher the ratio of the base to the length of the flap the better the chance of primary wound healing. Equally important is gentle handling and the close abutment without tension at the skin edges.
There have been many different fashions in the management of muscle. The early German workers attempted to cover the bone end to produce a muscle pad. In more recent times Dederich (1967), Berlemont (1961), Weiss (1969), Burgess and Romano (1968) and others have emphasized the need to attach the muscles in some way to the end of the stump. Dederich (1967) demonstrated improved vascular supply to the stump end after myoplastic revision and Hansen-Leth and Reimann (1972) demonstrated in laboratory female rabbits a better blood supply to the stump end when muscle stabilization was used.
Management of the divided nerve has been the subject of controversy for a very long time. It is believed that the generally accepted practice now is to perform a high clean cut to ensure that the inevitable neuroma is located in such a situation that it is not in direct contact with distal scar tissue and thus neither interferes with prosthetic fitting nor produces significant symptoms.
When bone is transected, it must be sculpted to avoid high concentrations of the forces involved in walking. This is particularly applicable in below-knee amputation but may also be required in the shape of rounding off the anterior edge of a cut femur. Where feasible the medulla should be closed off by a periostea flap to retain normal intramedullary pressures.

Stump environment

The environment in which the stump is placed immediately following operation may be critical to wound healing and the survival of the stump. The problem has interested clinicians for a very long time. In the Peliponnesian war 431-404 B.C. cautery of the stump and cover was achieved by applying a small bucket of tar. Our friend Celsus (1938) used a variety of techniques including a sponge moist with vinegar which he applied to the stump. If there was much bleeding, he elevated the part and used cold and hot applications. Gersdorff in (1517) employed rabbit's fur and egg white in a pig's bladder (Taylor, 1933). Heister (1847) used a dry lint dressing again with a pig's bladder.
The essence of the problem is that the effect of surgical trauma is to produce a tissue response resulting in the clinical phenomenon of oedema and the effect is greater the more distal the wound. The responsibility of the surgeon is to ensure that this response does not affect

adversely the blood supply. If oedema is permitted to develop, interstitial pressure may rise sufficiently to depreciate an already precarious blood supply. This subject is discussed by Murdoch (1983) with a personal recommendation for the use of the rigid cast and controlled environment treatment.

Individual amputations

In amputation through the thigh, tissue management follows the principles already referred to. If we set aside the pathology and its influence then amputation should be carried out ideally 12-13 cm above the knee joint as most of the adductors have found their attachment by then and the major neurovascular bundles have arrived at their destination. The method advocated by the author (Murdoch, 1968) is division of the medial and lateral hamstrings and any adductors at the level of the severed bone and then attachment via drill holes. The medulla is closed off with a periosteal flap and the whole of the quadriceps complex is drawn over the end of the bone and sutured to the aponeurosis of the hamstrings and the adductors. This technique ensures a stump of notably smooth contours, of stable shape and volume and avoids the gross changes of shape and displacement of bone in stumps where muscle attachment has not been secured. Following above-knee amputation no circular bandage is used but instead a simple dressing with vertical strips of Elastoplast is employed.

The supracondylar and transcondylar amputations such as those described by J Callander (1935), Slocum (1949), Gritti (1857) and Stokes (1870) have all had their protagonists, usually because of a good reputation for primary wound healing. One suspects that it is achieved at the expense of losing a number of knee joints. Whatever attributes they may have, the stumps produced are not end bearing to any significant degree and there is insufficient room in the prosthesis for artificial knee mechanisms.

The knee disarticulation procedure provides a stump capable of true end bearing with good proprioception, excellent rotational stability between stump and socket and which, because of its bulbous end, ensures excellent suspension. It is a valuable procedure in childhood as it retains the epiphysis and in the elderly if a below-knee amputation cannot be performed. Syme advocated a posterior flap for this procedure but later condemned it because of poor wound healing. For many years the long anterior flap technique was employed but in the past ten or more years disarticulation employing lateral and medial flaps have become more prevalent. First advocated by Velpeau (1830) in France and Smith (1825) of the United States it is increasingly popular especially in Scandinavia under the advocacy of Kj0lbye (1970) and now Jansen and Jensen (1983). The procedure is simple and non-traumatic, few muscles are cut and haemostasis is easily obtained. It is important to ensure that when the operation is complete there is no tension at the suture line, which should be in the sagittal plane lying between the condyles. It is, therefore, very important that the medial flap is fashioned in such a way that it is capable of covering comfortably the larger medial condyle. Jansen and Jensen (1983) advise a circular incision 10 cm below the level of the knee with tailoring of the flaps at the end of the operation—a reversion to Velpeau's technique. It is important that tissues remaining are left undissected. They emphasize division of the heads of the gastrocnemius at 2 or 3cm below their attachment to ensure the survival of the superior genicular vessels. The patellar tendon is sutured to the divided cruciate ligaments, but the patella should not be dragged down too far into the intercondylar notch.

In the below-knee amputation which is being performed for conditions other than vascular deficiency, osteomyoplasty as described by Ertl (1949) is strongly recommended. For those patients with vascular deficiency the posterior flap amputation should be used. Increasing experience is likely to demonstrate the value of techniques such as the sagittal flap of Persson

(1974) and others designed individually for the patient.
The philosophy behind osteomyoplasty is to produce a bony bridge between the tibia and fibula and to secure both anterior and posterior muscle groups over the bridge. This results in a particularly tough organ of locomotion subject to little change in volume and retaining muscles which demonstrate very satisfactory phasic muscle activity. The procedure as described by Ertl (1949) requires no modification in this author's view.
The level of the posterior flap operation is to a large extent dependent on the pathology. As outlined there are now several excellent ancillary methods of assessing levels of viability available to us including Doppler ultrasound, skin perfusion pressure and thermography. In a slim patient and with a competent prosthetist it is possible by this method to make good below-knee stumps which are no longer than 4 or 5 cm although the preferred length is about 10-13 cm. The anterior flap is no more than 1 cm and the posterior flap must, of course, is long enough to cover the end of the stump. The antero-lateral group of muscles are exposed and divided giving access to the neuro-vascular bundle and the fibula. Both bones are divided either with a Gigli saw or a power saw and the fibula cut no more than 1 cm shorter than the tibia. Practice varies in relation to the posterior flap. The author advocates excision not only of the deep posterior muscles but also the whole of the soleus as well because of the large venous sinus. Other surgeons use a shelving cut running obliquely through the soleus to the end of the flap.
Syme's amputation (Murdoch, 1976), first described in a series of articles dating from 1843-1857, remains a useful procedure and produces a stump which in the child retains the distal tibial epiphysis and at all ages provides for a large measure of end bearing if required. Both incisions, dorsal and plantar, are made from the lateral malleolus to just below and behind the medial malleous. Both are carried down to bone and dissection is thereafter developed throughout with the knife against bone thus ensuring the integrity of the heel flap. The bones are divided at the dome of the ankle joint with the saw cut parallel to the ground and the heel flap must be placed precisely over the cut end of the bone and secured in position.
Over the years since Syme first described this procedure, various modifications have been recommended. Few have stood the test of time. In particular the procedure advocated by Elmslie in an attempt to improve cosmesis and requiring higher bone division is doomed to failure because of the reduced area presented by the bone and the inability to locate the heel pad. The resultant stump from the Syme amputation has one defect and that stems largely from the large medio-lateral diameter which leads to poor cosmesis. The close fitting modern Syme prosthesis does not permit the stump to be wholly end bearing and accordingly it seems entirely proper to remove the malleolar projections provided the level of amputation is not changed.
A variety of partial foot amputation procedures have been described over the years. Pirogoff s procedure retains part of the os calcis and its associated heel pad and provides excellent end bearing properties (Pirogoff, 1854). However, it requires that bony union takes place between the os calcis and the cut end of the tibia and the resultant stump is so long that a modern prosthesis cannot be fitted. Even so within certain cultures it may remain a valuable procedure.
Chopart's procedure located at mid-tarsal level has few adherents today because of the tendency of the stump to become inverted and plantar flexed even with tendon fixation (Fourcroy, 1792). The stump is very short and difficult to fit.
In Lisfranc's procedure the forefoot is disarticulated along the tarso-metatarsal line (Lisfranc, 1815). This operation has few adherents today again because of the short stump and because of its poor cosmesis.
The transmetatarsal amputation is widely used in a variety of situations, for example in

trauma and diabetes. It is essential that there should be an adequate plantar flap sufficient to cover the divided and sculptured metatarsal bones.
Amputation of all five toes remains a valid procedure. It provides a stump which requiresnot more than a special insole incorporating an arch support and toe spacer within normal footwear.

Rehabilitation and prosthetic fitting.
A prosthesis dating from 300 B.C. and apparently intended for a below-knee amputation and demonstrating a remarkable level of workmanship was on display in the Royal College of Surgeons of England; unfortunately it was lost in a fire in 1941. That was the earliest example of a prosthesis known to be in existence. Several varieties of the peg leg were used over many centuries and it is still used today. During the fifteenth, sixteenth and seventeenth centuries, prostheses were mainly made for military persons who were usually mounted, the prosthesis being intended primarily to conceal the amputation. Fare's prosthetic designs, developed with the help of his armourers, survived with little fundamental modification until the Second World War. For the most part, so far as the stump and socket interface is concerned, little change took place over the centuries. Sockets tended to be little more than conical pots. No doubt the adaptability of sweat soaked leather helped in the fit. Conical sockets, of course, demanded conical stumps and accordingly the surgery and stump management with aggressive bandaging programmes were designed to meet this situation.
The modern prosthesis at whatever level is now being designed on an increased understanding of biomechanics. The introduction of the patellar tendon bearing prosthesis for the below-knee amputee by Radcliffe and Foort (1961) has emancipated the knee joint and permitted the rehabilitation of patients not capable of rehabilitation in the past. Mazet et al, (1959) and Olejniczak (1967) indicate that as recently as 25 years ago some 90% of patients above the age of 55 had above-knee amputations performed and only some 10% were rehabilitated. The increasing accuracy and discrimination of ancillary methods of assessment, the rapid containment of oedema, the patellar tendon bearing below-knee prosthesis and aggressive rehabilitation procedures across the board have completely revolutionized amputation in the elderly.
Conclusion
My experience has taught me that most amputating surgeons need no longer be regarded as they were by Guy Patin in the seventeenth century.
"Mere booted lackeys—a races of extravagant coxcombs who wear moustaches and flourish razors".
The surgery is now more considerate and more in tune with the patient's needs. Indeed the surgeon involved in amputation surgery is perhaps more sensitive to solutions other than amputation because of his awareness of the life of the amputee.
Equally increasingly, where replantation teams have been organized and micro-surgical competence is established, the completely severed limb with little local tissue damage may be considered for replantation.
This field of scientific endeavour covers the whole range of disciplines in medicine and the physical sciences and it is now clear that the rehabilitation of the amputee does not depend only on the surgery and the prosthetic procedures but that a team approach is necessary if the amputee is to be rehabilitated to his home and work place. Historically the team approach may prove to be the most important advance of modern times.

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