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RESEARCH AND DEVELOPMENT WITHIN SURGICAL AMPUTEE MANAGEMENT

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A comprehensive view of the amputee and his medical care quickly reveals the multi-disciplinary nature of this field of medical activity, and a survey of the historical development reveals that many factors other than strictly medical ones have played equally important roles in improving the amputee's rehabilitation. Accordingly, a comprehensive review of developments would inevitably touch on many subjects outside the scope of this study, which is focused on the amputating surgeon and his concern with causal conditions, techniques and levels of amputation, and the environment of the stump.

Vascular disease

Typically the patient is elderly and subject to other handicaps (Troup et al. 1975). The disease affects the vascular tree to a varying degree and the effect of loss of nutrition to the tissues is difficult to measure. Therefore, in the past, most of these patients were given high amputations to ensure early wound healing. Mazet et al. (1959) reviewed 1356 leg amputations in patients over the age of 55 and found that in only 10 per cent of these patients had prostheses been described. It should be noted that 90 per cent of the amputations were above the knee. Olejniczak (1967) reported on a similar group of patients and noted that 73 per cent had had amputations above the knee, and just under 10 per cent had received prosthetic treatment.

One recent event has focused attention on the lot of the amputee, namely the advent of "immediate post-surgical fitting" of prostheses. The first record of this is Berlemont's (1961) report which emphasised improved wound healing, whereas Weiss (1966) of Poland underlined the maintenance of neuro-muscular patterns. Experience at that time was largely with patients outside the geriatric range, but the Seattle experience (Burgess & Romano 1968) demonstrated its possible ap-

plication on elderly patients with atherosclerosis and diabetes. The technique has been successful in several centres and condemned outright by others, the use of the immediate post-surgical applicance being blamed by the amputating surgeon for his failure to achieve healing in below the knee stumps. As workers began to analyse the problems presented, it became apparent that identification of the correct level of amputation, a careful surgical technique, the environment of the stump and the application of a total care programme are basic to successful rehabilitation.

Selection of level of amputation

Murdoch (1967), in discussing the ancillary methods of investigation, pointed out that arteriography always represents the vascular situation at a disadvantage. Burgess confirmed this view in a close analysis of those patients in his series who had arteriograms (Burgess et al. 1971, Burgess & Romano 1971), there being no consistent relationship between the severity of vascular insufficiency and the failure of the below the knee amputation to heal.

We have been fortunate in that a number of physical scientists have begun to apply their skills to the investigation of biological situations and, as a result, a number of devices and techniques have been developed which suggest that real help can be gained in assessing levels of tissue viability. There has been, for example, a good deal of interest in blood flow and attempts to develop non-invasive methods of investigation. Measurements of the volume changes in a limb, viz. plethysmography, give a good measure of total blood flow and a variety of methods are available. However, Holstein & Lassen (1943) pointed out that in severe occlusions and in situations where the blood flow is very small, volume expansion is insufficient to stretch the strain gauge, thus depreciating its usefulness in a situation where very precise determination is required.

A good deal of work has been devoted to the build-up or wash-out of radioactive tracers, and the most promising techniques appear to be concerned with the estimate of skin blood flow and skin blood pressure. Kostuik et al. (1975) employed epicutaneous application of Xenon 133, a method described by Sejrsen (1971), and showed the value of skin blood flow in determining levels of tissue viability. When flow rates above 1.5 ml/min per 100 g of tissue were recorded, the amputation generally healed. Of 29 patients subjected to amputation in a blind

study, 26 healed primarily. The two failures had flow rates of 0.56 and 0.13 ml/min per 100 g of tissue. Clearly in these two cases the amputation should have been performed at a higher level.

Perhaps measurement of the skin blood pressure will offer more significant information regarding skin nutrition. Holstein & Lassen (1974) employing a radioisotope clearance technique first described by Nilsen et al. (1967) and Dahn et al. (1967) were able to measure cutaneous perfusion blood pressure. This technique employs 4-iodo-antipyrine tagged with ^{125}I or ^{131}I mixed with an equal volume of histamine diphosphate in isotonic saline 1 per cent w/v to produce local vasodilation.

Browse (1973) made the point that it is the blood supply *after* amputation that is important and indicated a number of factors such as surgical technique, oedema, thrombosis and infection as being significant. Lassen & Holstein (1974), employing the technique mentioned above, made a further contribution to this problem. They showed that five out of five amputations with a skin blood pressure below the 22 mmHg mark failed because of ischaemic necrosis. Three out of 12 amputations with a skin blood pressure of between 20 and 40 mmHg again failed because of ischaemic necrosis, but none of 34 amputations with a skin blood pressure above 40 mmHg failed. In 11 subjects, wound healing occurred by secondary intention and it was Lassen & Holstein's impression that the delay often was related to poor skin circulation, especially where sutures had been placed. Most of these cases exhibited a skin blood pressure in the 20–40 mmHg range. If this is true, valuable information can be gained by a "pseudo-amputation", where the blood pressure cuff is inflated above systolic pressure level. Using a photoelectric technique to determine skin blood pressure, the level was shown to be above 40 mmHg in 47.6 per cent of 43 cases, whereas the pseudo-amputation technique revealed that 64.3 per cent of the same group had blood pressures above 40 mmHg. This should be seen against results of estimations of those patients amputated in the so-called "safe" group, i.e. those who had levels over 40 mmHg. Before amputation, 49.1 per cent of the patients were in this group, but after the amputation this group accounted for 63.4 per cent of the patients. This approach holds promise of providing a means of accurately predicting the blood supply to critical tissues after amputation.

Estimation of temperature remains a valuable technique in predicting tissue viability, whether it be by the examining hand, the thermocouple or as part of total heat emitted estimations by thermograph. The

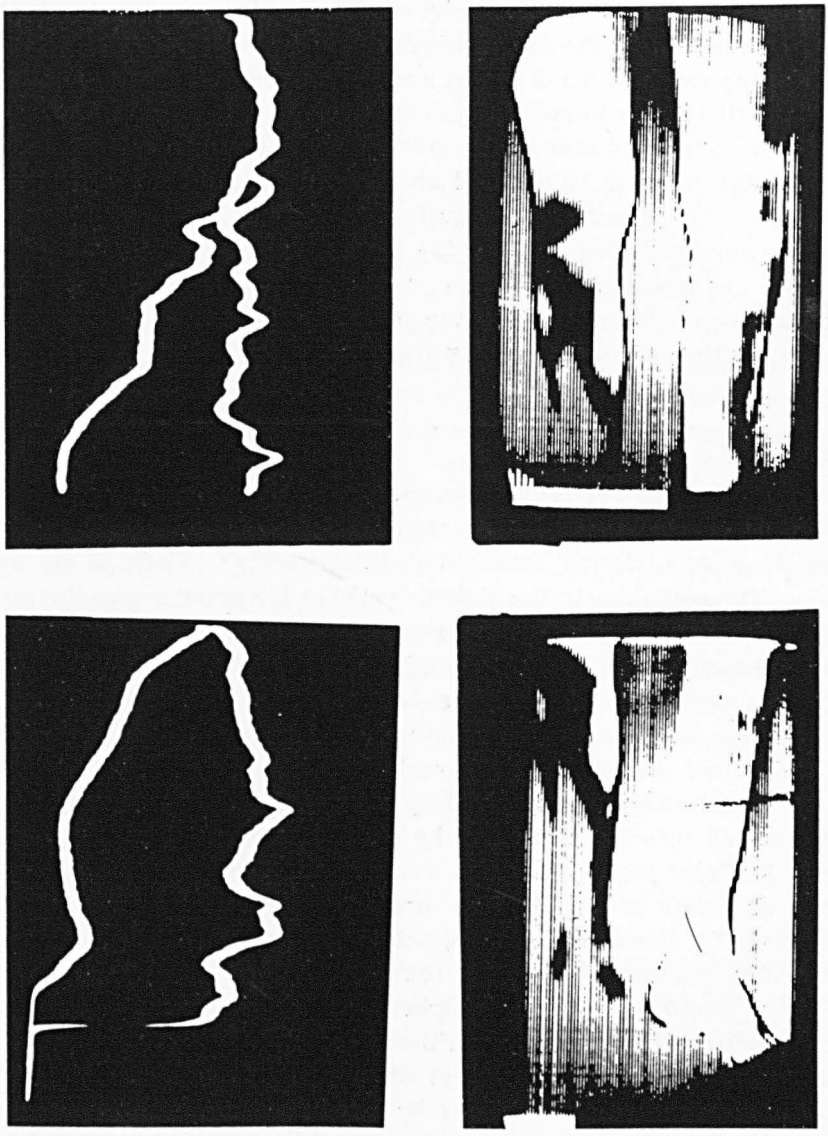


Figure 1. Atherosclerosis. The illustrations at the top show the situation in and around the knee and those at the bottom the situation at the foot and ankle. On the left the trace records are demonstrated over a range of 6° C. The case illustrated had had a right below-knee amputation. It was felt that because of the ischaemia on the lateral aspect of the stump, an amputation with a medial flap might have succeeded.

latter technique has not been fully explored and one factor which may have served to limit the use of this device is that most detectors operate within the range of 3.5–5 μm in a situation where the wave length of heat emitted by the human body is in the range of 0–20 μm with a mean of 10 μm. A thermograph under test in Dundee has a detector operating within the range 6–14 μm and an example of a record is shown in Figure 1. Our experience suggests that it may provide information closely parallel to the state of the local skin blood supply. The technique is, of course, non-invasive, causes no discomfort to the patient and may provide information not only about the level of amputation but about the orientation of skin flaps as well.

The diabetic foot

Some 25 to 50 per cent of patients presenting for leg amputations with vascular disease suffer from diabetes. The latter are often described as suffering from "diabetic gangrene". There is no such thing. The pathology in the diabetic's foot or lower leg can be the result of small vessel disease, major vessel occlusion as in atherosclerosis in the absence of diabetes, neuropathy, or infections to which diabetic tissue is more prone. All or some of these factors may be operating in a given case and thus each case must be assessed individually. When there is not a major vessel occlusion above or below the knee, some diabetic feet can be saved by surgically excising all dead tissue, opening all infected areas and by careful pressure dressings, and, if need be, local toe amputations and sometimes skin grafting. Partial foot amputations and Syme's procedures may also offer feasible solutions for these patients. Meggitt (1973) underlined these points in recording the management of 151 diabetic feet. He showed that 18 per cent could be saved from higher amputation by a Syme's amputation performed in two stages, although a further 12 per cent required higher amputation. The concept of a two-stage performance of the amputation was proposed first by Hulnick et al. (1949) and later demonstrated as an advantageous method by Spittler et al. (1954) in a series of 36 cases. The technique is advocated for those patients with overt infection from whatever source, and Meggitt used it to good effect in his series. It ensures a barrier of articular cartilage, and once the infection is controlled or the wound healed, removal of the malleoli can be performed. These procedures will surely fail if the blood supply is inadequate due to proximal occlusions. The preponderance of distal

pathology and the more frequent occurrence of major vessel occlusion below the knee will normally mean that the amputation need not be above the knee.

Trauma

We all have to deal with traumatic injuries and it can be difficult to decide whether to amputate and at what level. These past few years have seen no reduction in road traffic accidents and I regret to say there has been no shortage of wars. Long-established principles still hold, viz., to conserve all viable tissue, to close wounds where feasible, to employ open flaps where there has been much tissue destruction and where tissue of doubtful viability has been left, and to use a circular amputation in the presence of infection. The Vietnam war experience provided solid affirmation of the need for skin traction in open amputations (Welch et al. 1969, Mayfield et al. 1972, Brown 1970).

Many amputations treated in this way will heal well and be fitted without more ado. However, revision and stump reconstruction procedures should be seen as part of the natural history of the traumatic amputation. The patient, prosthetist and surgeon should discuss thoroughly among themselves the patient's next 30–40 years of prosthetic wear to see whether any further procedures are desirable, e.g. excision of the fibula in very short stumps, osteomyoplasty (see below) or even simple excision of an adherent scar. This sort of discussion should take place even when the patient is, for the moment, satisfactorily fitted.

Bone tumours

Osteosarcoma continues to be the scourge it has always been, with a 5-year survival rate ranging up to little more than 20 per cent, regardless of the primary treatment employed. Tragically, most of the patients involved are young adults, and within 2 years four out of five of them have died, usually from lung metastases.

Dahlin & Coventry (1967) reported on 600 cases and confirmed the typical occurrence about the knee and that amputation remains the main weapon of treatment through the hip or sometimes the femoral shaft. The report by Sweetnam (1973) suggests that while it is difficult to demonstrate improved survival rates, the higher amputation probably reduces the chance of local recurrence and its attendant misery. Radiotherapy has not significantly improved the patient's chances

(Sweetnam et al. 1971), although its application as recommended by Cade (1955) has spared many patients needless amputation by reserving the ablative procedure for those most likely to survive.

In cases in which the metastases are disseminated, chemotherapy has not been very useful. There has been some experience with the alkylating agents, none with nitrogen mustard and little with the antimetabolites. Jaffé's (1972) report on the use of high-dose methotrexate with citrovorum factor and that of Cortes et al. (1973) employing adriamycin in causing regression of pulmonary metastases created new interest, particularly as Marcove et al. (1970) had shown clearly the close relationship between the occurrence of pulmonary metastases and death. Further recent communications provide encouraging news of the use of chemotherapy given prophylactically immediately after amputation. Jaffé et al. (1974), using a combination of high dose methotroxate (with citrovorum factor) and vincristine, reported 11 out of 12 cases still free of metastases between 6 and 27 months after amputation. Cortes et al. (1974), using doxarubicin (adriamycin), reported 10 out of 13 patients free of disease 9 to 40 months after amputation. Sutow et al. (1974) used a four-drug combination including doxorubicin and reported 10 out of 18 patients with no metastases 15 months after amputation; a later analysis of the same group of patients (Burchenal 1974) shows no recurrence in any of them 9 to 23 months after the cessation of chemotherapy—in all, between 27 and 40 months after amputation. Clearly while this work may well presage a major breakthrough, further experience is required using combinations of a wide range of drugs in differing doses before the optimum can be determined. To ensure a sufficiently large case load to improve validity it is necessary that as many centres as possible be involved. It is to this end that the Medical Research Council of the United Kingdom has set up a working party to co-ordinate a national trial of chemotherapy as prophylactic adjuvant treatment.

Jaffé et al. (1974) stress the importance of primary amputation and suggest that anything less may potentiate the development of resistant cells. This will pose serious problems for those clinicians employing a régime of radiotherapy and delayed amputation. Indeed it casts serious doubt on the efficacy of radiotherapy. There will also be many problems with the inevitable side effects of chemotherapy—some serious and many certainly unpleasant. Most clinicians will be happy to face up to these problems if the reward is 2 to 3 times the usual number of survivors.

Congenital limb deficiency

Congenital limb deficiency is comparatively rare in the experience of any one surgeon and the management of these cases is perhaps best undertaken by special centres. Even in these circumstances concern about a basic understanding of the nature of the defects and the difficulties in comparing methods of management has been expressed by a number of authors attempting to name and classify the defects. This problem has been of interest to the Committee on Prosthetic Research and Development, National Academy of Sciences in the United States. In order to promote international discussion and perhaps reach international agreement, the work of that committee and of professionals throughout the world was recognized in the formation of a Sub-committee on Nomenclature and Classification in Congenital Limb Deficiency under the auspices of the International Society for Prosthetics and Orthotics. Through the medium of a series of working groups, a measure of agreement has been reached which serves to overcome difficulties expressed in a series of publications. A system has been evolved and has been exposed to an international field application study involving some 500 congenitally deficient limbs. The proposed classification has presented little trouble in the great majority of these cases, but further work and trials are required to illuminate some of the problems presented. In essence the system requires that all congenital limb deficiencies are to be classified as transverse or longitudinal deficits.

1. *Transverse deficiencies.* This category substitutes for the terminal transverse subsection of the Frantz/O'Rahilly (1961), Hall (1962) and Burtch (1966) systems and the peromelia of the German nomenclature.

Essentially, the defect presents as an amputation-like stump. In the proposed new nomenclature the deficiency is classified by naming 1) the level at which the limb terminates, or 2) the most proximal segment that is missing, it being understood that all elements distal to the level named are also absent. The nomenclature for describing the appropriate level is reproduced in Figure 2 and the application of this terminology to one of the most common types of transverse deficiency is shown in Figure 3.

2. *Longitudinal deficiencies.* All skeletal limb deficiencies other than the transverse type are placed in the longitudinal category. Thus, this subsection includes the terminal longitudinal, intercalary transverse, intercalary longitudinal and ectromelia subdivisions of previous systems.

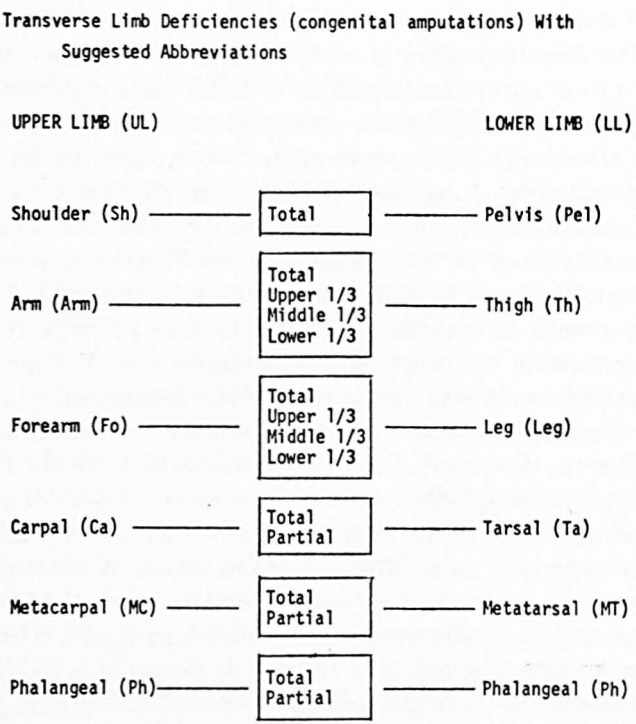
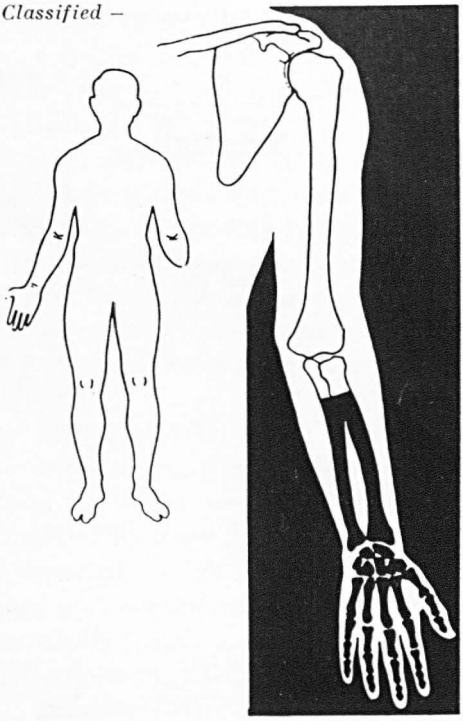


Figure 2. Language used in proposed classification.

In identifying deficiencies, all absent bones or portions of bones that are missing are named. Any bones not named as being missing are understood to be present. Figure 4 presents the application of the system to a fairly common longitudinal defect, while Figure 5 presents in chart form the language used in classifying this type of defect.

It appears that none of the cases so far reported are unclassifiable under the system. Some uncertainties remain and will be the subject of further work. The World Health Organization is apprised of these developments and it is hoped that ultimately the system will be included in the International Classification of Disease. If authors can be persuaded to follow the proposed nomenclature and classification, it will then be possible to compare reports and the body of knowledge collected will provide valuable statistical evidence as to trends and occurrence.

Figure 3. Typical transverse deficiency. Classified – T–L, Fo upper 1/3.



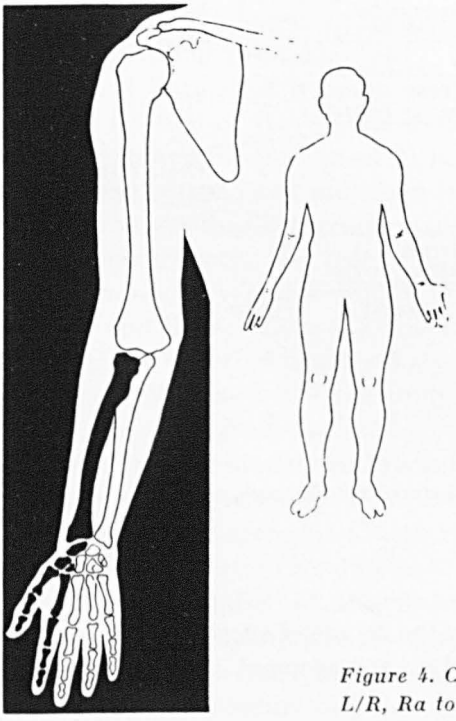


Figure 4. Common longitudinal defect. Classified – L/R, Ra total; Ca partial; Rays 1,2 total.

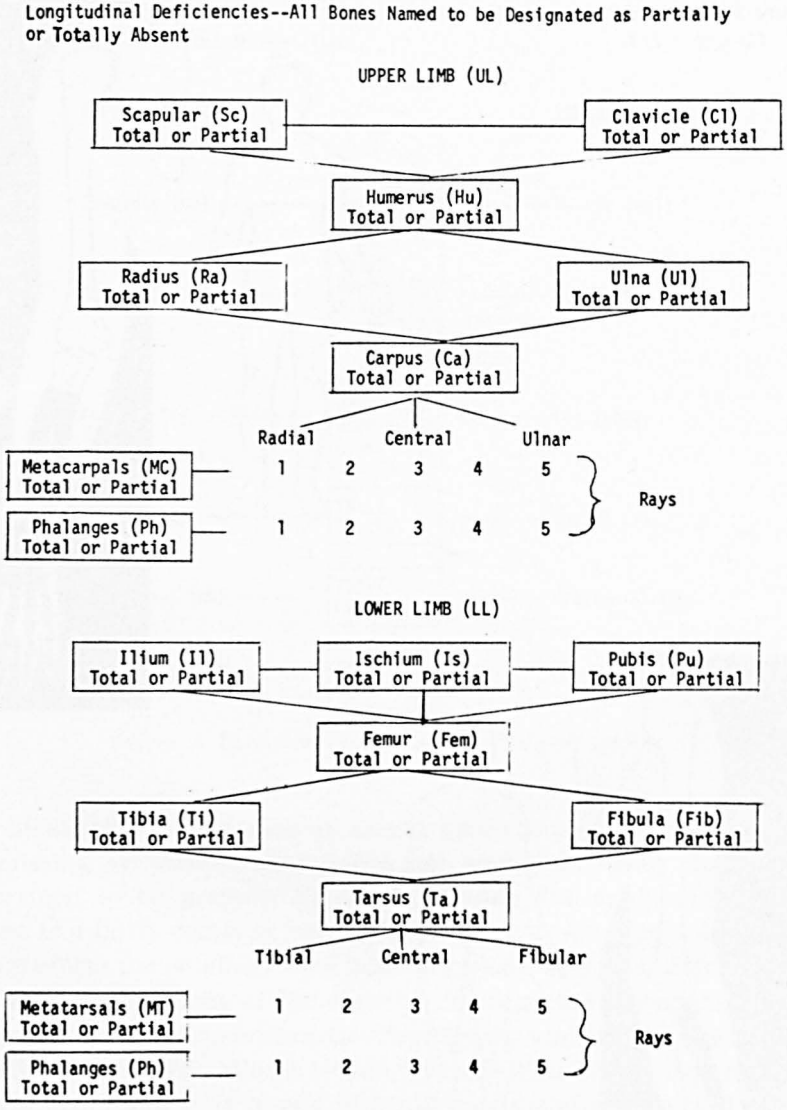


Figure 5. Language and classification employed.

Surgical technique

It is necessary to consider briefly the details of surgical techniques in amputation. This in effect concerns management of the individual tissues.

Bone. Since the early German authors there has been continuing interest in the treatment of the bone end in amputation surgery and I am glad to record that authors now refer to "sculpturing" the bone end, e.g., of the tibia, and not to "bevelling".

Control of bone growth in relation to skin growth in the juvenile amputee is a continuing problem. Swanson's work of implanting a silicone end prosthesis offers the possibility of avoiding repeated bone resections during growth. In the same way osteomyoplasty should be considered for some of these children who have been subjected to below-knee amputation, instead of a procedure retaining the epiphysis, but it is likely that an international trial will be required before any judgement can be made as to its efficacy.

Osteomyoplasty, as described by Ertl (1949) is, in my opinion, a positive contribution, because it provides a stump which is uniquely tough. It does not change shape, socket changes are rare, and it can sustain a measure of end bearing. Regrettably there have been no long-term reviews. Deffer et al. (1971) reported on 155 patients in whom this kind of operation was performed as a secondary procedure. Only four failed and all others were successfully fitted.

Muscle. Early attempts at fixation of the muscles had the primary goal of providing a muscle "pad". Recently Dederich (1967), Weiss (1969) and Burgess & Romano (1968) have emphasised the need of securing fixation of the muscle units to the end of the stump bone. Muscle stabilisation is claimed to be more physiological, providing a more stable shape, less muscle wasting, better proprioception with retention of existing neuromuscular mechanisms, more efficient vascular dynamics, etc., but few studies exist. Dederich (1967) demonstrated improved vascular supply to the stump end after myoplastic revision, and Hansen-Leth & Reimann (1972) demonstrated in laboratory animals a better blood supply to the stump end when muscle stabilisation was used. A small study in Dundee suggested that muscle stabilisation does give rhythmic, phasic muscle activity on walking in contrast to the continuous but irregular pattern of EMG activity in unsecured muscle (Figure 6). The advantages of muscle stabilisation in thigh amputations seem even more valid and perhaps more important in view of the interface conditions.

Nerve. Management of the divided nerve(s) and its inevitable neuroma has been a subject of controversy for more than a century. The present practice of a high, clean cut with the addition of ligature when necessary to secure intraneural vessels appears to be reasonably

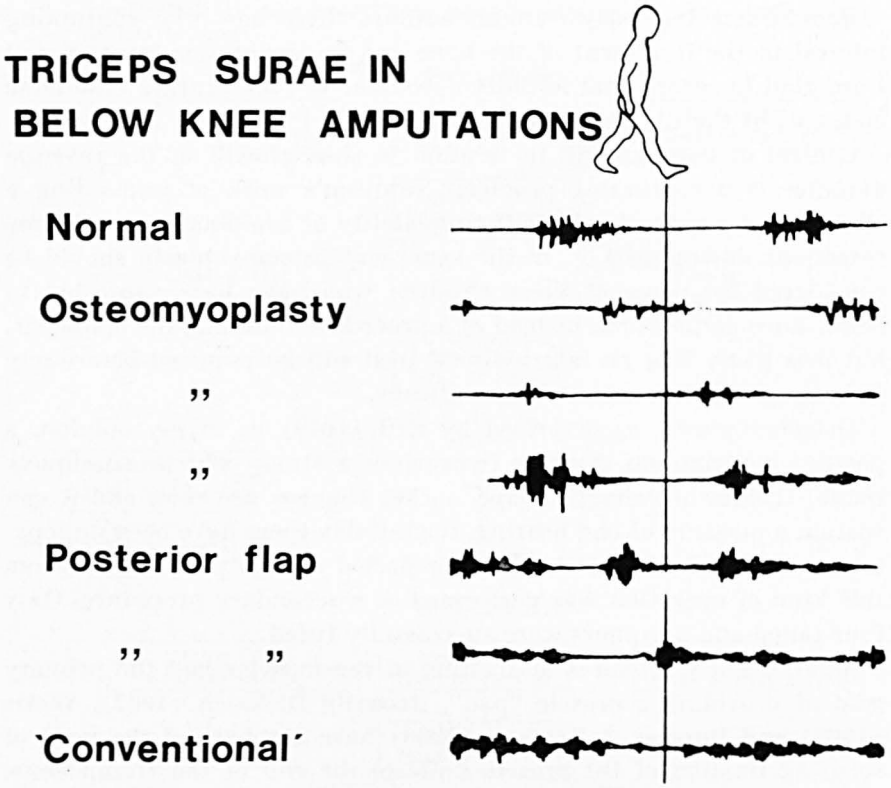


Figure 6. EMG record of triceps surae in below-knee amputees. In the osteomyoplasty cases, phasic activity is recorded approaching the normal. In the first case there is additional activity immediately before heel contact (? acting as accessory knee flexor). In the posterior flap, amputation activity is not so well defined, and in the conventional amputation it is entirely random.

satisfactory. Swanson et al. (1972), basing their work on animal experiments, have shown in clinical practice that painful neuromas can be excised and the nerve capped with a silicone device to obviate recurrence. They suggest with good reason that the technique could well be applied as a primary procedure.

Skin. A great deal of work has been done on the architectural nature of skin and its stress-strain relationships. Certainly in the skin of the atherosclerotic patient and for every good reason in other patients, gentle handling and close apposition of the skin edges is necessary. Browse (1973) proposed a technique which ensures precise apposition without the localised ischaemic effect produced by the suture. Essenti-

ally it consists of the use of fine intradermal interrupted sutures and steristrips.

Amputation levels. The value of the so-called end bearing stump such as knee disarticulatoin and the Syme's procedure have never been in doubt and have had recurrent spells of popularity. Equally as often, there have been flirtations with other procedures, e.g., transcondylar and supracondylar procedures at the knee, and the Emslie procedure at the ankle, because these procedures were more proximal and could more easily be fitted with a prosthesis that was cosmetically acceptable. Many of these more proximal procedures still have their advocates, but most would prefer the knee disarticulation and the Syme's procedure if it were not for their cosmetic deficiencies. The author (Murdoch 1975) has been faced with the same dilemma and on the basis of his clinical experience postulated that "the classical Syme's stump when fitted with a modern prosthesis does not bear the full body weight on its end". The method employed was to undertake a direct measurement employing a dynamometer consisting of three pillars instrumented to measure axial loading only. The dynamometer was securely fixed to the prosthesis spanning the narrowest point of the stump. A cut was then made at that point, completely through the prosthesis and through any liner (Figure 7). The patient then walked and the signals from the device were transmitted to instrumentation consisting of amplifiers, a display oscilloscope and a two camera split-screen videotape recording system. The patient then walked over a force plate fitted flush with the surface of the floor, thus providing a measure of the total force transmitted from the ground to the prosthesis. The signals from the

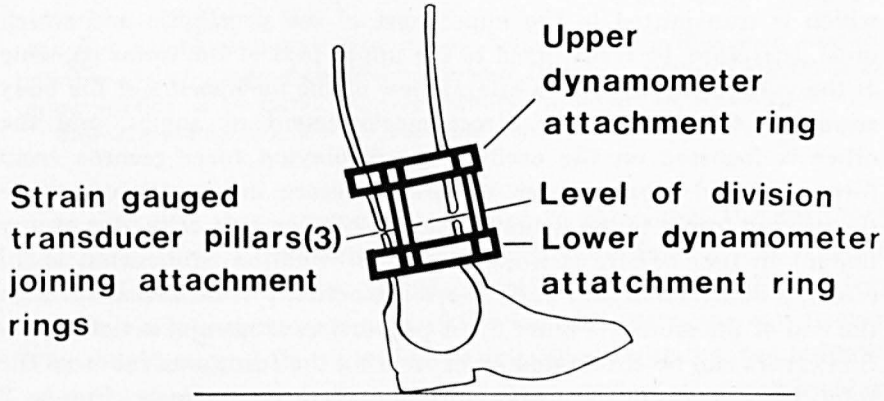
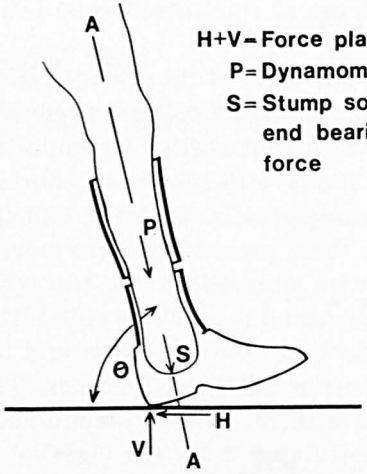


Figure 7. Figure shows arrangement of dynamometer in relation to prosthesis.



For Equilibrium
The sum of the forces in the direction AA is zero

$$\text{i.e. } \lesssim F_{AA} = 0 \quad \uparrow \text{positive}$$

$$\therefore \quad = -P-S+V_{AA}+H_{AA} = 0$$

$$\therefore \quad = -P-S+V\sin\theta + H\cos\theta = 0$$

$$\therefore \quad S = -P-V\sin\theta + H\cos\theta$$

Figure 8. Diagram illustrating forces involved and calculation required to demonstrate stump socket end bearing forces.

dynamometer provide a measure of that fraction of the total force which is transmitted to the upper part of the prosthesis and which must, therefore, be transferred to the upper part of the lower leg. One of the video cameras gives a lateral view of the movements of the body segments, thus permitting direct measurement of angles, and the other is focussed on the oscilloscope displaying force records from force plate and dynamometer. We are, therefore, in a position to relate the ground forces to the actual force lying in the axis of the leg at any instant in time. There is now enough information to do what is, in effect, a subtraction and state the force actually transmitted through the end of the stump (Figure 8). A proportion of normal instrumentation errors can be eliminated by expressing the results as ratios of the total force transmitted through the end of the stump. Figure 9 tabulates the results.

RESULTS OF FORCE PLATE/DYNAMOMETER STUDIES

Expressed as a ratio of the end bearing force to the total force acting down the long axis of the 'leg' during stance phase. (mid stance).

Subject AH	47% 40%	All fitted with a Plastic Laminated Prosthesis
Subject JB	73% 65%	
Subject AM	49% 43%	
Subject LE (Child)	75% 71%	Average 53%
Subject CE	34% 33%	
Subject JM	64% 62%	Side Bars Thigh Lacer
Subject JS	88% 90%	Enclosed Metal Crustacean

Figure 9. Results of dynamometer studies. Patients fitted with modern prostheses all show partial nature of end bearing. Subject JM using traditional prosthesis uses heavy padding on his stump and very tight lacing. Subject JS, showing the highest degree of end bearing, wore a prosthesis which did not intimately fit stump.

In my view there is enough evidence to show that the customary precise shaping of the modern laminated prosthesis to control rotations of the stump within the socket also *pari passu* causes significant force transference to the upper part of the leg, thus reducing end bearing. This would suggest that it will be permissible to countenance reduction of the medial/lateral diameter of the stump end as practised by Mazet (1968). Bone removal is confined to the malleolar projections and the

reduction in area is estimated to be 12 per cent of the total area presented in a classic Syme's procedure. It is our intention to employ an essentially similar method to test the end bearing properties of the knee disarticulation stump and, if the evidence permits, to modify the procedure without loss of its other attributes. If successful, these modifications will allow the fabrication of more cosmetically acceptable prostheses.

Stump environment. A constant response to trauma, accidental or operative, is the formation of oedema and this effect is greater the more distal the wound. The interstitial pressure may rise to a level where it may even affect the local blood supply, with the formation of more oedema, increasing pain and a real danger of forming a vicious circle. The longer the oedema is permitted, the more difficult it is to dissipate, and where the blood supply is already precarious, interstitial pressure may be sufficient to produce ischaemia. Accordingly, the environment of the stump after amputation may be critical to successful wound healing, especially in vascular cases.

Historically this environment might consist of no more than a simple wound dressing or a variety of bandaging techniques. It is not known how much bandage pressure the skin and subcutaneous tissues can withstand or for how long. Isherwood (1975) in presenting a pneumatic bandage provides an excellent review of the subject as outlined herewith. Müller & Vetter (1954) maintained that sustained pressures in excess of 25 mmHg are potentially harmful. Spiro et al. (1970) discovered that a sustained pressure of above 15 mmHg decreased blood flow. Intercapillary pressure varies with posture and in the recumbent position this is exceeded by externally applied pressures of 15–20 mmHg. As the intercapillary pressure varies with posture, the ideal bandage should provide a graded pressure which is maximum at the most dependent distal point, decreasing proximally. A hydrostatic bandage of this kind was described by Wood (1968). The situation is further complicated by the fact that, as shown by Husni et al. (1968), pressures greater than 15–20 mmHg applied to the popliteal fossa created a tourniquet pressure effect even when the entire limb was wrapped. Johnson (1972) believed that no dressing exceeding 10 mmHg should be left on overnight. Redhead et al. (1975), however, has beneficially applied to post-operative limbs cyclic pressures which did not drop below 25 mmHg. Clinical experience certainly suggests that some bandages applied immediately post-operatively have contributed to ischaemia of the stump. Similarly, while trained staff can apply

bandages without detriment to the patient, it is often exceedingly difficult to teach the patient or relatives to repeat this performance. Isherwood showed that the "bandage" designed by Puddifoot et al. (1973), which is essentially foam rubber pads within a sock, applied pressures of the order of 10 mmHg, although over some parts of the stump the pressures were as low as 5 mmHg and in unskilled hands pressures as high as 20 mmHg were imposed over other sites, particularly over the end of the stump.

The application of a plaster of Paris cast has been an integral part of the philosophy of immediate post-surgical fitting since its inception. Mooney et al. (1971) presented the results of a study to define the place of a rigid cast dressing and early ambulation in the post-operative care of below-knee amputations secondary to diabetic vascular disease. This was a strictly controlled study and showed that patients with a rigid cast as opposed to those with soft dressings healed faster.

The protocol regarding weight bearing, that is to say, the application of forces to the stump generated by walking, has been modified with experience. Weight bearing through a pylon attached to the plaster is now started later and applied by carefully controlled increments. Mooney and his co-workers suggest that while there is good experimental evidence that gradual application of functional mechanical stress to healing connective tissue in an appropriate quantity and direction leads to a mature wound better equipped to tolerate the normal stress of function, it is apparent that ischaemic wounds tolerate only minimal stress in their healing phase. Three papers are worth quoting in respect of early weight bearing, walking and exercise. Larsen (1973) and Koppelmann (1973) both demonstrated that when muscle is exercised both in normals and in patients with occlusive arterial disease, blood flow to the skin is decreased, i.e., there is a diversion of flow to the exercising muscle and away from skin and non-exercised muscle. This observation probably supports the view that weight bearing should be delayed. On the other hand, Schoop (1973) stated that muscle becomes "trained" by exercise and demands a smaller increase in blood flow for a given load than does untrained muscle, leaving more blood available for less well compensated muscles and other tissues such as the skin. This mechanism may in turn support the concept of a sustained exercise and early walking programme.

One interesting and perhaps revolutionary solution to the problems of peripheral wound management is offered by Redhead (1974). He and his colleagues have produced a device which is essentially a trans-

parent bag which encloses the limb and at the same time permits air to escape via proximal skirting and does not allow any ingress except through a controlled supply. There is, therefore, control over pressure, humidity, temperature and sterility. The pressure can be applied within the range of 0–50 mmHg and can be controlled within precise limits and operate cyclically as desired. Of 28 hand cases treated in this way following operation, significant reduction in post-operative discomfort was noted and 10 had only oedema. Twelve amputee cases were treated in this way and none exhibited stump oedema, haematoma or wound infection; two required re-amputation because of muscle and skin necrosis and a third case involving electrical burns healed but later became infected.

Troup et al. (1975) demonstrated the value of a well organised programme of total care in describing the management of some 500 primary amputees. It is apparent that even when the surgery is performed by a variety of surgeons using different techniques and different stump environments, timely prosthetic fittings and integrated medical, nursing and physiotherapeutic care will ensure that nine out of 10 patients can be restored to significant independence and a "home" environment. It follows that scientific effort, improved surgery, an appreciation of the problems of stump environment and skilled prosthetics will not suffice. These must be supplemented by government or institutional investment in the provision of specialised units for care of the amputee.

REFERENCES

Berlemont, M. (1961) Notre experience de l'appareillage precoce des amputés de membre inferieur aux establisements. Helio Marins de Berck. *Ann. Med. phys.* **4**, 4.

Brown, P. W. (1970) Rehabilitation of bilateral lower-extremity amputees. *J. Bone Jt Surg.* **52**-A, 687–699.

Browse, N. L. (1973) Choice of level of amputation in ischaemic arterial disease. *Scand. J. clin. Lab. Invest.* **31**, Suppl. 128, 249–252.

Burchenal, J. H. (1974) A giant step forward—If . . . *New Engl. J. Med.* **291**, 1029–1031.

Burtch, R. L. (1966) Nomenclature for congenital skeletal limb deficiencies. A revision of the Frantz and O'Rahilly classification. *Artif. Limbs* **10**, 24–35.

Burgess, E. M. & Romano, R. L. (1968) The management of lower extremity amputees using immediate post-surgical prostheses. *Clin. Orthop.* **57**, 137–146.

Burgess, E. M., Romano, R. L., Zettl, J. H. & Schrock, R. B. (1971) Amputations of the leg for peripheral vascular insufficiency. *J. Bone Jt Surg.* **53**-A, 874–889.

Burgess, E. M. & Romano, R. L. (1971) Level selection in lower extremity amputations. *Clin. Orthop.* **74**, 177–184.

Burgess, E. M. (1968) The stabilisation of muscles in lower extremity amputations. *J. Bone Jt Surg.* **50**-A, 1486–1487.

Cade, S. (1955) Osteogenic sarcoma. A study based on 133 patients. *J. roy. Coll. Surg. Edinb.* **1**, 79–111.

Cortes, E. P., Holland, J. F., Wang, J. J. & Sinks, L. F. (1973) Chemotherapy of advanced osteosarcoma. In: *Bone—Certain aspects of neoplasia*, ed. Price, G. H. G. & Moss, F. G. M., p. 265–280. Butterworths, London.

Cortes, E. P., Holland, J. F., Wang, J. J., Sinks, L. F., Blom, J., Senn, H., Bank, A. & Glidewells, O. (1974) Amputation and adriamycin in primary osteosarcoma. *New Engl. J. Med.* **291**, 998–1000.

Dahlin, D. C. & Coventry, M. B. (1967) Osteogenic sarcoma. *J. Bone Jt Surg.* **49**-A, 102–110.

Dahn, I., Lassen, N. A. & Westling, H. (1967) Blood flow in human muscles during external pressure or venous stasis. *Clin. Sci.* **32**, 467.

Dederich, R. (1967) Technique of myoplastic amputations. *Ann. roy. Coll. Surg.* **40**, 222–227.

Deffer, P. A., Moll, J. H. & LaNoue, A. M. (1971) The Ertl osteoplastic below knee amputation. *J. Bone Jt Surg.* **53**-A, 1028.

Ertl, J. (1949) Uber Amputationsstumpf. *Chirurg.* **20**, 218.

Frantz, C. H. & O'Rahilly, R. (1961) Congenital skeletal limb deficiencies. *J. Bone Jt Surg.* **43**-A, 1202–1224.

Hall, C. B., Brooks, M. B. & Dennis, J. F. (1962) Congenital skeletal deficiencies of the extremities. *J. Amer. med. Ass.* **181**, 590–599.

Hansen-Leth, C. & Reimann, I. (1972) Amputations with and without myoplasty on rabbits with special reference to the vascularisation. *Acta orthop. scand.* **43**, 68–77.

Holstein, P. & Lassen, N. A. (1974) Radioisotope clearance technique for measurement of distal blood pressure in skin and muscles. *Scand. J. clin. Lab. Invest.* **31**, Suppl. 128, 143–147.

Hulnick, K. A., Highsmith, C. & Bouton, F. J. (1949) Amputations for failure in reconstructive surgery. *J. Bone Jt Surg.* **31**-A, 639–649.

Husni, E. A., Ximenes, J. O. C. & Hamilton, F. G. (1968) Pressure bandaging of the lower extremity. *J. Amer. med. Ass.* **206**, 2715–2718.

Jaffe, N. (1972) Recent advances in the chemotherapy of metastatic osteogenic sarcoma. *Cancer* **30**, 1627–1631.

Jaffe, N., Frei, E., Traggis, D. & Bishop, Y. (1974) Adjuvant methotrexate and citrovorum-factor treatment of osteogenic sarcoma. *New Engl. J. Med.* **291**, 994–997.

Johnson, H. D. (1972) Mechanics of elastic bandaging (Correspondence). *Brit. med. J.* **3**, 767–768.

Koppelmann, J. (1973) Skin and muscle blood flow during exercise in intermittent claudication. *Scand. J. clin. Lab. Invest.* **31**, Suppl. 128, 93–96.

Kostuik, J., Wood, D., Hornby, R., Feingold, S. & Mathews, V. (1975) The measurement of skin blood flow in P. V. D. by the epicutaneous application of Xenon-133. In press.

Larsen, O. A. (1973) Xenon-133 clearance studies during walking: effect on muscle

and skin blood flow. Routine application with comment on branch thrombosis below the knee. *Scand. J. clin. Lab. Invest.* **31**, Suppl. 128, 89–92.

Lassen, N. A. & Holstein, P. (1974) Use of radioisotopes in assessment of distal blood pressure in arterial insufficiency. *Surg. Clin. N. Amer.* **54**, 39–55.

Marcove, R. C., Mike, V., Hutter, R. V. P., Huvos, A. G., Shoji, H., Miller, T. R. & Kossloff, R. (1970) Chondrosarcoma of the pelvis and upper end of the femur. *J. Bone Jt Surg.* **54**-A, 561–572.

Mayfield, G. W., Burkhalter, W. E. & Ballard, A. (1972) Ambulant treatment of lower extremity amputees with open stumps. *J. Bone Jt Surg.* **54**-A, 1571–1572.

Mazet, R., Schiller, F. J., Dunn, O. J. & Neufeld, A. J. (1959) Influence of prosthetic healing on the health of geriatric amputees. Report of project 431. Office of Vocational Rehabilitation, Washington, D.C.

Mazet, R. (1968) Syme's Amputation. A follow-up study of fifty-one adults and thirty-two children. *J. Bone Jt Surg.* **50**-A, 1549–1563.

Meggitt, B. F. (1973) Orthopaedic management of foot breakdown in the diabetic patient. Proceedings and Reports of Councils and Associations. *J. Bone Jt Surg.* **55**-B, 882.

Mooney, V., Harvey, J. P., McBride, E. & Snelson, R. (1971) Comparison of post-operative stump management: Plaster vs. soft dressings. *J. Bone Jt Surg.* **53**-A, 241–249.

Müller, E. A. & Vetter, K. (1954) The effect of pressure loads upon blood supply to the skin. *Arbeitsphys.* **15**, 295–304.

Murdoch, G. (1967) Levels of amputation and limiting factors. *Ann. roy. Coll. Surg.* **40**, 204–216.

Murdoch, G. (1975) James Syme; an appreciation of the man and his work. In press.

Nilsen, R., Dahn, I., Lassen, N. A. & Westling, H. (1967) On the estimatoin of local effective perfusion pressure in patients with obliterative arterial disease by means of external compression over a Xenon-133 depot. *Scand. J. clin. Lab. Invest.*, Suppl. 99; 19, 29.

Olejniczak, S. (1967) Summary of leg amputations and prosthetic replacement at Wayne County General Hospital during 1961–1965. *Michigan med. News* **66**, 723–726.

Pedersen, H. E. (1968) The problem of the geriatric amputee. *Artif. Limbs* **12**, 1–3.

Puddifoot, P. C., Weaver, P. C. & Marshall, S. A. (1973) A method of supportive bandaging for amputation stumps. *Brit. J. Surg.* **60**, 729–731.

Radcliffe, C. W. & Foort, J. (1959) *Manual of below knee prosthetics.* Biomechanics Laboratory, University of California, Berkeley.

Redhead, R. G., Snowdon, C., Burgess, E. M. & Vitali, M. (1975) Controlled environment treatment for the post-operative management of lower limb amputations and surgery of the hand. In press.

Schoop, W. (1973) Mechanism of beneficial action of daily walking training of patients with intermittent claudication. *Scand. J. clin. Lab. Invest.* **31**, Suppl. 128, 197–199.

Sejrsen, P. (1971) Measurement of cutaneous blood flow by freely diffusible radioactive isotopes—Methodological studies on the washout of Krypton-85 and Xenon-133 from the cutaneous tissue in man. Thesis, University of Copenhagen.

Spiro, M., Roberts, V. C. & Richards, J. B. (1970) Effect of externally applied pressure on femoral vein blood flow. *Brit. med. J.* 719–723.

Spittler, A. W., Brennan, J. J. & Payne, J. W. (1954) Syme Amputation performed in two stages. *J. Bone Jt Surg.* **36-A**, 37–42.

Sutow, W. W., Sullivan, M. P. & Fernbach, J. D. (1974) Adjuvant chemotherapy in primary treatment of osteogenic sarcoma. *Proc. Amer. Ass. Cancer Res.* **51**, 20.

Swanson, A., Boeve & Biddulph (1972) Silicone rubber capping of amputation neuromas—Investigational & clinical experience. *Inter-Clinic Information Bulletin* **11**, No. 5, 1.

Sweetnam, R. (1973) Amputation in osteosarcoma. *J. Bone Jt Surg.* **55**-B, 189–192.

Sweetnam, R., Knowleden, J. & Seddon, H. (1971) Bone sarcoma treatment by irradiation amputation or a combination of the two. *Brit. med. J.* **2**, 363–367.

Troup, I. M., Murdoch, G. & Condie, D. N. (1975) A statistical survey of amputee care within a specialised prosthetic unit. In press.

Weiss, M. (1966) Neurological implications of fitting artificial limbs immediately after amputation surgery. Report of Workshop Panel on Lower Extremity Prosthetic Fitting. Committee on Prosthetic Research & Development. National Academy of Sciences, Washington, D.C.

Weiss, M. (1969) Physiologic amputation, immediate prosthesis and early ambulation. *Prosthetics Int.* **3**, No. 8.

Welch, R. B., Metz, C. W., Becker, Q. H. & Rankin, E. A. (1969) The management of the battle incurred lower extremity amputee. *J. Bone Jt Surg.* **51**-A, 1041.

Wood, E. J. (1968) The venous system. *Sci. Amer.* **218**, 86–96.

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