Below-Knee Amputation Surgery

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Throughout the history of lower-extremity amputation surgery, the relative emphasis placed on various parts of the procedure has undergone many changes as new techniques have become available and as new goals have been appreciated. At present, the amount and direction of available knowledge demand the surgeon's concern with fundamental principles. Since some of these problems must be considered whatever level is chosen for amputation, they will be discussed before those that are peculiar to below-knee amputation.

As seen in the earliest reports on amputation, from the times of Hippocrates and Galen, this drastic measure was taken for the sole purpose of saving life but, as it usually turned out, it was instead a lethal procedure owing to shock and to loss of blood. Therefore, all emphasis was placed on the speed with which the operation could be completed. Patients who survived the operation frequently died of septicemia. After hemostasis, antisepsis and asepsis, and anesthesia all came into use in the mid-nineteenth century, however, speed became less important, less painful and extreme surgical procedures could be developed, and surgeons began to give more attention to conservation of tissues. Another change in emphasis was prompted by technical advances in articulated prostheses (first invented in the sixteenth century). Functional aspects of the stump then became the main consideration, and together with the prosthesis they came more and more to dictate the level and type of amputation.

This development is most fully illustrated by the popularity—which persists even now (P)—of the zur Verth scheme, or "site-of-election" concept. A "functional" means of determining the optimum amputation level, this arbitrary plan was obviously never intended for use in any and all situations, such as trauma, and certainly not under conditions of mass casualties, where conservation of tissue and open drainage are essential. But it has been used in such situations and has led to unnecessary loss of valuable segments of limbs. Dederich (*8*) points out that a military order of the German Army Medical Corps during the last part of World War II was necessary to prohibit use of zur Verth's scheme for primary and usually septic amputations, the order directing that tissue-sparing open amputations be used.

Since that time it has become increasingly clear that distinctions must be made in regard to the conditions under which the amputation is done and that the technique must be related to these distinctions. Under emergency conditions, the primary consideration of the surgeon is to treat for shock to save the life of the patient. His thought and his actions are directed toward preservation of the limb rather than toward amputation. Conservation of blood supply, restoration of nerve connections, and debridement of crushed tissue are his main concern. Large operative procedures should not be undertaken, because surgical shock cannot be added to the already existing shock. If amputation becomes a matter of life or death, the level is then not the choice of the surgeon. It is forced on him. He will try to preserve as much useful tissue as possible, but the general condition of the patient dictates the measures. It is because of these factors that even revised stumps are often not of a length that the limbfitter might consider ideal.

In a recent publication (7) of the Committee on Trauma of the American College of Surgeons, it was stated:

> For the lower extremity, the desideratum is weight-bearing, and for this reason adequate soft tissue coverage over the end of the stump is more important than extra length. If it appears likely, however, that revision of the stump will be necessary, it is best to leave as much length as possible at the primary amputation.

Also emphasized was the point that the preferences of the limbmaker should not be considered in emergency amputations, but approval was given for reamputations "in accordance with accepted concepts concerning elective levels for a prosthesis."

The implications of this persistent concept need to be examined, particularly since the surgeon, in fashioning a stump, is often faced with difficulties that are not related to principles of prosthetics at all. His decision as to the level of amputation has to be based on the reaction of individual tissues. Thus present-day practice should not have as much influence as present knowledge of anatomic and physiological changes that occur as the result of amputation of an extremity or of any part of it.

Unfortunately, few publications evaluate these changes completely and relate them to the functional losses. The techniques they recommend often seem inadequate and, in many instances, contradictory. Even techniques valuable in themselves are given limited application, and advances in amputation procedures have come about very slowly. Over the past 75 years a number of surgeons have published new techniques, successful in their hands, which were not widely accepted because definite and fundamental biological principles were lacking. Also implicated in this situation is the frequently found—and understandable—attitude of the physician who has attempted to save an extremity with all the skill at his command and makes the decision to amputate only as a last resort and reluctantly, then performing the operation as expediently as possible.

For the patient, however, amputation initiates a new life with a whole set of new problems. In addition to the functional loss, psychological trauma is inevitable. Preamputation psychological preparation is, if time permits, always advised, but while it can do much to alleviate some of the problems it is not enough if persistent physiological disorders prevent the patient from using a prosthesis adequately. The goal of rehabilitation, which may in this way begin before amputation, is return of the amputee to as near a normal life as possible, and this calls for coordinated efforts by various workers—efforts that should begin with the surgeon's understanding of the many biological and biomechanical principles involved.

It was postulated at the Biomechanics Laboratory, University of California, that these principles could be derived from a cooperative, interdisciplinary approach to the various aspects of lower-extremity amputation and then applied back to specific procedures and treatments *(13).* It is from this point of view that the following sections review the known principles and how they have been and can be brought to bear in surgical practice in regard to pain, bone, muscles and fascia, and skin. First to be described are the special problems of below-knee amputation and how other workers have sought to solve them.

SPECIAL PROBLEMS IN BELOW-KNEE AMPUTATION

It has long been accepted, but for varying reasons over the years, that the middle third of the leg is the best site for a below-knee amputation. This gives a stump of 5-1/2 to 7 in. below the knee joint. Current opinion *(1,2,11,19)* is based mainly on reasons of circulation, which is often reported to cause problems when amputation is done in the lower third where the circulation is relatively poor, and on prosthetics practice, which is conventionally most able to make use of a bone lever at least 2 in. long. It must be remembered, however, that satisfactory results can be achieved with both longer and shorter stumps. As Watermann *(21)* has indicated, very short below-knee stumps are preferable to reamputation at an above-knee level, providing that the insertion of the patellar ligament is retained or re-established, and long below-knee stumps may be kept if soft-tissue and circulatory conditions are adequate.

Peculiar to below-knee amputation is the presence of two bones. The tibial crest, lying close to the surface of the skin, is always beveled slightly. But the fibula, normally a non-weight-bearing bone, has received various treatments. Its complete excision is frequently recommended *(1,11,14,21),* at least in very short stumps, first because of its tendency to lateral deviation and rotation caused by pull of the tendon of the biceps and, secondly, because of the protuberance of the head, which is subjected to pressure by the prosthetic socket. For stumps of average length, the advice usually is to section the fibula 1 to l-1/2 in. above the end of the tibia in order to facilitate fit in the socket *(1,14,19).* This treatment does not, however, take account of certain surgical provisions, which are discussed more fully in the next section.

TREATMENT OF TISSUES

The whole problem of pain in the amputee, both in the stump and in the phantom, is known to be extremely complex. It is clear that removal of so large a mass of tissue must cause a gross disturbance in the balanced input of peripheral sensory nerve impulses. For one thing, a neuroma forms at the cut end of nerves. Its regenerating nerve fibers intertwine, and it may be considered a grossly abnormal "receptor organ" *(17)* which is painful on mechanical stimulation. The mobilization of skin in forming flaps is inevitably accompanied by partial denervation and often by regeneration that is faulty and incomplete. Transection of muscles naturally deprives them of their insertions so that they then lack normal antagonistic action, and impulses from the muscle spindles and Golgi organs in the tendons are altered or absent. Other scars and inflammatory lesions of the soft tissues and bone may contribute to the generation of impulses that are interpreted as pain. Furthermore, it is known that painful stimuli elsewhere in the body tend to produce pain in the stump or phantom.

In the knowledge of these unavoidable, devastating changes, the surgeon has the obligation to try to prevent any tissue destruction that is unnecessary or that can be circumvented in any way. He must try to fashion a stump that will function in as nearly "normal" a way as possible. This will eliminate at least some kinds of pain and help to normalize sensory return.

BONE

Bone is a living tissue composed of ossein (a protein) intimately combined with inorganic substances, chief among which is calcium phosphate. The inorganic substances give hardness and rigidity to the bone, while the ossein determines its toughness. Bone function is affected by alterations in nutrition and in the metabolism of both organic and inorganic substances, as well as in conditions of loading.

Of the various functions of normal bone, the principal one with which we are here concerned is to transmit load. The long bones of the thigh and leg transmit loads that, at moments, amount to many hundreds of kilograms. These forces, together with muscle forces, determine the final detailed form and internal structure of the bone *(18).* When the bone is severed and no longer bears weight in its long axis, changes in the mineral metabolism occur rapidly, and osteoporosis, which can be a cause of exquisite tenderness and spontaneous pain, sets in. Severing the diaphysis of a long bone leaves an open-end medullary cavity, thus altering normal conditions of pressure and circulation within the bone. In addition, joints proximal to the amputation show such degenerative changes as sclerosis and narrowing of the joint spaces. These changes are the usual lot of most lower-extremity amputees today. If, however, direct loading along the long axis of the bones can be provided after amputation, many of these undesirable changes can be prevented. In this case, the socket of the prosthesis transfers the floor reaction to the skeletal system via the distal end of the stump. This theoretically desirable goal is, however, not easy to attain, which explains why it is not even attempted by most surgeons or planned for by most prosthetists. The great majority of amputees cannot stand pressure on the distal end of the stump for any length of time, even when the tissues are confined in a cuplike socket end to provide hydrostatic cushioning by the soft tissues. Deep palpation of the tissues over the transected end of the bone usually causes pain in the hypersensitive bone.

Many methods have been proposed for making the distal end of the stump less sensitive and more capable of bearing weight. In 1893 Bier *(3)* described the pain felt over the cut end of the bone and ascribed it to the "Knochennarbe," or bone scar. He recommended an osteoplastic procedure in which the cut end of the bone was covered with a flap of cortical bone attached by a periosteal hinge. This method was later largely abandoned, perhaps because of difficulties similar to those we often encountered when we attempted to use it: sometimes bony union did not take place; some plates became sclerotic, others required an excessively long healing time.

The next attempt to desensitize the end of the bone was that of Bunge (5), who attempted to achieve an "ebonized" end by stripping the periosteum to a few millimeters from the distal end of the bone and scraping out the endosteum to the same level. This technique became much more popular and is still recommended by some textbooks *{11,19,20)*. Since, however, this procedure destroys the periosteal and endosteal blood supply to the end of the bone, it usually results in a ring sequestrum that may cause foreign-body reactions and that may even be eliminated by the body. Even without this drastic procedure, avascular necrosis develops at the end of the transected bone, and this greatly inferior bone tissue is a constant source of irritation and pain.

How might this zone of avascular necrosis be eliminated? Even if Bier's osteoplastic procedure *(3)* was not entirely satisfactory, it still seemed logical to cover the cut end of the bone with osteogenic material. Ertl *(10)* developed a special adaptation—the pliable osteoperiosteal flap for below-knee amputees. As he described this procedure, three periosteal flaps, with small flakes of cortical bone attached to them, are cut, two from the tibia and one from the fibula. The three flaps are fashioned into a tube, which is attached to the two bones in such a way as to bridge them and cover both distal surfaces (Fig. 1). The method has several advantages: *(a)* elimination of the exposed cut surfaces of the bones and thus of the possibility of avascular necrosis; *(b)* provision of an insensitive surface capable of partial end-bearing; *(c)* prevention of lateral deviation and rotation of the residual fibula; *(d)* occlusion of the medullary cavities of both tibia and fibula, thus restoring normal intramedullary pressure and normal deep venous return; and *(e)* provision of a protective wall for the cut ends of nerves and vessels in the interosseous space. For this procedure, the fibula should be sectioned at the same level as the tibia, and the anterior tibial crest should be beveled in the usual manner.

MUSCLE

The principal function of normal skeletal muscle is to provide motion, stabilization, or restriction of bony structures. In the conventional amputation, the muscles are severed, usually through the muscle bellies, and are thus deprived of their distal attachments and consequently of the length-tension relationships under which they normally act to best advantage. In the typical conventionally amputated stump, the muscle tissue atrophies rapidly; circulation becomes poorer, especially since venous return is no longer aided by the muscle pump, so that stasis and edema may result. Mondry *(16)* developed a satisfactory method of dealing with this problem. The flexors, tapered if necessary, and the extensors, including the musculature of the fibula, are sutured together over the osteoperiosteal bridge and to the periosteum of the tibia (Fig. 2). Thus the muscles have new attachments and are able to become more functional. The stump is stronger and, with improved circulation, much healthier. When a total-contact prosthesis is used, the well-developed muscles are able to hold the prosthesis on by their contraction alone.

BLOOD VESSELS AND NERVES

Blood vessels should be dissected out carefully, with the veins separated from the arteries, ligated, and cut at different levels. The main nerve trunks are cut high under moderate traction. Trunks of both nerves and blood vessels are buried in the interosseous space proximal to the osteoperiosteal bridge.

Such techniques for the treatment of nerves as alcohol injection, cauterization of the cut end of the nerve, and suturing of the sheath over the cut end have not seemed to influence the formation of neuromas or the presence of phantom sensation or pain, as has been claimed for them, but not enough evidence has been obtained to allow anv conclusions. Further study must also be undertaken before state-

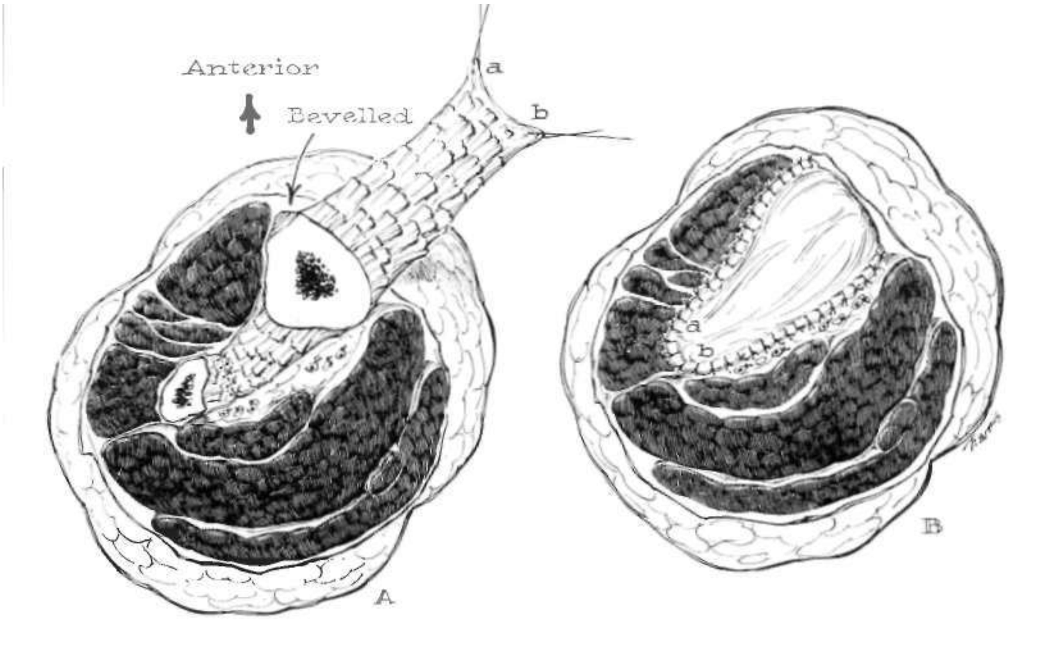


Fig. 1. Ertl's osteoplastic procedure. Before the bones are sectioned, two small periosteal flaps, the fibular one being the shorter, with flakes of cortical bone attached, are chiseled from the opposing surfaces of the tibia and fibula and sutured together, and a third flap, similar but larger, is cut from the anteromedial surface of the tibia *(A).* The anterior crest of the tibia is beveled, as in other amputation procedures, but the two bones are sectioned at the same level after the flaps have been cut free. *B,* The third flap (points labeled *a* and *b* are holding sutures) is brought across the two bones to cover their distal surfaces and is sutured to the other flaps and to the periosteum of the bones, forming a tubelike connection, or bridge, between the two bones.

ments can be made about Lenggenhager's technique *(12),* in which three progressively weaker compression points are applied at successive distances of about 1 cm. from the transected area of the nerve for elimination of phantom pain. In another method of altering conditions with which pain occurs, as studied by Boldrey *(4),* the nerve end is removed from mechanical irritation by being implanted and thus protectively enclosed in the medullary cavity of the residual bone. The neuroma that might then develop is also said to be reduced in size, but, again, results have not been conclusive.

FASCIA

The fascia should be kept in place as much as possible during the amputation procedure, and any part that has been separated from the underlying muscle should be entirely removed since otherwise this mobilized fascia reattaches itself to the musculature in the form of a hard fibrous cover that forms a barrier to the penetration of the blood vessels serving the skin. It may even become necrotic and be extruded shortly after operation.

SKIN

One reason for skin breakdown is poor circulation in the stump, with resulting stasis, edema, and anoxia. Attempting to provide, at the time of surgery, for as good circulatory conditions as possible is, therefore, requisite to the subsequent health of the skin *(13).* Impairment of the blood vessels and nerves serving the skin cannot be avoided in amputation, but it can be minimized by the following procedures: *(a)* placement of the skin flaps directly over well-functioning muscles; *(b)* moderate reduction of subcutaneous fat; and *(c)* careful suturing of the skin, with avoidance of excessive tension on the flaps and place-

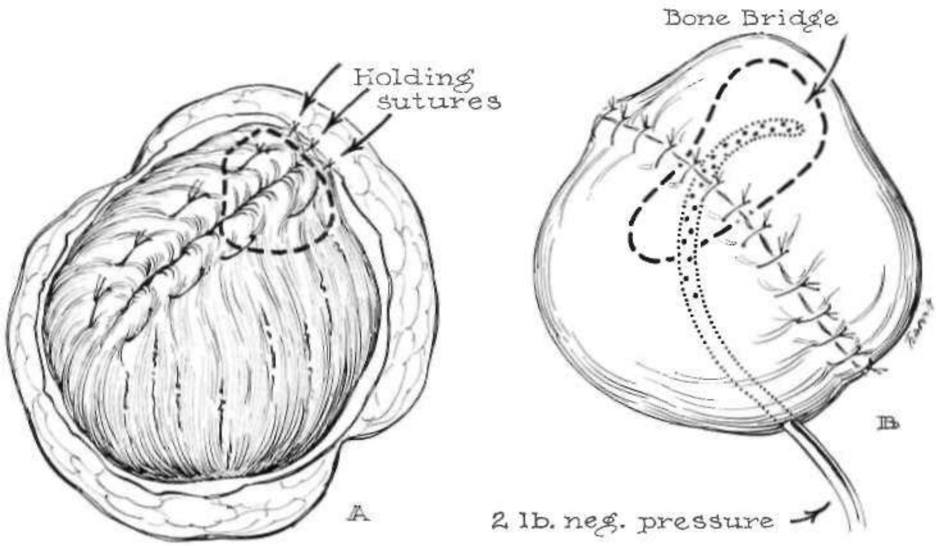


Fig. 2. Mondry's myoplastic procedure. *A,* The anterior tibial and fibular muscle groups, which, depending on their bulk, should be tapered, are joined under moderate tension to the gastrocnemius-soleus muscle group over the osteoperiosteal bridge, with sutures as well to the periosteum of the tibia *(dashed* line). As much of the fascia is kept in place as possible, and what is mobilized should be resected. *B,* The terminal suture line of the oblique skin flaps is at right angles to the osteoperiosteal bridge *(dashed* line) and muscle sutures. The suction tube is shown in place.

merit of the scar so that it does not lie directly over the end of the bone and is not subject to irritation by the prosthesis. Other than this consideration, the position of the scar is immaterial if healing is *per primam.* A good choice is an anterolateral-to-posteromedial suture line, the resulting scar lying at right angles to the suture line of the muscles (Fig. 2*B)*. The skin flaps should then be of equal length. This approach is in agreement with Marquardt *(15).*

PREOPERATIVE AND POSTOPERATIVE TREATMENT

Prolonged and intensive preoperative care is essential for the success of an osteoplastic-myoplastic amputation or revision. The patient should be hospitalized preoperatively for a minimum of three weeks, preferably for six. During this time everything possible should be done to improve the condition of the limb. If localized infections are present, they should be treated topically. The skin should be given the best of care. Hydrotherapy for stimulation of circulation and drugs (intra-arterial procaine to the femoral artery of the affected side) to increase peripheral circulation may be administered. The limb should be exercised within the limits of tolerance of the patient.

Equally important is proper postoperative treatment. Postoperative hematoma should be prevented by use of suction-drainage (negative-pressure bottle), which will help avoid tissue destruction because of pressure, painful distention, and the presence of a medium for growth of bacteria.

A splint should be used for two to three weeks with the knee in slight flexion; no exercises are prescribed for this period. Then an Ace bandage should be applied and exercises gradually increased over a period of time, the aim being especially to strengthen the anterior

Fig. 3. Case 1. Roentgenogram showing evidence of development of synostosis between tibia and fibula of patient whose amputation was done 32 years earlier at the age of 9.

Fig. 4. Case 2. Roentgenogram showing solid, well-formed bone bridge 8-1/2 years after osteoplastic-myoplastic revision.

tibial and calf muscle groups. A shrinker should be used only if distention is present. The distal surface of the slump should be toughened by pounding and by vibration treatments.

After eight to ten weeks, well before solidification of the bone bridge, the prosthesis can be fitted. A pad should be put in the bottom of the socket and the pressure on the distal end gradually increased. This procedure will accelerate the solidification of the bone bridge and further decrease postoperative edema and the sensitivity of the distal end of the stump.

BRIEF REPORTS OF CASES

Of the cases illustrated here, 2 through 6 are of amputees seen in Herborn, Marburg, and Bonn, Germany, in 1958, and 1, 7, and 8 are taken from recent experience with osteoplastic-myoplastic procedures at the Biomechanics Laboratory.

CASE 1

Figure 3 shows evidence of partial synostosis between the tibia and fibula of a man whose primary amputation was done 32 years ago, when he was 9 years of age. This roentgenogram substantiates the statement made by Ertl *(10)* that Nature itself tries to connect the transected surfaces of the fibula and tibia, thus showing the way for surgical action.

CASE 2

Reamputation of both legs of a 52-year-old man was done by Mondry in 1950. The left stump, which is 7 in. long, is shown in Figure 4. Excellent results were obtained in this case by the osteoplastic-myoplastic procedures used at reamputation. At the time of examination, 8 years postoperatively, the patient reported that he could walk well, with good control of his prostheses, and that he had proprioception in both stumps and no phantom pain. Examination showed good temperature and no discoloration of the skin or hypersensitivity at the distal end of the stumps; the bone bridge was palpable through the soft-tissue pad; and there was full range of motion of the knee joint. Some atrophy of the gastrocnemius-soleus muscle group had occurred. It is unfortunate that the prostheses did not provide for at least some end-bearing, since the patient

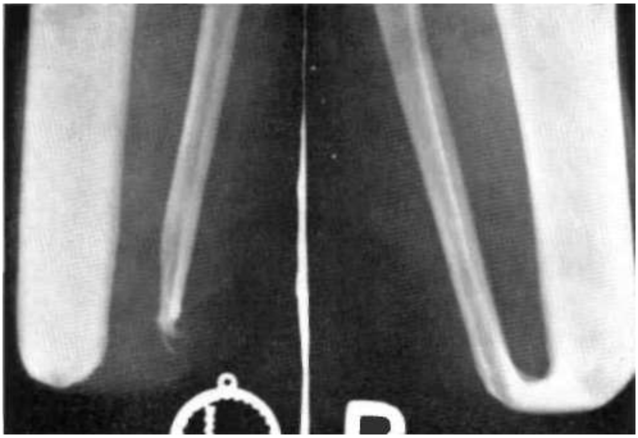


Fig. 5. Case 3. Roentgenograms of bilateral amputee with osteoplastic revision of right stump only (taken 11 years after revision). Relative increase in thickness of cortex of fibula and tibia of right stump, with normal appearance of bone tissue, is remarkable,

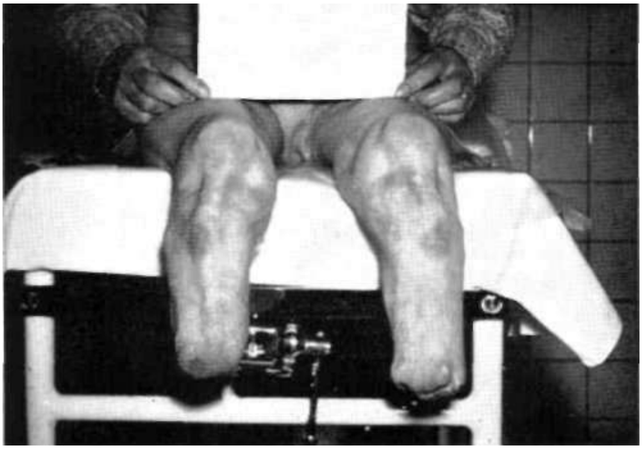


Fig. 6. Case 3. Unrevised left stump (viewer's right) and osteoplastically revised right stump (viewer's left), same as in Figure 5. Muscle atrophy is evident in both stumps, since myoplasty was not done at time of revision of right stump. Skin changes resulting from inadequate prosthesis are less severe on the right stump.

could support weight on both stump ends. The roentgenogram shows a well-rounded bone bridge, with good bone tissue extending to the distal ends of both bones except for slight osteoporosis resulting from use of a prosthesis that did not provide for any axial loading.

CASE 3

A 58-vear-old man, also a bilateral amputee, had revision of his right stump only. The operation was performed by Ertl in 1947 with use of the osteoplastic technique because of pain, increased sensitivity of the bone, inability to wear a prosthesis, and, finally, penetration of the bone through its inadequate skin cover. The two sides may be compared in Figure 5 and from the following observations. With respect to the right stump, no complaints of the sort heard before revision were heard afterward. Shortened to 71/4 in., the bone was soon insensitive and capable of bearing weight, although no postoperative physical therapy for toughening of the stump had been given. At the time of examination the left stump (8 in. long) was, however, reported by the amputee to be subject at times to inflammation, neuritis, and radiation of pain into the adductor region of the thigh. Both stumps had only skin over the bone at the distal end, and the bone bridge of the right stump was palpable. Myoplasty had not been done at the time of revision of the right stump, and resulting atrophy of the anterior tibial group was noticeable. On the left (unrevised) side, an exostosis was present on the medial aspect of the distal end of the fibula. While the left stump was sensitive to palpation, the right stump was completely insensitive, even to heavy punishment. Skin changes resulting from use of open-end prostheses with thigh corsets were present but less severe on the right side (Fig. 6).

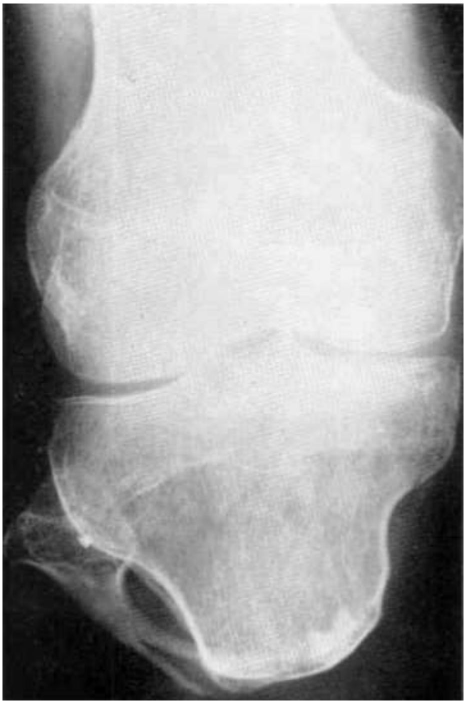


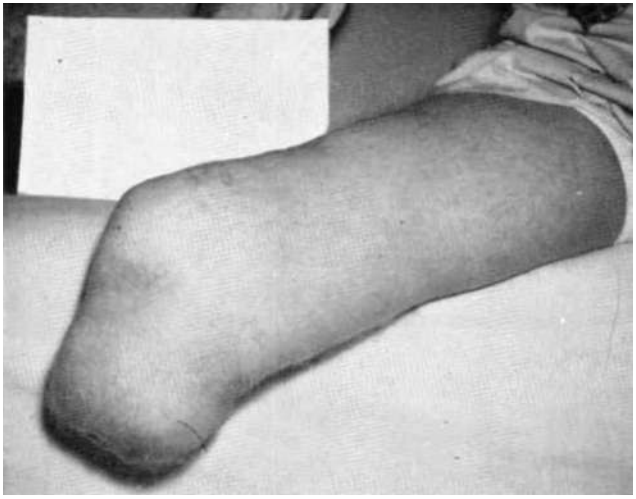
Fig. 7. Case 4. Roentgenogram taken shortly after osteoplastic revision to anchor head of fibula in short stump.

CASE 4

Figure 7 shows a bone bridge in formation soon after revision was done for the purpose of anchoring the fibula in a very short stump. The resulting short but well-shaped and functional stump is shown in Figure 8.

CASE 5

A variation of the osteoplastic technique was successfully done in another case. In order not to reduce length, a homogeneous graft from the anterior tibial crest was applied in bridging the two bones (Fig. 9). The operation, including a myoplastic procedure, was performed by Ertl in 1947. When the amputee, a 34-year-old man, was examined in 1958, he stated that since revision he had never had any discomfort in his stump and could walk considerable distances. His socket provided for weight-bearing over the medial tibial flare



Fig, 8, Case 4. View of short, well-shaped stump, same as in Figure 7.

Fig. 9. Case 5. Roentgenogram taken 11 years after revision with homogeneous bone graft to form bone bridge.

none over the stump end. The stump (Fig. 10) was pointed and its musculature somewhat atrophied; there was hyperkeratosis anteriorly over the distal end of the tibia, as well as abrasions and signs of constriction in the area of weight-bearing. These conditions, along with discoloration from the supporting thigh corset, were evidence that the patient's prosthesis did not exploit the potentialities of his stump. He had full range of motion at the knee joint, and the muscle power was good.

CASE 6

Figure 11 shows a fracture that occurred in the bone bridge of an unusually athletic amputee. The shortness of the fibula in relation to the tibia, with resulting curved and slanting bone bridge, should be noted. At the lime of examination the stump was, however, completely insensitive over the distal end, and the patient had no complaints.

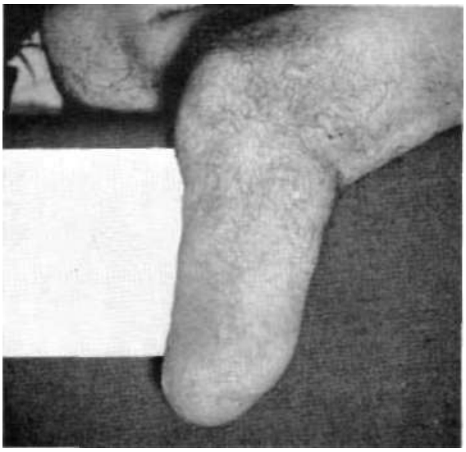


Fig. 10. Case S. Lateral view of stump, same as in Figure 9.

Fig. 11. Case 6. Roentgenogram showing fracture in sagittally slanted bone bridge

CASE 7

Primary amputation of the left leg of a 31-year-old man was done in 1951 because of a war injury. After recurrent breakdown of the redundant soft tissue along the surgical scar, persistent severe stump and phantom pain which had led to drug addiction and prevented rehabilitation, and prevailing coldness of the

Fig. 12. Case 7. Roentgenogram taken 4 months after osteoplastic-myoplastic revision, showing satisfactory progress of ossification of bone bridge.

Fig. 13, Case 8. Roentgenogram taken 7 months after osteoplastic-myoplastic revision, with slow development of bone bridge in presence of osteoporotic tissue.

stump skin, osteoplastic-myoplastic revision was carried out on March 24, 1961. The roentgenogram shown in Figure 12 was taken on July 31, 1961. At the time of writing, the shape and condition of the stump are most satisfactory—warm and insensitive to pressure, with normal skin color. The patient is wearing a well-fitting prosthesis with a total-contact socket that provides for patellar-tendon-bearing and partial end-bearing. He has no localized or phantom pain and has resumed a normal life with steady employment.

CASE 8

In 1955, when the patient was 48 years old, his left foot was crushed in a railway accident. After a variety of efforts to save the foot had failed on account of prolonged osteomyelitic suppuration, a below-knee amputation was done in December 1956. Because the patient had continuous, severe stump and phantom pain, which was established to be of peripheral origin, an osteoplastic-myoplastic procedure according to Ertl and Mondry was done in January 1961. At this time the bone tissue was found to be of a deep yellow color, with rarefication of the trabeculae and almost no points of bleeding from the bone. Although healing was slow (see Fig. 13, photo taken 7 months after revision), the patient's condition appears to be considerably improved. He no longer has the acute phantom pain that used to torture him; phantom pain now occurs only during occasional stump pain. The latter, considerably less than before, is probably due to the poor bone material with its protracted healing time. The patient's stump is being toughened by percussion and by use of a total-contact prosthesis which provides vertical loading of the bone.

CONCLUSIONS

The osteoplastic-myoplastic procedure, occasionally used as a primary procedure under special conditions, is indicated for revision of below-knee stumps (*a*) when there is intractable stump pain with clearly established peripheral cause; (*b*) when the stump is severely hypersensitive, either superficially or in the deeper tissues; (c) when the stump has gross circulatory deficiencies, is easily distended and edematous, or is subject to skin breakdown, ulceration, or types of hyperplastic growths that may become malignant; (*d*) when the stump has redundant tissue and excessive scar tissue, adherent or nonadherent to deeper tissues, preventing tolerance of the prosthesis; (e) when the stump is long and has atrophic retracted musculature; and (/) when there is at the distal end of the stump a localized, deep infection which after nonoperative treatment has proved inadequate, must be resected *in toto* with reamputation at a slightly higher level. For unequivocal success, however, it is important to amputate through viable, well-vascularized bone. In the presence of advanced atrophy and osteoporosis, the solidification of the bone bridge takes much longer, and complete elimination of spontaneous, deep-seated pain becomes questionable (Case 8).

Much has been written about the optimum level of amputation below the knee, and usually from the point of view of how well the conventional prosthesis could be applied. Thus, the main reason for the 2-in. minimum given by various authors has been the problem of maintaining the stump in the socket. With certain prosthetic advances that are now coming into use, however, a shorter stump can be fitted successfully, provided some weight-bearing potential exists at the distal end. Most very short stumps are completely insensitive over the cut surface of the tibia because the cancellous bone at this high level heals well with formation of a solid bony cover. The main problem, then, is the presence of the head of the fibula, which, when it is deprived of much of its interosseous membrane, is subjected to the full force of the pull of the biceps tendon, with resulting abduction of the distal end of the residual fibula and rotation of the head. The solution many surgeons recommend is resection of the head of the fibula, but doing so gives a conical stump even more difficult to fit because of excessive stump rotation inside the socket.

What might be done in these cases is demonstrated in Case 4, in which a modification of Ertl's technique was done. Not only was anchorage of the head of the fibula achieved in this case, but allowance was made for full use of the knee joint in an adequate prosthesis. Because of the high level of amputation in this type of case, the anterior tibial group is dissected at or close to its tendinous origin, so that a muscle plasty is not only technically difficult to perform but also not essential.

A shortening of the stump occurs as a result of fashioning the osteoperiosteal flaps from the surfaces of the tibia and fibula, but the surgeon should not hesitate to make this sacrifice in length when an increase in function can thereby be obtained. Because of sensitivity of bone or excoriated skin, most conventional stumps can be fitted snugly in the proximal half only. The distal half is subjected to excursion and resulting mechanical irritation in a loose socket because it has to be relieved of pressure. When the hypersensitivity of the tissues is eliminated by the osteoplastic and myoplastic procedures herein described, the stump can be fitted closely over its full length, thereby reducing excursions in the socket and actually increasing functional length. If, however, the surgeon is reluctant to shorten the bones in the presence of adequate viable soft tissue at the distal end, an equally satisfactory bridge can be formed with use of a homogeneous bone graft, as is illustrated by Case 5.

Contrary to the recommendations, given with other surgical techniques, to shorten the fibula in relation to the tibia, with the osteoplastic technique best results are obtained when the two bones are transected at the same level. The bridge is then approximately horizontal to the ground. When the fibula is shorter, the bone bridge must be formed on a sagittally directed slant. While the presence of the bridge is, in any case, desirable to prevent biological difficulties, any slant will subject it during weight-bearing to vertical shearing forces it may not be able to withstand. The fracture reported in Case 6 is one of two seen in 1958—both being diagnosed only through roentgenograms since they were asymptomatic and did not prevent the patients from participating in competitive sports.

Of relatively less importance is the placement of the scar. Even if it falls across the distal surface of the bone, the well-vascularized, relatively insensitive skin is able to withstand socket rub and shear effectively.

Good circulation to the deep as well as to the superficial tissues is one of the most advantageous results of the osteoplastic-myoplastic operation *(13).* The muscles, able to contract by virtue of distal attachments, are used continuously. The bones, protected by the bone bridge and used for weight-bearing throughout their length, are preserved from the avascular necrosis to which the distal ends of conventionally amputated bones are ordinarily subject. Participation of the fibula in weight-bearing leads to hypertrophy of the cortex and increase of the over-all diameter. Finally, support of weight on the distal end leads to much greater proprioception, with resulting greater security in walking and improved ability to use the prosthesis easily even in poor light.

In 1923, Burrows *(6)* had conceived of stumps that were functional in much the same way and for the same reasons as have been described in this paper, but he felt forced to abandon his idea of an osteoplastic operation to create conditions for end-bearing because, as he said, "it seems to be impossible to get a limb-maker to get out of his groove and make a suitable limb for such a stump," and he had to conclude that, until more imaginative prosthetists were found, "osteoplastic flaps must be classed as surgical mistakes." Now we are no longer faced with this dilemma. The patellar-tendon-bearing cuff-suspension prosthesis is easily adapted for total contact and partial end-bearing, so that now there is no excuse for inadequate amputation surgery. Results of clinical experience in Germany and at the Biomechanics Laboratory of the University of California have shown definitely the advantages to be had from the osteoplastic-myoplastic procedure.

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