Controversies in lower extremity amputation

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Michael S Pinzur
Loyola University Medical Center

Douglas Smith
University of Washington Seattle

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AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

Controversies in Lower-Extremity Amputation

By Michael S. Pinzur, MD, Frank A. Gottschalk, MD, Marco Antonio Guedes de S. Pinto, MD, and Douglas G. Smith, MD

An Instructional Course Lecture, American Academy of Orthopaedic Surgeons

Using the experience gained from taking care of World War II veterans with amputations, Ernest Burgess taught us that amputation surgery is reconstructive surgery. It is the first step in the rehabilitation process for patients with an amputation and should be thought of in this way. An amputation is often a more appropriate option than limb salvage, irrespective of the underlying cause. The decision-making and selection of the amputation level must be based on realistic expectations with regard to functional outcome and must be adapted to both the disease process being treated and the unique needs of the patient. Sometimes the amputation is done as a life-saving procedure in a patient who is not expected to walk, but more often it is done for a patient who should be able to return to a full active life. This lecture addresses amputations done to return the patient to full activity. Our purposes are to assist the reader in (1) establishing reasonable goals when confronted with the question of limb salvage versus amputation, (2) understanding the roles of the soft-tissue envelope and osseous platform in the creation of a residual limb, (3) understanding the method of weight-bearing within a prosthetic socket, and (4) determining whether a bone bridge is a positive addition to a transtibial amputation.

The Lower Extremity Assessment Project (LEAP) has provided objective outcome data on patients with mutilating limb injuries[1]. Five hundred and sixty-nine consecutive patients with mutilating limb injuries treated at eight academic trauma centers provided objective observational outcome data relative to limb salvage and amputation. One hundred and forty-nine underwent lower-extremity amputation during the course of their care. This ongoing study is providing a realistic understanding of the less-than-favorable results associated with both limb salvage and amputation. Much of what has been learned from LEAP can be applied to the care of patients with a nontraumatic amputation.

A reasonable functional goal should be established before an extremity amputation is performed. The goals for a young individual who is going to reenter the workforce after a traumatic amputation are very different from those for an elderly debilitated patient with diabetes who has a limited life expectancy. Before surgery is performed, four issues need to be addressed, in order to create a needs assessment:

1. If the limb is salvaged, will the functional outcome be better than it would be after an amputation and fitting of a prosthetic limb? This question needs to be addressed regardless of whether the patient has a mutilating limb injury, a diabetic foot infection, a tumor, or a congenital anomaly.

2. What is a realistic expectation following treatment? The realistic expected functional outcome is the average functional outcome for patients with the same comorbidities and level of amputation; it is not the best possible outcome.

3. What is the cost of care? This cost goes beyond resource consumption. Can the patient and his or her family afford the multiple operations and the time off from work necessary to accomplish limb salvage, or are they best served by amputation and fitting of a prosthetic limb?

4. What are the risks? Limb-salvage surgery for any diagnosis is riskier than an amputation. When a patient has had an infection in an ischemic limb, the risk of recurrent in-

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fection and sepsis is far lower when the limb is removed than when it is retained.

Once these issues have been addressed, the patient and the surgical team generally have sufficient data to support the decision-making process.

When performing an amputation as a reconstructive effort after trauma, infection, tumor, or vascular insufficiency, one should strive to create:

1. Optimal residual limb length without osseous prominences.

2. Reasonable function in the joint proximal to the level of the amputation to enhance prosthetic function.

3. A durable soft-tissue envelope. Although new prosthetic technology allows compensation for a suboptimal soft-tissue envelope, it is well accepted that amputees fare better with a durable soft-tissue envelope and fare worse when the skin is adherent to bone or there is a split-thickness skin graft in areas of high pressure or shear[2,3]. Therefore, muscles should be secured to bone to prevent retraction. When possible, full-thickness myocutaneous flaps should be used, with muscle cushioning in areas of high pressure and shear (Figs. 1-A through 1-D).

Disarticulation Compared with Transosseous Amputation

The more distal the level of lower-extremity amputation, the better the walking independence and functional outcome, unless the quality of the residual limb creates so much discomfort that it negates the potential benefits of limb-length retention. Therefore, the amputation should be done at the most distal level that will result in a functional residual limb. Efforts to create a functional residual limb should take into account the method of weight-bearing (load transfer) and the tissues available to create a soft-tissue envelope.

The best residual limb cannot duplicate the unique weight-bearing properties of a normal foot. The foot has multiple bones and articulations that function as a shock absorber at heel strike, a stable platform during stance phase, and a "starting block" for stability at push-off. The multiple bones and joints allow positioning of the durable plantar soft-tissue envelope in an optimal orientation for accepting load. An amputee has, in place of a foot, a residual limb that must tolerate weight-bearing (load transfer) with the socket of a prosthesis.

When the amputation is through a joint (disarticulation), the load transfer can be accomplished directly; i.e., there is end-bearing. When the amputation is done through the bone (transosseous), the load transfer must be accomplished indirectly by the entire residual limb, through a total-contact socket of the prosthesis, as weight-bearing on the end of the residual limb is too painful. Disarticulation allows dissipation of the load over a large surface area of less stiff metaphyseal bone. With a well-constructed soft-tissue envelope to cushion the residual osseous platform, the direct-transfer prosthetic socket need only suspend the prosthesis. This differs from transosseous amputation at the transtibial or transfemoral level, where the surface area of the end of the bone is small and the diaphyseal bone is less resilient. The end of the bone must be "unweighted" by dissipating the load over the entire surface of the residual limb. This indirect load transfer requires a durable and mobile soft-tissue envelope that can tolerate the shearing forces associated with weight-bearing. The socket fit becomes crucial. When a patient loses weight the residual limb tends to bottom out, and painful end-bearing or tissue breakdown develops. Patients who gain weight are not able to fit the limb into the prosthesis. The choice of disarticulation or transosseous amputation must be individualized for each patient.

Transtibial (Below-the-Knee) Amputation

The standard transtibial prosthetic socket is fabricated with the knee in approximately 10° of flexion, in order to unload the distal part of the tibia and optimally distribute the load. Load transfer is accomplished by distributing the load over the entire surface area of the residual limb, with a concentration over the anterior-medial and anterior-lateral areas of the tibial metaphysis.

Mutilating limb injuries frequently disrupt the interosseous membrane, disengaging the relationship between the tibia and fibula. This loss of integrity of the interosseous membrane prevents the fibula from participating in normal load transfer. In other situations, the residual fibula may become unstable following transtibial amputation because of loss of the integrity of the interosseous membrane or as a result of loss of the integrity of the proximal tibiofibular joint even without an obvious traumatic disruption.

Individuals with instability of the residual fibula following transtibial amputation can have pain due to several causes. When the residual limb is compressed within the prosthetic socket, the residual fibula may angulate toward the tibia with prolonged weight-bearing. The result is a conical, pointed residual limb, which tends to bottom-out during prolonged weight-bearing. The conical residual limb acts as a wedge, leading to painful end-bearing and soft-tissue breakdown over the terminal tibia. When the residual limb is short, or the interosseous membrane has been disrupted, the residual fibula can be abducted as a result of unopposed action of the biceps femoris muscle (Fig. 2)[4,5]. These alterations of the load-bearing platform become accentuated in younger, more active amputees, with higher demand, or with prolonged activities[6,7].

During World War I, Ertl proposed the creation of an osteoperiosteal tube, derived mostly from tibial periosteum, and affixing it to the fibula to create a stable residual limb[8]. Following World War II, his concept was successfully introduced in the United States by Loon[4], Deffer[9], and others[10]. Arthrodesis, or bone-bridging, of the distal parts of the tibia and fibula has recently become a controversial topic, with both ardent supporters and strong detrac-

Fig. 1-A

Fig. 1-B

Fig. 1-A Photograph made at the time that a young, active male patient first returned to the operating room following a traumatic amputation. **Fig. 1-B** The remaining gastrocnemius muscle was used to create a cushioned soft-tissue envelope. The skin was degloved and did not survive.

tors. Recent investigations suggest that the technique may provide a potential benefit for an active amputee by creating a stable platform with an enhanced surface area for load transfer[5,11,12] (Figs. 3-A and 3-B). Most supporters suggest that the technique should be reserved for younger, more active amputees who will benefit from the potentially enhanced functional residual limb and are more able to tolerate the increased morbidity risk associated with the additional surgery necessary to obtain the bone bridge.

The surgery can also be performed as a late reconstruction for active amputees with residual limb pain that appears to be associated with an unstable or disengaged residual fibula. These patients may have a conical end-bearing residual limb, usually with pain at the end of the residual limb and occasionally with tissue breakdown. Others may have pain along a prominent or unstable fibula. On examination, the fibula usually can be felt to be unstable.

The operation involves use of a long posterior myocutaneous flap. For the average 6-ft (1.8-m)-tall patient, the optimal residual tibial length should be a minimum of 10 to 12 cm in order to create an adequate weight-bearing platform, but it should not be longer than 15 to 18 cm. (An excessively long residual limb requires the prosthetic socket to be put into full extension. This leads to increased distal pressure, increased end-bearing, and more stump failures.) The fibula is divided 4 cm distal to the tibia to allow the creation of the bone bridge. Care is taken to maintain as many muscular attachments to the distal aspect of the fibula as possible. One centimeter of the fibula is removed at the level of the distal tibial cut to allow rotation of the vascularized bone. A notch is made in the lateral cortex of the residual tibia to accept the rotated fibular segment. Stability can be obtained by suturing the fibular segment through drill-holes, or with screw fixation (Fig. 3-B).

The transferred fibular segment used between the distal parts of the fibula and tibia can be supplemented with a vascularized periosteal sleeve taken from the tibia, as described by Ertl[8]. The periosteum on the anterior surface of the tibia, which is quite thick, is raised from the tibia distal to the level of the tibial transection. When the periosteum

Fig. 1-C

Fig. 1-D

Fig. 1-C Following the use of vacuum-assisted wound management, there was an adequate base for split-thickness skin-grafting. **Fig. 1-D** The residual limb at eighteen months following the injury. The patient used a silicone suspension liner within the prosthetic socket in order to compensate for the split-thickness skin graft over the residual anterior aspect of the tibia.

is raised, it is important to keep it attached proximally and to take a thin slice of cortical bone with it. This almost guarantees that the periosteum obtained has maintained its vascular supply. A 1-in (2.5-cm) osteotome is used to raise the periosteum and the thin slice of cortical bone. The periosteal sleeve is sutured over the rotated fibular segment. The periosteal graft alone has also been used in place of the fibula, but we have no experience with that technique and do not recommend it.

The anterior aspect of the distal surface of the tibia is beveled, and a durable full-thickness myocutaneous flap is repaired to the anterior aspect of the tibia through drill holes or by suturing the posterior gastrocnemius fascia to the anterior periosteum of the residual tibia and the anterior compartment fascia.

When the surgery is performed as a late reconstruction or if there is no distal part of the fibula with which to create the bone bridge, a tricortical iliac crest bone graft is wedged between the terminal residual tibia and fibula after the inner surfaces of both have been prepared with a burr (Figs. 4-A, 4-B, and 4-C).

Postoperative Care

A rigid plaster dressing is applied to protect the residual limb and to control postoperative swelling. Another option is to use elastic bandages for a compressive dressing, but these need to be put on carefully so as not to produce a pressure sore. This is especially important when a patient has a peripheral neuropathy. Our experience has been that if the patient has pain at the end of the stump or in the stump shortly after surgery it is due to a local problem and the dressing needs to be changed, but pain that seems to be in the distal, amputated part of the limb is the so-called phantom-limb phenomenon. Phantom sensation is a normal response after an amputation that usually resolves. Telling the patient before the surgery that they will have phantom sensations tends to decrease anxiety about this phenomenon.

Weight-bearing with a temporary prosthesis is initiated when the residual limb appears capable of tolerating weight-bearing. Pain with weight-bearing lasts longer for patients who have had a bone-bridge reconstruction than it does for those without a bone bridge. The pain may last for six to nine months and seems to resolve as the bone bridge heals. It is assumed that the site of healing between the fibula and tibia remains tender until the bone becomes solid. The pain should be treated nonoperatively unless there is a sign of inadequate placement of the graft or sutures. Usually, the patient can be fitted for a prosthesis, but he or she may not be able to bear full weight until the tenderness resolves.

Skin Flap for Transtibial (Below-the-Knee) Amputation

Load transfer following transtibial am-

Fig. 2

Anteroposterior and lateral plain radiographs of a patient with an unstable fibula due to disruption of the interosseous membrane by a transtibial amputation. The short unstable fibula is not able to serve as an efficient platform for weight-bearing. The abducted residual distal part of the fibula also creates an osseous prominence that interferes with prosthetic limb fitting. (Reprinted, with permission, from: Pinzur MS, Pinto MA, Schon LC, Smith DG. Controversies in amputation surgery. Instr Course Lect. 2003;52:448.)

putation appears to be enhanced when the residual limb has a large osseous surface area covered with a durable soft-tissue envelope composed of a well-cushioned mobile muscle mass and full-thickness skin. This desired result is best achieved through use of a long posterior myofasciocutaneous flap. Despite the fact that the standard posterior flap for transtibial amputation is satisfactory for most patients, retraction of the flap over time can lead to a troublesome pressure point overlying the anterior aspect of the distal part of the residual tibia. The standard transtibial amputation technique, popularized by Burgess et al., often places the surgical incision directly over that portion of the residual tibia[13]. This raises the potential for adherent scarring of the skin to that part of the tibia or for inadequate cushioning of this region during weight-bearing. When the anterior aspect of the distal part of the residual tibia is not sufficiently padded, there is an increased likelihood of localized discomfort, blistering, or tissue breakdown associated with the normal pistoning that occurs between the re-

Fig. 3-A

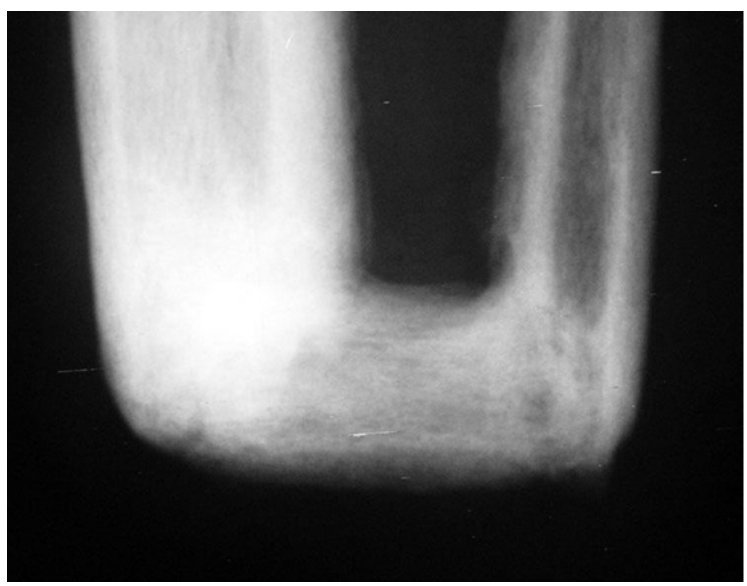

Fig. 3-B

Fig. 3-A This patient was able to stand directly on the residual limb because he had a stable platform for weight-bearing following the creation of an Ertl bone bridge between the distal parts of the tibia and fibula. (Reprinted, with permission, from: Pinzur MS, Pinto MA, Schon LC, Smith DG. Controversies in amputation surgery. Instr Course Lect. 2003;52:449.) **Fig. 3-B** Radiograph made one year following the creation of the bone bridge.

sidual limb and the prosthetic socket during normal walking. An extended posterior flap appears to prevent these potential morbidities by providing improved cushioning and comfort even for individuals who are capable of only limited activity[14]. The encouraging results of this relatively simple modification support the well-accepted notion that an optimal residual limb should be composed of a sufficient osseous platform and a durable and cushioned soft-tissue envelope[11].

The extended posterior flap is created by increasing the length of the standard posterior flap by several centimeters (Figs. 5-A and 5-B). The posterior myocutaneous flap is created and the osseous cuts are performed in the traditional manner. The myocutaneous flap is generally created from the gastrocnemius muscle and overlying skin, with removal of the soleus muscle belly in all but very thin patients. Care is taken in the handling of the transected nerves to avoid the development of sensitive, painful neuromas. It is advised to avoid clamping of the nerves prior to transection in order to avoid the pain so frequently encountered following crushing injuries. The nerves should be dissected proximal to the level of the bone transection, with use of gentle traction with a sponge, and then they are transected with a fresh scalpel blade. This allows the inevitable terminal neuroma to be cushioned within bulky muscle. To avoid a bulbous stump, the posterior and lateral compartment muscles (except the gastrocnemius) should be transected at the level of the transected tibia. Anterior skin is removed to allow proximal attachment of the muscle flap and proximal placement of the wound scar. A myodesis of the posterior muscle flap to the tibia can be performed through drill holes. The posterior gastrocnemius fascia is secured to the transected anterior compartment fascia and tibial periosteum with horizontal mattress sutures (Figs. 6-A and 6-B). A rigid plaster dressing is applied, and prosthetic fitting is initiated when the residual limb appears capable of weight-bearing.

Transfemoral (Above-the-Knee) Amputation

Transfemoral amputation is performed less frequently than in the past, but it is still necessary in some patients with severe vascular disease, a neoplasm, infection, or trauma in whom reconstruction at a more distal level is not feasible[15,16]. The energy expenditure for walking, even on a level surface, by an individual with a transfemoral amputation has been shown to be as much as 65% greater than that for similar, able-bodied individuals[17,18]. Energy expenditure can be minimized by a properly performed above-the-knee amputation.

The anatomical alignment of the lower limb has been well defined. The

Fig. 4-A

Fig. 4-B

Fig. 4-C

Fig. 4-A An active patient with a transtibial amputation complained of pain in the distal part of the residual limb after prolonged activity. The conical shape of the residual limb allowed it to wedge into the prosthetic socket, creating painful end-bearing. **Fig. 4-B** Radiograph made one year after a successful bone-bridge procedure with a tricortical iliac crest bone graft placed between the fibula and tibia. **Fig. 4-C** The more square shape of the residual limb created an excellent platform for load transmission. The residual limb no longer bottomed out in the prosthesis, providing better comfort with weight-bearing.

mechanical axis lies on a line from the center of the femoral head through the center of the knee to the center of the ankle. In normal two-limbed stance, this axis measures 3° from the vertical axis and the femoral shaft axis measures 9° from the vertical axis[19]. The femur is normally oriented in relative adduction, which allows the hip stabilizers (the gluteus medius and minimus) and abductors (the gluteus medius and the tensor fasciae latae) to act on it to reduce the lateral motion of the center of mass of the body, producing an energy-efficient gait (Fig. 7).

In most individuals who have undergone a transfemoral amputation, the mechanical and anatomical alignment is altered as a result of disruption of the adductor magnus insertion at the adductor tubercle and the distal part of the linea aspera[20]. This allows the residual femur to drift into abduction as a result of the unopposed action of the hip abductors. Many patients who have undergone a transfemoral amputation encounter difficulties with prosthetic fitting due to inadequate muscle stabilization at the time of the amputation[21]. The unstable femur disrupts the relationship between the anatomical and mechanical axes of the limb. The abductor lurch, so common after transfemoral amputation, is a consequence of the unopposed action of the intact hip abductors. This dynamic deformity overcomes the capacity of even modern prostheses to compensate.

Traditional transfemoral amputation is done by suturing the femur flexors to the extensors—i.e., creating a myoplasty—while ignoring the adductors that contribute to stability of the residual femur[22]. When the adductors are not anchored to bone, the hip abductors are able to act unopposed, producing a dynamic flexion-abduction deformity. This deformity prepositions the femur in an orientation that is not conducive to efficient walking[23,24]. The retracted adductor muscles lead to a poorly cushioning soft-tissue envelope, further complicating prosthetic fitting[25].

The cross-sectional area of the adductor magnus is three to four times larger than that of the adductor longus and brevis combined. It has a moment arm with the best mechanical advantage. Transection of the adductor magnus at the time of amputation leads to substantial loss of cross-sectional area, a reduction in the effective moment arm, and loss of up to 70% of the adductor pull[20,25]. This results in overall weakness of the adductor force of the thigh and subsequent abduction of the residual femur (Fig. 7). The decrease in overall limb strength is due to (1) a reduction in muscle mass at the time of the amputation, (2) inadequate mechanical fixation of the remaining muscles, and (3)

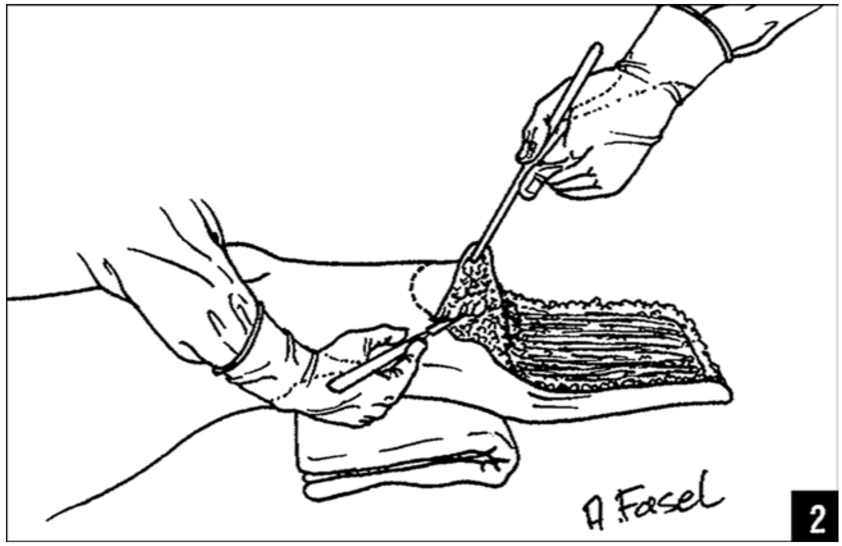

Fig. 5-A

Figs. 5-A and 5-B Artist's drawings of the extended posterior myocutaneous flap. (Reprinted, with permission, from: Assal M, Blanck R, Smith DG. Extended posterior flap for transtibial amputation. Orthopedics. 2005;28:544.) **Fig. 5-A** The long posterior flap is several centimeters longer than the traditional posterior flap.

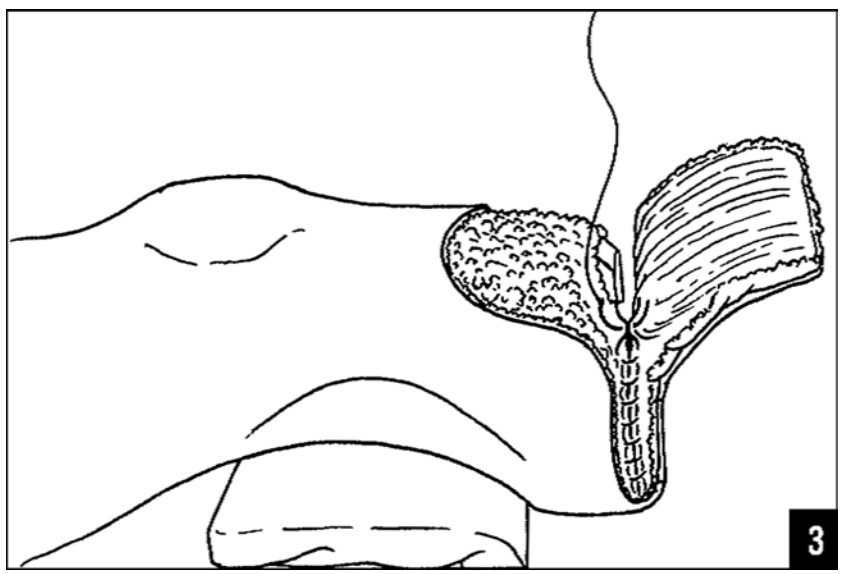

Fig. 5-B

A corresponding amount of proximal skin is removed to advance the suture line proximal to the anterior aspect of the distal tibial region.

Fig. 6-A

Fig. 6-B

The appearance of an extended posterior flap immediately after closure. The bulbous end will shrink and smooth contours will develop with time.

atrophy of the remaining muscles[26,27].

Magnetic resonance imaging has demonstrated a 40% to 60% decrease in muscle bulk after a traumatic transfemoral amputation. Most of the atrophy is in the adductor and hamstring muscles, whereas the intact hip abductors and flexors show smaller changes, ranging from 0% to 30%[28,29]. As much as 70% atrophy of the adductor magnus has been found. The amount of atrophy correlates with the length of the residual limb, and this atrophy is most likely due to loss of the muscle insertion.

Electromyographic studies of residual limbs following transfemoral amputation have revealed normal muscle phasic activity; however, the active period of the retained muscles appears to be prolonged[29]. The electrical activity of sectioned muscles varies, depending on whether the muscles have been reanchored and on the length of the residual femur. Furthermore, asymmetric gait has been related to residual limb length, and lateral bending of the trunk has been correlated directly with atrophy of the hip stabilizing muscles[30].

All of these findings indicate the need to preserve the hip adductors and hamstrings. Preservation of a functional adductor magnus helps to maintain the muscle balance between the adductors and abductors by allowing the adductor magnus to maintain its power and retain the mechanical advantage for positioning the femur. Preservation is best accomplished with a myodesis. The patient is positioned supine with a sandbag under the buttocks to avoid performing the myodesis with the hip in a flexed position and

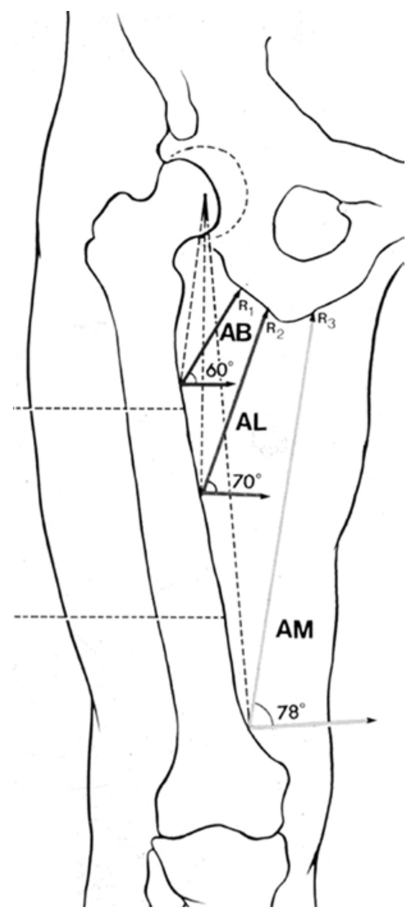

Fig. 7

Diagram of the resultant forces of the adductor muscles. The relative insertion sites of the abductors are indicated. The shorter the residual femur, the weaker the limb. AB = adductor brevis muscle, AL = adductor longus muscle, and AM = adductor magnus muscle.

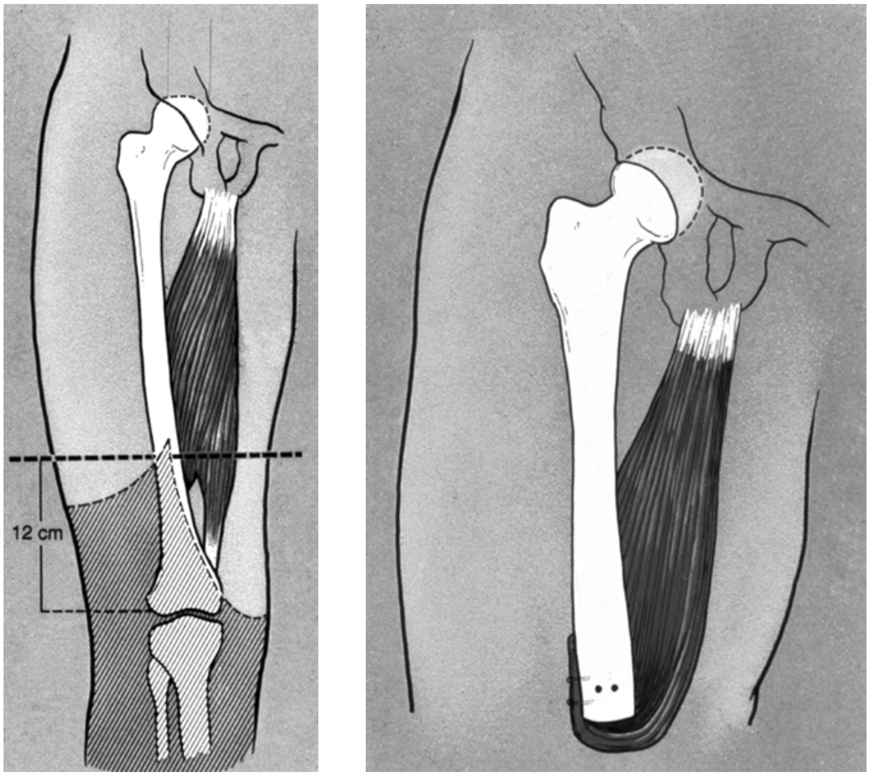

Fig. 8-A Fig. 8-B

Figs. 8-A and 8-B Adductor myodesis method of transfemoral amputation. (Reprinted, with permission, from: Gottschalk F. Transfemoral amputation: surgical management. In: Smith DG, Michael JW, Bowker JH, editors. Atlas of amputations and limb deficiencies. 3rd ed. Rosemont, IL: American Academy of Orthopaedic Surgeons; 2004. p 537-8.) **Fig. 8-A** Skin flaps and proposed bone cut. The osseous transection is optimally created at 5 in (12.5 cm) proximal to the knee joint, but it can be more proximal if necessary. **Fig. 8-B** The adductor magnus tendon is secured to the residual femur through drill-holes in the lateral cortex.

thus producing an iatrogenic hip flexion contracture. A tourniquet is generally not necessary for patients with peripheral vascular disease. Depending on the size of the patient, a standard, or a sterile, tourniquet can be used when the transfemoral amputation is being performed because of a traumatic injury or a tumor and normal femoral vessels can be expected.

Equal anterior and posterior flaps should be avoided, as such flaps place the suture line under the end of the residual limb, making prosthetic fitting more difficult and adequate muscular padding less likely. A long medial-based myofasciocutaneous flap is dependent on the vascular supply from the obturator artery, which generally has less severe vascular disease and is thus preferred (Figs. 8-A and 8-B)[31]. The flap configuration may need to be modified, in order to preserve residual limb length, when an amputation is done after trauma or because of neoplastic disease. The tendon of the adductor magnus is detached. The femoral vessels are identified in Hunter's canal and are ligated. The major nerves should be dissected 2 to 4 cm proximal to the proposed bone cut, gently retracted, and sectioned with a new sharp blade. The quadriceps is detached just proximal to the patella, with retention of some of its tendinous portion. The smaller muscles, including the sartorius and gracilis and the more posterior group of hamstrings (biceps femoris, semitendinosus, and semimembranosus) should be transected 2 to 2.5 cm longer than the proposed bone cut to facilitate the anchoring of those muscles in bone.

The femur is then transected with an oscillating power saw 12 to 14 cm proximal to the knee joint to allow sufficient space for the prosthetic knee joint. Drill-holes are made in the distal end of the femur to anchor the transected muscles. The adductor magnus is attached to the lateral cortex of the femur while the femur is held in maximum adduction. This allows appropriate tensioning of the anchored muscle. The hip is positioned in extension for reattachment of the quadriceps to the posterior part of the femur, and the remaining hamstrings are anchored to the posterior area of the adductor magnus or the quadriceps[32].

Postoperative Care

A soft compression dressing with a "mini-spica" wrap above the pelvis is used in the early postoperative period. Because the residual limb is relatively short, it is difficult to maintain a rigid plaster dressing. Range-of-motion exercises and early walking are encouraged. Preparatory prosthetic fitting can be initiated as soon as the residual limb appears capable of accepting the load associated with weight-bearing. This varies with individual patients and the experience of the rehabilitation team.

Overview

In conclusion, an amputation should be considered the first step in the rehabilitation of a patient for whom reconstruction of a functional limb is not possible. Care should be taken to create a residual limb that can optimally interact with a prosthetic socket to create a residual limb-prosthetic socket relationship capable of substituting for the highly adaptive end organ of weight-bearing. A well-motivated patient in whom the amputation is done well and who is taught how to use the prosthesis will be able to return to most activities.

Michael S. Pinzur, MD
Department of Orthopaedic Surgery and Rehabilitation, Loyola University Medical Center,

2160 South First Avenue, Maywood, IL 60153. E-mail address: mpinzu1@lumc.edu

Frank A. Gottschalk, MD
Department of Orthopaedic Surgery, University of Texas Southwestern, 5323 Harry Hines Boulevard, Dallas, TX 75390

Marco Antonio Guedes de S. Pinto, MD
Centro Marian Weiss, Rua Mourato Coelho 1417, Vila Madalena 05417-012, Sao Paulo, Brazil

Douglas G. Smith, MD
Department of Orthopaedic Surgery, University of Washington Medical Center, Harborview Medical Center, 325 9th Avenue, Box 359798, Seattle, WA 98104

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