Chapter 4

REHABILITATION OF THE LOWER LIMB AMPUTEE

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INTRODUCTION

The care of war injured amputees is a major problem facing any army during wartime. Historically, amputations are a very common consequence of modern warfare. In the civilian setting, the primary cause of leg amputations is vascular disease,[1] accounting for 93% of amputations. Other causes include trauma, malignancy, and congenital amputations. The devastating trauma suffered during armed conflicts results in substantial numbers of traumatic upper and lower extremity (LE) amputees.

During the Civil War, 3 million troops were mobilized and 20,993 major amputations were documented in the Union Army. Of these amputations, there were 8,518 upper extremity and 12,475 LE amputations.[2]

The official statistics for World War II, covering the period between 1 January 1942 and 31 March 1946, indicate that 14,912 amputees were treated in the Zone of the Interior (the continental United States). These figures do not reflect those casualties who died overseas, or the nondisabling toe amputations that did not preclude continued military service. There were 10,620 amputations of the lower limb, of which 870 were bilateral amputations. The majority of the leg amputations were at the below-knee level.[2]

During World War II, because of the enormous numbers of amputees, the United States military established five "amputation centers" at ports of debarkation. The major center was at Walter Reed General Hospital (currently Walter Reed Army Medical Center), in Washington, DC. Training of medical officers, therapists, and prosthetists was vigorously pursued to ensure that healthcare providers were up-to-date in procedures used in caring for amputee soldiers. Even with substantial resources dedicated to amputees, additional development of prosthetic technology was required to best meet soldiers' needs. To refine and develop prosthesis construction, civilian consultants were used. Because the army was responsible for definitive prosthetic fabrication in World War II, contracts were established with companies for purchasing large quantities of prosthetic devices.[3]

In April 1943, the U.S. Army Surgeon General directed that all amputees be transferred "as soon as possible" to designated amputation centers. The original five army amputation centers (Bushnell General Hospital in Brigham City, Utah; Lawson General Hospital in Atlanta, Georgia; McCloskey General Hospital in Temple, Texas; Percy Jones General Hospital in Battle Creek, Michigan; and Walter Reed General Hospital in Washington, DC) were not adequate to meet the treatment needs of the many amputees sustained in such a long and protracted global war. By 1944, it was clear that the original amputation centers could not handle the enormous workload. This was particularly true after the intense fighting in Europe during the winter of 1944–1945. Because U.S. Army hospitals were responsible for the amputee's full rehabilitation, long military hospital stays were required; therefore, two additional army amputee centers were established: Thomas M. England General Hospital in Atlantic City, New Jersey; and McGuire General Hospital in Richmond, Virginia. Each hospital had its own prosthetic shop with trained prosthetists. In order to educate these "orthopedic mechanics" (prosthetists), 3-month training courses were established. Amputee servicemen, themselves, were sometimes trained as prosthetists and utilized in the limb fabrication shops.[3]

The Army Surgeon General was insistent that extreme care be exercised to ensure that the fittings of prostheses were entirely satisfactory and that each amputee be taught to use his prosthesis competently before his discharge.[3]

That considerable numbers of amputees required care at a continental military hospital was illustrated during the Vietnam War, when between May 1966 and May 1969,[4] Fitzsimons General Hospital in Colorado, treated over 500 casualties with major amputations. Of these 500 patients, 342 sustained loss of an LE, with 44 of those 342 losing parts of both lower limbs.

Even a brief conflict can produce a substantial number of amputees requiring rehabilitation. The relatively short Persian Gulf War in 1991 resulted in a single medical center (Walter Reed Army Medical Center, Washington, DC) receiving 14 amputees for rehabilitation.[5] These casualties frequently sustained comorbid conditions, such as peripheral nerve injuries, which complicated functional restoration.

Intense wars produce tremendous numbers of traumatic amputations in distributions much different from those seen in the civilian world. For this reason, amputee care in the military must remain at the forefront of technology, maintaining its readiness to assume the full care of an amputee soldier. This requires the establishment of designated ma-

jor medical centers with organized multidisciplinary rehabilitation services that would initially be directed by the primary surgeon, then by a military physiatrist. The World War II rehabilitation system, with designated amputee centers, provides a model for optimal present day military amputee care. Rehabilitation services at major military hospitals with modern prosthetic laboratories, expert prosthetists, physiatrists, occupational therapists, physical therapists, psychologists, and social workers, are best suited to meet the specific needs of the individual amputee soldier. Early temporary prostheses and definitive state-of-the-art prosthetic devices must be available to the amputee for full rehabilitation to occur. Early weight bearing, using temporary prostheses, was found to be quite beneficial to amputees. In fact, during World War I, the Belgian Army Medical Corps demonstrated that early weight bearing improved circulation, hastened stump shrinkage, and prevented muscle atrophy and contractures.[6] Waiting until the casualty transfers to a Veterans Affairs (VA) hospital to institute rehabilitation and prosthetic training yields suboptimal care; if rehabilitation has not already begun by the time casualties reach a VA hospital, contractures will develop and deconditioning will occur. These conditions make full functional restoration difficult.

In summary, military medical centers must be able to accommodate many amputees, initiate rehabilitation, and provide temporary prostheses and state-of-the-art permanent prostheses. To maximize the functional potential of the soldier, the amputee must be the center of a well-coordinated, interdisciplinary rehabilitation effort. This chapter addresses such an approach.

MANAGEMENT OF NEW AMPUTEES

Management of the soldier with a traumatically injured extremity initially begins with resuscitation measures. Life threatening injuries need to be evaluated and the soldier must be stabilized. Once the soldier is stabilized, attention may be directed toward the traumatized extremity. Thorough debridement of devitalized tissues should be performed by surgeons in the operating room. Necrotic muscle left in the wound is a good medium for bacterial growth and subsequent infection. Furthermore, necrotic muscle may result in severe myoglobinuria and subsequent renal failure.[7] Initial evaluation by an experienced orthopedic and vascular surgeon is preferable. Further testing may be needed, such as radiographic and vascular studies. The surgical team can then decide to proceed with limb salvage or amputation.

Limb Salvage vs Amputation

With advances in both vascular and orthopedic reconstructive surgery, limb salvage has become an option for limbs that previously would have been amputated. Today, the surgical team must decide whether to attempt limb salvage or perform amputation. The main goal of treatment is to provide the optimum functional result—physically, cosmetically, and psychologically. Limb salvage may not provide the best functional outcome. Saving an insensate, paralyzed limb may be considered a failure when compared to an optimal residual limb with a prosthetic device. Additionally, limb salvage may be emotionally taxing and require longer hospital stays than a primary amputation.[8] Furthermore, individuals may have limitations of mobility and function despite limb salvage. However, a prosthetic limb is not a substitute for a sensate limb with residual motor function.[9] Hence, the goal should be limb salvage, providing that the salvaged limb is more functional than a prosthetic replacement.

The decision as to when to amputate or when to attempt limb salvage remains controversial. General concepts and scales (presented below) developed to aid in this decision remain subjective and controversial. Additionally, the military environment and tactical needs of the unit pose further problems related to surgical options and must be considered in the surgical decision. For the most part, combat wounded amputees present with completely amputated limbs, which the surgeon then debrides and provides hemostasis (Figures 4-1 and 4-2).

In examining the traumatized limb, the limb may be divided into skin, bone, muscle, nerve, and vascular components. If three of the above five components are destroyed beyond repair, then amputation should be considered. Enough viable skin is needed to provide eventual wound coverage. Myocutaneous flaps, free skin grafting, and porcine heterografts may be options when insufficient skin is present. After thorough debridement, evaluation of the amount of musculature remaining needs to be determined in reference to functional use of the limb. Tendon repairs may be performed, but they require immobilization and skin coverage. Fractures will need to be evaluated in terms of status of blood supply to the fracture, joint injury, limb shortening,

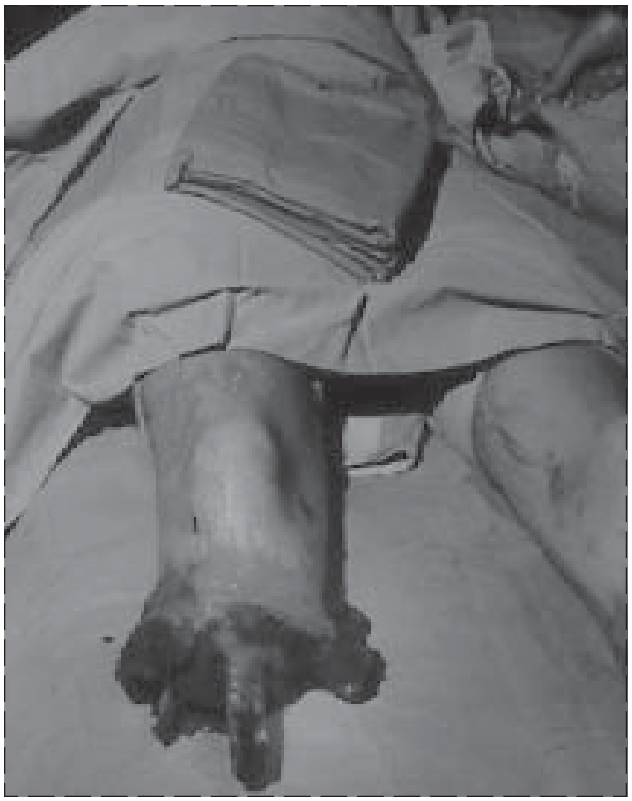


Fig. 4-1. This injury was caused by a Claymore mine. Note the extensive soft tissue damage and the resulting exposure of the tibia and fibula. A high below-knee amputation was performed. However, given the paucity of soft tissue, a knee disarticulation or even a low above-knee amputation would have been options.

and ability to achieve fixation.[7] External fixation of bone should be performed early, before vascular repair, to prevent further soft tissue or vascular damage.[7,8]

Nerve status must be evaluated to establish the degree of nerve injury—neurapraxia, axonotmesis, or neurotmesis. A poorer prognosis exists for nerve recovery in the case of neurotmesis, with better outcomes for axonotmesis. Results from microfascicular nerve repair has been disappointing. Also, nerve recovery in an LE is poor compared to that in an upper extremity. Both venous and arterial damage need to be assessed. A variety of vascular reconstructive procedures may be performed, depending on the injured structures and potential graft sources. Usually, amputation for vascular damage alone is not indicated except when warm ischemia lasts more than 6 hours.[7] Hence, flow should be reestablished before 6 hours has elapsed. Mechanism of injury, interval from injury to treatment, and degree of wound contamination are important factors in the decision process; however, when applied to the individual patient, these general concepts do not necessarily take into account all factors in the decision process. Furthermore, the concepts are dependent on the subjective interpretations and experience of the surgeon. For these reasons, scales to assist the surgeon have been developed.

The Mangled Extremity Syndrome Index (MESI)[10] was developed to aid decision making for limb salvage vs amputation. If 3 of 4 organ or tissue systems are significantly injured, the scale classifies an extremity as mangled. The systems are skin, nerve, vascular, and bone. The scale takes into account severity of general injuries, shock, age, preexisting disease, skin, nerve, vascular supply, bone, and time postinjury greater than 6 hours. Retrospectively, 7 of 17 casualties with an MESI less than 20 had limb salvage success. The other 10 with MESIs greater than 20 eventually had to have amputation. Average hospital stays for patients with salvaged limbs vs those with primary amputation were 75 and 36 days, respectively.[10]

Lange and associates[11] evaluated 23 cases retrospectively with Type IIIC tibial fractures (a Type IIIC tibial fracture is an open fracture with concomitant arterial injury) and concluded *absolute* indications for amputation were anatomic complete disruption of the posterior tibial nerve and crush injuries with

Fig. 4-2. This is a forefoot amputation of the type that typically results from the detonation of a buried antipersonnel mine. There was insufficient viable plantar skin to allow reconstruction as a Syme's amputation at the ankle joint. A below-knee amputation was performed.

warm ischemia for longer than than 6 hours. *Relative* indications for amputation were associated serious polytrauma, severe ipsilateral foot trauma, and an anticipated protracted course of treatment to obtain soft tissue coverage and tibial reconstitution. The presence of 2 to 3 relative indicators was considered to be justification for amputation as opposed to salvage.[11] In addition to the small sample size (23) and retrospective design, the study was criticized for the indicators being subjective and requiring substantial experience on the part of the surgeons.[8]

Another scoring system for Type IIIC tibial fractures has been developed based on a modification of the MESI.[12] This score is based on the mechanism of injury to the musculoskeletal system, degree of shock, degree of ischemia, ischemia greater than 6 hours, and patient age. Those with scores greater than seven had to undergo amputation.

Despite the scales and general concepts, there is currently no definitive method for objective determination of whether a patient should undergo limb salvage or primary amputation.[8] If feasible, a multispecialty surgical team with experience in both limb salvage and amputations should be consulted. Additionally, the patient should be included in the decision process, and a visit by an amputee may be helpful. A physiatrist is a valuable member in the decision process because of the physiatrist's expertise in function, especially with amputations complicated by other musculoskeletal or neurologic injuries elsewhere in the body.

Amputation

The trauma and treatment before amputation usually determines the level of amputation or, in the case of an already amputated limb, reamputation (revision).[13] In selecting the level, attention must be given to providing the best functional outcome. Improved function is usually associated with levels that require less energy consumption. Additionally, preserving joints is beneficial secondary to their mechanical advantages and preservation of proprioception. More proximal amputations are associated with increased energy consumption and sacrifice of the benefits from retained joints. Hence, preservation of limb length is functionally beneficial.

Functionally, the better amputation levels in order of preference are transmetatarsal, Syme's, below-knee, knee disarticulation, above-knee, hip disarticulation, and hemipelvectomy.[14] Advantages of the knee disarticulation are improved weight bearing distally and improved prosthetic control. In the past, prosthetic components for a knee disarticulation were a problem. However, newer components, especially in knee designs, have solved the prior disadvantage. The Lisfranc's (tarsometatarsal) and Chopart's (tarsotarsal) amputations may be the exception to improved outcome with preserving length. In many cases, these amputations have the disadvantage of developing equinus deformities, thus prohibiting optimal prosthetic fitting[14]; performing these amputation levels yields suboptimal results.

In the battlefield environment, there may be delays in seeing a wounded soldier, and the wounds may be grossly contaminated. The combination of delayed surgical treatment and grossly contaminated wounds has rendered the open circular amputation the method of choice.[15] Briefly, this technique consists of circular incision of layers, allowing each layer to retract before proceeding to the next layer. The procedure is then followed by continuous skin traction. Skin traction is maintained during transportation[6] and is very important in avoiding soft tissue retraction of the open amputation. If soft tissue retraction or skin retraction is allowed to occur, significant bone loss with revision is frequently necessary. This can lead to loss of function for the amputee and should be avoided. In the past, a common error was the early discontinuance of skin traction, which led to a sacrifice of limb length.[16] Skin traction should continue until the limb is ready for revision or has healed from secondary intention.

Some open amputations and unsuccessful limb salvage procedures require revision or definitive amputation, respectively. The definitive amputation procedure is performed on an elective basis. The procedure is directed toward healing, providing an optimum residual limb for prosthetic ambulation, and is viewed as a reconstructive procedure. The various procedures are described by the specific levels of amputation; however, general concepts should be followed.

During secondary closure, the skin should be closed without tension. The scar should be placed to avoid scar adhesion to bone and trauma from pressure points in the prosthesis. Bone should be beveled distally to prevent a sharp end from causing discomfort or soft tissue breakdown with prosthetic wear. Myodesis or myoplasty should be performed to provide better muscle balance and control of the residual limb[17]; this also provides soft tissue coverage distally by preventing muscle retraction. Nerves should be sharply divided under

tension, thereby facilitating retraction into healthy soft tissue. This prevents later irritation of the nerve endings by the prosthesis.[13]

Rehabilitation

Rehabilitation should begin as soon after the emergent amputation as possible. The main goal of rehabilitation is to prevent any complications of immobility while awaiting the definitive amputation procedure. Other goals include patient education, conditioning, functional training, and psychologic support.

The bedbound patient is at risk of developing myriad complications, such as deep vein thrombosis, pulmonary embolus, atelectasis, pneumonia, orthostatic hypotension, decubitus ulcers, loss of strength, osteopenia, and contractures.[18] These complications can often be prevented by early mobilization. The specific prevention strategies for many of these problems will be addressed in Chapter 12, Prevention of Medical Complications of Immobility Through Early Rehabilitation, in the second of this two-book series on rehabilitation. Problems specific to the amputee are the development of contractures and deconditioning. Contractures can seriously affect final outcome for the amputee. Proper bed positioning, with scheduled turnings, is necessary to prevent contractures.[18] Range-of-motion exercises should be performed four times daily.[14] To prevent deconditioning, the patient must follow a daily exercise program. A physical therapist may be helpful in exercise training, and early mobilization will help in strengthening, improving endurance, and preventing contractures.

Functional training should begin early, with a physical therapist in attendance. The patient is taught to independently transfer from bed to wheelchair and to use crutches. Once independent in these functions, the patient progresses to toilet transfers. Mobility training begins in the wheelchair or with crutches, depending on the functional level of the patient. Early mobilization, besides preventing complications of immobility, provides valuable preprosthetic training. Furthermore, independence in ambulation helps the patient's morale. Not being able to move from one room to another or to use the bathroom without assistance can be disheartening.

Independence should be further encouraged by training to enhance skills in activities of daily living (ADL), where dressing, eating, toileting, and showering are addressed. An occupational therapist will assess and teach these skills.

At the start of rehabilitation the patient is given information regarding the surgical, rehabilitation, and prosthetic training processes. Education becomes more specific as the patient progresses. Often, a meeting with a successful amputee is helpful to the new amputee.

The new amputee undergoes a grieving process and will need to adjust to an altered body image. Concerns of self identity, social acceptance, employment, and sexual function should be addressed. Patient education helps in the psychologic adjustment of the patient. Formal psychologic counseling is usually not required unless the patient's emotional status interferes with the rehabilitation process.[19] Also, early rehabilitation helps patient adjustment.

Postoperative rehabilitation begins after the definitive amputation procedure. The goals in this phase are wound healing, early limb maturation, prevention of complications of immobility, functional independence, and acquisition of a prosthesis. Postoperatively, wound healing and early limb maturation may be accomplished through the use of a nonremovable rigid dressing. The rigid dressing protects the wound, prevents the development of edema, and assists healing. The rigid dressing also provides for early maturation through edema control and shaping of the limb. The dressing is changed weekly. Usually, after the second week, the sutures are removed, and the rigid dressing is changed to a removable rigid dressing with a pylon and prosthetic foot (see Below-Knee Amputation section).

Gradual increase in weight bearing is begun, which allows early limb maturation and quicker fitting of a prosthesis. This is followed with gait training by a physical therapist. Experienced personnel educate the amputee in how to properly fit the removable rigid dressing with residual-limb socks and how to check the residual limb for signs of excessive weight bearing; proper limb hygiene is also taught.

Mobility and ADL training are continued to achieve the maximal functional result for the patient. The functional training should be specifically directed toward vocational and avocational goals, and the amputee should be referred to a vocational counselor for guidance regarding future vocational plans.

Once the residual limb volumes have become relatively stable, the limb is fitted with a temporary prosthesis. The amputee is evaluated in the prosthesis and then educated in proper prosthetic care and fitting. The independent amputee with a properly fitting prosthesis is discharged with close

follow-up. Thereafter, the amputee is followed on a regular basis indefinitely. During the first year after discharge, because of continued shrinkage of the residual limb, most new amputees require refitting of their prosthesis.

The use of immediate postoperative prosthetic fitting and a rehabilitation team concept has been shown to result in shorter hospital stays, more efficient rehabilitation, and a greater likelihood of ambulation.[20] A retrospective study[21] of 182 diabetic amputees revealed quicker healing and earlier prosthetic fitting when rigid dressings were used. Another study[22] demonstrated that only 4 of 238 lower limb amputees referred from a tertiary care hospital to a rehabilitation center had good enough residual limbs to allow preparatory prosthetic fitting. Many of the limbs were nonhealed, bulbous, edematous, infected, or dehised. Many amputees also had hip or knee (or both) flexion contractures greater than 15°.[22] These studies support the need for early comprehensive rehabilitation to prevent complications and to achieve a higher functional outcome. The physiatrist should be consulted early to plan and manage the rehabilitation program.

PARTIAL FOOT AND SYME'S AMPUTATIONS

The goal of surgical treatment is to remove as little tissue as possible while treating the limb injury. Partial foot amputations should be performed with a clear understanding of the potential functional outcome for the patient. Partial foot amputations are particularly problematic because of the rather poor quality of the arterial vascular system. As a general rule, the greater the anatomic loss of the foot, the more involved will be the rehabilitation and the prosthetic restoration.

The selection of the surgical level of amputation is probably one of the most important decisions that will be made. The viability of the soft tissues, as determined by skin bleeding at the time of surgery, will usually determine the most distal possible level for amputation. Sophisticated predictive techniques to optimize the level of amputation are in use, but their reliability is limited.[23–26] After surgery, the patient will have to use the residual limb as a weight bearing structure. Ideally, full body weight of the patient will be carried on a newly created man–machine interface (the socket/residual limb). Bony prominences, adherent skin scars, traction, shear, and perspiration will complicate this function. For these reasons, the residual limb must be surgically constructed to optimize the transfer of loads, maintain muscle balance, and assume the stresses inherent in its new function. The more bone and muscle lost as a result of amputation, the greater the loss of the normal locomotor mechanisms and, therefore, the greater the energy cost of ambulation and the greater the degree of impairment and need for prosthetic restoration. Syme's amputation (ankle disarticulation), when correctly performed, will provide an excellent weight bearing surface that permits short distance ambulation without the use of a prosthesis (helpful for the inevitable middle of the night bathroom trip).

The skin is the crucial interface between the residual limb and the modified footwear or prosthesis. For this reason utmost care in the management of the skin is essential to (*a*) provide a pain free extremity that can tolerate weight, (*b*) have enough sensation to provide protective feedback, and (*c*) have a durable soft tissue cover. Distal metatarsal and toe amputations should be considered only when full skin thickness coverage can be provided. Midfoot amputations, such as that described by Lisfranc in 1815 (tarsometatarsal) and Chopart in 1792 (tarsotarsal), both cited in Pinzuer etal,[27]should be contemplated only under special circumstances and when primary skin coverage can be obtained. Insensate skin graft coverage is an inadequate interface surface that will tend to become adherent and will have frequent breakdowns; additionally, the inevitable foot deformities caused by muscle imbalance may further increase disability.

Surgical Technique

Toe. Toe amputations can be performed either with side to side, or plantar to dorsal flaps and must utilize the best available soft tissue. The bone should be shortened to a level that allows adequate soft tissue closure without tension. In great toe amputations, if the entire proximal phalanx is removed, often the sesamoids will retract and expose the keel shaped, plantar surface of the first metatarsal to weight bearing. This may lead to high local pressures, callous formation, or ulceration. The sesamoid bones should be removed.

Isolated second toe amputations should be avoided, as a severe hallux valgus deformity commonly results. This deformity may be prevented by second ray amputation or first metatarsal phalangeal fusion. In metatarsal phalangeal joint toe amputations, transfer of the extensor tendon to the capsule may help elevate the metatarsal head and promote a more even distribution of weight.

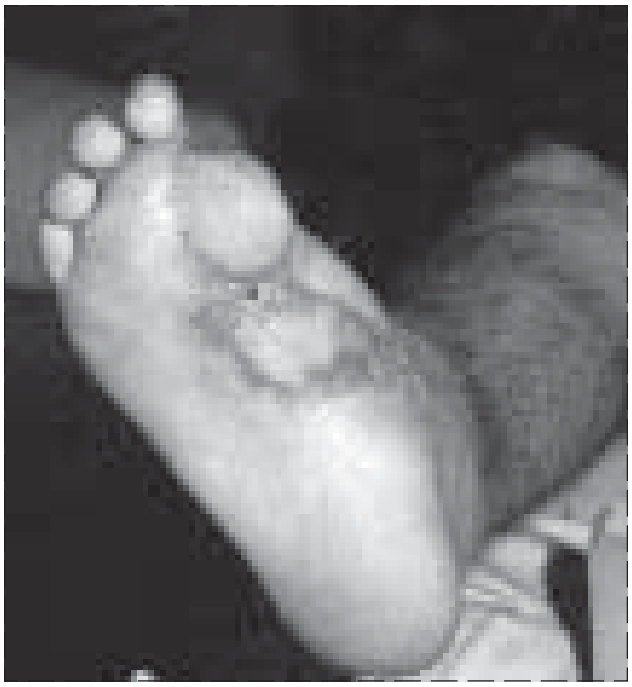


Fig. 4-3. First ray resection requiring flap coverage.

Ray. A ray amputation removes the toe and all (or some of) the corresponding metatarsal. Isolated ray amputations are useful; however, multiple ray amputations can narrow the foot excessively. This results in reduction of the weight-bearing area with potential for callous formation and ulceration. Surgically, it is often difficult to achieve primary closure of ray amputations, as more skin is usually required than is readily available (Figure 4-3). Instead of closing these wounds under tension, it is advisable to leave the wound open and allow secondary healing, although this may result in a less than optimal residual limb and interfere with the rehabilitation program; a reevaluation of the level of amputation may be required.

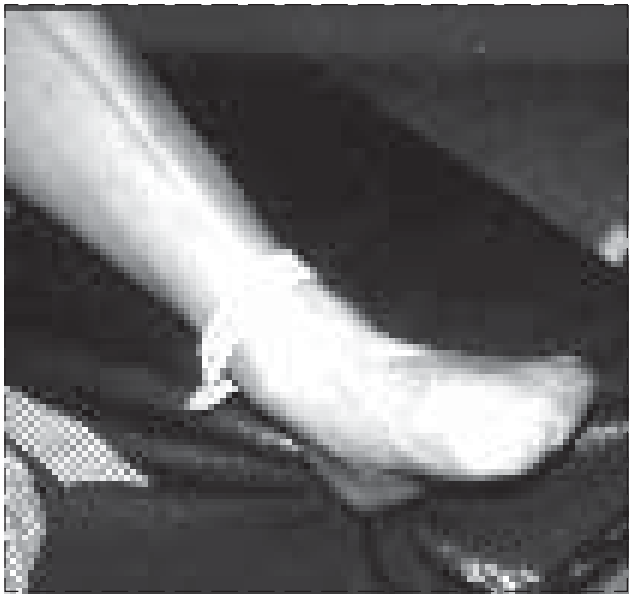


Fig. 4-4. Transmetatarsal amputation.

The fifth ray amputation has been the most useful of all the ray amputations. Plantar and lateral ulcers around the fifth metatarsal head often lead to exposed bone and osteomyelitis. A fifth ray amputation allows the entire ulcer to be excised and the wound to have primary closure.

Midfoot. The transmetatarsal (Figure 4-4) and Lisfranc (tarsometatarsal) amputations produce highly acceptable functional and cosmetic residual limbs. Surgically, a healthy, durable soft tissue envelope is more important than a specific anatomic amputation level, so bone should be shortened to allow soft tissue closure without tension, rather than to a specific described surgical level. A long plantar flap is preferable, but equal dorsal and plantar flaps work well, especially for metatarsal head ulcers. The major disadvantage of transmetatarsal amputation is the high risk of nonhealing.

Preoperatively, careful evaluation should be made of the muscle balance around the foot, with specific attention to heel cord tightness, anterior tibialis, posterior tibialis, and peroneal muscle strength. Midfoot amputations significantly shorten the lever arm of the foot, so Achilles tendon lengthening may have to be done. Tibial or peroneal muscle insertions should be reattached if they are released during bone resection. Postoperative casting prevents deformities, controls edema, and speeds rehabilitation.

Hindfoot. A Chopart (tarsotarsal) amputation (Figure 4-5) removes the forefoot and midfoot while preserving the talus and calcaneus. Tendon transfers for rebalancing are required to prevent equinus and varus deformities. Achilles tendon lengthening, transfer of the anterior tibialis or extensor digitorum tendons to the talus, and postoperative casting are all usually necessary. The Boyd hindfoot amputation consists of a talectomy and calcaneal-tibial arthrodesis. The Pirogoff hindfoot amputation is a talectomy with calcaneal-tibial arthrodesis after vertical transection of the calcaneus through the midbody, and a forward rotation of the posterior process of the calcaneus under the tibia. These latter two amputations are performed mostly on children to preserve length and growth centers, pre-

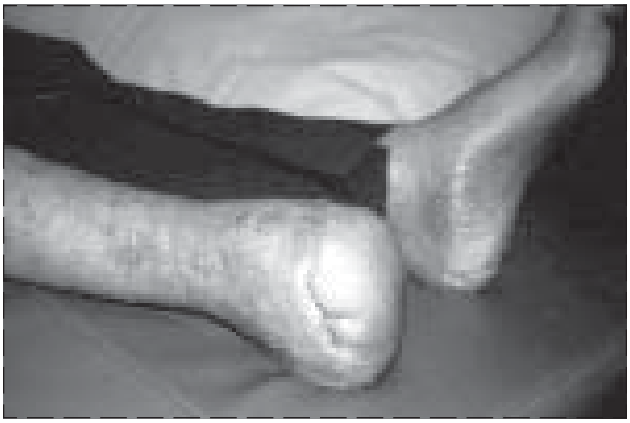


Fig. 4-5. Chopart amputation.

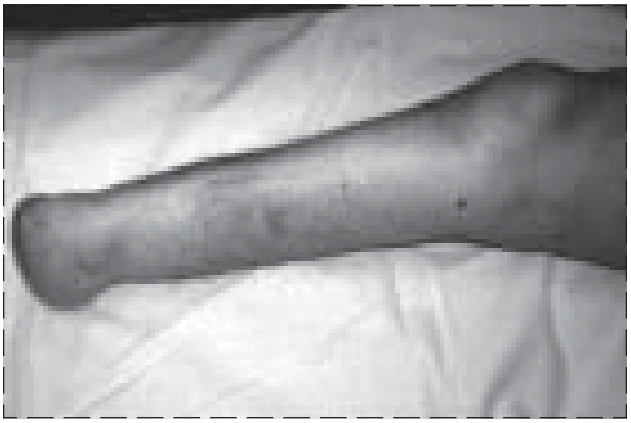


Fig. 4-6. Symes amputation.

vent heel pad migration and improve socket suspension.[28] The hindfoot prosthesis requires more secure stabilization than a midfoot prosthesis to keep the heel from pistoning during gait.

Partial Calcanectomy. Partial calcanectomy, excision of the posterior process of the calcaneus, should be considered a proximal amputation of the foot. In patients with large heel ulceration or calcaneal osteomyelitis, this can be a very functional alternative to a below-knee amputation.[29]

Syme's Amputation. The Syme's level of amputation was described in 1843[30] as a disarticulation of the ankle, affording ease of execution, less risk to life, a comfortable residual limb, and resulting in some distinct advantages regarding mobility and prosthetic fitting. The surgical technique, as described by Harris[31] in 1961, requires that the calcaneus and talus be removed with careful dissection of bone to preserve the heel skin and fat pad to cover the distal tibia (Figure 4-6). The malleoli must be removed and contoured. A late complication of the Syme's amputation is the posterior and medial migration of the fat pad. Options to stabilize the fat pad include (*a*) tenodesis of the Achilles tendon to the posterior margin of the tibia through drill holes; (*b*) transfer of the anterior tibialis and extensor digitorum tendons to the anterior aspect of the fat pad; or (*c*) removal of the cartilage and subchondral bone to allow scarring of the fat pad to bone, with or without pin fixation. Careful postoperative casting can also help keep the fat pad centered under the tibia while it heals.[31–33]

The Syme's amputation is an end-bearing level. Retention of the smooth, broad surface of the distal tibia and the heel pad allows direct transfer of weight from the end of the residual limb to the prosthesis with improved proprioception. Because of the ability to end bear, the amputee can ambulate without a prosthesis in emergency situations, or for bathroom activities. The larger circumference of the distal leg at the level of the malleoli and their flares allows the use of a socket that is totally self suspending, and eliminates the need for any form of proximal auxiliary suspension. These same two advantages are also the two main drawbacks for prosthetic fitting. The long length of the residual limb places some minor limitations on the options for prosthetic ankle/foot systems that can be used. The bulbous nature of the distal residual limb that permits excellent self suspension of the prosthetic socket can also result in a prosthesis that is cosmetically unacceptable. A leg length discrepancy can be a problem with and without the prosthesis.

Acute Postamputation Rehabilitation

Pain control, maintenance of range of motion and strength, and promotion of wound healing are the goals of this stage, which begins with the surgical closure of the wound and culminates with healing after the sutures are removed. Pain control and residual limb maturation should be aggressively pursued. For edema control, use of an immediate postoperative rigid dressing (IPORD), or a soft elastic bandage and subsequent pneumatic compression are indicated. Another method of wound protection and early shaping and shrinking is the use of the removable rigid dressing, as proposed by Burgess and associates.[34] This dressing is easily changed to accommodate stump shrinkage until the residual limb stabilizes in size and is ready for the first prosthetic casting. In addition, this dressing protects the residual limb while ambulation training with gait aids and other essential mobility skills are practiced

by the patient. For the Syme's and partial foot amputee, the IPORD is more difficult to apply and it makes it more difficult to maintain skin integrity because of the patient's tendency to attempt weight bearing. IPORD techniques offer the advantages of early rehabilitation and control of edema and pain, and are preferred if the patient has no history of chronic arterial compromise, and if the expertise to apply it is available. Soft compressive dressings alone are used in many centers.[21] The dressing should be extended proximal to the midtibia to improve its suspension. Proper postoperative positioning and rehabilitation are essential to prevent ankle and knee contractures.

Pain Management. Pain control can be best achieved initially with a patient controlled analgesia (PCA) system, followed by the use of scheduled oral analgesia. A skin desensitization program that includes gentle tapping, massage, soft tissue mobilization, and skin lubrication is recommended for the patient who uses a removable, soft, or elastic dressing.

Postoperative Care. Postoperative edema is common following amputation; if soft dressings are used, they should be combined with stump wrapping to control this, especially if the patient is a prosthetic candidate. A major complication from stump wrapping is too tight an application of the elastic wrap at the proximal end, which actually causes congestion and worsens edema. A figure-8 wrapping technique is best, and it should be reapplied every 4 to 6 hours. The preferred treatment approach is the use of an IPORD to control postoperative edema, protect the limb from trauma, decrease postoperative pain, desensitize the limb, and allow early mobilization and rehabilitation. Immediate postoperative weight bearing can be initiated safely in selected patients, usually young traumatic amputees where the amputation was performed above the zone of injury. An IPORD and an immediate postoperative prosthesis (IPOP) need to be applied carefully, but their application is easily learned and well within the scope of interested physicians.[34]

When the patient is medically stable, early mobilization is initiated, along with general endurance and strengthening exercises (with emphasis on the knee flexor and extensor muscles and the avoidance of joint contractures) and improvement in sitting and standing balance. It is important physically to emphasize the strength and function of remaining limbs, with specificity of training as the preferred type of training. Strengthening of upper limb musculature is essential for wheelchair propulsion, transfers, and walker and crutch ambulation. Whenever possible, patients should be placed in a cardiovascular conditioning program before the amputation.

At this time also, emotional counseling should be implemented for the patient and family, with special attention to the significant other and children. The counseling should include a psychosocial evaluation of the patient and family to assess and manage the existence of depression, anxiety, or both. Patient participation in the decision making process during this phase is important to encourage independence.

Phantom Limb. Phantom limb sensation is the feeling that all or a part of the amputated limb is still present. This sensation is perceived by nearly all acquired amputees, but is not always bothersome.[35] Phantom sensation usually diminishes over time, and the sensation that the phantom foot or hand has moved proximal toward the stump (telescoping), commonly occurs.

As many as 70% of amputees perceive phantom pain in the first few months after amputation. However, such pain will usually disappear or decrease sufficiently so as not to interfere with prosthetic fitting and day to day activities.[36] A smaller percentage will experience pain long term, while others will have recurrence later in life. When the phantom pain persists for more than 6 months, it usually becomes chronic and is extremely difficult to treat. Perceived pain intensity is closely related to anxiety level, depression, prosthetic fitting problems, and other personal factors.[37]

Joint Contractures. Joint contractures usually occur between amputation and prosthetic fitting. In the Syme's and partial foot amputation, the deforming forces are to knee flexion and ankle plantarflexion and inversion. Tibialis anterior and extensor hallucis reattachment during surgery can prevent the deforming forces. After surgery, patients should avoid (*a*) propping the leg up on a pillow, (*b*) prolonged sitting, and (*c*) should be started on active and passive motion exercise early. Sitting with the knee fully extended prevents knee flexion contractures. Strengthening of the knee extensors should be encouraged. Efforts should be directed at prevention of joint contractures, with aggressive rehabilitation beginning soon after surgery.

Gait Training. Gait training is integral in the rehabilitation process. This program should be a coordinated effort between the physical, occupational, and recreational therapists and the prosthetist, with frequent physiatric input. Each team member will use different techniques to teach and review all of

the important topics that need to be learned by the amputee.

Initial gait training should address technique and velocity on flat surfaces. Then training for mobility on uneven surfaces and elevations is introduced by all the therapists. A review and practice of the use of the prosthesis in transfers, driving, sports, and other activities should always be included.

Prosthetic Fitting And Training

Prosthetic prescription options for the amputee have changed dramatically over the past decade. Selection of the most appropriate prosthetic devices for functional restoration of the lower limb amputee is an extremely challenging task in view of the variety and complexity of new prosthetic feet, socket fabrication techniques, suspension systems, and available materials. Ideally, this task should be accomplished by an expert team of professionals in close communication with the patient. Members of the team should include a surgeon, a physiatrist knowledgeable in amputee rehabilitation and prosthetics, a certified prosthetist, an occupational therapist, a physical therapist, a recreational therapist, a psychologist, a social worker, and the patient and his family.

The patient should learn prosthetic management, including the basic principles behind the function of each of the components in the prosthesis, its maintenance and care. The patient should practice how to put on and take off the prosthesis, the techniques to adjust it, and how to determine the appropriate sock thickness to wear. Skin care and inspection techniques are also reviewed.

Prosthetic Restoration and Socket Characteristics. Following a lower limb amputation, the residual limb, instead of the foot, must bear the weight of the body when standing on the prosthesis. The socket provides the surface for contact and transfer of body weight from the residual limb to the prosthesis. It is this interface between residual limb and socket that is probably the most critical factor in determining the successful fit and function of a lower limb prosthesis. Considerable forces of varying types and magnitudes (eg, weight bearing, shear, traction, hemodynamics) occur at this interface. To provide adequate comfort and avoid breakdown, the socket must be designed to assure these forces do not exceed tolerances of the residual limb tissues. The amount of force the residual limb can tolerate varies with the amputation level.[38] Disarticulation (eg, Syme's or through-knee amputations) with broad intact distal joint or bone surfaces are able to tolerate high forces concentrated on a small surface area. The end-bearing capability of disarticulation amputations can minimize many of the socket interface problems seen with other levels of amputation.

Toe and Ray Amputation. Loss of one or more toes with preservation of the metatarsals will have minimal impact on level walking. But these amputation levels will have an impact on more demanding activities such as running or jumping. Within the shoe, a toe filler can be used to prevent collapse of the toe box, prevent irritation of the residual foot skin, support the foot, and improve the shoe's appearance. A soft shoe with a carbon graphite insert may be used instead of an orthopedic shoe. The loss of two or more rays will result in a narrower forefoot. Loss of the first or fifth toe will shift the normal weight bearing pattern to the adjacent metatarsal head. A modified shoe insert to support the metatarsals, redistribute weight bearing to the remaining metatarsal heads, and provide a filler for the absent rays and toes may be necessary.

Transmetatarsal Amputation. With the transmetatarsal amputation, the anatomic toe lever of the foot is shortened, which reduces the ability to control dorsiflexion, push off normally, and elevate the body's center of gravity. The traditional prosthetic restoration includes a transmetatarsal silicone custom shoe insert (Figure 4-7) with an arch support attached to a toe filler. This can be used in conjunction with an extended steel or carbon graphite

Fig. 4-7. Springlite toe fillers for partial foot amputations. Photograph: Courtesy of Springlite, 97-E Chinook Lane, Steilacoom, WA 98388.

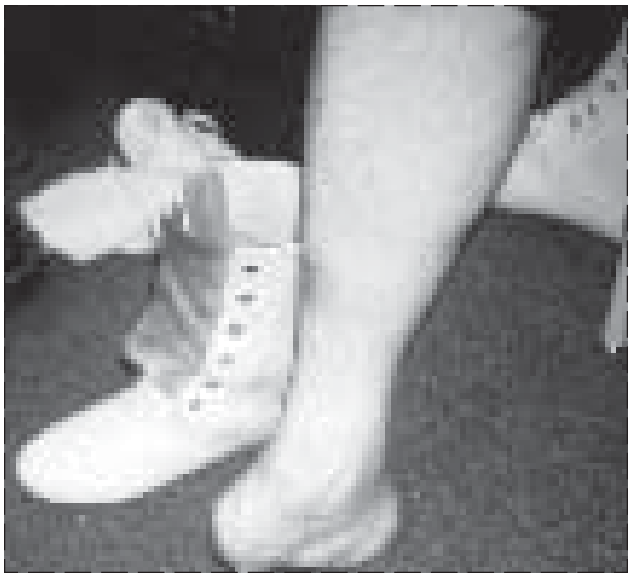


Fig. 4-8. Self-suspending partial foot prosthesis socket made of flexible resin and silicone.

shank in the shoe. The shank should be extended distally to the point of the former metatarsal heads to restore normal toe lever length and improve push off. The addition of a rocker sole to the shoe can also help to restore a more normal gait pattern. With the development of very thin, lightweight carbon fiber shanks or inserts, such as those made by the Springlite Company (Steilacoom, Washington), it is possible to incorporate the shank directly into the insert itself. An ankle/foot orthosis (AFO) can also be attached to this partial foot prosthesis.

Life-like prosthetic replacements are available for transmetatarsal amputations and are designed to provide comfortable residual limb and prosthesis interface, redistribution of weight bearing, acceptable cosmesis and shoe fit, and to maintain the biomechanics of walking. They are made of silicone, which should be shaped and intrinsically colored to match the remaining foot. The major drawback of this form of prosthesis is the high cost and limited durability. In very active individuals, the silicone prosthesis may not provide sufficient resistance to ankle dorsiflexion late stance, which would result in a drop-off gait. This problem can be corrected by reinforcing the shoe with a metal or carbon graphite shank, or attaching it to an AFO.

With amputation through the more proximal portion of the metatarsals, it may be more appropriate to consider a partial foot prosthesis similar to those used for the more proximal partial foot amputations, such as for the tarsometatarsal and midtarsal amputations.

Tarsometatarsal and Midtarsal Amputations. Tarsometatarsal and midtarsal amputations present the special problem of the partial foot being short in length, which makes it difficult for the individual to keep on a low-quarter shoe. In the past, prosthetic options have utilized either a high-top, boot, or AFO type of design to extend the prosthetic replacement well above the ankle in an attempt to provide adequate suspension and restore the biomechanics of walking. Several partial foot prostheses, including self-suspending sockets made of flexible resins or silicones with laminated forefoot and shank, have resulted in highly cosmetic and functional prosthetic options for these previously difficult to manage amputation levels (Figure 4-8).[39,40] These latter designs often make it possible for the amputee to wear low-quarter shoes instead of boots. Yet even with the best of these prostheses, it is often necessary to add a rocker sole or rigid sole plate to the shoe to simulate the action of normal push off (Figure 4-9).

Syme's Amputation. In fitting a prosthesis for Syme's amputations, the distal half of the socket must have either an opening or a circumference slightly larger than that of the distal residual limb so the residual limb can fit into the socket. The pos-

Fig. 4-9. Springlite Chopart prosthesis. Photograph: Courtesy of Springlite, 97-E Chinook Lane, Steilacoom, WA 98388.

terior (Figure 4-10) or medial (Figure 4-11) opening Syme's prostheses permit widening or removal of part of the distal portion of the socket to allow passage of the bulbous distal residual limb into the socket. Once in the prosthesis, the wall or door is replaced and held in place with a strap that provides excellent suspension of the prosthesis. Because of the tibial flare, the Syme's sockets are usually self suspending, and their key functions are that they provide a comfortable residual limb or prosthesis interface; an efficient energy transfer to the prosthesis; a secure suspension of the prosthesis; and acceptable cosmesis. Although these socket designs provide an outer socket contour that more closely resembles the anatomic leg, they still result in a limb that is larger in circumference than the nonamputated limb. The difficulty with these two designs is a potential anterior failure (fracture) of the socket due to the concentrated stresses, especially at push off. Reinforcing this area of the socket with carbon fibers is a good solution for this problem, but may increase the overall weight of the device.[41]

The closed socket design is inherently stronger than those with anterior or medial windows. Thus a thinner lamination is possible, which results in a lighter prosthesis. To permit entry of the residual limb into the socket, the distal diameter must be sufficient to allow passage of the bulbous residual limb. This means that the outer shape of the distal one third to one half of the prosthetic socket will appear cylindrical and much larger than the nonamputated leg. The normal anatomic contours will not be present, resulting in poor cosmesis. With this type of design either a removable expandable liner or a fixed silastic expandable air-filled inner liner may be used. In the former, the friction between the removable liner and the socket lamination provides the suspension; in the latter, the compression of the expandable inner wall of the socket, as well as increased pressure of the enclosed air chamber, provides for suspension of the prosthesis. This closed chamber prosthetic system will not permit transpiration and the air chamber will work as an insulator, further trapping heat, and thereby making this design less desirable in warm climates.

There are several choices for weight bearing in the Syme's amputation. A distal end pad can be used to optimize weight bearing comfort. If the amputee is unable to tolerate distal end bearing, it is possible to add a patellar tendon-bearing proximal brim trim line to the prosthesis and partially unload the distal end. It is also possible to manufacture a prosthesis that will share the load between

Fig. 4-10. Posterior windowed Symes socket attached to a Flex foot.

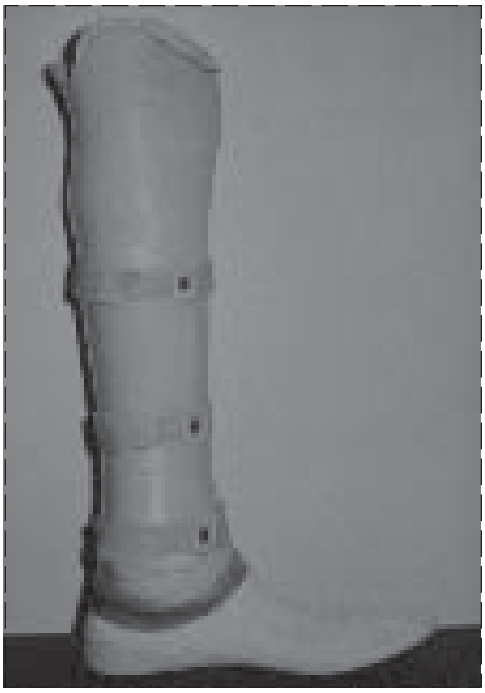


Fig. 4-11. Medial opening Symes socket.

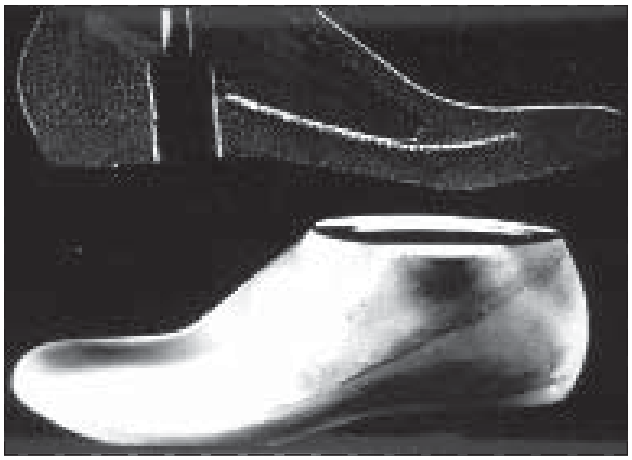


Fig. 4-12. Solid-ankle cushion heel (SACH) foot.

proximal and distal ends, as tolerated by the patient. If necessary, any of the common transtibial prosthetic suspension systems can be added, such as a sleeve or supracondylar cuff.

Modifications to Syme's sockets include a carbon graphite reinforced hybrid of the posterior opening with a flexible inner socket, without the use of an outer door to close the opening. This is usually done to provide relief for tender bony areas. The open socket designs permit the prosthetist greater access to the distal socket should any modification or adjustment of the socket be necessary for changes in fit.

Traditionally, a modified solid-ankle cushion-heel (SACH) foot, which has a lower profile, has been used in the Syme's prosthesis (Figure 4-12). Several of the low profile dynamic response feet are available (ie, Seattle light, Carbon Copy II, and SAFE) for the Syme's amputees.[42,43] The Flex Syme's (see Figure 4-10) and the low profile Springlite prosthesis (Figure 4-13) incorporate carbon graphite construction and longer lever arms to improve their dynamic response.

Long-Term Follow-up

The patient who has successfully completed a rehabilitation program should be seen for follow-up by at least one team member a minimum of every 3 months for the first 18 months. These visits may need to be more frequent and will include other members of the team if the patient is having difficulties with prosthetic fitting, the residual limb, specific activities, or psychosocial adjustment. After this critical 18-month period, the patient should be seen at least every 6 months to assure adequate prosthetic fit and function, for prosthetic maintenance, and for assessment of overall patient condition. It may be necessary to replace a Syme's prosthesis or parts of it every 2 to 3 years. For the partial foot, more frequent replacements may be necessary. Table 4-1 illustrates the increased metabolic demand of walking for foot amputees and highlights the need for optimal prosthetic fit and comfort to achieve the best possible functional result.[44–46]

If a pain-free and scar-free residual limb was created, if optimal prosthetic restoration and training were provided, if no other significant comorbidity exists, patients with partial foot and Syme's amputations can be expected to return to a high functional level. The rehabilitation team should be able and ready to assist the patient throughout the rehabilitation program.

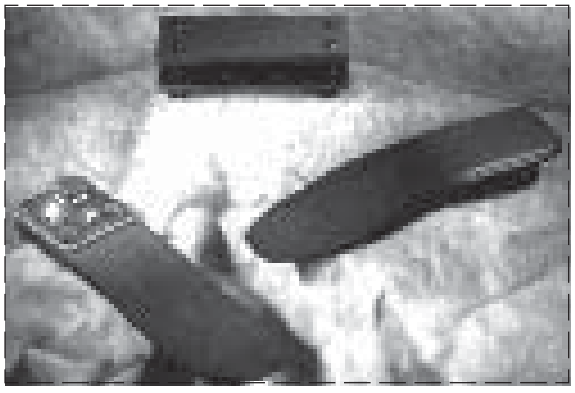


Fig. 4-13. Springlite Symes prosthetic foot. Photograph: Courtesy of Springlite, 97-E Chinook Lane, Steilacoom, WA 98388.

TABLE 4-1

AVERAGE ENERGY CONSUMPTION INCREASE AT DIFFERENT LEVELS OF LOWER LIMB AMPUTATION

Level of Lower Limb Amputation	Metabolic Energy Increase (%)
Transmetatarsal	10–20
Symes	0–30
Transtibial	40–50
Transfemoral	90–100
Bilateral transtibial	60–100
Hip disarticulation	> 100

BELOW-KNEE AMPUTATIONS

Historically, the below-knee amputation (BKA) has been quite common among war-injured soldiers. In World War I, from 1917 to 1918, there were 525 BKAs and 1,282 above-knee amputations (AKAs); 19.5% and 47.7% of all amputations, respectively.[3] During World War II, from 1 January 1943 to 1 May 1944, five medical centers reported 627 BKAs and 550 AKAs, 35.7% and 31.3% of all amputations, respectively.[3] In the continental United States, from 1 January 1942 to 31 March 1946, 11,631 soldiers were treated for at least one LE amputation, with the majority sustaining BKA. These numbers demonstrate the importance of knowing how to manage BKAs that result during times of conflict.

Mortality rates are lower in BKAs compared to AKAs. In World War I, mortality rates were reported to be 18% BKAs and 40% AKAs, respectively.[47] Mortality rates in AKAs of three- to four-times that of BKAs have been reported.[7] This higher mortality is likely due to femoral artery injuries and a greater potential for sepsis due to larger muscle mass. The importance of salvaging the knee joint should not be underestimated, as this procedure offers the amputee numerous advantages compared to AKA. One advantage is the reduced energy the amputee expends with ambulation. For below-knee amputees, energy expenditure has been estimated to increase by 9% to 40% compared to nonamputees, and increases by 25% to 50%, or greater, for above-knee amputees[44,45] (see section on Through- and Above-Knee Amputations). Another advantage of BKA compared to AKA is walking speed. In comparing comfortable walking speeds, Waters and associates[45] found the following gait velocity differences: normal was 82 m/min; traumatic BKA was 71 m/min; traumatic AKA was 52 m/min; dysvascular BKA was 45 m/min; dysvascular AKA was 36 m/min; and dysvascular Syme's amputation was 54 m/min.

The length of the residual limb in below-knee amputees also affects energy expenditure. Gonzalez et al[46] evaluated nine below-knee amputees who were divided into short and long lengths defined as 6% and 8% of body height. They found the increase in energy expenditure compared to nonamputees was 10% and 40% for long and short residual limbs, respectively.[44] Hence, not only is saving the knee joint important, but salvaging length is also important.

In evaluating functional results, Purry and Hannon[48] studied 25 traumatic below-knee amputees and found the following: 84% wore a prostheses for more than 13 hours per day; 32% left their prosthesis off for more than 4 days in the previous year; 72% could walk one mile; 84% drove cars; 96% worked; 64% did not require any sick leave; 72% participated in sports; 84% considered themselves not very or not disabled at all; and 68% felt their lives were similar to the lives of nondisabled people.[48] In regards to employment, one study[49] on LE traumatic amputees found an overall return to work rate of 87%. However, jobs were usually changed to less physically demanding work. Positive factors for return to work were use of a prosthesis, age less than 45 years, and availability of vocational services. In comparing below-knee and above-knee amputees, the use of the prosthesis has been reported to be approximately 74% and 27%, respectively.[13] Of note, is that these estimates included mainly dysvascular amputees.

Another reported advantage of a BKA compared to an AKA is spared sensory input from the knee joint. In the dark, the above-knee amputee is unable to sense the location of the prosthetic foot; but the below-knee amputee knows the prosthetic foot is in line with the remaining tibia.[14]

Classification

BKAs can be classified by the length of the residual limb. A long BKA is from above the Syme's level to the junction of the lower and middle thirds of the tibia.[14] A standard or medium length BKA is from the junction of the lower and middle thirds to the junction of the middle and upper thirds of the tibia. A short BKA is from the middle and upper third junction to slightly below the tibial tubercle. The ultrashort BKA is just below the tibial tubercle. The tibial tubercle is critical in BKAs because it is the site of insertion of the patellar tendon, which is needed for knee extension.

Surgery

Amputation for trauma is either emergent or elective.[15] Indications for emergent amputation include a nonviable extremity secondary to massive injury, infection, or gangrene that endangers life; hemorrhage in the presence of severe infection; and trauma with serious associated polytrauma.[11,15] The level selected for amputation is usually predetermined by the trauma and treatment prior to amputation.[13] However, it is paramount to preserve the

knee and as much below-knee length as possible.[15] Indications for a BKA may include (*a*) crush injury with warm ischemia greater than six hours; (*b*) severe ipsilateral foot trauma; (*c*) traumatic injury to the leg with complete, anatomic severance of the posterior tibial nerve; and (*d*) severe soft tissue and bone destruction not amenable to reconstruction or more distal amputation.[11,13,47]

Because war injuries are usually grossly contaminated,[50] an open amputation is usually performed. The open, circular technique, as described by Peterson,[6] followed with immediate skin traction, has been the standard amputation for the war injured soldier.[6,15,16] Basically, this technique consists of a series of circular incisions performed in layers, with each layer being allowed to retract before the next layer is cut. The first layer is cut down to deep fascia at the lowest viable level of the extremity. A short flap is allowed to conserve skin for later closure.[51] Muscle is cut in layers, allowing retraction before proceeding to the next layer. After the last layer retracts, the bone is cut. Nerves are transected under tension and large vessels are double ligated. The end of the stump is covered with a fine mesh gauze soaked in betadine and a fluff gauze. A stockinette is applied and secured with benzoin tincture.[15] The residual limb is then wrapped with an elastic bandage with gentle compression, decreasing compression proximally. Finally, skin traction of 5 to 6 lb of force is applied immediately using weights and pulleys or a contained traction unit. A self-contained unit is made from rubber tubing extending from a wire ladder splint to the stockinette (Figure 4-14). Traction is applied continuously, except for dressing changes.[15]

Failure to use skin traction often results in unacceptable soft tissue retraction, an error commonly seen early in World War II.[6,51,52] Thompson and Alldredge[16] state that the most common mistake in open amputations is failure to use, or the premature discontinuation of, skin traction. Soft tissue retraction results in bone projection beyond the level of skin, and surgical closure results in sacrifice of considerable bone length.

Another error in skin traction management is casting the transtibial amputee in knee flexion. This is done to prevent rotation of the cast, but results in knee flexion contractures. Better results are obtained by casting the knee in extension, thereby avoiding flexion contracture.[51]

Skin traction is applied until healing occurs by secondary intention or until the limb is ready for revision with closure. When good granulation tissue is present, cultures will be unremarkable, radiographs will show no signs of infection, and normal skin can be closed without tension or bone shortening; the limb is ready for revision.[16] Revision consists of removal of granulation tissue, scar, and just enough bone for subcutaneous and skin closure without tension. The tibia is beveled, fibula cut just proximal to tibia, and skin undermined to secure smooth approximation of skin margins.[16,51] If tension on the suture line becomes evident, skin traction is applied. The advantages of the open, circular technique include the following:

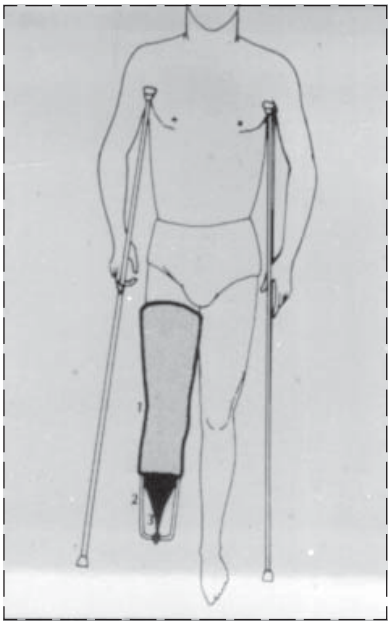


Fig. 4-14. Self contained skin traction unit. Tension in the stockinette provides skin traction and should be adjusted to provide approximately 5 to 6 lb of force. (1: cast material, 2: frame, and 3: stockinette with traction).

- The procedure can be performed quickly under adverse conditions.
- Safe evacuation from a field hospital can occur after 48 hours or even earlier.
- The technique provides optimal removal of all devitalized tissue that may otherwise serve as a source of infection.
- It provides wide drainage.
- Soft tissue or bone infections are rare.
- Limb length is preserved.
- Blood supply is good.
- Muscle and deep fascia adhere to the bone.
- Only a simple revision is needed.[6,16]

The disadvantages include the following:

- The technique requires a protracted period of treatment.
- There is a need for secondary reconstructive operations.
- Frequently there is excessive bone at the end of the residual limb that requires surgical excision.[51]

Other techniques are frequently used for limb revision or subsequent closure. The open, flap technique consists of conserving all viable tissue as a myofasciocutaneous flap.[13] Orientation and length of the flaps are dictated by the trauma. The open flap technique was used in World War I when there were surgical resources available.[6,51] However, in times of heavy conflict, difficulties with the large number of casualties and the need to evacuate to other hospitals led to problems. In these delayed circumstances, the open flap technique could be complicated by serious infection if the wounds were closed too soon.

In World War II, use of long flaps was avoided because of the prevalence of infection when early wound closure was employed. However, the use of short flaps was not without problems.[51] Whatever approach was used, the goals were prevention of infection, preservation of maximum length, and simplified revision without loss of residual limb length.[13,47] The main disadvantage was infection.[2,6,51]

Internal and external fixation has been used to preserve length in the traumatic amputee. Segmental fractures can be stabilized to proximal segments using fixation.[13] However, Thompson and Alldredge,[16] reporting on their experience in World War II, state that in the presence of a compound fracture, pin fixation should not be used proximal to the site of injury because of risk of subsequent amputation at the proximal pin site, resulting in loss of length.

Elective transtibial amputations may be performed after unsuccessful salvage of the traumatically injured leg. The posterior flap method uses a posterior myofasciocutaneous flap created from the posterior compartment muscles, which is brought anteriorly to cover the amputated limb in a semicircular fashion, avoiding dog ear formation.[13] In the operation, nerves are cut sharply under tension and allowed to retract into muscle. The tibia is stripped of periosteum to the level of transection, cut, beveled, smoothed, and contoured to avoid bone spur formation or sharp edges. The fibula is transected obliquely to form a posterolateral facet at the same level or slightly shorter than the tibia, which creates the desired cylindrical shaped limb. The posterior compartment muscles are tapered distally. The gastrocnemius can be excised and the soleus trimmed to decrease bulk, thereby providing the optimal distal tibial padding. Myodesis is created by fixing the posterior compartment myofascia and anterior investing fascia to the tibia. An alternative to myodesis is myoplasty, which consists of attaching the posterior to the anterior myofascia. Either myodesis or myoplasty should be performed to avoid undesirable muscle retraction. Myodesis is contraindicated in severe dysvascular cases.[13] The main advantage of the posterior flap method is improved healing in the dysvascular patient because the major source of collateral blood supply is through the posterior compartment muscles.[47,53]

Another method consists of equal anterior and posterior flaps. In this method, a midlateral incision is made to create equal anterior and posterior flaps. Myoplasty of the anterior and posterior flaps is created over the distal tibia.[13] This procedure is indicated to salvage bone length.

The sagittal flap method uses equal medial and lateral flaps with side-to-side myoplasty over the tibia.[54] This method has been used in dysvascular cases. The procedure should not be used in the presence of a rigid knee flexion contracture, debility that would preclude a second operative procedure, failure of the skin to bleed at that level, or infection near the operative site.[55] A reported advantage of the sagittal flap method in dysvascular cases is improved healing.[13,54] The postulated reasons for the improved healing are that the wide based, very short flaps used in this procedure improve viability compared to long flaps; and the use of sagittal flaps reduces usage of poorly vascularized anterior skin.[13,54] Improved bone coverage with side-to-side myoplasty is also reported.[54]

In trauma with damage to posterior or anterior skin, the intact skin with sagittal flap usage may allow bone coverage without sacrificing length. The skew flap method combines posterior and sagittal flaps to create posterolateral and anteriomedial flaps. This procedure has been used in dysvascular patients with major vessel occlusion. The skew flaps contain the collateral circulation that accompanies the sural and saphenous nerves, providing blood supply to the flaps.[13]

The ERTL procedure, osteomyoplasty, was designed for revision of transtibial amputations in the war wounded.[13] The procedure uses osteoperiosteal bone flaps created from the tibia distal to the level

of bone transection. The osteoperiosteal bone flaps are sutured to the fibula and to each other, and create an osteoperiosteal bridge from the tibia to the fibula for weight bearing. The main disadvantage cited is the sacrifice of bone length to make the bridge.

The Singer procedure uses the heel pad and sole as a flap to give an end weight bearing residual limb. This procedure has limited use and is indicated when there is unreconstructable tibial diaphyseal bone loss, but there is an intact posterior tibial nerve and an artery to the foot.[13]

Skin flaps and split-thickness skin grafts (STSGs) have been used in special circumstances to preserve length. Intact skin is rotated over the anterodistal tibia, where prosthetic stresses are highest.[13] Uncovered areas posteriorly receive STSGs. The procedure is indicated in degloving injuries and in the presence of sufficient bone and muscle, but insufficient skin coverage.[13,47] The skin graft should not be taken from the amputated side because healthy skin is optimal for prosthetic stress tolerance.[16] Reported complications with STSG usage include the need for subsequent revision with excision of the grafted skin, and bone resection in 50% of BKAs.[47] However, modern prosthetic sockets may allow suboptimal skin to tolerate the pressures of weight bearing.

Late revision of healed, very short residual limbs can include the Ilizarov technique of stump lengthening. A few case reports have been published in British literature.[56,57] Latimer and associates[57] report three cases of below-knee amputees who underwent residual limb lengthening ranging from 1.2 to 4.9 cm with a mean of 3.5 cm. Eldridge and colleagues[57] report one case with a lengthening of 4.5 cm using the Ilizarov technique. Complications in these cases include thinning of the skin distally with subsequent breakdown, which may necessitate further bone debridement, pain with lengthening, loss of knee range of motion, and loss of distraction length with too early weight bearing.[56,57]

There is a variety of BKA procedures that can be performed. As mentioned before, the open, circular technique followed by immediate skin traction has been the standard procedure in the war casualty requiring amputation. Other techniques have evolved in the civilian treatment of traumatic amputation. The Emergency War Surgery handbook[15] states there is no ideal or standardized level of amputation in the combat theater. The final decision on the type of amputation is up to the surgeon, and is influenced by the surgeon's experience and skill and the tactical situation. The physiatrist can assist the surgeon by offering expertise in functional outcomes for various amputation levels, especially when associated with other injuries or disabilities, and by coordinating and organizing rehabilitation interventions.

Postoperative Dressing

Once the definitive amputation procedure has been performed and there is wound closure, a decision regarding which type of postoperative dressing needs to be made. A variety of postoperative dressings exist. The predominant choices are soft dressing, IPOP, and rigid dressing.

Soft Dressing. The soft dressing consists of a conventional dressing of sterile and fluff gauze.[21] A soft dressing allows easy wound inspection and dressing changes. Soft dressings may be used with or without an elastic wrap. Without an elastic wrap, the soft dressing lacks edema control, risks knee flexion contracture, lacks protection to the residual limb from bed trauma, and slows limb maturation.[58] A soft dressing with an elastic wrap improves edema control, but has the disadvantages of sometimes choking the residual limb from a tourniquet effect, and skin breakdown from excess pressure.[58,59]

Immediate Postoperative Prosthesis

The IPOP utilizes a plaster dressing with a pylon and SACH foot applied in the operating room at the completion of surgery.[60] At the completion of the amputation a sterile, nonadherent dressing is placed over the suture line. Three to four layers of fluff gauze are placed over this dressing and the distal residual limb. An Orlon-Lycra-Spandex sock is placed over the residual limb and suspended above the knee. Preformed polyurethane pads, with adherent backing, are used to provide relief to pressure-intolerant areas of the residual limb (Figure 4-15). A longitudinal

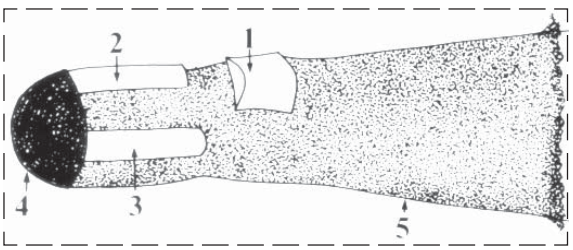


Fig. 4-15. IPOP construction. Pad placement provides relief or padding to pressure intolerant areas: (1) Patellar pad, (2) lateral tibial crest, (3) medial tibia, (4) distal tibia, and (5) stockinette over residual limb.

pad is placed medial to the tibial crest and extends past the distal tibia. Additionally, the pad has a proximal posterior extension along the concave aspect of the medial tibial condylar flare. The lateral pad is placed approximately 0.25 in. distal and lateral to the tibial crest. Again the pad extends distal to the tibia. The medial and lateral pads provide a relief channel for the tibial crest. In addition to the medial and lateral padding the anterior tibia can also be padded if there is friable skin in this area. The distance between the pads is approximately 0.5 in. A prepatellar pad is placed over the entire patella. A reticulated polyurethane pad, 4 to 5 in. in diameter is placed over the distal limb in a hemispheric shape to overlap the distal aspect of the medial and lateral pads. The preformed pads are trimmed and beveled to fit the patient. The knee is kept in 5° to 15° of flexion for the rest of the procedure.

Two layers of elastic plaster of Paris are applied to give tissue compression and a smooth, total contact fit. The wrap starts distally and in a direction that will take tension off the suture line (Figure 4-16). The elastic plaster is brought 3 to 4 in. proximal to midthigh, with tension decreasing proximally. A tourniquet effect must be avoided to prevent constriction and distal limb ischemia. The elastic plaster is then reinforced with either conventional plaster or fiberglass. Fiberglass results in a lighter dressing. A 1-in. cotton strap with a safety buckle is affixed to the dressing and provides attachment for waist belt suspension. This webbing is folded in a loop, with the safety buckle attached, and incorporated into the fiberglass wrapping (Figure 4-17). The strap should be centered anteriorly. Taking care to avoid the bony prominences of the condyles, anterior and medial-lateral (ML) compression is applied to the cast just proximal to the femoral condyles (Figure 4-18). This compression

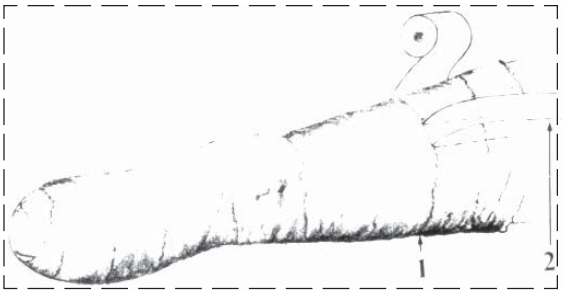


Fig. 4-17. IPOP construction. Incorporation of cotton strap (2) for suspension into the cast. Plaster rolls (1) anchor the suspension strap.

Fig. 4-16. IPOP construction. Elastic plaster compression dressing placed over stockinette and padding. The wrap is placed such that tension is removed from the incision. Additionally, the wrap should provide mildly increased pressure distally with gradually decreasing compression proximally. The decreasing compression gradient and avoidance of circular wraps are important in preventing a tourniquet affect. The wrap should extend to the midthigh level.

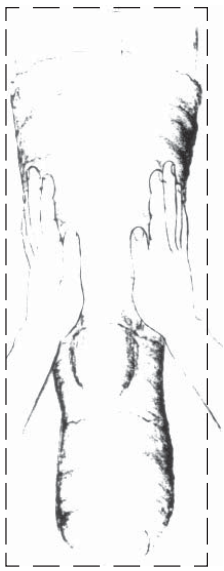


Fig. 4-18. IPOP construction. Gentle compression is applied just proximal to the femoral condyles. The slight indentations provide some suspension and resistance to rotation. Care must be taken to avoid excessive compression causing a tourniquet affect.

Fig. 4-19. IPOP construction. Attachment of the pylon plate (1), and pylon (2). The cage is molded to fit the dressing. Plaster or fiberglass is then used to attach the cage. All gaps under the plate should be filled with casting material.

provides some suspension for the dressing. Tension on the sock is now released. The sock is trimmed, and the proximal free edge is folded back and incorporated with fiberglass into the cast. The completed dressing is now attached to the waist belt.

Next the pylon and SACH foot are attached to the dressing. The body and leg must be positioned for proper alignment of the pylon and prosthetic foot. The socket attachment plate is now fitted to the cast. The plate for pylon attachment is positioned at a 90° angle to the operating table (Figure 4-19). The center of the plate is inset 0.5 in. from the line drawn from the middle of the knee. The cage is molded to the exterior of the cast. Strips of fiberglass casting material are folded onto and placed between the distal cast and pylon plate. The cage is attached to the cast with the fiberglass casting material. The pylon and SACH foot in neutral position are attached, and the pylon is cut to the proper length. The pylon and foot are then removed and utilized later in therapy when controlled weight bearing can be ensured. Finally, a circular cut is made in the cast over the prepatellar region (Figure 4-20). The cut should be made smaller than the pad to allow the pad to be removed and also provide relief over the patella.

On postoperative day 1, the patient may do touchdown weight bearing at the bedside. After the first few days, the patient may be advanced to 10% weight bearing in the parallel bars. During the second week, weight bearing is increased to 50%. After two weeks (at the time of the second cast change), the patient may be advanced to full weight bearing with gait training in the parallel bars.[61] Full weight bearing with IPOP is controversial as some proponents are not in favor of full weight bearing.[60,61] For traumatic amputees IPOP is indicated, but for dysvascular amputees, this early weight bearing may result in skin breakdown.

The cast is changed at 1-week intervals until the wound has healed and the sutures are removed. This usually occurs two weeks postoperation in the uncomplicated traumatic amputation. At each IPOP change, the wound is inspected and, if no complications exist, another cast is applied immediately. While the limb is not in a rigid dressing, it should be elevated. If there is a delay in applying the next rigid dressing, the limb should be wrapped in an elastic bandage and kept elevated. In the presence of increased or unexplained pain, discomfort,[60] fever, or excess drainage, the cast should be removed and the wound appropriately investigated.[62] The surgeon will then decide whether to reapply the dressing. Once the wound is healed and sutures are removed, a temporary prosthesis or a removable rigid dressing with a pylon/foot assembly can be applied.

The advantages of the IPOP include edema prevention,[17] edema reduction,[58] trauma protection, reduced pain, decreased phantom pain,[58] psychological benefit, early weight bearing, and prevention of knee flexion contracture.[62] Disadvantages include the inaccessibility of the wound, the need for a prosthetist, and poor wound healing if weight bearing is excessive (caused by a lack of close monitoring during therapy).[21,58,63]

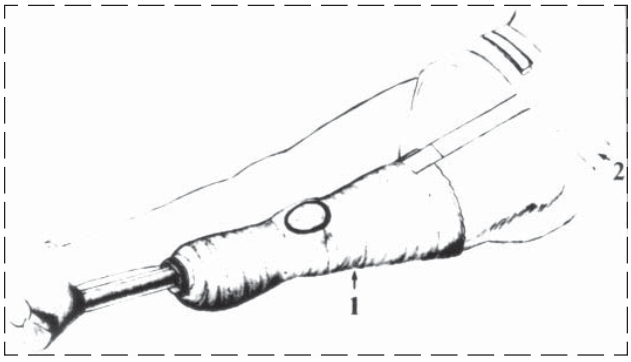


Fig. 4-20. IPOP with pylon and SACH foot (1), and waistbelt suspension (2). Note the patellar cutout that was made over the patellar pad.

Long Rigid Dressing. The application of an IPORD is similar to that of an IPOP except that a pylon and foot are not added. This IPORD is applied using the same techniques as when applying an IPOP, except the knee is cast in full extension.[62] The dressing is changed weekly until sutures are removed and the wound has healed. The patient is then fitted with a removable rigid dressing with pylon and foot, or with a temporary prosthesis. The reported advantages are the same as those for the IPOP, except there is no early weight bearing and no psychological advantage of awakening to see a foot. However, there is no wound breakdown secondary to excessive weight bearing,[21] and a prosthetist is not required.

Short Removable Rigid Dressing. A short, removable rigid dressing may be used immediately postoperatively or after the first or second IPORD change. The dressing is constructed of elastic plaster reinforced with conventional plaster or fiberglass. The dressing is carried anteriorly to midpatella, and trim lines are cut posteriorly in the popliteal space to accommodate the hamstring tendons and allow comfortable knee flexion. Instead of pads to create pressure relief, cotton cast-padding is used to make spacers over the tibial tubercle, tibial crest, and fibular head. Additionally, before casting, padding is added proximally over the residual limb. Once casted, the spacers and padding are removed. This allows the dressing to be removable even for a bulbous limb.[64]

This dressing may be suspended by a supracondylar cuff or waist belt attached directly to the dressing (Figure 4-21). The patient is instructed in proper donning of the rigid dressing, the suspension, and the varying thicknesses of stump socks to achieve a proper fit.

A short, removable rigid dressing with a pylon and foot is considered a preparatory or temporary prosthesis for the below-knee amputee. It is "temporary" because it requires changing as the residual limb decreases in size, but it is quite beneficial for early ambulation.

At 10 to 14 days postoperation, a gradual increase in weight bearing is started.[64] Weight bearing in the rigid dressing can be with or without a pylon and foot (see Figure 4-21). Weight bearing without a pylon is accomplished by standing with the dressing resting on a stool. A gradual weight bearing program is begun while standing. Before each increase in weight bearing, the limb is checked for duration and amount of skin erythema. Additionally, sock thicknesses are increased to give a continually snug fit, resulting in gradual decrease in stump edema.

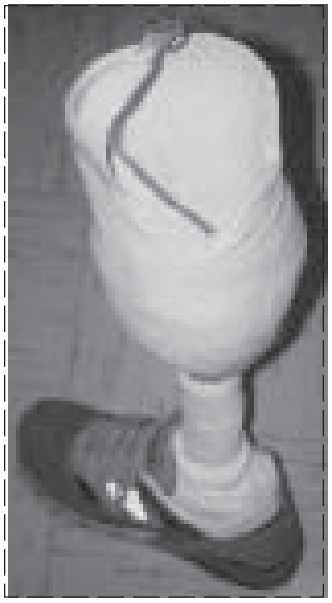


Fig. 4-21. A short removable rigid dressing (temporary prosthesis) with attachment strap for waistbelt suspension. Pylon and foot are attached.

The advantages of a short, rigid dressing compared to an IPORD are wound accessibility for easy wound examination during increases in weight bearing, and easy addition of socks, which facilitates quicker shrinkage.[64] Disadvantages of a short, rigid dressing include the possibility for development of knee flexion contracture, and for skin breakdown from excessive weight bearing before wound healing is complete.

Experience with Postoperative Dressings. The use of rigid dressings or IPOPs has generated concern regarding wound breakdown. In a small study on dysvascular amputees, Cohen and colleagues[63] reported problems with wound breakdown when using IPOPs. Burgess and associates[53] operated on 159 dysvascular patients and utilized either a rigid dressing or an IPOP; they reported failure to heal with revision to a higher level in 12 patients. Seven of the 12 were felt to have failed secondary to improper level selection and 5 failed from inadequate postoperative management. The time to definitive prosthesis wearing was significantly shortened to less than 60 days in 123 of the 150 BKAs.[53] Malone and associates,[20] when comparing IPOP and the team concept to soft or rigid dressing without weight bearing or team concept, reported improved healing and markedly shorter rehabilitation times and hospital stays. However, Baker and associates[65] reported no significant difference in healing rates

between soft and rigid dressings, although the rigid dressing patients' rehabilitation times were shorter. Mooney and associates[21] prospectively compared soft dressings, rigid dressings, and IPOPs in diabetics undergoing amputation. In general, they found healing times were shortest for the rigid dressing patients and slowest for the IPOP patients. Surprisingly, soft dressings had the highest percentage of nonhealing. The amount of time before receiving a definitive prosthesis was shortest when rigid dressings were used and longest when the soft dressings were used.[21]

Recommendation. To obtain the benefits of a rigid dressing without the risk of wound breakdown from excessive weight bearing, an IPORD may be used. The dressing is constructed as described earlier but without the pylon-foot assembly. The dressing is changed weekly until the wound has healed. Once sutures are removed, a short, removable rigid dressing (temporary prosthesis) is made.[64] Fiberglass casting is used for reinforcement (see Figure 4-21). The anterior trim line is to the midpatella with medial and lateral trim lines cut back posteriorly to the popliteal space to allow comfortable knee flexion. Suspension is through the waist belt (Figure 4-22). Alternatively, a supracondylar cuff suspension can be used with auxiliary waist belt suspension. A pylon and SACH foot assembly is attached as with the IPOP. Usually, for the first day, the dressing is not removable, but with stump shrinkage, the dressing becomes removable. The dressing is remade when the amputee is using 10 to 15 total ply stump socks. This temporary prosthesis allows early weight bearing. Temporary prefabricated prostheses, after initial rigid dressing or soft dressing, can be used for early weight bearing (Figure 4-23).[66–68]

Fig. 4-22. Soldier with temporary fiberglass/plaster prosthesis with waistbelt suspension.

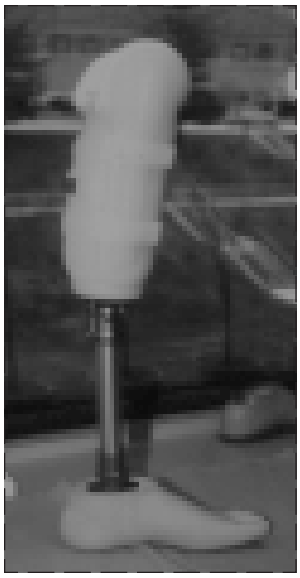


Fig. 4-23. Temporary, prefabricated, adjustable prosthesis with pylon and foot.

Rehabilitation of the Below-knee Amputee

Preoperative. Ideally, the amputation team should see the patient in the preoperative phase when the patient is awaiting amputation or has an open amputation that requires closure or a definitive procedure. For the war-injured amputee this usually involves awaiting closure of the open wound. The primary goal at this time is to prevent skin and soft tissue retraction by using skin traction (see Figure 4-14). Other important goals in the preoperative phase are (*a*) physical evaluation, (*b*) patient education, (*c*) prevention of medical complications, (*d*) physical conditioning, and (*e*) functional training.

A thorough patient evaluation must be obtained in order to plan the rehabilitation program. Medical problems affecting the musculoskeletal, neurologic, cardiac, pulmonary, vascular, and dermatologic systems may directly impact on both short-term and long-term functional goals and prosthetic usage. Besides a general examination, the following should be assessed:

- joint range of motion,
- joint stability,
- arthritic changes,
- amount of pain,
- relative strength,
- unusual sensations,
- patient coordination and balance,
- vision,
- cognition,
- pathologic reflexes and abnormal tone,
- vascular status in the involved limb, and
- dermatologic condition of the residual limb.

Knowledge of the patient's preinjury and current functional status is important. The preinjury functional status helps in establishing long-term goals for functional restoration. The current functional status provides the baseline for initiating therapy and developing short-term goals. The functional evaluation should assess ambulation, transfers, dressing, eating, bathing, and personal hygiene, and determine whether assistance in performing an activity or assistive equipment is needed. In particular, the initial functional examination should include bed mobility, sitting balance, standing balance, and transfers.

The psychological status and available personal support systems of the amputee and amputee's family are important factors affecting rehabilitation. A young amputee may express difficulty or concern with self-identity, body image, social acceptance, loss of function, employment, loss of income, peer acceptance, and sexual function. The psychological aspects of amputation or lack of a social support system may further increase distress.[19] The amputee may experience bereavement over the loss of a limb. This may include anxiety, despair, and anger. Often, a formal psychological or psychiatric consultation is not required. However, if the amputee's psychological status is affecting participation in rehabilitation, formal consultation should be obtained. Also, the effect the amputation has on the amputee's family members and the amputee's relationship with family members needs to be addressed.

Educational and vocational history is important in planning a return to gainful employment. Specific considerations may include (*a*) highest level of education attained; (*b*) jobs held, including dates and duration of employment; (*c*) specifics regarding physical tasks of the jobs; (*d*) job satisfactions and dissatisfactions; (*e*) relationship with coworkers; and (*f*) future employment plans and goals. Other factors that need to be addressed are recreational interests; financial status; location of residence; and availability of health care, prosthetic, and rehabilitation professionals in the patient's community. It is rare for amputees to remain on active duty.

Involvement of the patient as an active member in the rehabilitation process is important. To facilitate involvement, patient education is crucial. Specific explanations should be provided regarding the surgery, postoperative care, phantom sensation, phantom pain, the rehabilitation process, and prosthesis use. The amputation should be viewed as a reconstructive procedure instead of a destructive procedure. The surgeon should address questions about the surgery and postoperative surgical management. The physiatrist may explain other areas of amputee care. Other team members may provide further specific education regarding their areas of expertise. Meeting with a successful amputee, who has been screened by the amputation team, allows the patient to see the functional level that an amputee can achieve. Additionally, the successful amputee may further explain the process from the amputee's perspective and provide psychosocial support. For the prosthetic candidate, education regarding the prosthetic process and prescription is important. The potential prosthetic candidate should be educated regarding the differences between preparatory, intermediate, and definitive prostheses. The prosthetist can further describe the process and provide sample prostheses and components for viewing.

Prevention of complications during the preoperative phase is crucial, because complications may drastically slow or adversely affect the rehabilitation outcome. Complications of immobility include deep vein thrombosis, pulmonary embolism, pneumonia, atelectasis, orthostatic hypotension, decubitus ulcers, loss of muscle mass, osteopenia, and contractures.[18]

In particular, the transtibial amputee is at risk of developing knee flexion, hip flexion, hip abduction, and hip external rotation contractures.[58] Contractures may develop from poor bed positioning and stump pain. The risk of contractures can be further increased by flaccid paralysis, spasticity, edema, ischemia, and bleeding.[18]

A hip flexion contracture can result in decreased contralateral step length from limited hip extension.[58] A knee flexion contracture can decrease step length, create abnormal forces at the involved knee, and prohibit prosthetic fitting.

Contractures can be prevented by frequent position changes, prone lying, and a daily range-of-

motion program.[18] Bed position changes should be done on a scheduled basis. Prone lying is not always needed in the transtibial amputee[59]; however, if the patient is at risk for or is developing a hip flexion contracture, prone lying should be encouraged. The risk of developing a hip flexion contracture is increased with prolonged sitting and use of a soft mattress. Hip abduction contracture risk is increased with use of a pillow between the legs. Hip external rotation contracture is increased in the bedbound patient but the risk is reduced with use of a trochanteric roll. In transtibial amputees, placing a pillow under the thigh or knee should be prohibited to avoid a knee flexion contracture. Also, for sitting in a wheelchair, a knee extension board for the residual limb should be used to avoid knee flexion contracture.[59] Lastly, early ambulation will maintain joint range of motion. If a contracture occurs, an active and passive range-of-motion program with terminal stretch should be instituted.

With bedrest, normal individuals can lose 10% to 15% of their strength per week, or 50% of their strength in 3 to 5 weeks. The quadriceps and back extensors are particularly affected.[18] Weakness in these muscles can adversely affect the transtibial amputee's ability to ambulate.[59] To prevent loss of strength, the patient can perform 20% to 30% maximum isometric contraction for several seconds each day, or 50% maximum for 1 second.[18]

For the transtibial amputee in the preoperative phase, a more specific exercise program should be initiated. Isometrics of the back extensors, hip abductors, hip adductors, abdominals, gluteals, quadriceps, shoulder depressor, elbow extensor, and wrist extensor muscle groups should be performed for 10 seconds at regular 1-hour intervals in the daytime.[58,59] Once the patient is doing well with isometrics, he can progress to concentric and eccentric isotonic exercises. General conditioning can be performed using an arm ergometer. Arm strength is particularly important because amputees use crutches and canes initially for ambulation.

If medically feasible, the physical therapist can begin mobility training in the preoperative phase. Stand pivot transfers should be taught to allow independent transfers between the bed and wheelchair. Once bed transfers are mastered, toilet, tub, and car transfers should be taught. Use of a trapeze should be avoided unless clinically necessary, because the trapeze promotes use of the biceps rather than the triceps, which are normally used for transfers.[59] Also, the patient is unlikely to have a trapeze for use at home, whether visiting on pass or after discharge from the hospital. Wheelchair skills should also be taught. These skills will promote independence while in the hospital before crutch ambulation is mastered. Additionally, this activity helps maintain general conditioning and prevent complications of immobility. The patient will also need these skills in the postoperative phase, and the skills are easier to teach preoperatively than immediately postoperatively. Additionally, some amputees may require wheelchair mobility for long-distance mobility, or for times when they are unable to wear their prostheses. Prolonged wheelchair sitting should be avoided, however, because it leads to hip flexion and knee flexion contractures.

Crutch ambulation should also be instructed preoperatively. First, the patient should master sitting, and then standing balance. Gait training can then begin in parallel bars, advancing appropriately until crutch ambulation is achieved. Once crutch use is mastered on the level surface, training moves toward independent crutch ambulation on stairs and rough terrain.

Independence in basic ADLs should be promoted based on the patient's current function in the preoperative phase. An occupational therapist can evaluate and provide training in feeding, toileting skills, bathing, dressing, and orofacial hygiene. Additionally, the preoperative evaluation and training will help to delineate postoperative capabilities and rehabilitation needs.

Postoperative. The postoperative phase of rehabilitation would be for those individuals who have undergone their definitive amputation procedure. The main goals during this phase are (*a*) wound healing, (*b*) early limb maturation, (*c*) prevention of complications, (*d*) functional independence, and (*e*) prosthetic fitting. Some amputees achieve independence in functional activities sooner than others. The following discussion is a general overview of a typical postoperative rehabilitation program.

Healing is crucial, because delayed healing results in delayed rehabilitation. Causes of delayed healing may include an improperly applied rigid dressing, or excessive weight bearing. If a rigid dressing is poorly fitted, the dressing should be remade. If wound breakdown occurs from excessive weight bearing, weight bearing should be discontinued until healing is complete. The complications of immobility and methods of prevention need to be followed as in the preoperative phase. The postoperative program includes the previously described dressings.

During the first postoperative week, exercises, functional training, and education will continue. On postoperative day 1, isometric gluteal and quadri-

ceps exercises along with gentle range-of-motion exercises of the residual limb are started.[58] Active range-of-motion and progressive resistive exercises are begun on the contralateral limb and upper extremities. The patient should begin standing at bedside. The physical therapist will assist the patient in sit-to-stand transfers and standing balance at bedside.

As the week progresses, wheelchair transfers, wheelchair mobility, and crutch ambulation are begun. The benefit of preoperative training is now apparent, as the patient is already prepared for transfers and crutch ambulation. Crutch ambulation is important to prevent complications of immobility. If the patient is unable to crutch ambulate independently or for long distances, wheelchair mobility should be encouraged. As in the preoperative phase, an extension board for the residual limb should be utilized.

Basic ADL training continues through week 1, based on the patient's current functional and medical states. If the patient was not seen preoperatively, education regarding the rehabilitative process and prosthetic process should now be given. Additionally, education regarding phantom limb sensation and pain should be provided. At the end of week 1, the first IPORD change occurs. The limb is examined and if no complications are present, the second IPORD is applied.

During week 2, gentle resistive exercises for the residual limb begin, and functional training continues. At the end of the second week, if the wound is healing well, the patient is changed to a short, removable rigid dressing with a pylon/foot assembly (temporary prosthesis). If the residual limb shows any areas of nonhealing, the rigid dressing can be continued, or replaced with elastic wrapping to allow close skin monitoring; the pylon/foot assembly is kept in physical therapy to be used for controlled gait training, thereby preventing the patient from harm due to inappropriate weight bearing.

Exercises to increase strength and endurance continue. After the residual limb is inspected for any skin breakdown, functional training in physical therapy advances to progressive gait training with the temporary prosthesis. First, the residual limb is inspected for any skin breakdown. If there is breakdown, the physician should be consulted before any weight bearing is allowed. Second, the amputee is instructed and assisted in sit-to-stand transfer in the parallel bars. Third, the amputee is allowed to weight bear 40 lb through the residual limb.[69] The amount of weight is measured by having the amputee stand on scales under each limb. The prosthetic side is limited to roughly 40 lb initially, then increased as the limb tolerates. Fourth, alignment is checked and should be similar to a patellar tendon-bearing prosthesis (Figure 4-24). The foot

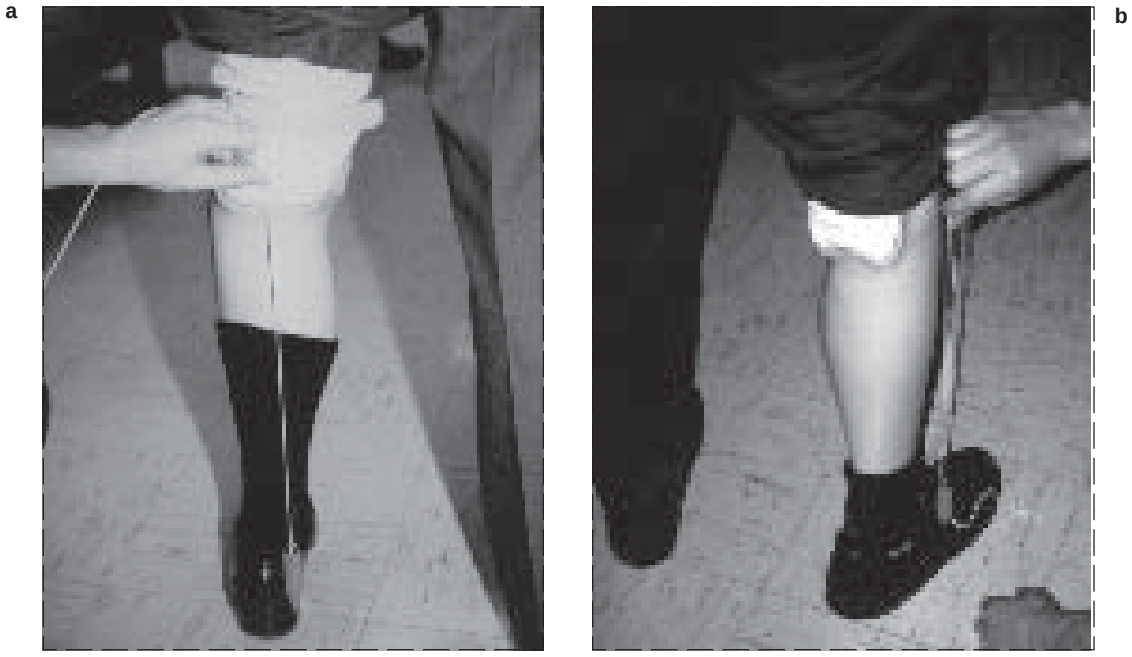


Fig. 4-24. Static alignment is done using a plumb line, (**a**) posterior and (**b**) lateral.

should be flat on the ground and iliac crest height symmetric, suggesting equal leg lengths. The socket should be in 5° to 10° of flexion and 2° to 5° of adduction. A plumb line dropped posteriorly from the middle of the socket should fall approximately 0.5 in. medial to the heel center (see Figure 4-24).[70] A plumb line dropped laterally from the middle of the socket should fall approximately 0.5 in. anterior to the breadth of the heel. The foot is externally rotated 5° to 7° and is symmetric when compared to the opposite limb. Static alignment may only be approximate until the amputee is able to bear equal weight through both legs. Dynamic alignment is evaluated later. Static alignment corrections should be made before proceeding with ambulation. Fifth, standing is done with a bathroom scale under each limb. Only 40 lb of weight bearing is allowed on the amputated side. After standing for a short period, the amputee sits down and the rigid dressing is removed. The residual limb is inspected for evidence of total contact, usually seen by the presence of sock print left on the limb, and for any excess pressure areas and pain caused by the rigid dressing. Any malalignment that has caused pain and excess pressure is corrected. If the problem is inherent in the dressing, a new rigid dressing is fabricated.

If no complications have occurred, gait training continues. Ambulation with assistance in the parallel bars begins with a 40-lb weight bearing limit on the amputated side. (In reality, weight bearing during ambulation cannot be controlled very well without measuring directly the force in the pylon and providing audio feedback when the limit is exceeded.) After the patient ambulates one length of the parallel bars, the residual limb is inspected. Additionally, dynamic alignment (discussed later) is assessed with ambulation. If no complications are noted, another session occurs in the afternoon. If complications attributed to the rigid dressing occur, corrections are made. If the dressing or malalignment was not the cause, the amount of weight bearing is decreased until signs of excessive pressure are resolved.

Advancement of the gait training program includes daily distance increases in parallel bar ambulation. Also, every 2 to 3 days the weight bearing may be increased by 40 lb until full weight bearing is achieved.[69] With each increase in weight bearing, proper weight shifting and standing balance should be mastered before advancing gait training. Proper arm, trunk, pelvic, intact leg, residual limb, and prosthetic movements are practiced.[59] Once parallel bars are mastered, the amputee is progressed to bilateral forearm crutch ambulation within the weight bearing restrictions.

Transfer training is continued with the goal of independence in sit-to-stand transfers with the prosthesis. Because the amputee will not initially have the pylon-foot complex, he or she must first become independent in one-legged stand-pivot transfers.

Basic ADL training with occupational therapy is addressed. In dressing, attention is especially paid to LE dressing along with donning and doffing of the rigid dressing and stump socks. While the amputee with good balance may stand for most bathing procedures, washing of the intact leg and foot usually requires sitting and the use of a tub bench and hand-held shower. In some complicated cases where there are other coexistent injuries, toileting, eating, and personal hygiene may need special training or adaptive equipment.

The purpose of the rigid dressing for limb maturation, edema reduction, protection, and early ambulation is taught. The amputee must be aware of edema development when the rigid dressing is off, especially after showering with the limb dependent. Proper donning of socks is performed with the seams not crossing the incision and without wrinkles. Stump socks give a proper fit to the rigid dressing as the limb shrinks. The amputee maintains steady tension on the socks to prevent excess stress to the incision when donning the rigid dressing. The amputee may wear a nylon stump sheath to decrease shear. Both sheaths and socks should be cleaned and changed daily. The amputee must regularly examine the limb for any skin breakdown, with initial skin checks done in the morning, after any ambulation, and before bedtime.

Another method of edema control, particularly if a temporary prosthesis cannot be used, is elastic wrapping of the residual limb. Elastic wrapping incorporates a figure-8 configuration to avoid the tourniquet effect of circular wraps (Figure 4-25). The wrap begins distally, taking tension off of the incision line and properly shaping the limb. The elastic wrap extends proximally to include the distal third of the thigh. The elastic wrap should be firm but not tight, removed every 4 hours for inspection, and worn at all times when the rigid dressing is off. The residual limb should not be dusky-colored or develop blisters from wrapping.[59]

When applying a shrinker sock, the seam should not cross the incision, no pocket should be formed at the end, and the proximal band should not be too tight (Figure 4-26). A shrinker sock is an elastic sock designed to compress the residual limb and

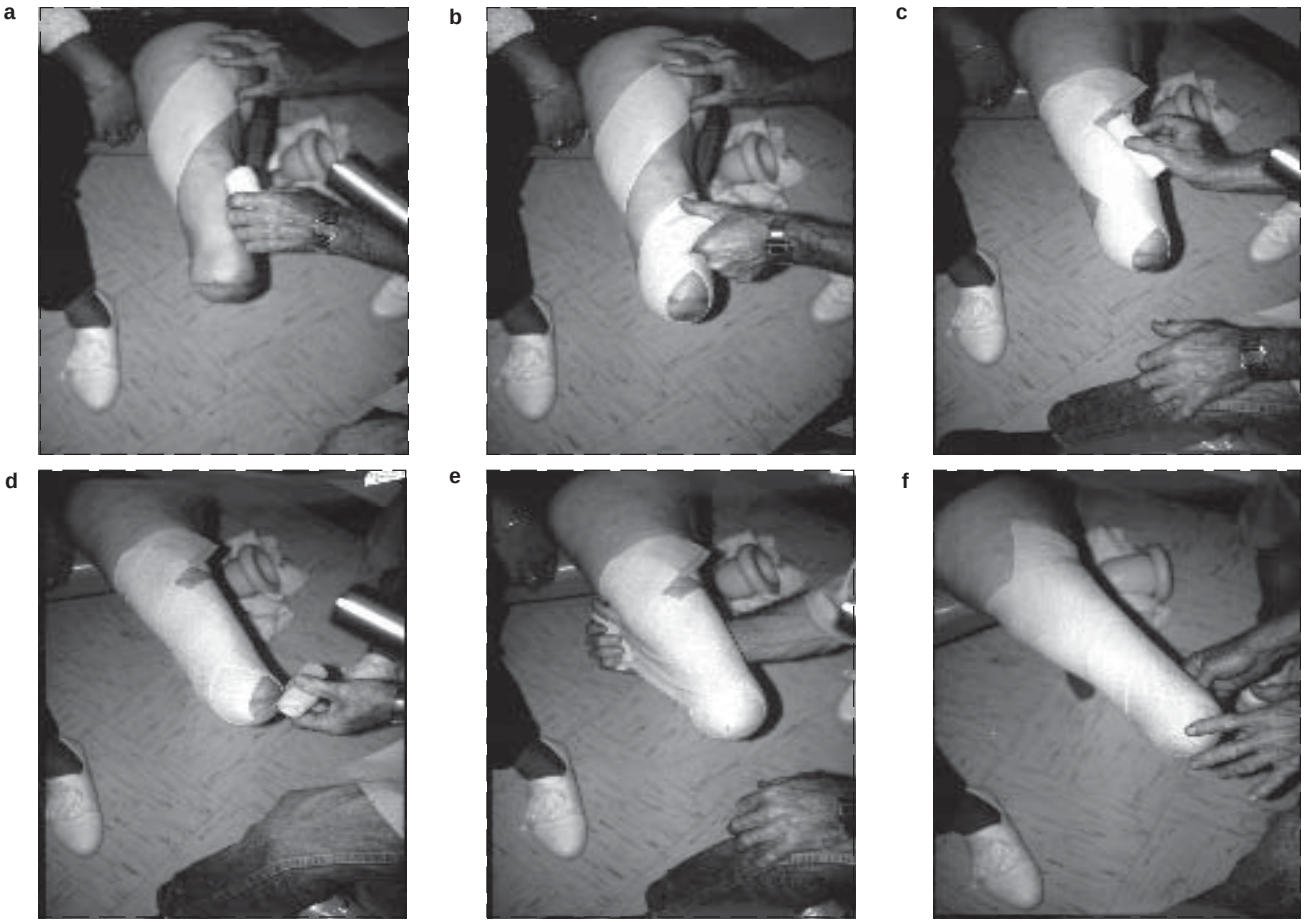


Fig. 4-25. Elastic wrapping is done in a figure-8 configuration. Note how tension is taken off the suture line and shaping of the residual limb is affected by the wrap.

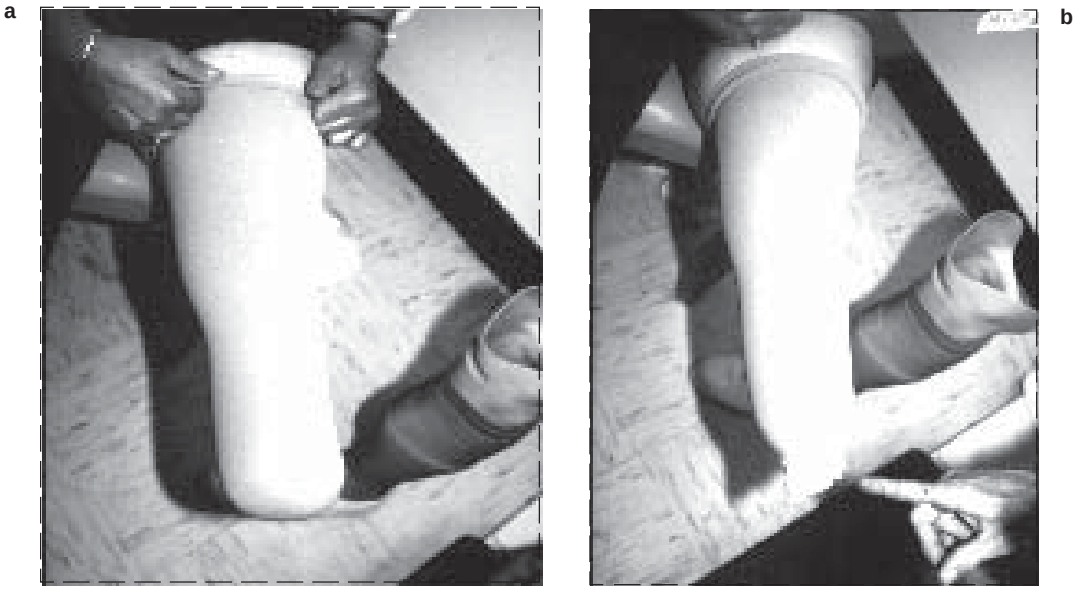


Fig. 4-26. Shrinker with (**a**) proper application and (**b**) improper donning with a distal pocket that allows edema accumulation.

reduce edema. The prosthetist can provide the appropriate size.

As the limb shrinks and matures with proper shaping, the rigid dressing may be substituted with a shrinker or an elastic wrap while sleeping at night. Again, the residual limb must be in the rigid dressing, an elastic compressive wrap, or a shrinker sock to prevent edema accumulation, which can occur rapidly.

Controversy exists over using a shrinker or an elastic wrap. The advantage of the elastic wrap is that it conforms to the residual limb. The disadvantages include tourniquet risk, stump damage with excessive compression, difficult application, slippage, and variation in tension with repeat applications.[59] The shrinker is easier to apply, but may slip down, causing a distal pocket of edema. This can be solved with use of a garter belt. One study[71] of 12 LE amputees evaluated the effectiveness of edema reduction utilizing either an elastic wrap or shrinker. The shrinker was more effective. However, the study can be criticized for small sample size and large standard deviations in edema measurement results. Whether an elastic wrap or shrinker, proper usage and application are most important, and the two items should not be concomitantly used on the same limb, as pressures may become excessive. Once the amputee has stable residual limb volumes throughout the day, an overnight trial without a shrinker or elastic wrap may be tried. If there is no difficulty donning the prosthesis the next day, the shrinker or elastic wrap may be discontinued.[59]

During the second and subsequent weeks, gait training continues with the goal of independent ambulation without assistive devices. The amputee should have forearm crutches for use when unable to wear a prosthesis. Once level surfaces are mastered, advanced gait training should begin. The amputee should become independent in stairs, uneven terrain, and ramps. If feasible, for the amputee living in an area with snow or ice, training on these surfaces should be addressed. The amputee is also trained in more advanced transfers, such as car and floor-to-standing transfers.

Once basic ADLs are mastered, advanced ADL training ensues. Advanced ADL training is individualized toward the patient's home, community, and work environments. Common areas include independence in the kitchen, grocery shopping, and driving. Adaptive equipment needed to perform ADLs is provided prior to discharge from the hospital. These may include tub benches, hand-held showers, wheelchair, and forearm crutches. Necessary equipment should be ordered early in the hospital course to avoid delaying discharge from the hospital secondary to pending equipment. For right transtibial amputees, adaptive pedals are available for operating the car gas and brake pedals. Some states require these adaptations. The amputee should consult his local driver's license bureau and insurance company regarding special requirements for amputees.

The amputee should meet with a vocational counselor regarding future vocation. This will often be handled through the VA vocational counselor. A small percentage of highly motivated soldiers will want to remain on active duty.

Once residual limb volumes are fairly stable with use of the removable rigid dressing, usually about 6 weeks postoperative in the uncomplicated patient with the above protocol, an intermediate prosthesis should be fitted. The intermediate prosthesis consists of a socket, liner, suspension, endoskeletal pylon, and ankle/foot assembly. The advantage of the endoskeletal pylon is the ability to adjust alignment as the patient's gait and function changes in the intermediate period.[72] Once the prosthesis is complete, the amputee is evaluated in the new prosthesis for fit and alignment. Any malalignment is corrected before accepting the prosthesis and allowing ambulation. An improperly aligned prosthesis can result in harm to the residual limb and a less functional outcome. If the prosthesis fits and is aligned correctly, basic and advanced gait training in the prosthesis is taught by the physical therapist. This process is rapid if the amputee has already mastered ambulation skills prior to receiving the intermediate prosthesis. The amputee is thoroughly educated in maintenance and care of the prosthesis. The socket requires daily cleaning. The intermediate prosthesis can often be used for many months.

Many amputees will require at least socket changes during the first year, if not a completely new prosthesis. The amputee is checked in 4 weeks and every few months afterwards if no complications necessitate more frequent follow-up. Over the first year, there will be continued residual limb volume shrinkage with potential need for a new prosthesis. After the first year, the amputee should be followed at least every 6 to 12 months indefinitely.[62]

Prosthetic Prescription

The prosthetic prescription is based on the medical condition, residual limb characteristics, and functional goals of the patient. The patient's overall health and medical condition, especially cardiopulmonary, neurologic, and musculoskeletal must be considered. Residual limb factors include length,

shape, skin condition, soft tissue coverage, joint stability, muscular strength, edema, and presence of contractures. The patient's vocational goals, avocational goals, cosmesis, home and work environment, climate, cultural background, and the availability of prosthetic services also impact the optimal prosthetic prescription.

A knowledge of different prosthetic components is necessary to achieve the appropriate prescription. The prescription requires a team effort with active participation of the patient, physiatrist, therapists, and prosthetist.

Sockets. The socket contains the residual limb and forms the union between the residual limb and prosthesis.[14] The function of the socket is to provide stability, transmit forces, support, and contain the residual limb.

The standard socket in use for below-knee amputees is the patellar tendon bearing, total contact socket (PTB-TCS).[17] This socket allows improved transmission of forces compared to the bucket fitting sockets, which transmit forces primarily through the end of the residual limb. The PTB-TCS, by being a total contact socket, distributes forces over a wider surface area than the bucket fitting sockets, and thus, results in decreased pressures to the residual limb. (Pressure is defined as force per unit of area.) However, not all areas of the residual limb tolerate pressure equally. For example, excess pressure to a bony prominence, such as the tibial crest, may lead to skin breakdown or pain, while a soft tissue region, such as the anterior compartment muscles of the leg, may accommodate the same pressure without difficulty. These areas are termed *pressure intolerant* and *pressure tolerant*, respectively. Pressure intolerant areas in the socket are the distal tibia, distal fibula, fibular head, tibial crest, lateral tibial flare, tibial tubercle, and peroneal nerve.[14,72] These will require pressure relief. The pressure tolerant areas of the socket include the patellar ligament, medial tibial flare, medial tibial shaft, lateral fibular shaft, and anterior compartment muscles.

The anterior wall of the PTB-TCS extends proximally and covers the distal one third of the patella, with an indentation pushing on the patellar tendon (Figure 4-27). The indentation, termed the patellar bar, distributes pressure over a pressure tolerant area. The posterior aspect flares outward to provide relief for the hamstrings. The proximal aspect of the posterior wall may indent to provide a counterforce, which maintains patellar bar contact. The posterior wall must be trimmed to provide relief for the hamstring tendons and allow comfortable knee flexion. The medial and lateral walls extend to the level of the adductor tubercle. Together, the walls provide mediolateral and rotational stability. The medial wall contacts the medial tibial flare for weight bearing. The lateral wall has a pressure relief area for the fibular head.[72]

Fig. 4-27. Patellar tendon bearing, total contact socket (PTB-TCS) endoskeletal design. Lateral view showing the indentation anteriorly below the patella, which represents the patellar bar.

The soft PTB-TCS refers to sockets utilizing a compressible liner. The liners are made from a variety of materials: different types of soft foam padding, leather, silicone gel, etc. The liners are designed from the positive mold of the patient's residual limb, and are worn inside the socket to provide shock absorption, decrease shear forces, and provide comfort. The soft PTB-TCS socket is indicated for amputees with fragile skin, insensate or tender limbs, limbs with excessive scar or sharp bony prominences, skin grafts, and peripheral vascular disease; for bilateral transtibial amputees, to reduce shear force; and for the highly active amputee.[17,72] The disadvantages of liners are decreased hygiene (with absorption of sweat and dirt), increased weight, increased bulk at the knee, and deterioration of the liner over time, leading to loss of prosthetic fit.[72,73]

The hard PTB-TCS does not incorporate a liner. Usually, a distal pad is placed in the hard socket to provide padding for the distal residual limb. A hard socket may be used when there is a mature, cylindrical residual limb with good soft tissue coverage. The hard socket should not be used in the presence of peripheral vascular disease, diabetes mellitus, thin skin, skin grafts, skin predisposed to breakdown, excessive scar, or by new amputees. The main advantages of the hard socket are better hygiene (it is easy to clean and produces less odor compared to liner use) and the capability to make precise socket modifications.[72] The distal pad in the hard socket provides increased comfort and helps prevent distal edema.[14,72] The main disadvantage is that it causes difficulty in fitting bony or sensitive residual limbs. The hard socket with distal pad may be helpful for those with distal skin problems, edema, and impaired proprioception.

The supracondylar PTB-TCS is a variant of the PTB-TCS socket (Figure 4-28). The anterior and posterior walls are essentially unchanged; however, the medial and lateral walls extend proximally over the femoral condyles. The higher medial and lateral walls provide more mediolateral and rotational stability along with increased surface area for pressure distribution. Additionally, suspension is provided by purchase above the femoral condyles. The socket is used with a soft liner with buildup over the medial femoral condyle to provide suspension and still allow the amputee to enter into the socket.

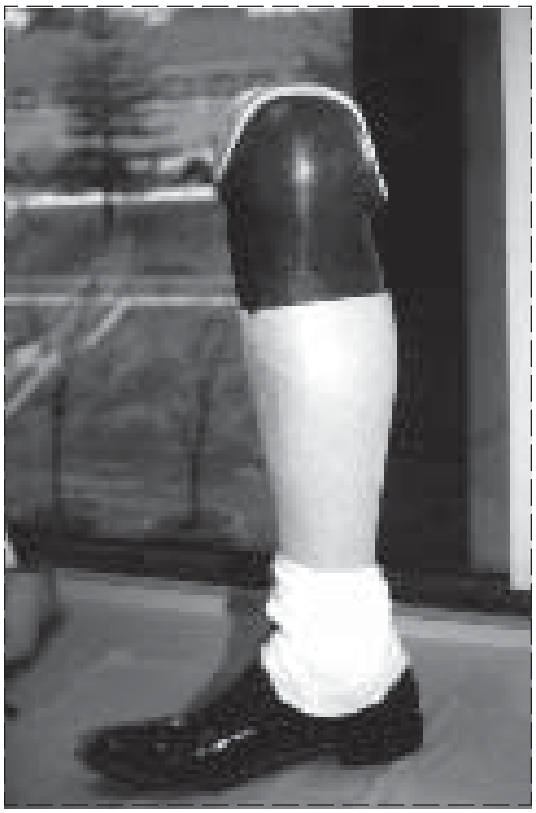


Fig. 4-28. Supracondylar thermoplastic patellar tendon bearing, total contact socket (PTB-TCS). The medial and lateral walls extend above the condyles and indent to provide suspension, mediolateral stability, and rotational control.

Fig. 4-29. Supracondylar exoskeletal PTB-TCS with removable medial brim.

There are two variants for this form of supracondylar suspension: (1) the removable medial brim, which allows donning with suspension provided by reattachment of the brim (Figures 4-29 and 4-30), and (2) the removable medial wedge, which is a foam wedge that is inserted between the socket and medial femoral condyle to provide suspension. The supracondylar PTB-TCS is indicated in patients with a short residual limb, mild knee instability, or as an optional suspension. It is relatively contraindicated in obese and some muscular individuals whose thigh shape may preclude the ability to achieve purchase on the femoral condyles. Individuals with moderate laxity may need the extra stabilization of a thigh corset with side joints.[72]

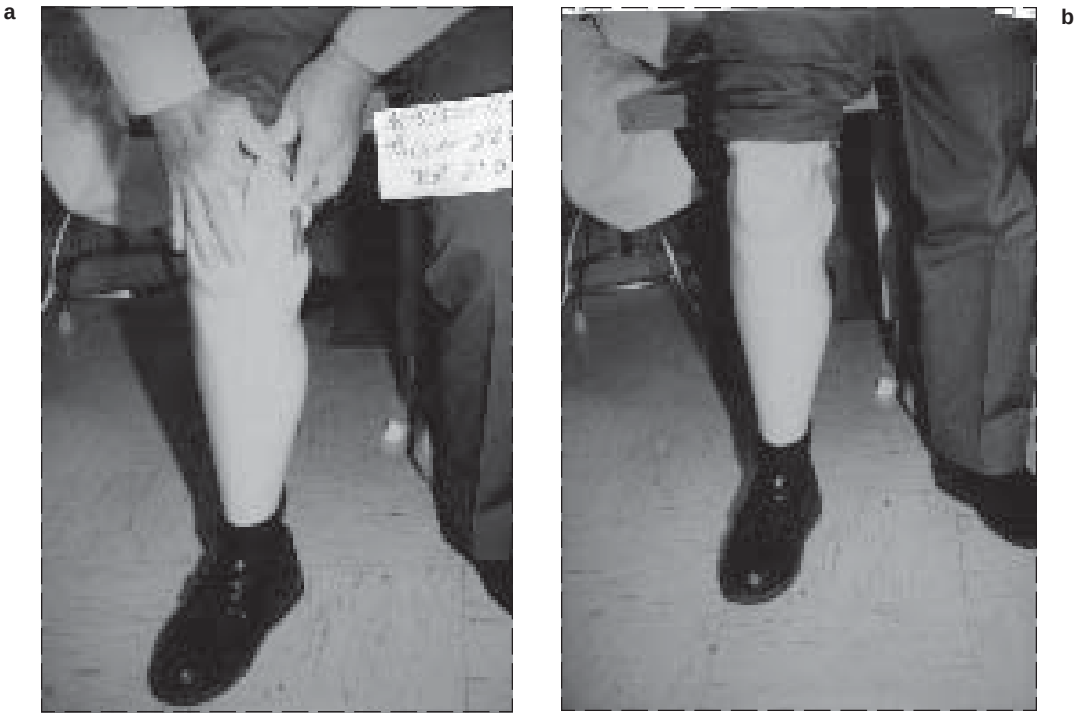


Fig. 4-30. Donning supracondylar patellar tendon bearing, total contact socket (PTB-TCS) with removable medial brim. (**a**) Insertion of medial brim and (**b**) medial brim in place.

The suprapatellar-supracondylar patellar tendon bearing socket is similar to the supracondylar PTB-TCS but with the extension of the anterior wall which covers the patella. Additionally, there is an indentation just proximal to the patella that is termed the quadriceps bar. The quadriceps bar provides a knee extension stop. Compared to the supracondylar variant, this socket provides better distribution of mediolateral, torsional, and surface area pressure. Furthermore, the supracondylar-suprapatellar variant provides anterior-posterior stability and resistance to genu recurvatum.[72] The socket has the same indications as the supracondylar PTB-TCS and the addition of patients with genu recurvatum. The relative contraindications of the suprapatellar-supracondylar socket are the same as those of the supracondylar socket; also, the suprapatellar-supracondylar socket should not be used for patients who frequently kneel.[72]

Thermoplastics now allow fabrication of flexible inner sockets that can be held in a rigid outer frame (Figure 4-31). Flexible sockets may be made from polyethylene, copolymer polypropylene, and polypropylene homopolymer.[72,74] The rigid frame is placed over primary weight bearing areas.[72] The flexible socket covers the bony prominences, providing relief from the rigid frame.[72,75] The degree of socket flexibility can be further increased for improved flexibility and comfort.[75] The advantages include decreased weight, increased comfort, increased heat loss, and the ability to replace the flexible socket for residual limb–socket interface changes.[72,75] The potential disadvantages are decreased cosmesis and difficult fabrication.[72]

Fig. 4-31. Thermoplastic socket with flexible inner socket and rigid outer frame.

Thermoplastics also allow fabrication of below-knee prostheses composed entirely of thermoplastic materials (see Figure 4-28).[76,77] The socket and shank are thermoplastic, with the prosthetic foot incorporated into the shank(see Shank section below). The thermoplastic shank and foot may provide some dynamic response. An average thermoplastic below-knee prosthesis weighs approximately 1.5 to 2.3 lb. The main advantages are decreased weight, dynamic response, low inertial mass, cosmesis, comfort, and ease of suspension secondary to the reduced weight.[76,77] The main disadvantage is that only minor socket modifications and alignment changes can be made after fabrication; however, refabrication is simple.[76]

Suspension. The main goal of suspension is to keep the prosthesis securely attached to the residual limb without causing excessive pressure or shear forces, discomfort, apprehension, impaired function, or choking of the residual limb.

Supracondylar cuff suspension is the most common form of suspension used in the transtibial amputee (Figure 4-32).[7,17,78] The cuff is made from leather-lined Dacron. The cuff wraps around the thigh just proximal to the patella and femoral condyles. The cuff utilizes the patella and condyles for suspension. It is closed by an anterior Velcro strap or buckle and attaches to the socket just posterior to the midsagittal line. This placement assists in resisting knee hyperextension forces, and allows the knee to be slightly withdrawn in knee flexion. The cuff is indicated in most transtibial amputations that exhibit good knee stability. The cuff should not be used in short or ultrashort residual limbs,[72] which need supracondylar/suprapatellar or supracondylar types , or sockets with thigh lacer and side joints. Also, sensitive skin or excessive scarring in the region of the cuff may preclude use of the cuff. The reported advantages of the cuff include ease of donning and doffing, adjustability, easy replacement, adequate suspension for most transtibial amputees, and moderate knee extension control. The disadvantages may include socket pistoning, no mediolateral stability, pinched soft tissue posteriorly between the cuff and socket with knee flexion, and restricted circulation from too tight an application.

A thigh corset with side joints consists of a leather corset with anterior laces encircling the distal two-thirds of the thigh, and metal side joints (single axis or polycentric) attaching the corset to the socket (Figure 4-33). The single axis joints must be precisely located to avoid excessive movement between

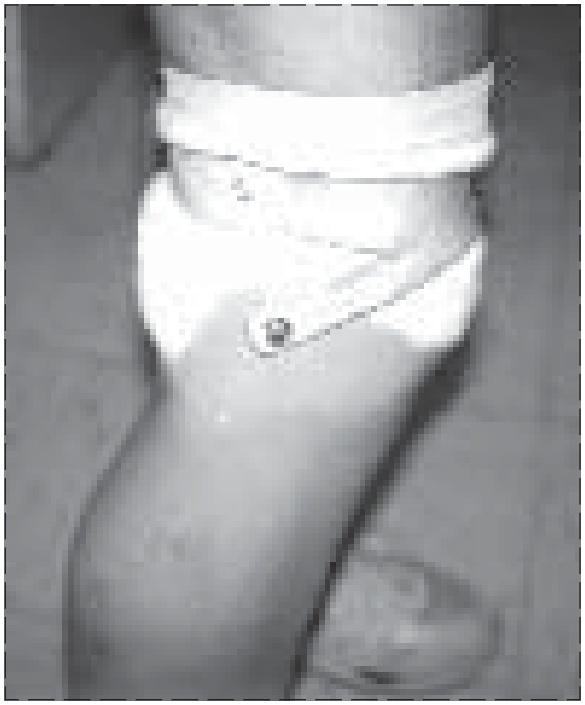


Fig. 4-32. Types of suspension. Supracondylar cuff suspension.

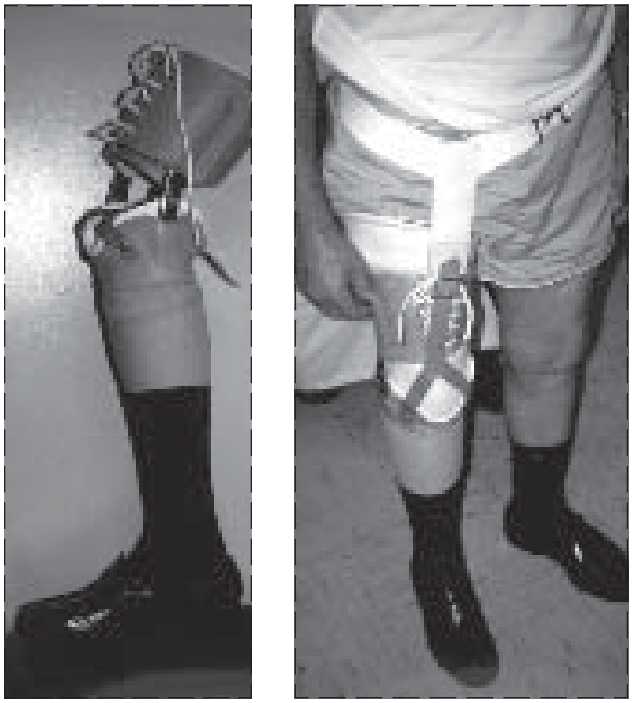


Fig. 4-33. Types of suspension. Thigh corset with side joints (left) and with waist belt suspension (right).

the socket and residual limb. With the knee in full extension, the joints are located slightly posterior and superior to the anatomical joint center. To limit knee extension or control genu recurvatum, a posterior check strap may be attached from the posterior socket to the corset. The thigh corset and side joints provide not only suspension, but also shared weight bearing.[72] Often, this suspension is accompanied by waist belt suspension.

A thigh corset with side joints is indicated when maximal anterior-posterior or mediolateral stability is needed, as in an unstable knee joint. It is also indicated for amputees engaged in very heavy work, or for those who need shared weight bearing to partially unload the residual limb in the socket.[72] Additionally, it may be of benefit to individuals who are obese, lift and carry weights, or have knee joint arthropathy.[14]

Other reported advantages of the thigh corset and side joints are the shared torque and weight bearing, maximum mediolateral stability, maximum reduction of genu recurvatum, and increased proprioceptive feedback.[72] Drawbacks include thigh atrophy, proximal constriction, increased weight, bulk, decreased cosmesis, increased fabrication time, nonhygienic attributes of leather, discomfort in hot weather,[14] and excessive wear on clothing. Also, single axis joints need precise placement to avoid excess movement between the prosthesis and residual limb, and there is the occasional need for auxiliary waist belt suspension (see Figure 4-33).

Waist belt suspension consists of a belt worn above the iliac crests or between the crests and greater trochanter, with an anterior strap suspending the prosthesis. The anterior strap is elastic and connects to a buckle at midthigh. The buckle is connected to another strap attached to a supracondylar cuff or inverted Y-strap. The midthigh buckle is used to adjust the suspension. The waist belt suspension may be used by itself or as auxiliary suspension. Waist belt suspension is indicated in the initial management of a postoperative patient using an IPOP or a temporary prosthesis. Suspension is maintained despite the fluctuations in volume during maturation. Other indications include the need to eliminate proximal constriction, provide auxiliary suspension in sports, and patient preference.[72] The waist belt is contraindicated if there is a scar and sensitive skin in the region of the belt. Problems with waist belt suspension include discomfort in wearing a belt, uneven suspension during swing phase, and no resistance to knee extension.[72] In patients with axillary to femoral or iliac artery grafts, waist belts can occlude the graft.

Sleeve suspension consists of a latex or neoprene sleeve.[14] The sleeve extends from the prosthesis to 2 to 3 in. proximal to the end of the residual limb socks. Suspension is created by negative pressure during the swing phase from the seal created by the sleeve. Suspension is also created from friction between the sleeve and the skin or prosthesis and the longitudinal tension of the sleeve. The latex sleeve provides the best seal and resultant suspension. The neoprene sleeve provides an acceptable seal, while the cloth-lined neoprene sleeve does not work well. Sleeve suspension may be used alone, or as auxiliary suspension for the suction below-knee prosthesis and with cuff suspension during recreational or sporting activities. Sleeve suspension should not be used as the sole suspension with short transtibial residual limbs. Amputees who kneel frequently, or who live in hot, humid climates may be unable to use sleeve suspension because the sleeve is not as durable as other suspensions, and allows perspiration buildup. Reported advantages of sleeve suspension are decreased pistoning, good auxiliary suspension, simplicity, and cosmesis.[73] Disadvantages include decreased suspension if the sleeve becomes torn; lack of durability, causing frequent replacement; skin irritation; contact dermatitis; possible decrease of full knee flexion; undesirable odors; and the need for good hand function to don and doff the sleeve.[14,72,73]

Suction transtibial prostheses are available, but the need for precise fit makes fabrication difficult. The prosthesis is fitted exactly to the shape of the limb with weight bearing over the entire distribution of the residual limb. Two check sockets are utilized to give precise fit. Suction is provided by making the volume of the socket smaller than the residual limb. The smaller socket creates tension on the skin, and increases friction between the limb and socket interface. This process creates suction. The residual limb is lubricated with powder, cream, or lotion to get it into the socket. A valve on the socket allows air to escape while donning the socket. A clear rigid check socket allows the limb to be viewed for exactness of fit and for any discoloration, which would indicate too tight a fit. The residual limb should maintain a normal color while in the socket. The hard socket is adequate for walking, but not for more vigorous activities because of discomfort. For more active amputees, prostheses should be made with soft liners, which have a distal valve to allow suction suspension. For both hard and soft suction sockets, auxiliary suspension with a sleeve is recommended in case of failure of the suction suspension.[73]

Another suction method is the silicone suction socket (3S). The 3S uses a silicone suspension liner fabricated over a mold of the residual limb. At the end of the silicone liner is a small protruding notched pin that secures the silicone liner to the prosthesis (Figure 4-34). Socks may be utilized to provide cushioning. The reported advantages of this prosthesis include decreased shear forces, improved knee range of motion, and no need for an auxiliary suspension.[79] Disadvantages cited are difficulty in donning the liner and loss of suspension if the liner should become punctured.[72] Use of this prosthesis is indicated for individuals with a cylindrical residual limb who desire a suction suspension and are highly motivated, compliant, have an understanding of the function of the valve and liner, and are willing to undergo multiple fittings and modifications. Difficulty in fit may occur with conical shaped limbs.[73] Relative contraindications are fluctuating residual limb volumes, skin hypersensitive to touch, poor hand function, excessive distal soft tissue redundancy, and patients who have never been satisfactorily fitted with any prosthesis.[79]

Overall, reported advantages of any suction suspension system are decreased pistoning, improved circulation from intermittent pressure changes with walking, better prosthetic control, improved sensory feedback, improved cosmesis, improved comfort, and improved mobility. Disadvantages reported are the more difficult fabrication of the socket, the risk of proximal constriction or excessive unremitting negative pressures with resultant distal edema, difficulty in maintenance of suction, possible skin irritation, and the frequent need for liner replacements. Relative contraindications are new amputees with fluctuating volumes, noncompliant patients, and limbs with less than 5 in, of length.[80]

Shank. The shank provides the length of the prosthesis from socket to foot. The shank is the connec-

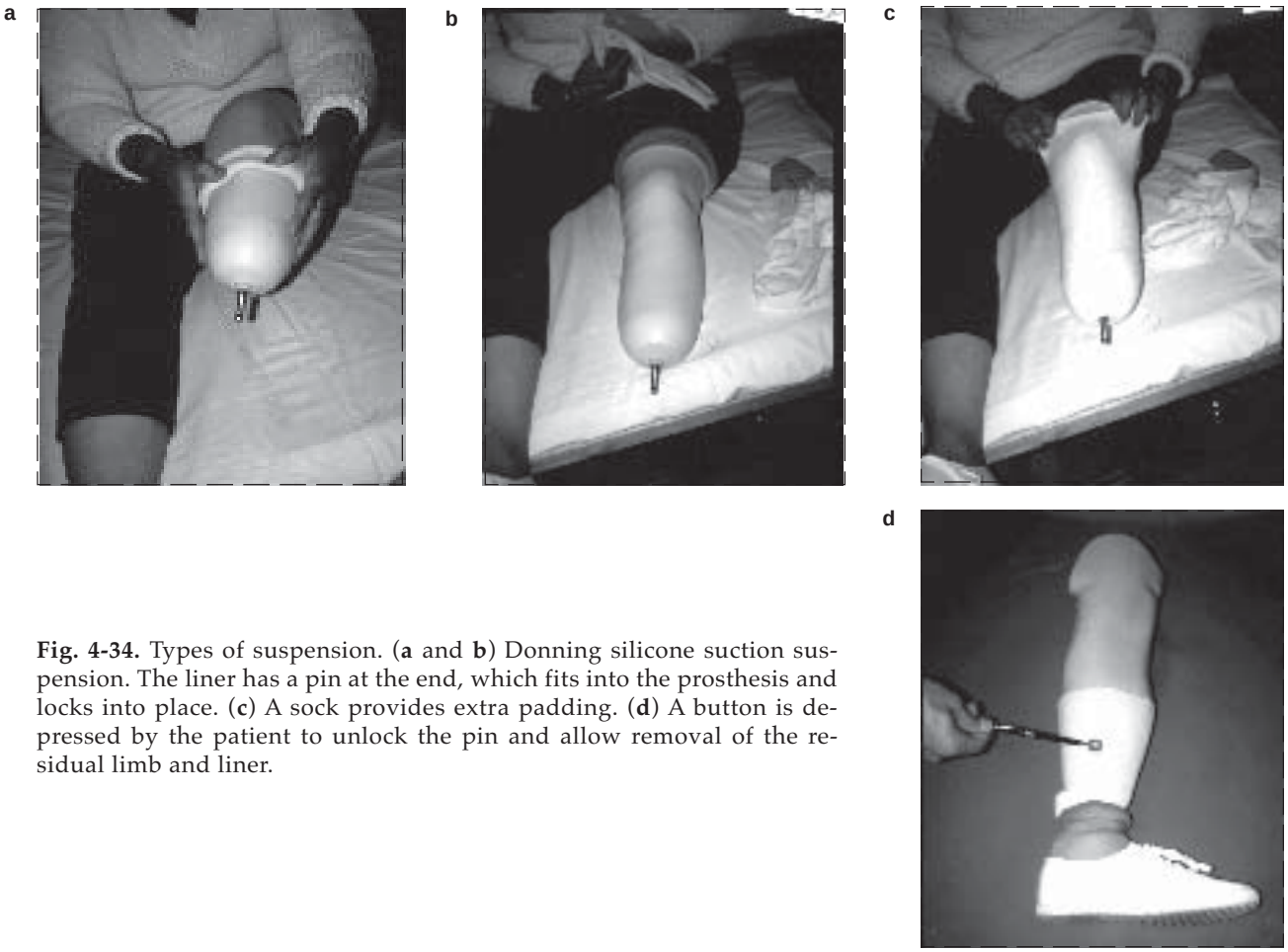


Fig. 4-34. Types of suspension. (**a** and **b**) Donning silicone suction suspension. The liner has a pin at the end, which fits into the prosthesis and locks into place. (**c**) A sock provides extra padding. (**d**) A button is depressed by the patient to unlock the pin and allow removal of the residual limb and liner.

tion between the socket and ankle/foot mechanism. The shank may be of *endoskeletal* or *exoskeletal* construction. The endoskeletal construction consists of metal or composite pieces connecting the socket to the foot (see Figure 4-27). Endoskeletal prostheses often have a cosmetic foam cover and skin tone nylon stockinettes. The reported advantages of the endoskeletal construction is the interchangeability of components for trial or replacement, its lightweight construction, adjustable alignment after fabrication, and cosmesis. The main reported disadvantage for the endoskeletal design is that the foam cover may become torn and need regular replacement.

The exoskeletal shank is made of wood or polyurethane with rigid plastic lamination (see Figure 4-29).[81] This durable construction is its advantage.

A rotator unit can be placed in the shank to allow rotational movement. This may be helpful for those amputees involved in activities requiring rotation, such as golf. Also, a rotator unit may help decrease shear at the socket–residual limb interface.[13]

The Prosthetic Foot. The goal of the prosthetic foot is to simulate normal ankle/foot function. In meeting the demands of a normal ankle/foot complex, the prosthetic foot should provide a stable base of support, simulate ankle/foot joints and muscles, provide shock and torque absorption, and be cosmetic. Different types of the prosthetic foot meet these goals to varying degrees. The prosthetic foot can be divided into four types based on function: (1) SACH, (2) single axis, (3) multiaxis, and (4) dynamic response.

SACH. The SACH foot consists of a wood or aluminum keel, and a molded foam cover (Figure 4-35). At heel strike, the heel cushion provides shock absorption, thus reducing the knee flexion moment. Different heel densities are available and need to be selected to balance the above functions.

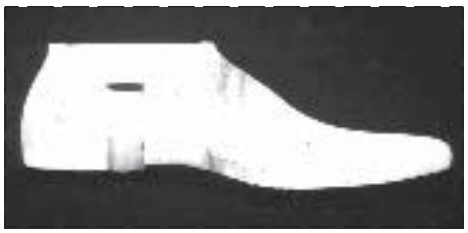


Fig. 4-35. SACH foot. A: keel, B: cushioned heel, and C: belting to prevent end of keel piercing through foam at the toebreak.

When combined with the solid ankle, the keel simulates plantar flexion at push off.[72] The length and width of the keel influences stability. Keel width contributes to mediolateral stability, with a wider keel giving more mediolateral stability, although it may make shoe fit more difficult. A longer keel provides more plantar flexion simulation, greater knee hyperextension force in late stance, and increases stability from falling forward. Too short of a keel results in less forward stability, less plantar flexion simulation, early heel off, and decreased step length.[72] The goal of keel length is to simulate push off without creating a knee hyperextension force in late stance, provide forward stability, and a toe break symmetric with the intact side. The molded rubber sole provides minimal dampening of inversion and eversion forces. The molded foam rubber foot with toes provides the foot shape and cosmesis.

The reported advantages of the SACH foot are moderate weight, durability, low maintenance, low cost, improved late stance stability, and accommodation of different heel heights and shoe styles.[82] The disadvantages cited are heel cushion deterioration over time, lack of adjustability of dorsiflexion and plantar flexion, difficulty ascending inclines, and rigid forefoot with poor shock absorption for vigorous activities.[72,83]

Those amputees requiring increased knee stability may benefit from multiaxis feet or dynamic response feet, which provide greater absorption at heelstrike.

Single-Axis Foot. The single-axis foot consists of a metal, single-axis joint, rubber plantar flexion bumper; rubber dorsiflexion wedge; wooden keel; and rubber foot (Figure 4-36). The single-axis joint allows true plantar flexion and dorsiflexion joint movements. Conceptually, this is its main difference from the SACH foot. The plantar flexion allowed at heel strike provides a smoother transition to foot flat, decreasing the knee flexion moment and increasing stance phase stability.[72]

The rubber dorsiflexion wedge limits the degree of dorsiflexion movement through the single-axis joint. The amount of limitation is dependent on the firmness of the rubber wedge. Forward stability is influenced by the dorsiflexion wedge and keel length.

The advantages are improved knee stability, adjustable plantar flexion, and less difficulty with descending inclines. The disadvantages are a tendency for noisy joints, breakdown of the rubber bumper, lack of mediolateral movement, increased maintenance, increased weight, and less cosmesis.[72,82]

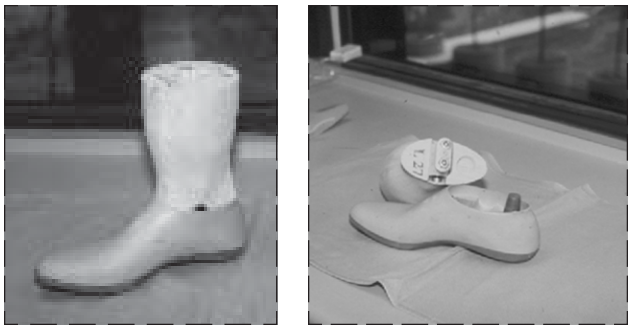


Fig. 4-36. Single-axis foot. External view (left). Components: metal, single axis joint and plantar flexion bumper demonstrated (right). The wood keel is not shown.

The foot may be indicated in amputees with weak quadriceps, which require a reduction of the knee flexion moment at heel strike, or those who have difficulty walking on inclines. The foot has more of a role in transfemoral amputees and is not frequently used in transtibial amputees.[72]

Multiaxis. The multiaxis foot is for amputees who walk on uneven terrain. This foot provides plantar flexion, dorsiflexion, inversion, and eversion joint simulation.

The *Greissinger* is a multiaxis foot consisting of a planter flexion rubber bumper, wooden keel, rubber heel, rubber rocker block, and metal rocker insert (Figure 4-37). The plantar flexion bumper and keel serve the same function as in the single-axis foot. The rubber heel serves the same purpose as in the SACH foot.

The main components that give the foot multiaxial function are the oval-shaped, rubber rocker block and the metal rocker insert. These components simulate inversion and eversion.[72] The degree of simulation is dependent on the various resistances of rubber inserts that can be provided. Shock is absorbed through the rubber heel, plantar flexion bumper, and rocker. While walking stability on uneven surfaces is increased, standing stability may be decreased by the greater movement allowed.

The advantages are multiaxis capability, improved stability on uneven terrain, adjustability, and reduced limb torque.[72,82] Disadvantages are increased maintenance, possible frequent replacement of rubber components, increased weight, reduced static mediolateral stability, and poorer cosmesis.[8,72,84] The foot may be used for individuals who often ambulate on uneven surfaces and have access to a prosthetist for maintenance.

The *multiflex ankle/foot* utilizes a ball-and-joint configuration with rubber components. The foot allows controlled plantar flexion, dorsiflexion, inversion, eversion, and transverse rotation. Advantages are multiaxis function, lightweight, and adjustability for different heel heights.[84] The disadvantage is that the foot can only be attached to an Endolite prosthesis by a certified Endolite prosthetist.

SAFE stands for stationary attachment, flexible endoskeleton. Although the SAFE foot has some dynamic response, the foot may be classified in the multiaxis category.[82] The foot consists of a flexible endoskeleton keel, a plastic bolt block, two polyester bands, a cushioned heel, and a molded foam cover (Figure 4-38). The polyester bands attach posteriorly and then run along the plantar surface. One

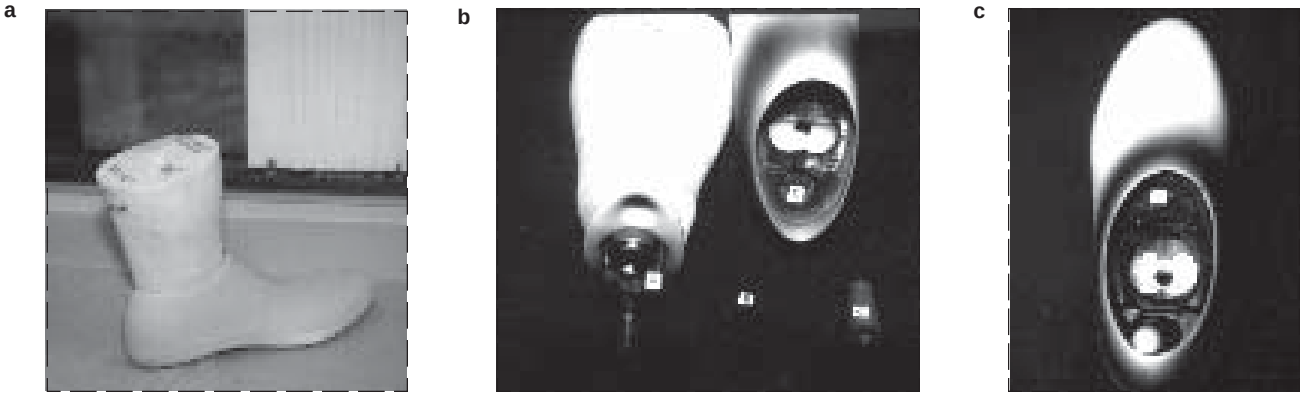


Fig. 4-37. Greissinger foot. (**a**) External view. (**b**) Components: A: metal rocker insert, B: rubber rocker block, C: plantar flexion bumper, and D: location of plantar flexion bumper in foot. (**c**) Superior view of foot with rubber rocker block inserted.

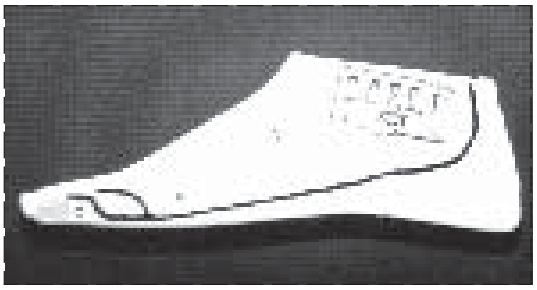


Fig. 4-38. SAFE foot, sagittal view. A: flexible endoskeleton keel, B: plantar ligament band, C: plantar fascia band, D: bolt block.

band attaches to the metatarsal head region and simulates the long plantar ligament. The other band attaches into the toe region to simulate the plantar fascia. The half dome simulates the normal foot bony arch at ground contact.[85]

The flexible endoskeleton simulates the transverse tarsal joint by absorbing torque along the foot axis created during the stance phase. Furthermore, the flexible endoskeleton simulates inversion and eversion joint motions. Using the windlass mechanism, the plantar fascia band simulates the plantar fascia at push off by converting the flexible endoskeleton to a semirigid lever arm.[85]

The advantages cited are some ability to absorb torque forces, multiaxis function, improved stability on uneven terrain, improved dynamic response compared to the SACH foot, improved ascent of inclines, and availability of different heel heights.[82–84,86] The disadvantages cited include increased weight, decreased cosmesis, and not as much dynamic response compared to some of the dynamic response feet.[82,86] Weight can be decreased with a nonwaterproof oak bolt block instead of plastic.[84] Also, cosmesis can be improved with the SAFE II foot, which has cosmetic toes.

The multiaxis *Graph-lite* is a lightweight foot, with a carbon graphite multidirectional pin and four rubber bumpers that also provide dynamic response.

Dynamic Response. The *Dynamic Response* foot, also known as an energy storing foot, is an attempt to simulate the push off phase of gait. The concept is for the foot to store energy created by dorsiflexion that occurs during stance and to release the energy at push off. Most prosthetic feet utilize a spring mechanism that deforms proportionally to the load created at stance. Hence, the foot responds dynamically, based on load. In comparison to normal push off generated by the ankle plantar flexor muscles, the dynamic response foot does not generate force, it only releases stored energy.[87] Some of the more common prosthetic feet in this category will be discussed.

The *Seattle Foot* was designed to provide push off during walking and running.[88] It consists of a leaf spring keel, cushioned heel, toe reinforcement pad, and polyurethane cosmetic molded foam cover (Figure 4-39). The leaf spring keel simulates plantar flexion at push off by compressing at foot flat and then extending at push off.[86,88,89] Additionally, the keel absorbs energy at heel strike. The length

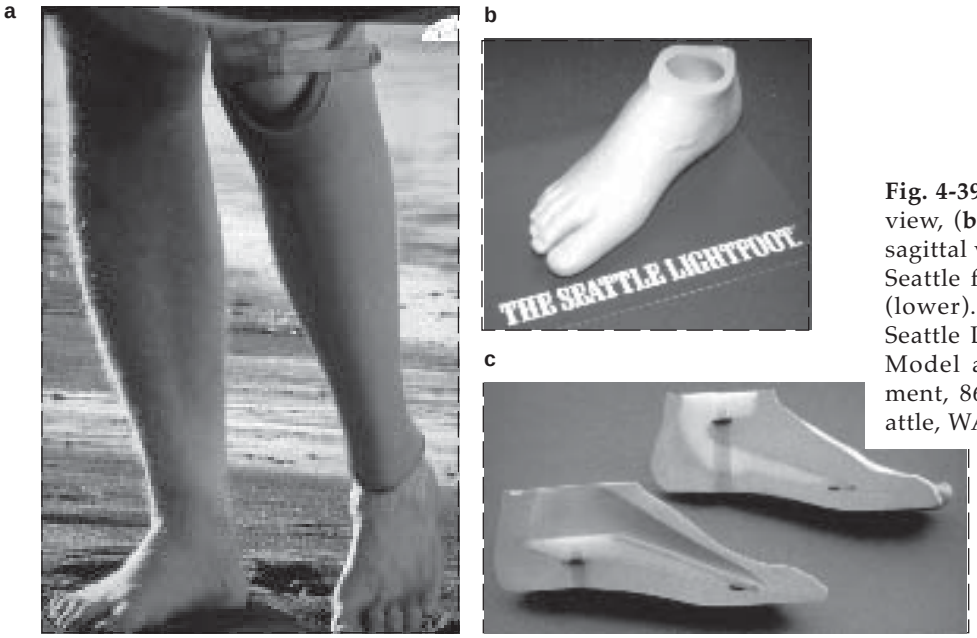


Fig. 4-39. Seattle Foot: (**a**) External view, (**b**) Seattle Lightfoot, and (**c**) sagittal view demonstrating keel of Seattle foot (upper) and Lightfoot (lower). Photograph: Courtesy of Seattle Lightfoot and Seattle Foot, Model and Instrument Development, 861 Poplar Place South, Seattle, WA 98144.

and width affect mediolateral and anterior-posterior stability, as described with other keels.

The cushioned heel serves a similar function as with the SACH. The molded foam cover was developed from male and female molds for excellent cosmesis.[88]

The advantages cited are enhanced performance with running and fast walking, improved ascent of stairs and inclines, completely waterproof, better cosmesis, availability of a wide range of sizes and keel stiffnesses, and smooth roll-over.[82,88,89] The disadvantages cited are that the wide foot may be difficult to fit into narrow shoes, the keel may break during activity, increased weight, and foam breakdown with barefoot use. Keel breakage is felt to be less of a problem if manufacturer recommendations for amputee weight and activity level are followed along with use of a heavier keel for more active users.[82,88] The cosmesis of the foot is felt to have led to barefoot use and resultant foam breakdown.[88] This has been addressed with a reinforced toe pad and the recommendation to run only while wearing shoes.

The *Seattle Lightfoot* has addressed some of the disadvantages cited. The Seattle Lightfoot is approximately half the weight with similar performance of the Seattle Foot. Additionally, the Lightfoot is slimmer with a decreased medial arch prominence, allowing easier shoe fit. The Lightfoot can be used with the Seattle Ankle with enhanced plantar flexion and dorsiflexion abilities.[84] Indications for the Seattle Foot or Lightfoot may include an amputee who desires enhanced activity performance, improved cosmesis, or waterproofness.

With the *Carbon Copy II* (Figure 4-40), the main design principle is the utilization of two carbon deflection plates to deform with loading and release at push off. This foot consists of the two carbon deflection plates, Kevlar sock, cushioned heel, thermoplastic nylon-Kevlar keel, and urethane foam molded cosmetic cover.[90]

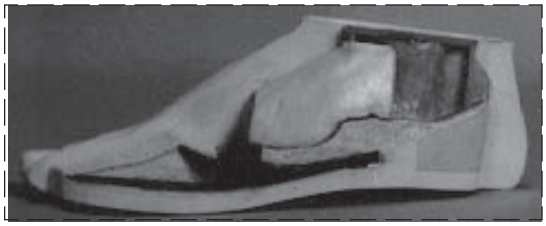


Fig. 4-40. Carbon Copy II, sagittal view demonstrating the two carbon deflection plates. Photograph: Courtesy of Carbon Copy II and III, Ohio Willow Wood Company, 15441 Scioto-Darby Road, Sterling, OH 43143.

The primary deflection plate extends from the heel to the toe region. Arbogast and Arbogast[90] postulate that plantar flexion contraction at push off is simulated by the plate storing energy obtained after midstance and releasing the energy at the last few degrees of toe off. The extension of the plate into the toe region provides a stiffer forefoot, resisting the drop off at push off seen with conventional keels.

The secondary deflection plate is shorter and deflects at higher loads, such as in fast walking and running, or when descending stairs. The plate also provides stability from falling forward by resistance to bending at midstance until the primary deflection plate bends.[90]

A Kevlar sock incorporates the plates to prevent knifing of the plates through the polyurethane mold.[90] The cushioned heel is similar to the SACH heel.[86] The thermoplastic keel was successfully designed to prevent bolt breakage, which is often seen with deformation of wooden keels. Additionally, the thermoplastic keel is reported to dampen vibration at impact, assisting in shock absorption.[90] The foot uses live foot molds for cosmesis and is flat on the bottom to assist with mediolateral stability.

The advantages are graded and enhanced performance, lighter weight, better cosmesis, and mediolateral stability.[86,90] The disadvantage is the width, which causes a difficult shoe fit.[82] Also, the investigations of Barth and associates[83] suggest dysvascular amputees should use caution with this device secondary to increased loading of the contralateral leg. The foot may be used for those desiring enhanced performance.

The *Carbon Copy III* system consists of a carbon fiber and Kevlar shank-ankle-foot unit (Figure 4-41). The foot contains three deflection plates instead of two. The plates come in different levels of stiffness for different amputee needs. The shank absorbs rotational forces and can be aligned by heating and deforming it. The system is light and modular.[84]

The main design difference in the *Flex Foot* is the incorporation of the shank and foot into one carbon graphite unit (Figure 4-42). The foot consists of two broad carbon graphite leaves and a soft cover.

The primary leaf extends from the inferior aspect of the socket to the toe region. The leaf provides dynamic compression in midstance with rebound plantar flexion at push off.[87] The leaf allows dynamic dorsiflexion in late stance. The posterior leaf at heel strike provides shock absorption, propels the prosthesis forward, and simulates plantar flexion joint motion.[86]

Fig. 4-41. Carbon Copy III, sagittal view showing the three deflection plates and Kevlar shank. Photograph: Courtesy of Carbon Copy II and III, Ohio Willow Wood Company, 15441 Scioto-Darby Road, Sterling, OH 43143.

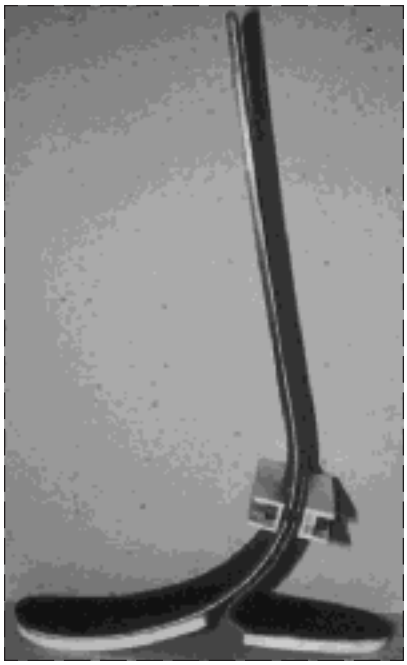
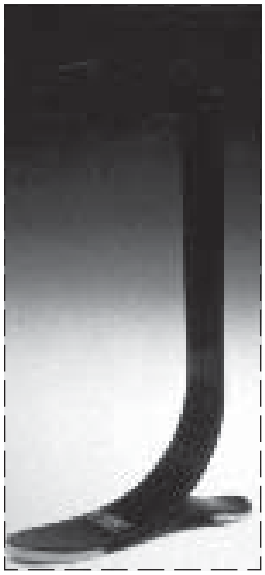


Fig. 4-42. Flex Foot. Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653.

Fig. 4-43. Flex Foot, with cosmetic foot cover. Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653.

The advantages cited are its high level of enhanced performance, lighter weight, smoother running, improved jumping, improved ambulation on inclines and stairs, mediolateral stability, availability of junior sizes for adolescents, and adjustability of the leaves.[82–84,86,91] The disadvantages are difficult alignment, cost, and minimal inversion and eversion.[82,86] Cosmesis has been improved with a cosmetic foot cover (Figure 4-43). The foot may be indicated in those desiring a high level of enhanced performance, or involvement in vigorous sporting events, such as running and jumping.[82,86,88]

Variants of Flex Foot are the Modular Flex Foot, Split Toe Flex Foot, Flex Walk, Flex Foot Symes, Flex Sprint, Vari-Flex, Air-Flex, and Vertical Shock Pylon (Figures 4-44 through 4-51). The Modular variant makes alignment, fabrication, and changing of sockets easier by use of bolt attachment instead of bonding.[79,82] This is an advantage for new amputees and adolescents who may need to replace sockets. The Split Toe model allows some inversion and eversion. The Flex Walk does not include the carbon graphite shank, which allows fit onto long transtibial amputees and may be of more benefit for less active amputees.[84] The Flex Foot Syme's is for Syme's amputees. The Flex Sprint is modified with plantar-flexed spring for sprinting. The Vari-



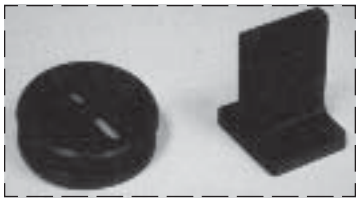


Fig. 4-44. Modular Flex Foot III. Foot (left) and T-system for modular attachment of foot to socket (right). Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653

Fig. 4-45. Split Toe Flex Foot. Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653

Fig. 4-46. Flex Walk II. Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653.

Fig. 4-47. Flex Low Profile Syme's. Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653.

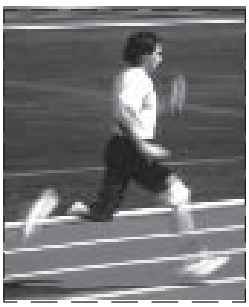


Fig. 4-48. Flex Sprint. Flex Sprint (left) and individual sprinting with Flex Sprint (right). Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653

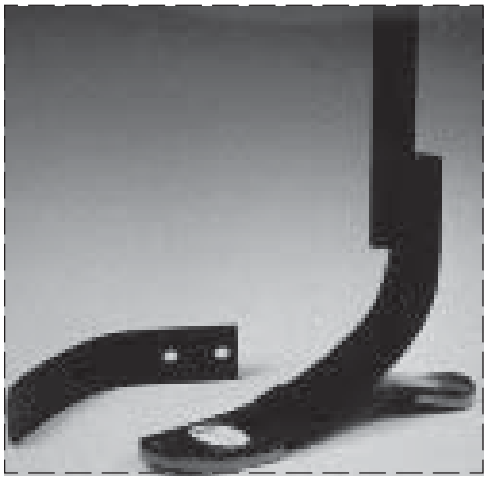


Fig. 4-49. Vari-Flex Foot. Addition of plate allows variable resistance. Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653

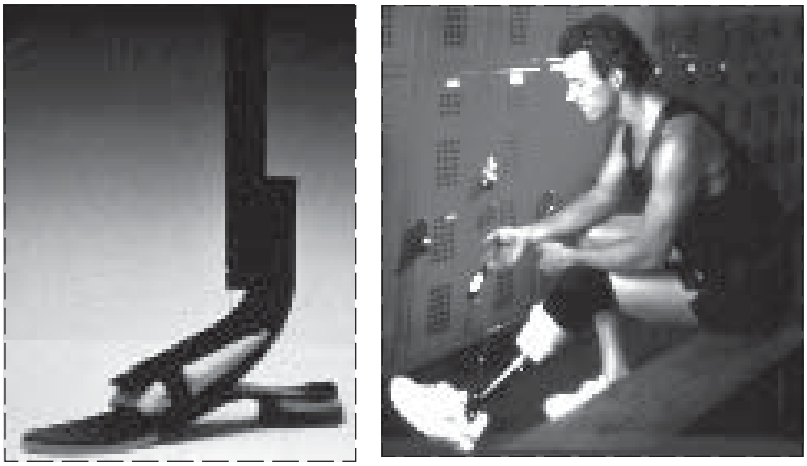


Fig. 4-50 Air-Flex Foot. Air-Flex (right) and Pumping-up the Air-Flex to increase resistance (far right). Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653.

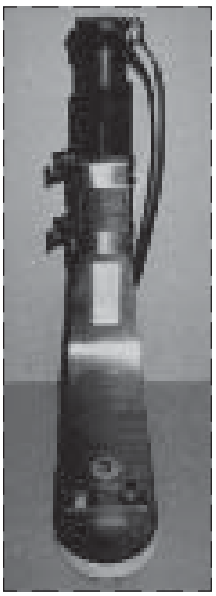


Fig. 4-51. Flex Vertical Shock Pylon. Photograph: Courtesy of Flex Foot Inc., 27071 Cabot Road, Suite 606, Laguna Hills, CA 92653.

Fig. 4-52. Springlite with cosmetic foot cover. Photograph: Courtesy of Springlite, 97-E Chinook Lane, Steilacoom, WA 98388.

Flex and Air-Flex are two models that allow the amputee to vary resistance in the foot and thereby meet performance or growth needs. The Vari-Flex resistance is changed by the prosthetist to match a change in activity level or growth in an amputee. This makes the Vari-Flex useful for the growing child. The Air-Flex allows the amputee to vary resistance by filling an air bladder in the foot during more demanding activities. The Vertical Shock Pylon is under development and will provide increased shock absorption.

Springlite II is similar to the Flex Foot concept that utilizes a carbon fiber and epoxy composite shank, heel, and foot. The main differences are that the Springlite II has one-piece construction, no foot clamp, and a removable rubber heel plug (Figure 4-52).[84] Also, its cosmetic foot cover, improved resistance to breakage, and cosmesis are benefits of the one-piece construction with no foot clamp.[84,92] The removable rubber plug, available in different densities, allows the amputee to select heel resistance according to activity level. The rubber plug varies the heel lever arm, affecting eccentric dorsiflexion simulation. Clamp fitting of shank to socket allows easier alignment and changing of sockets.[92] The stiffness of the foot is customized to the amputee's weight and activity level.

The advantages cited are enhanced dynamic response, cosmesis, availability of junior sizes, ability to change sockets and to tailor heel resistance for activity level.[84,92] Disadvantages are the inability to fit long transtibial amputees, and the higher

cost because of custom fabrication and difficult alignment.[84] The foot may be indicated for those amputees desiring enhanced performance and the ability to select heel resistances, or for those who require socket changes.

The *Sabolich* foot consist of a Delrin longitudinal arch. It absorbs energy at heel strike with further absorption at midstance by the arch and release at push off.[84]

With the *STEN* (STored ENergy) Foot, the main design feature is the use of an articulated keel. The foot consists of an articulated keel, rubber block articulations, dual plantar belting, cushioned heel, polyurethane foam covering, and rubber sole (Figure 4-53). The keel is three wood blocks separated by rubber blocks with plantar fabric belting connections. The articulations correspond with the metatarsophalangeal and tarsometatarsal joint articulations.[82] The articulated keel allows inversion, eversion, smoother roll-over compared to a SACH foot, and energy dissipation with compression, but it has little energy storage and release.[82,84,86] The heel, foam cover, and rubber sole are similar to the SACH and serve the same function.[82,86]

Advantages include smooth roll-over, mediolateral stability, and a wide range of shoe sizes and heel heights.[82,84] Disadvantages are increased weight and decreased anterior stability for higher level amputees. The foot may be indicated for those desiring a smoother roll-over compared to what the SACH provides.[82] The STEN does not have as much inversion and eversion capabilities as the SAFE foot, but it is lighter.[86]

The *Otto Bock 1D10 Dynamic Foot* consists of a wooden keel extending to the midfoot with a flexible plastic surrounding the keel and extending into the toe region, a cushioned heel, and a polyurethane foam cover with a split first web space.[84,86] The foot provides good shock absorption, but with minimal dynamic response.[84] Its advantages are that it is lightweight, has good shock absorption, provides accommodation to uneven terrain, and gives a smooth roll-over.[84,86] A disadvantage is its minimal dynamic response.[84]

Summary. In deciding which type of prosthetic foot to use, the functional properties of the foot should be matched with the amputee's medical and functional status, and goals. For new amputees undergoing training in the immediate postoperative period, a SACH foot may be used. A SACH foot may also be a good choice in less active amputees involved in mainly level surface household or community ambulation.

Amputees who ambulate on uneven surfaces may benefit from multiaxis feet, such as the Greissenger or Multiflex foot. However, if moving parts and maintenance are concerns, a multiaxis foot without moving parts (such as the SAFE, SAFE II, or Otto Bock 1D10 Dynamic Foot) may be good choices. If multiaxis and dynamic response is needed, the Flex Foot Split Toe variant or Graph-Lite may be good choices.

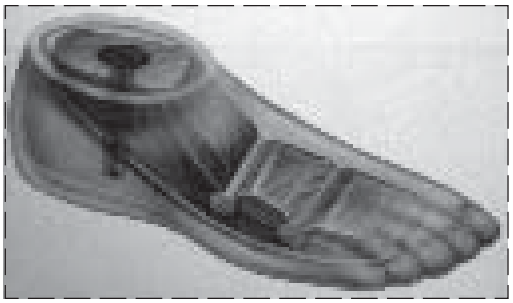


Fig. 4-53. STEN Foot. Photograph: Courtesy of STEN Foot, Kingsley Manufacturing Company, Costa Mesa, CA.

For active amputees who walk at varying velocities or are involved in athletics, a foot with dynamic response may be beneficial. Good choices include the Seattle Foot or Lightfoot, Carbon Copy II or III, Flex Foot, and Springlite II. For a newer amputee or a growing adolescent, modular components are beneficial for reusing the foot on remade sockets.

As newer prosthetic feet increase choices, it is important to analyze the biomechanical aspects of the foot or ankle/foot complex to meet the functional and cosmetic needs of the amputee. After this, the most important test is amputee satisfaction in maximizing quality of life.

Computer Aided Design/Computer Aided Manufacturing

Computer aided design (CAD) and computer aided manufacturing (CAM) utilize surface topography measurements of the residual limb, which are entered into a computer to generate a quantitative positive mold for socket manufacturing. Computer aided socket design may be beneficial for (*a*) quantitating successful socket designs, (*b*) ease of replicating sockets for amputees needing socket replacement, and (*c*) reducing the time needed to make a socket.[93–95]

To understand the differences between CAD/CAM and traditional prosthetic socket fabrication, the traditional method will be reviewed. The traditional process can be broken down into a series of steps as described by Staats and Lundt[73]: First, the

residual limb is measured anterioposteriorly, mediolaterally, and circumferentially; then a plaster cast impression is made of the residual limb. The cast is removed and placed in a gimbal-ring casting stand for alignment. Alginate is placed into the cast and to give an intimate fit, the amputee puts on the cast and bears weight while in the casting stand. The residual limb is then removed and the cast is filled with plaster of Paris. A metal pipe is placed in the middle with which to grasp the inner cast. The outer cast is removed from the plaster of Paris positive mold and modifications are done on the positive mold as needed. A clear check socket is made over the positive mold and fitted to the amputee. Any modifications are noted and added to the plaster positive mold. The process of check sockets and plaster positive mold modifications are repeated until correct fit and alignment are achieved.

By comparison, computer aided socket design (CASD) consists of entering the topographical measurements of the surface of the residual limb into a computer, which then generates and displays the image developed from those measurements and existing templates of residual limb shapes. The positive mold image can be modified based on the computer software capabilities. This quantitative information of the completed positive mold is sent electronically to a computer milling system that generates a polyurethane positive mold. Computer aided manufacture of the socket is done by a vacuum forming machine that makes a thermoplastic socket over the positive mold. The polyurethane mold is broken out of the socket. The check socket is then tried on by the amputee and any socket modifications are made via the computer. From these modifications, another check socket is fabricated. The process is repeated until proper fit and alignment are achieved.

The way in which surface topography is measured varies. One method uses manually obtained measurements of the anteroposterior, mediolateral, and circumferential dimensions of the residual limb, which are then entered into the computer.[95,96] These measurements, along with preexisting templates of nine socket shapes (small, medium, and large of cylindrical, conical, and bulbous shapes) are combined to create the positive mold computer image.[96]

Another method uses multiple cameras and laser beam scanning of the residual limb with the measurements sent directly to a computer.[93] From these data, a computer generated image of the residual limb is obtained for creating the positive mold. Another method uses the electromechanical digitization of plaster cast molds of the residual limb.[97] These data are combined with preexisting templates of socket designs to create the positive mold computer image. Other methods include computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound measurements.

Clinical trials[96,97] comparing below-knee prosthetic sockets created by traditional methods and those created with CAD/CAM have been conducted. One study evaluated the CANFIT system in 48 below-knee amputees.[96] The CANFIT system utilizes hand measurements of the residual limb along with preexisting templates of socket shapes to create the computer generated positive mold image. Utilizing two check sockets for the traditional method and CANFIT method, only 21% of the amputees preferred the CANFIT socket. When five check sockets for the CANFIT system were compared to two check sockets for the traditional method, 54% preferred the CANFIT method. Topper and Fernie[96] concluded that in its current form, the CANFIT system was useful only in limited cases, with a more accurate residual limb measurement method needed and more trials to produce an adequate fit. They also concluded that CANFIT was more time consuming, and not cost effective; however, with resolution of these limitations, the system could be beneficial.[96]

In a multicenter study[97] utilizing prototype equipment from University College of London Bioengineering Center (UCL-BC), computer-made sockets were compared to traditional socket fabrication. The modified UCL-BC system used electromechanical digitization of plaster casts from the residual limb along a with preexisting template of socket design to create the positive mold computer image. The system provided for residual limb lengths between 8.0 and 38.5 cm. In regards to overall satisfaction, 94% of computer made socket users rated the socket from very good to fair. In comparison, 80% of traditional users rated their sockets in the very good to fair range. However, more subjects rated the traditional method highest in terms of comfort, fit, and function. Also, the computer generated method had difficulty in fabricating sockets for those users who were highly active or had short limbs, and required significantly more time to do so. Based on the study, a number of recommendations were made for further developing CAD/CAM into a useful prosthetic tool. Overall, CAD/CAM for below-knee prosthetic socket fabrication is in the developmental stages, but it holds promise as a prosthetic tool of the future.

THROUGH- AND ABOVE-KNEE AMPUTATIONS

Amputation does not signify a surgical failure and should never be viewed as such, but rather as the means to return the patient to a functional level. The value of approaching amputation positively and with a reconstructive philosophy cannot be overemphasized. As discussed earlier in the Partial Foot and Syme's Amputations section, the decision to amputate is an emotional process for the surgeon, the patient, and the family, and the rehabilitation team should stand ready to respond and assist them. Once healing has occurred, it is critical to avoid scar tissue adhesions.

General Surgical Techniques and Definitions

Above-knee amputation includes amputations through the knee (knee disarticulation) and above the knee (transfemoral). These two amputation levels require the same type of rehabilitation interventions and similar prosthetic components. In the general population, the transfemoral level of amputation for dysvascular disease is the second most common level for lower limb amputees. Advantages of knee disarticulation include the surgical technique, which lessens the operating room time and blood loss and provides direct end bearing characteristics for the residual limb and improved self suspension with a decrease in socket length. It also maintains the integrity of the thigh musculature, which results in better biomechanics for walking. One major disadvantage to be considered, mostly for the young female, is the created thigh/shank length disproportion, which results in a marginal cosmetic appearance that, in the long run, may outweigh the above-mentioned advantages. For the bilateral transfemoral amputee, the knee disarticulation is a more desirable level when possible.

In surgical techniques, soft tissue handling is especially critical to wound healing and functional outcome. The tissues are often dysvascular or traumatized, and the risk of wound failure is high. Flaps should be kept thick, and unnecessary dissection between the skin, subcutaneous, fascial, and muscle planes should be avoided. All bone edges should be rounded, and prominences beveled for optimal prosthetic use.

When the skeletal attachments are divided during amputation, muscle loses its contractile function. Stabilization of the distal insertion of muscle can improve residual limb function. Myodesis is the direct suturing of muscle or tendon to bone. This technique is most effective in stabilization of the strong muscles, which are needed to counteract strong antagonistic muscle forces, as found in the transfemoral and knee disarticulation levels. Myoplasty involves suturing muscles to periosteum, or muscle to muscle over the end of the bone. Myoplasty does not provide as secure a distal stabilization of the muscle as does myodesis. A mobile sling of muscle over the distal end of the bone may result in a painful bursa and should be prevented. The excessive shortening of hip flexor musculature at the time of the amputation is not uncommon due to the position of the limb during surgery; if not accounted for, this may result in a hip flexion contracture.

All transected nerves will form neuromas. Careful retraction and clean transection of a nerve to allow the cut end to retract into the soft tissues, away from the scar and prosthetic pressure points, should always be attempted. STSGs are generally discouraged except as a means to save essential residual limb length. Skin grafts do best with adequate soft tissue support, and are least durable when closely adherent to bone.

Trauma. The absolute indication for amputation in trauma is an ischemic limb with unreconstructible vascular injury. As vascular reconstruction techniques improved, many limbs were initially salvaged, only to be amputated after multiple surgical procedures, and substantial investments of time, money, and emotional energy. Massively crushed muscle and ischemic tissue release myoglobin and cell toxins, which can lead to renal failure, adult respiratory distress syndrome, and even death. Recent studies show the value of early amputation (when salvage is unlikely to result in a functional limb), not only in saving lives, but in preventing the emotional, marital, financial, and addictive disasters that can follow unwise and desperate attempts at limb salvage.[98–100]

Salvage should be based on providing an extremity that can tolerate weight bearing, have enough sensation to provide protective feedback, and have a durable soft tissue cover. A lower limb functions poorly without sensation, and unless the limb can tolerate full weight bearing, is relatively pain free, and has durable skin and soft tissue coverage that does not break down whenever walking is attempted, it will often function worse than a modern prosthetic replacement. Recently, several scales for grading mangled lower limbs have been developed and should serve as guidelines to help the surgeon realize the gravity of the injury and the

subsequent risks of salvage (see Management of New Amputee section).[98–100]

For patients with multiple injuries and elderly individuals, salvage of a mangled limb, even though technically possible, may be life threatening; these patients may be best served by early amputation. This is a truly difficult but extremely important decision.

Tissue injury from cold exposure can involve both direct freezing of tissue, and a related vascular impairment from endothelial vessel injury and increased sympathetic tone. If the skin is wet, or directly exposed to the wind, cold injury can result even in above-freezing temperatures. The immediate treatment involves restoring the core body temperature, and then rewarming the injured body part in a 40°C to 44°C water bath over a 20 to 30 minute time period. Rewarming can be painful, and often requires strong analgesia. Care should be taken to maintain skin integrity.

It may not be unusual to wait several months before definitive surgery. A zone of dry gangrene develops distally, and a zone of intermediate tissue injury forms just proximal to this. Even at the time of clear demarcation, the tissue just proximal to the gangrenous zone continues to heal from the cold insult, and although the outward appearance is often pink and healthy, this tissue is not normal. Delaying amputation surgery, even after clear demarcation, can improve the chance of primary wound healing. In spite of having mummified tissue, infection is rare if the tissue is kept clean and dry.

The Rehabilitation Program

The amputee rehabilitation program should be designed to cover the wide spectrum of care beginning with preamputation and continuing to the patient's reintegration into the community and long-term follow-up.

Preamputation Counseling. In the case of war related amputations, it is not often possible to address prosthetic issues until the soldier arrives at a medical center. At the earliest opportunity, it is essential to develop a communication flow between the patient, the family, and the physician regarding the need for amputation and the expected surgical outcome. Communication with the physiatrist, therapist, and other members of the team should be facilitated. At this point it is appropriate to have initial discussions about phantom limb sensation and expected functional outcomes. Prosthetic devices and their fitting should be discussed, and when possible, an arranged demonstration of such devices by a trained volunteer with a similar level of amputation should be part of the discussion. If a rigid dressing is being considered, an explanation should be given for its use, and the pros and cons should be discussed. Family involvement throughout this process should be encouraged. For any level of amputation the program should include strengthening exercises for the thighs, hips, and upper limb musculature and stretching of hip flexors and adductors, when possible.

Amputation Surgery

Selection of a transfemoral level amputation over a transtibial amputation presents a number of important dilemmas in rehabilitation. The lack of an anatomical knee joint will require increased energy consumption during ambulation[45] and increased effort and cost for prosthetic restoration. The value of preserving the knee is so important that with current surgical techniques, it is advisable to attempt a transtibial amputation even when there may be a risk of requiring revision to a higher level amputation at a later time. Transtibial amputees will be more likely to accept and utilize a prosthesis than will transfemoral amputees. In most instances, transfemoral amputations do heal.

Knee Disarticulation. For the critically ill patient, knee disarticulation is a less traumatic procedure than other amputation levels. For patients who are expected to walk, the advantages over a transfemoral amputation include improved socket suspension by contouring above the femoral condyles, the added strength and prosthetic control of a longer lever arm, the retained muscle balance of the thigh, and most important, the end bearing potential for direct weight transfer to the prosthesis, thereby obviating the need of ischial weight bearing transmission. Additionally, there is usually a lower surgical risk because no bone and muscle transection is required and minimal blood loss results. Until recently, clinicians have discouraged the use of this level of amputation, finding it difficult to fit with a satisfactory, functional, and cosmetic prosthetic substitute. However, the past few years have shown significant improvements in knee disarticulation prosthetics, including new socket fabrication materials and techniques that allow a less bulky interface to be manufactured. Improvement has also been achieved because of refined polycentric (four bar linkage) and multiaxial knee units with hydraulic or pneumatic damping mechanisms that can fold under the socket and improve the biomechanics of walking and the appearance of the pros-

thesis when sitting. Disarticulation through the knee joint is indicated in ambulatory patients when a transtibial amputation is not possible, but when suitable soft tissue is present for a knee disarticulation. This most commonly occurs in trauma. In dysvascular patients, the blood supply to the soft tissues is such that most patients who would be capable of recovering from a knee disarticulation will also be able to heal from a short transtibial amputation. Knee disarticulation is indicated in dysvascular patients who are nonambulatory, especially if knee flexion con-tractures are present. Sagittal flaps appear to improve healing compared to traditional anterior-posterior flaps.[34] The patella is retained and the patellar tendon is sutured to the remaining cruciate ligaments to stabilize the quadriceps complex. The hamstring tendons should also be stabilized to the crutiate ligaments. Although many techniques have been described to trim the condyles of the femur, radical trimming should be avoided because this can decrease some of the suspension advantages of the knee disarticulation.[101]

Transfemoral Amputation. The above-knee amputation is usually performed with equal anterior and posterior fish-mouth flaps. Since increased prosthetic control and function are directly proportional to length of the residual limb, atypical flaps can and should be used to save all possible femoral length in cases of trauma. Muscle stabilization is more important in transfemoral amputation than in any other major limb amputation.[102]

The major deforming force is into abduction and flexion. Myodesis of the adductor muscles through drill holes in the femur can counteract the abductors, improve prosthetic control, and prevent the adductor tissue roll in the groin. Without muscle stabilization, the femur commonly migrates laterally through the soft tissues, much like a stick would migrate in a bowl of gelatin. Newer transfemoral socket designs attempt to better control the position of the femur, but they are not as effective as muscle stabilization.[102] Careful balance of the hip flexors and extensors during the surgical procedure should be achieved to avoid promoting contractures of this joint.

In the traumatic transfemoral amputation it is not uncommon to find a pelvic or proximal femoral fracture, which may, temporarily or in a permanent way, interfere with the optimal gait pattern because of changes in the normal biomechanics of the hip and pelvis and their musculature.

Hip Disarticulation and Hemipelvectomy. The traditional racquet shaped hip disarticulation incision with an anterior apex is used in dysvascular patients and, when possible, in trauma cases. In tumor surgery, creative flaps based on the uninvolved anatomic compartments must be designed.[103] Prosthetic replacement can be successful in healthy, young patients who require hip disarticulation because of trauma or malignancy, but its success is limited in elderly dysvascular patients. Because residual limb capabilities to propel an artificial limb are lost, compensatory trunk movements are required at an energy cost that is significantly higher than crutch walking with a swing-through gait (see Table 4-1).[43]

Hemipelvectomy is performed infrequently, but may be required for trauma or malignancy involving the pelvis. Prosthetic use is extremely rare after this procedure, as the body weight must be transferred from the sacrum and thorax to the prosthetic socket. To maintain a leveled pelvis, special considerations for seating, such as a prosthetic bucket, may be required.

Acute Postamputation Rehabilitation

Pain control, maintenance of range of motion and strength, and promotion of wound healing are the goals of this stage, which begins with the surgical closure of the wound and culminates with healing after the sutures are removed. In war injured amputees, who by necessity have open wounds, maintenance of skin traction during transport from the battlefield to the medical center and until the wound is closed (operatively or by secondary intention) is of paramount importance. Figure 4-54 shows a skin traction device that allows the amputee crutch mobility.

Pain control and residual limb maturation should be aggressively pursued. The IPORD or soft elastic bandage and subsequent pneumatic compression are indicated for edema control. For selected amputees, the IPOP can also be used. An increasingly popular method of wound protection for early shaping and shrinking is the removable rigid dressing as proposed by Burgess and associates.[34] This dressing is easily changed to accommodate stump shrinkage until the residual limb stabilizes in size and is ready for the first prosthetic casting. In addition, this dressing protects the residual limb while the patient practices ambulation training with gait aids and other essential mobility skills. IPORDs are more difficult for the transfemoral amputee to apply and keep positioned than for those patients who experienced more distal amputations. IPORD techniques

Fig. 4-54. Skin traction device. 1: plaster attachment to the body, 2: outrigger, and 3: stockinette attached to skin of residual limb placed under tension and secured to outrigger.

do offer the advantages of early rehabilitation and control of edema and pain, and are preferred if the patient has no history of chronic arterial compromise and the expertise to apply it is available. Soft compressive dressings alone are used in many centers.[21] This dressing should be extended proximal to the hip and around the pelvis to prevent the development of an adductor soft tissue roll, and to improve suspension of the dressing. Proper postoperative positioning and rehabilitation are essential to prevent hip flexion and abduction contractures.

Acute Pain Management

Initial pain control can best be achieved with a PCA system followed by the use of scheduled oral analgesia. This is also a time for the patient to adapt emotionally to the new body image and learn to function without the prosthesis, which is essential for later life experiences when there are times that the prosthesis will not be worn. A skin desensitization program that includes massage, soft tissue and scar mobilization, and lubrication is recommended for the patient who is managed with a removable, soft or elastic dressing.

When the patient is medically stable, early mobilization, general endurance and strengthening exercise (with emphasis to the gluteus medius and maximus and the avoidance of joint contractures), and improvement in sitting and standing balance are initiated. Strengthening of upper limb musculature is essential for wheelchair propulsion, transfers, walker, and crutch ambulation and are also aggressively pursued. It is important physically to emphasize the strength and function of the remaining limbs. For this purpose the Universal Below-the-Knee Bicycle Attachment was developed.[104] This device permits early endurance exercise with controlled weight bearing, using a stationary bicycle. Whenever possible, patients should be placed in a cardiovascular conditioning program before the amputation. At this time emotional counseling to the patient and the family, with special attention to the significant other and children, should be implemented.

Psychosocial evaluation of the patient and family should be initiated to assess and manage the existence of depression and anxiety or both. It is important during this phase to assure and promote patient participation in the decision-making process to encourage independence. This is a time for introspection and reassessment of goals in life. This process can result in the individual's taking a more mature approach toward life plans and pursuit of goals. Occasionally, however, a patient may become so emotionally disturbed by the limb loss that there is failure to cope. This will affect the rehabilitation outcome.[105]

Postoperative Care

Postoperative edema is common following amputation; if soft dressings are used, they should be combined with stump wrapping to control edema, especially if the patient is a prosthetic candidate. The ideal shape of a residual limb is cylindrical, not conical. The major complication from stump wrapping results from applying the elastic wrap too tightly at the proximal end, which actually causes congestion and worsening edema, and results in a dumbbell shaped residual limb. A figure-8 wrapping technique should be reapplied every 4 to 6 hours (see Figure 4-25).

The preferred treatment approach is to use an IPORD to control postoperative edema, protect the limb from trauma, decrease postoperative pain, desensitize the limb, and allow early mobilization and rehabilitation. In selected patients, usually

young traumatic amputees where the amputation was performed above the zone of injury, immediate, limited postoperative weight bearing can be safely initiated. An IPORD and immediate IPOP need to be applied carefully, but their application is easily learned and well within the scope of interested physicians and prosthetists.[21,34]

Phantom Limb. As discussed earlier, phantom limb sensation is the feeling that all or part of the amputated limb is still present. This sensation is felt by nearly all acquired amputees, but is not always bothersome.[35] The traditional explanation for phantom limb sensation and its associated pain is that the remaining nerves in the amputated limb continue to generate impulses that flow through the spinal cord and the thalamus to the somatosensory areas of the cerebral cortex. Another theory suggests that the phantom arises from excessive, spontaneous firing of spinal cord neurons that have lost their normal sensory input from the missing body part, while yet another suggests that the phantoms are caused by changes in the flow of signals through the neuromatrix in the brain.[35] (For more detail, see the Medical and Surgical Complications section below.) The management of phantom limb sensation should include prosthetic socket revisions, desensitization techniques, transcutaneous electrical nerve stimulation (TENS), neuropharmacological intervention, and the voluntary control of the phantom limb. For severe cases, nerve blocks, steroid injections, and epidural blocks may be useful. Nonsurgical interventions are far more successful than surgical ones. Clearly, the source of phantom limbs is more complex than any of the theories presented here would suggest, and treatment is complex. Important issues to discuss with the patient are normal phantom sensation; phantom pain; and the relationship between tension, anxiety, stress, and pain perception.

Joint Contractures

Joint contractures usually occur between the time of amputation and prosthetic fitting. In the transfemoral amputee, the deforming forces are due to flexion and abduction. Adductor and hamstring stabilization during surgery can oppose the deforming forces. As with BKA, after surgery, patients should avoid propping the leg up on a pillow and prolonged seating. The patients should also be started on active- and passive-motion exercises early, including lying prone to stretch the hip. Strengthening of the hip extensors and abductors should be encouraged. Efforts should be directed at prevention with aggressive rehabilitation, beginning soon after surgery.

Preprosthetic Rehabilitation

In the last two decades, with the advent of specialized treatment teams and new prosthetic devices, the outlook for the lower limb amputee has improved. The patient who has undergone a lower limb amputation may quickly become deconditioned and most likely depressed. A preprosthetic rehabilitation program must be initiated as soon as possible. Pain control and residual limb maturation should be continued during this phase.

Preparatory Prosthetic Fitting. The use of a preparatory or temporary prosthesis should be implemented at this stage. The prosthetic device is intended to serve as a short-term, gait training tool. In most instances the prosthesis is simplistic in its components, but when possible, it should permit the same function as that of the expected permanent prosthesis so that retraining can be minimized. The device should allow for easy adjustability of the socket fit and alignment. The alignment will change as training and increased weight bearing progress and as patient confidence increases.

The preparatory prosthesis should promote residual limb maturation and desensitization and allow the patient to build up wearing tolerance. The patient must develop the understanding of normal residual limb volume fluctuations and how to accommodate for them.

At times, delayed wound healing or other soft tissue or bone injuries will prevent weight bearing on the residual limb, complicating the rehabilitation process. Because of architectural limitations, ambulation may be a requirement for a patient to return home or, because this function is viewed by many patients as the primary goal in their rehabilitation, it may be necessary to allow bipedal ambulation with a modified preparatory prosthesis. It is possible to use a bypass prosthesis, which transfers most of the weight bearing function to a more proximal segment by using a thigh corset or ischial weight bearing and a modified socket.[106] This is used when there are healing limb fractures as well as the amputation.

The use of upper limb support for balance will be necessary for most amputees in the preparatory prosthesis fitting stage. Usually a cane or single crutch on the opposite side will be sufficient for the unilateral amputee. All unilateral transfemoral amputees should be safe ambulating with bilateral crutches without prosthesis as there may be times when the

artificial limb may not be used. In some cases, due to other injuries, a walker may be used, which admittedly makes for a poor gait pattern, but this is preferable to not being able to ambulate at all.

Pneumatic compression can be used to further promote residual limb maturation, decrease swelling, desensitize the tissues and increase tolerance to pressure. When, over a period of 2 months, no significant volume fluctuation is noted in the residual limb, consideration should be given to the fitting of the first permanent prosthesis. Serial circumferential measurements of the limb at preestablished locations, and weight of the patient are the simplest techniques to determine residual limb size stability.

Prosthetic Fitting

In view of the variety and complexity of new prosthetic components (feet, ankles, and knees); socket fabrication techniques; suspension systems; and available materials, the selection of the most appropriate components for prosthetic restoration of the lower limb amputee is an extremely challenging task. Ideally, this task should be accomplished by an expert team of professionals in close communication with the patient. Members of the team may include a surgeon; a physiatrist knowledgeable in amputee rehabilitation and prosthetics; a certified prosthetist; occupational, physical, and recreational therapists; a psychologist; a social worker; and the patient and his family.

Prosthetic Feet. The human foot is a complex anatomical structure that provides a stable weight bearing base, absorbs impact, and generates dynamic propulsion essential for normal locomotion. Most patients who suffer a lower limb amputation and undergo prosthetic restoration will require ankle/foot mechanisms for their prostheses.

A variety of new prosthetic ankle/foot components has developed from a better understanding of the biomechanics of human locomotion and through progress in materials technology, including new plastic resins, carbon graphite composites, and synthetic fibers. These changes have resulted in improvements in the durability, weight, mass distribution, and cosmesis of the components and have provided dynamic characteristics to the prosthetic ankle/foot (see Figures 4-39 and 4-41 through 4-53).[84]

Some of the new dynamic response prosthetic feet have been based on the widely used SACH concept, which is known for its reliability. Other, more assertive designs attempt to use the foot, ankle, and part of the shank to improve the dynamic response. Not all of the newer ankle/foot systems provide a dynamic response; some have been improved by increasing energy dissipation characteristics, incorporating the capability for adjustment to uneven terrain, achieving a major reduction in weight, decreasing requirements for maintenance, and by providing an easy adjustment to different heel heights (see preceding sections on Below-Knee Amputation for details regarding prosthetic feet).

With the availability of more scientific information regarding the biomechanical performance of the many dynamic response feet,[84] their effects on human function, and the nature of the energy exchanges which occur at the ankle joint,[107] it has become evident that replacement of the normal ankle/foot function cannot be accomplished with the prosthetic foot.

Available data seem to indicate differences in metabolic energy consumption at high walking velocities, walking up inclines, and running using different feet.[108,109] For sedentary amputees, weight reduction and improved cosmesis appear to be the major contributors to the improvement in their quality of life. A recent, well-organized description of the most widely utilized and better known ankle/foot devices has been summarized by Esquenazi and Torres.[84]

Prosthetic Knees

A great many prosthetic knees are available for use in the treatment of the transfemoral amputee. Important to the selection of these components are the features of knee stability during stance, control of knee flexion and extension during swing, weight, and cosmesis. Knee stability during stance can be provided with a stable static alignment that keeps the knee axis posterior to the line of gravity when it traverses from the greater trochanter through the knee to the ankle—the trochanter, knee, ankle (TKA) line.

Other available choices are the use of a weight activated brake mechanism which allows knee flexion during swing phase, but prevents accidental knee flexion during stance. Several options are available for this purpose. One system is a knee with a brake mechanism that is activated during the weight bearing portion of walking while the knee is in no more than 20° of flexion (the safety knee). The brake is disengaged when weight bearing is removed, as occurs in the swing phase of walking. This knee can be very light when endoskeleton components are manufactured from titanium or other

lightweight alloys. This type of knee joint will prevent knee flexion during weight bearing but, if not well adjusted, will require that the weight be completely off the prosthesis before swing phase knee flexion occurs. It will also interfere with stand-to-sit transfers and step-over-step stair descent.

A different approach to the same problem of knee control is the use of a biomechanically stable knee joint. This system uses a polycentric knee that has two axes of rotation ("four bar linkage") (Figure 4-55). From early to midstance, the TKA line will be maintained in a position anterior to one or the other mechanical axes of rotation of the prosthetic knee. These knees have a smooth motion and allow better cosmetic accommodation for longer residual limbs. Because they are heavier, they may give a sense of instability when walking. This problem is caused by the desirable mechanical tendency of the knee to attain an extended position. When the knee is in slight flexion (10°–20°) and the foot contacts the ground, the knee is thrust into extension instead of retaining a given flexed position. This sudden push of the knee into extension can produce a sense of instability.

The use of fluid control for the knee can be compared to the fluid-filled cylinders used in shock absorbers of an automobile. As increased velocity is generated by the walking patient, the fluid- (air or oil) filled cylinder used in the prosthetic knee will become more resistant to motion. This unique characteristic allows some degree of cadence response (velocity dependent) by the device. In some instances it will permit stair descent, step over step. In swing phase, caution should be taken to not underestimate the force generated by the residual limb, which may not be controlled by a small cylinder. These types of knees, when appropriately adjusted, best resemble the function of the normal human knee, but they have the disadvantage of significantly increased cost, weight, and maintenance.

Some patients, because of weakness, short residual limb, or other complications, may need a manual knee lock to use during ambulation. This produces the undesirable, energy consuming side effect of a stiff knee during the swing phase of ambulation; this mechanism should be avoided whenever possible. It is useful for people who must stand for long periods in their vocational or avocational activities.

Some prosthetic knees have combined two of the features described above to permit both braking during stance phase and fluid control during swing phase. The two major classifications of prosthetic knees are shown in Table 4-2

Fig. 4-55. Four-bar hydraulic knee joint.

TABLE 4-2

CLASSIFICATION OF PROSTHETIC KNEE CHARACTERISTICS

Classification	Characteristics
Single Axis	Weight activated extension lock
	Fluid control (swing-only or swing-and-stance)
	Mechanical extension assistance
	Constant friction
	Hybrid (weight activated knee lock and swing-only fluid control)
	Manual lock
Polycentric (4-bar)	Weight activated stabilization
	Fluid control (swing-only)
	Mechanical extension assistance
	Friction

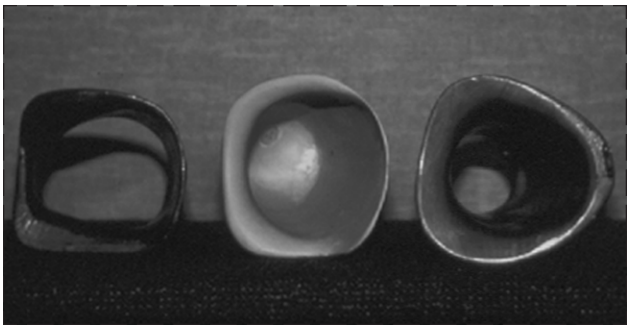


Fig. 4-56. Quadrilateral ischial weight bearing socket (left), ischial containment socket (center), and plug fit (right). The top of the illustration represents the anterior direction.

Prosthetic Sockets. Socket configuration and materials are another area of recent development. The key functions of a prosthetic socket include the comfortable total contact interface with the residual limb, efficient energy transfer from the residual limb to the prosthetic device, secure suspension, and good appearance A patient may fail to accept a prosthesis if the socket does not provide most of the above mentioned characteristics.

In the past, the plug fit socket (Figure 4-56) was carved out of wood. As the patient wore the device, blisters or other forms of skin irritation formed, indicating to the limb fitter where it was necessary to carve out more wood until a nonirritating fit was achieved. These sockets had the disadvantage of being open ended, which promoted residual limb swelling in the distal end with the potential development of chronic edema and trophic skin changes. In the mid 1950s, a federally funded research group developed the concept of total socket-residual limb contact.[110]

The quadrilateral socket was designed to match the anatomic shape of the transfemoral residual limb cross section, with appropriate relief for the muscles and tendons of the proximal thigh. The socket had a total-contact design, as opposed to the earlier open ended, plug fit socket. The weight of the bony skeleton of the body was intended to be transferred to the exoskeleton of the prosthesis from the ischial tuberosity as it sat on the horizontal ischial seat of the posterior brim of the socket. In this socket design, the ischium was not contained in the socket. To maintain the ischium on the prosthetic seat, an anterior counter force was required. Most of the pressure was applied over the Scarpa's triangle and often produced discomfort, skin irritation, and interference with the venous and arterial circulation of the limb. High temperature rigid plastic materials, such as polyester resin, are currently used instead of wood, thus decreasing the overall weight of the prosthesis and increasing the durability. More recently, acrylic lamination has replaced polyester in socket manufacturing.

In the 1970s, Long[111] noted the fact that radiographs of patients wearing conventional quadrilateral sockets demonstrated that the femur was always abducted. This led him to develop the theory that the wide mediolateral dimension of the quadrilateral socket did not provide adequate femoral control, and permitted femoral abduction to occur. He experimented with altering the dimensions of the quadrilateral socket design to improve the fit, control, and function of transfemoral prostheses, which ultimately resulted in the normal shape, normal alignment (NSNA) socket design. This socket is characterized by having a narrow medio-lateral dimension and containment of the ischial tuberosity, rather than having it rest on top of the posterior brim of the socket as occurs with the quadrilateral socket. Long's concepts also resulted in a specific static alignment for the NSNA socket/prosthesis, which came to be known as Long's Line.[111,112] Sabolich's[113] modifications to the concept of the narrow mediolateral ischial containment socket has become known as the Contoured Adducted Trochanteric/Controlled Alignment Method (CAT/CAM) socket (see Figure 4-56). In current practice, the ischial containment socket has become a very common design for transfemoral sockets. The original concepts of Long and Sabolich have undergone several modifications by the many prosthetists who adopted the use of these designs. The common variations appear to be the use of ischial containment, and narrowing the mediolateral diameter of the quadrilateral socket.[113–116]

Ischial containment has the advantages of maintaining a controlled anatomic relationship between pelvis and femur, as both are captured inside the socket. Many advocates of this socket design believe that the relationship between femur and pelvis maintains the proper femoral adduction in the socket, placing the hip abductors at a mechanical advantage, and thus giving narrow mediolateral ischial containment sockets a functional superiority over the quadrilateral sockets. Gottschalk and colleagues[102] have shown that the narrow mediolateral socket does not provide improved femoral abduction control, and that this control does require surgical reattachment of the adductor musculature for this to occur.

The ischial containment sockets have provided definite advantage for transfemoral amputees with

short residual limbs. Previously, fitting a transfemoral patient with a quadrilateral socket necessitated that the residual femur extend beyond the level of the ischial tuberosity. Ischial containment sockets have greater proximal extension, and thus contain more of the femur inside the socket. Amputees with shorter residual femurs have been successfully fitted with ischial containment transfemoral prostheses, rather than resorting to a hip disarticulation style prosthesis.

Sockets are custom made by obtaining a plaster of Paris wrap negative impression of the residual limb. This is then converted to a positive mold, which is modified by the prosthetist to distribute forces appropriately throughout the entire surface of the residual limb. Routinely, a transparent plastic socket is manufactured to permit direct visualization of the soft tissues during controlled weight bearing. The transparent socket (a check socket) is modified to assure comfortable total contact, and then a final socket is fabricated. Prior to the availability of transparent plastics, radiographic or xeroradiographic evaluation of the socket fit during weight bearing was used. This imaging technique continues to be used for the patient with very prominent bony structures, poor soft tissue coverage and painful residual limb during weight bearing.[117] More recently, the concepts of CAD/CAM have been adapted to prosthetic fabrication. Direct surface photographic imaging of the residual limb; ultrasound or MRI, or both; and direct digitization from a plaster of Paris mold are being used in some centers as sources of digital data to be manipulated in a computer environment. From there, a computer controlled carver can create a positive mold on wax or plaster from which a socket can be manufactured from vacuum formed thermoplastics. These systems promise significant time savings and the possibility of rapid socket duplication with or without further modifications (See Prosthetic Prescription section above).

New flexible plastic materials have made sockets lighter and more comfortable and energy efficient.[118] The utilization of these new materials in prosthetics has resulted in the development of improved socket construction techniques such as the Icelandic-New York (ISNY).[114,119–122] The inner socket provides total contact with the residual limb and is the interface that, if desired, provides suction suspension. The outer socket, or frame, is made of a more rigid material, thermoplastic or resin, and provides the structural integrity and weight bearing feature of the socket (Figure 4-57). When double sockets are used, windows can be cut out of the exterior frame so muscles can expand during contraction; this will improve comfort and sensory

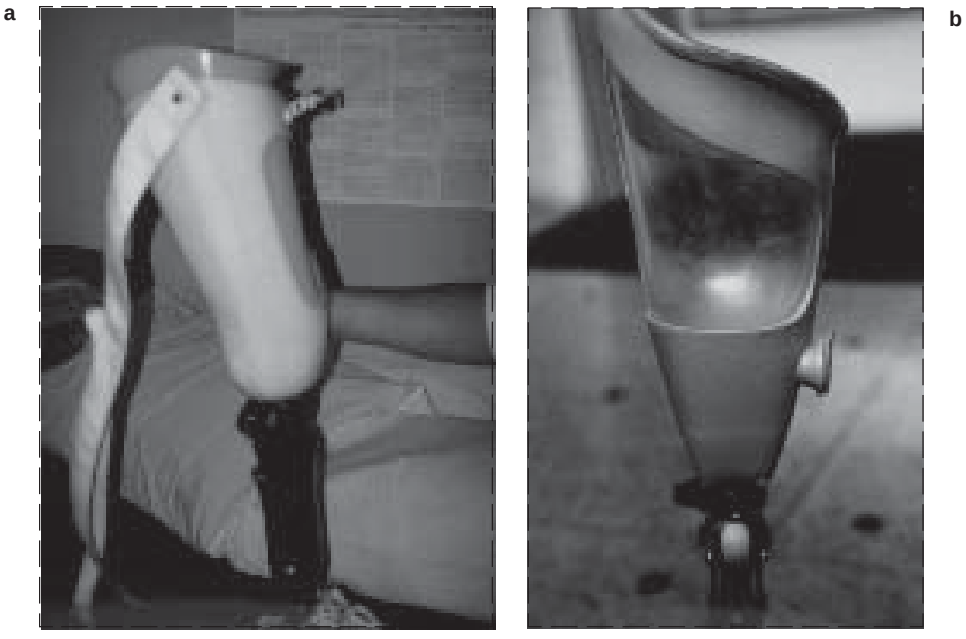


Fig. 4-57 ISNY (Icelandic-New York) transfemoral suction socket and flexible interface. (**a** and **b**) Two examples of the type of socket design.

feedback during sitting.[119] The flexibility of thermoplastic material results in a more comfortable fit at the proximal socket brim during standing. Although it is more costly and time consuming to fabricate, the frame socket design has the added advantage of allowing replacement with a new, inner socket to accommodate for residual limb changes without changing the external frame, knee, or foot units. This is an optimal design for war injured amputees, because it allows early ambulation with a prosthesis with definitive knee, shank, and foot components. As the limb changes shape, the inner socket can be changed without changing these components. It is a rather simple process to pull out the old liner and slip in the new one. The inner socket is usually held in place by Velcro or other removable fastener. The frame can be made for quadrilateral or ischial containment designs, and suction or nonsuction suspension systems.

Suspension Systems. Prosthetic devices need to be secured to the body. The more secure the suspension system, the better the prosthetic control and comfort the patient will experience. In the past, the lower limb amputee has been provided with suspension systems that consisted mostly of leather straps with metal attachments; those systems limited mobility and were ineffective and heavy.

The traditional nonsuction suspension mechanisms for transfemoral sockets included either a Silesian belt or a waist belt. The Silesian suspension attaches laterally to the outside of the socket and passes posteriorly around the pelvis over the opposite iliac crest and then attaches to the anterior socket. A significant problem with this suspension is its tendency to allow the socket to rotate internally on the residual limb. A modified Silesian suspension adds an additional strap that goes around the ipsilateral iliac crest. The waist belt suspension usually has a hip joint and pelvic band and is fabricated from leather and metal components. Lighter, plastic components are available, but plastic pelvic bands and hip joints do not control the tendency of internal rotation as well as do the metal pelvic bands. For the transtibial prosthesis, the total elastic suspension (TES) belt is a neoprene waist belt that is slipped over the prosthesis like the sleeve suspension and then encircles the waist to suspend the prosthesis. It has an anterior Velcro closure. Like the Silesian belt, the TES belt does not control rotation well.

The hypobaric suction suspension provides an excellent transition between nonsuction and suction suspension. This suspension system utilizes a sock that has a special silicone band in its proximal portion. This band creates a seal between the socket and the skin of the residual limb, and the resulting suction can be used for suspension. However, experience suggests that the suction suspension is often only partial, and an auxiliary suspension system, such as a Silesian belt, is necessary. The advantage of this suspension system is that changes in residual limb volume, which cannot be easily accommodated with a standard suction socket, can be managed simply by altering the number of ply (thickness) of the special residual limb socks. Another use for these socks is to control the internal rotation of the transfemoral socket. The friction of the band against the socket and the skin works well for this purpose.

In most cases, socks are used as an interface between the residual limb and the socket to adjust for the physiological volume changes that occur through out the day and from day to day. The only exception is when a suction socket is used. Patients must be educated about the need to appropriately alter sock thickness.

In some patients with very short and bulbous residual limbs, shoulder suspension (a type of suspender) may be used to improve suspension. This technique may be applicable to those patients who are unable to tolerate pressure over the abdominal wall.

For the transfemoral amputee, suction suspension (negative pressure) without the use of straps is preferred; this allows the patient optimal function, balance, strength, endurance and coordination. The socket is made small enough and is provided with a one-way valve that permits the expulsion of air during donning. The amputee dons the socket using a pull sock, Ace bandage, or wet fit (using a lubricant lotion on the skin of the residual limb). The intimate fit, especially proximally, results in a tight seal between the socket and skin. For doffing, it is necessary to break the vacuum seal and the valve is designed to allow this. To maintain proper suspension over time, the residual limb must be mature and volume stable.[43]

A novel idea infrequently used in this country is the TC-3[123] socket, developed in Japan at the Tokyo Metropolitan Rehabilitation Center. It permits the patient to handle the socket with the suspension system of choice separate from the prosthesis (Figure 4-58). This gives the patient the advantage of handling a smaller section of the prosthesis, with decreased bulk and weight for optimal application. The socket and residual limb are inserted into a thin, lightweight receptacle that has the knee, shank, and foot, and attaches with a Velcro strap. This system permits donning and doffing in the seated position

Fig. 4-58 TC-3 (Tokyo Rehabilitation Center) transfemoral socket. (**a**) Patient dons internal socket. (**b**) Velcro strap on the lateral aspect allows firm suspension of internal and external sockets.

and also is very helpful for the patient with limited hand function.

Cosmetic covers should be considered an integral part of the prosthesis, and for many patients it could be the catalyst that promotes success or failure. Exoskeleton prostheses do not afford as good visual or tactile cosmetic results, whereas the use of endoskeleton components allow the fabrication of a soft foam external cover. The shape of the cover may be derived from a mirror image of the sound limb and finished with one of the many plastic materials that resemble skin and is water resistant. Lifelike, custom made covers that use silicone or other materials can provide excellent cosmetic results, but may be very expensive and deteriorate rapidly (Figure 4-59).

For the through-knee amputee with a weight bearing bulbous end, a socket with a trap door, similar to a Syme's prosthesis, can be opened to allow donning, then closed, providing suspension by grasping the femoral condyles (see Figure 4-59). In this case, the socket does not have to extend proximally to the ischial tuberosity.

Hip Disarticulation and Transpelvic Amputation. Little change has occurred in the basic socket design for hip disarticulation or transpelvic amputations since the Canadian design was introduced in the 1950s. The major changes have been in slight modifications of the socket trim lines, suspension, and materials used to construct the socket. The standard Canadian socket design consists of a bucket-type socket, which encloses the residual pelvis and

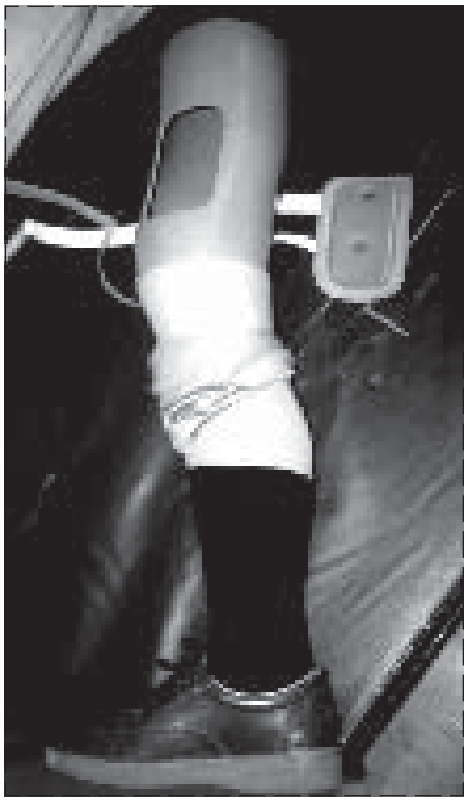


Fig. 4-59. Through-knee amputation endoskeletal prosthesis, showing lifelike foam cover and skin tone nylon stocking (turned down). Suspension via trap door closure over a bulbous end is similar to that of a Syme's prosthesis.

extends around the pelvis of the uninvolved side, leaving an opening for the nonamputated leg. The socket extends over both iliac crests and has an anterior opening to allow donning and doffing. By fastening the anterior opening, the socket is securely self-suspended from the iliac crests. The external appearance of the socket is similar for both levels of amputation. The interior surface contour is altered to provide total contact for the different levels of amputation.

As with sockets for other levels of amputation, thermoplastic materials are being used to provide lighter and more comfortable sockets. An obliquely trimmed socket brim (below the iliac crest on the nonamputated side), together with a Silesian belt over the nonamputated iliac crest for suspension, can be used to reduce the size of the traditional socket design. In the oblique modification, the socket still extends over the ipsilateral iliac crest of the amputated limb. For this high level of amputation, most of the advances in prosthetic design have occurred with new lighter components.

Prosthetic Training

Gait training is integral in the rehabilitation process. A new amputee or an experienced one who receives a prosthetic device that has different components should participate in such training. This program should be a coordinated effort between the physical, occupational and recreational therapists, and the prosthetist with frequent physiatric input. Each team member will use different techniques to teach to, and review with, the amputee all of the important topics that need to be learned.

The patient should learn the basic principles behind the function of each of the components in the prosthesis, its maintenance and care, and other points of prosthetic management. The patient should practice how to put on and take off the prosthesis, how to determine the appropriate sock thickness to wear, and techniques to adjust them. Skin care and inspection techniques are also reviewed. Weight shift techniques should be encouraged, including the use of stepping and a balance board. It is essential that gait training initially address proper technique, and after that training, addresses velocity on flat surfaces. Progress to uneven surfaces and elevations is then included. A review and practice in the use of the prosthesis in transfers, driving, sports, and other activities should always be part of the training.

Special Considerations for the Bilateral Transfemoral Amputee. For the bilateral transfemoral amputee, training should be initiated with very short nonarticulated prostheses (stubbies). As the patient gains balance and strength, first one and then the other knee can be articulated. After articulation of the bilateral knees has been achieved, then the length of the prosthesis may be increased. The goal of the prosthetic restoration should be to maintain the patient at a slightly lower-than-preamputation height to decrease the energy requirement of balance during standing, and to decrease the effort in energizing the prosthetic devices while walking. Alternate techniques for putting on the prosthesis are frequently required. These include using the bed for support of the prosthetic devices, or leaning against the wall.

For bathing activities, the patient with bilateral transfemoral amputations will require a shower and a shower wheelchair. In some cases, shower prostheses (devices that are waterproof and have nonslip feet) are indicated, and should be considered a medical necessity because they will allow the patient to safely perform this necessary activity.

Reintegration Into the Community

The reintegration into the community is best done as a gradual process. This process can be initiated early in the rehabilitation program with supervision by team members during organized trips for shopping, recreation, work, or school. When possible, a good system to foster community reintegration is the use of "day hospital" rehabilitation programs in which the patient participates in rehabilitation for 6 hours a day, 5 days a week and returns home every evening and weekend. When safe, the patient may return to work. Initially, modified or restricted work should be provided, but the patient should not be discouraged from returning to the premorbid work level, if it is safe to do so.

Long-Term Follow-up

The patient who has successfully completed a rehabilitation program should be seen for follow-up by a one or more team members at least every 3 months for the first 18 months. These visits may need to be more frequent and include more members of the team if the patient is having difficulties with prosthetic fitting, the residual limb, specific activities, or psychosocial adjustment. After this critical period, the patient should be seen at least every 6 months to assure adequate prosthetic fit and function, and attend to any prosthetic maintenance. It may be necessary to replace a prosthesis or parts

of it every 2 to 3 years.

Support Groups. For many patients, support groups are a source of information, peer counseling, and motivation, and ideally, these groups should be one more component of the comprehensive rehabilitation approach. Patients who have recently suffered an amputation will benefit from exposure to group members who are experienced amputees, while at the same time, the veteran amputee will appreciate being used as a resource.

Monitoring Residual Limb Problems. The skin of a patient who wears a prosthesis is subject to many stresses. Most prosthetic sockets prevent air circulation, thereby trapping perspiration. This can result in a variety of problems, such as hyperhydrosis, folliculitis, allergic dermatitis, and, where adherent scars are present, skin breakdown. Poor hygiene is frequently the cause of some of these problems; for this reason the patient should be carefully trained in proper washing technique for the leg, socks, and the socket and liner. A daily routine of washing the skin and the internal wall of the socket with a mild soap may suffice. At times it may be necessary to use concentrated antiperspirants, bacteriostatic or bactericidal soaps, antifungal powders, or antibiotics.

Stump edema syndrome is a condition with edema, pain, and increased pigmentation. It is commonly caused by proximal constriction, and usually responds to stump elevation, compression, prosthetic modifications, or temporarily discontinuing use of the prosthesis. Verrucous hyperplasia is a wartlike overgrowth of skin caused by a lack of distal prosthesis contact by the residual limb. Prosthetic modifications to improve distal contact must be made to address this problem and prevent recurrence (see Medical and Surgical Complications below).

Summary

The rehabilitation process for the patient with a transfemoral amputation is complex and is best accomplished by the patient who is able to cooperate with a comprehensive interdisciplinary specialized team. The team should be able and ready to assist the patient throughout the rehabilitation program, from preamputation to community reintegration. If no other significant comorbidity exists and optimal rehabilitation is provided, the otherwise healthy, war injured transfemoral amputee can be expected to return to a high functional level.

MEDICAL AND SURGICAL COMPLICATIONS OF AMPUTEES

Postoperative Complications

Mortality. In the Civil War, the mortality rates of above-knee and below-knee amputations were 54.6% and 32.3%, respectively. In World War I the mortality rates were 40% and 18% for above-knee and below-knee amputations, respectively. In World War II, the mortality rate for amputations in one hospital was 9%. Mortality rates decreased in the Korean and Vietnam conflicts.[47] In general, more proximal traumatic amputations yield higher morbidity. Mortality in traumatic amputations is also dependent on associated injuries and their severity.

Pain. Immediately postoperative, residual limb pain is severe; however, as healing occurs, the pain subsides significantly within the first week. Postoperative analgesics should be used to provide pain relief. However, if the pain worsens, a cause should be sought. Possible etiologies of increased pain include infection, ischemia, hematoma formation, improperly fitted rigid dressing, and excess weight bearing with an IPOP.

Infection. Infection is a major risk in traumatic amputations during wartime. Peterson[6] states that during World War II, infection was common in modified amputations with irregular skin flaps. Osteomyelitis was almost always present under these circumstances. In World War II, 1,670 patients who underwent primary stump closure reportedly had an infection rate of 8.9%. This amounted to about 149 patients. For the above reasons, primary closure was contraindicated, and the open circular technique was chosen as the amputation of choice.

After late revision and closure of the open amputation, the residual limb is monitored for signs of infection, particularly when there is increased pain in the immediate postoperative period. In cases of residual limb erythema with cellulitis, treatment should be initiated with systemic antibiotics. If deep wound infection occurs with abscess formation, wide drainage and antibiotic therapy is instituted.[124]

Hematoma. Hematoma formation may occur from inadequate hemostasis or drainage. Hematoma serves as a medium for infection. Additionally, hematoma formation may result in pain and skin edge necrosis. For small hematomas, aseptic drainage followed by compressive wrapping suffices.[47] For larger hematomas, evacuation in the operating room is usually required.

Delayed Healing

Delayed healing may be the result of improper amputation level selection, poor operative technique, infection, or poor nutrition. Improper amputation level selection mainly refers to the presence of inadequate circulation for healing. Circulation may be assessed preoperatively with vascular studies, including transcutaneous oxygen pressure ($TcPO_2$) determination, Doppler studies, and Xenon 133 isotope clearance. $TcPO_2$ determination may also be used postoperatively to assess vascular status. In one study[125] of postoperative amputations, amputees with a $TcPO_2$ equal to or greater than 40 mm Hg all healed. Those requiring revision related to nonhealing without infection had a $TcPO_2$ less than 40 mm Hg.

Poor operative techniques that may cause delayed healing include handling the skin with forceps, closing the skin under tension, and excess tension when closing muscle.[126] Obviously, infection requiring further debridement will delay healing. Nutrition is correlated with healing. Albumin levels of less than 3.5 g/dL and lymphocyte counts of less than 1,500 /mm^3 are associated with delayed healing; therefore, these parameters should be monitored, and proper nutrition provided via food supplements, if necessary.

Necrosis. Excess skin tension can result in necrosis. Improperly applied rigid dressings, particularly in patients with decreased sensation, can also result in skin necrosis (Figure 4-60). Additionally, an improper amputation level selection that results in inadequate circulation may lead to necrosis. Furthermore, proximal vessel thrombosis may lead to circulatory compromise and resultant necrosis.[47] If the area of necrosis is small, it may heal if all pressure is removed. Rigid dressing may continued without weight bearing.[124] If the area is large, revision may be required.[47]

Wound Dehiscence. Wound dehiscence may occur from one or several of the following: infection, premature suture removal, excess early weight bearing, or a fall onto the residual limb. Before treating, the cause needs to be determined. Treatment is based on the underlying cause. For example, in the case of infection, wide drainage and antibiotic therapy is the treatment. In uncomplicated cases, the wound may be closed in the operating room. However, if more than 6 hours had elapsed, the wound is left open with delayed closure performed.[47]

Contracture. The lower limb amputee is at increased risk for developing joint contractures secondary to immobilization, poor positioning, pain, and changes in agonist–antagonist muscle balance. Additionally, the risk of contracture is increased in the presence of flaccid paralysis, spasticity, edema, ischemia, and bleeding.[18] Contracture can prohibit prosthetic fitting, affect step length, place abnormal forces at joints, and increase energy expenditure during ambulation.[2]

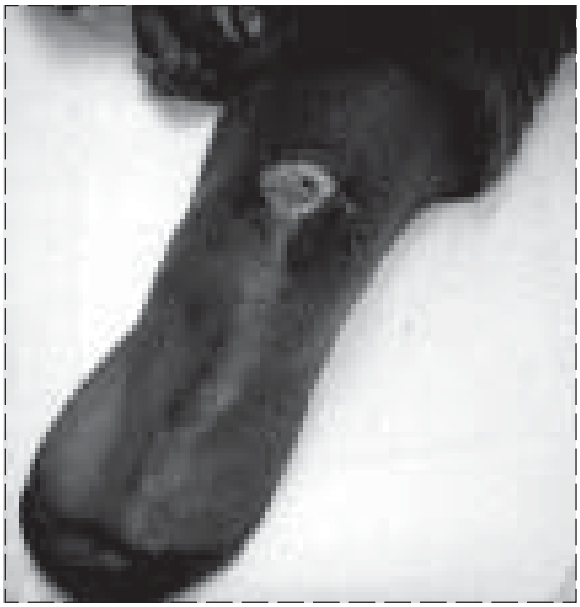


Fig. 4-60. Skin necrosis from excess rigid dressing pressure over patella.

Joint contractures may be prevented by proper positioning and exercise. Frequent bed position changes should be scheduled.[18] Prone lying should be encouraged to prevent hip flexion contractures. In the bedbound patient, a trochanteric roll may be helpful in preventing hip external rotation contracture. Prolonged sitting and use of a soft mattress should be avoided to prevent hip flexion contractures. A pillow between the knees or thighs can cause hip abduction contracture, especially in the above-knee amputee, and should be avoided.[59] A pillow under the thigh or knee should also be avoided to prevent knee flexion contracture. When sitting, the below-knee amputee should use a knee extension board.

Range-of-motion exercises should be done on a scheduled basis with a frequency of four times daily.[14] Early mobilization in a rigid dressing with pylon is very valuable in the prevention of contracture.[2,18] If a contracture occurs, an active and passive range-of-motion program with terminal stretch should be prescribed.

Skin Complications

Skin serves as an environmental barrier to infection, solutes, and water, and through sweat evaporation, is involved in temperature regulation. Other functions include sensation, pigmentation, and vitamin D synthesis. In the amputee, skin provides soft tissue protection to the mechanical forces induced by the prosthesis. To serve these functions, skin must be healthy.

In the amputee, residual limb skin would ideally be normal healthy skin with good elasticity, freely moveable, and adequately padded with subcutaneous tissue. Increased skin tension, which may subject the skin to an increased risk of breakdown, can result from discontinuing skin traction too soon or surgical closure with insufficient skin present. Tenting of skin over the end of bone or redundant skin folds should be avoided because of the increased risk for skin breakdown.[127] Skin tension can be further increased by skin stretching when donning a socket.

Scar location is important. Ideally, a surgical scar is linear and avoids bony prominences, the cut end of bone, and socket pressure points. Scar should be freely moveable, soft, pliable, and insensitive. Skin grafts present problems secondary to adhesions, inelasticity, and atrophy, making the graft susceptible to mechanical forces.[127] Scar adhesion to bone renders the scar immobile and increases the risk of skin breakdown due to excessive shear forces from the prosthesis. The adhered scar often undergoes breakdown, which necessitates discontinuance of the prosthesis. Treatment of adhered scar consists of friction massage to mobilize the scar from bone; care must be taken to avoid tension at the incision line with the massage. Additionally, a nylon sheath or liner may be used to decrease shear forces to the area.

Skin is challenged by shear and loading forces delivered by the prosthesis to the residual limb during ambulation. Furthermore, skin is taxed by the closed socket, which affects temperature regulation and creates a moist environment from sweat accumulation. When a socket is poorly fitted, pathologic skin changes may occur. Some of the more common skin disorders seen in amputees are discussed below.

Mechanical Injury. Mechanical forces imposed by the prosthesis on the residual limb are pressure, shear, and friction.[127] Excessive forces may result in skin destruction or proliferation.

Tissue Destruction. Maceration occurs because of rubbing over pressure points combined with moisture from sweat accumulation in the socket. Maceration can be treated with proper prosthetic fitting with appropriate pressure relief. Additionally, optimal residual limb hygiene should be followed.[127]

Blisters occur from the combination of friction and pressure, secondary to a loose or excessively tight fitting socket.[127] Inadequate suspension may also lead to blister formation. Risk areas include the socket brim and distal end of the residual limb. The socket should be checked for proper fit and suspension, and modified as necessary. Abrasions and erosions result from rubbing and pressure. Pressure points in the socket are risk areas. Socket fit, alignment, and suspension should be evaluated.

Ulcerations occur from excess mechanical forces. Risk factors include ischemia, edema, lymphatic blockage, adherent scars, impaired sensation, and systemic disorders such as diabetes.[127] Treatment includes proper prosthetic fit and alignment. Also, the prosthesis should not be worn until ulceration has healed.

Tissue Proliferation. Lichenification occurs secondary to excess mechanical forces. This is a common problem presenting with thickened, leathery skin. Exaggeration of the normal skin markings with a crisscross pattern is visible on examination. Furthermore, physical examination may reveal scaling, erythema, edema, fissuring, erosion, and pigmentation (Figure 4-61). The location of the lichenification is usually over pressure areas in the socket

Fig. 4-61. Lichenfication demonstrating thickened, leathery skin with hyperpigmentation.

or along the brim. The patient may complain of burning, itching, or soreness. Treatment consists of realignment of the socket to decrease pressure, or modification of the socket to reduce pressure over these areas. If the problem continues, a Teflon brim may be used for lichenification at the brim location. Temporary relief may be provided by corticosteriod cream.[127]

Callosities are circumscribed hyperkeratosis lesions, which usually occur over bony prominences and are secondary to chronic mechanical forces.[127] Treatment consists of pressure relief and good skin hygiene.

Follicular hyperkeratosis and coiled hairs result from mechanical forces that cause enlarged keratin plugs that trap and coil hair. The plugs may act as a foreign body with secondary infection. Some plugs may require manual expression. Treatment consists of proper fit, alignment, and, if needed, changing socket materials.[127]

Epidermoid Cysts. Epidermoid cysts are associated with the development of a tissue roll that is subjected to mechanical shear from the socket. Skin then undergoes invagination of surface keratin and epidermis, thereby forming a cyst. The cyst may enlarge and act as a foreign body with secondary infection with later sinus tract development. With prosthetic usage, cysts develop over months to years and may become painful with local inflammation or infection. In above-knee amputees, cysts tend to occur in the adductor region, the inguinal fold, and the ischium. In below-knee amputees, cysts tend to develop over the anterior tibial surface and popliteal region (Figure 4-62). Amputees may experience discomfort with prosthetic use, leading to eventual discontinuance of prosthetic usage. Individuals at increased risk for development of epidermoid cysts include those with cysts elsewhere, acne, and seborrheic dermatitis. Cyst development is prevented through good prosthetic fit, proper alignment, appropriate pressure relieves, smoothing of rough areas in the socket, use of a liner or socks, and good hygiene.[127]

Treatment consists of optimizing pressure relief and skin hygiene. The fluctuant cyst must be incised and drained. If there are signs of infection or purulent drainage, cultures are obtained and antibiotic therapy initiated.

Circulatory Complications

These disorders result from circulatory disturbance in either venous or arterial systems, or both. Selected disorders will be presented here.

Reactive Hyperemia. Reactive hyperemia tends to occur in new prosthetic wearers, especially those with poorly fitting sockets. The amputee may complain of tingling, warmth, and tightness. On removal of the prosthesis, the residual limb is noted to be flushed and warm. The flushing and warmth subsides without residual problems. In some cases, venous and lymphatic congestion may occur, leading to edema and small vessel hemorrhage, and causing a bruising discoloration. Later, residual brown pigmentation from hemosiderin deposits may be noted. Prevention consists of compression wraps.[127] A rigid dressing prepares the residual limb for mechanical stresses induced by prosthetic use.

Stasis Dermatitis. When there is insufficiency or stasis of venous flow, stasis dermatitis may develop. Causes of venous insufficiency or stasis include old thrombophlebitis, varicose veins, external pressure, neoplasia, anomalous veins, and arteriovenous fistulas. Additionally, inadequate distal residual limb prosthetic support may result in edema. Distal swelling may result in congestion, cyanosis, and

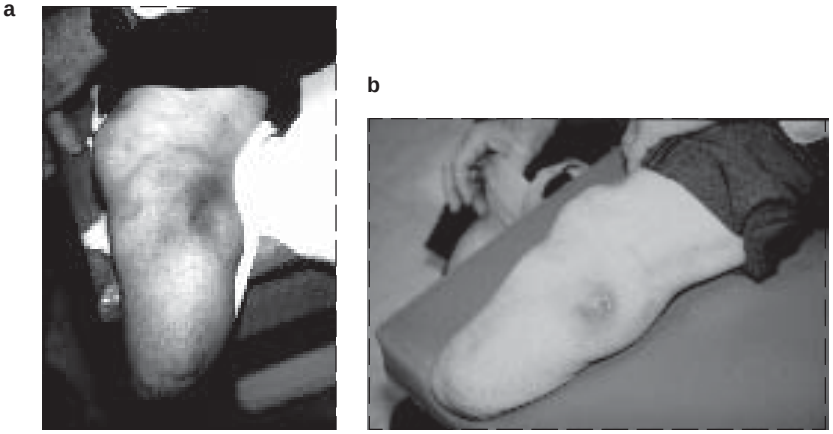


Fig. 4-62 Epidermoid cyst. (**a**) Fluctuant epidermoid cyst requiring incision and drainage and (**b**) same patient after incision and drainage. Socket modifications were required to correct a poorly fitting socket.

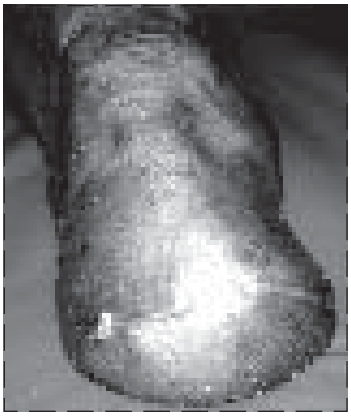


Fig. 4-63. Edematous residual limb.

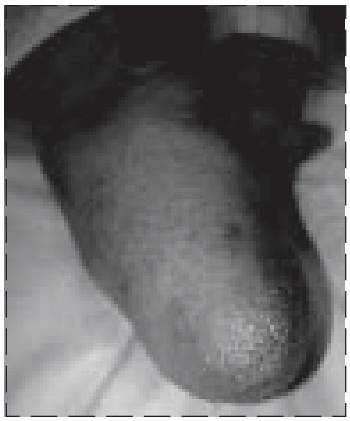


Fig. 4-64. Verrucose hyperplasia.

hemosiderin deposition. With venous insufficiency, the skin becomes pruritic and exhibits scaling. Differential diagnoses include contact dermatitis and fungal or bacterial infection. Stasis dermatitis treatment consists of removing the underlying pathologic condition causing the dermatitis. Prosthetic causes are corrected by ensuring total contact. Additionally, when not in the prosthesis, the limb should be in a compressive wrap or sock.[127] Contact dermatitis will be discussed later.

Stump Edema Syndrome. Proximal constriction of the residual limb from an external source may cause the stump edema syndrome. The external source of constriction may be an improperly wrapped elastic bandage or improperly fitting socket. Also, excess negative pressure from a suction socket may cause distal edema. Early signs may include narrowing proximally with bulbous soft edema distally (Figure 4-63). Over weeks to months the edema may become firm. With firm edema, palpation of a fold of skin between the fingertips reveals thicker and firmer skin compared to the same area contralaterally. Additionally, an orange peel appearance develops. There is an increased risk in overweight and sedentary patients.[127] Treatment consists of proper fitting with relief of proximal socket and suspension constriction and ensuring total socket contact, including the distal residual limb. A rigid dressing, temporary socket, or elastic bandage may decrease the edema. Proper education regarding wrapping and socket fit is important. The residual limb should be in a compression wrap or sock when not in the prosthesis or rigid dressing.

Verrucose Hyperplasia. Verrucus hyperplasia is a warty condition of the distal residual limb (Figure 4-64), caused by proximal constriction and vascular insufficiency from a poor socket fit. Treatment consists of distal compression, total contact socket, and relief of proximal constriction.

Contact Dermatitis

Contact dermatitis may be divided into primary irritant dermatitis and allergic contact dermatitis. The mechanism in each is cutaneous contact with the offending agent. Susceptibility to the offending agent may be increased by mechanical injury to the skin. Skin reaction may be mild and consist of slight erythema, burning, and minor itching; or a fulminant reaction may occur with local inflammation, vesiculation, crusting, and serous oozing[127] (Figure 4-65).

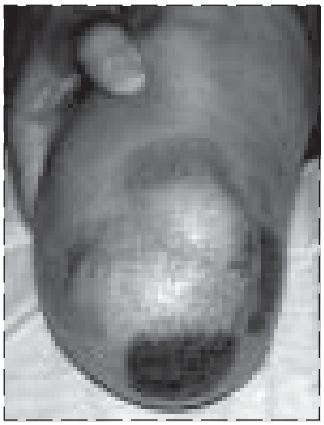


Fig. 4-65. Contact dermatitis from bandage tape. Note the contact pattern corresponding to the tape.

Primary Irritant Dermatitis. In most individuals, a primary irritant is a substance that results in an irritating skin reaction on first exposure (see Figure 4-65). A relative primary irritant requires prolonged contact and mechanical susceptibility of the skin, such as maceration. The patch test, described later, may be normal.[127]

Allergic Contact Dermatitis. Allergic contact dermatitis results from exposure to an allergen by skin antibodies, leading to an allergic reaction. It is an acquired hypersensitive state and requires preliminary exposure to a specific agent. There is a refractory period, incubation period, reaction time, and sensitive state in the development of allergic contact dermatitis. The refractory period is the time course during which potential sensitizers may be in daily contact with skin without sensitization. Once sensitization occurs, there is an incubation period before sensitization is complete. Then there is a variable time between exposure and first manifestations of sensitization, termed the reaction time. This time period is reduced by mechanical stresses (such as maceration) on the skin. With development of an allergic skin reaction, the sensitive state begins. The sensitive state may persist indefinitely. However, the skin reaction may diminish with time.[127]

Certain conditions may affect the severity of the skin response, including a higher concentration of irritant or allergen, and prolonged exposure. Environmental factors such as heat, moisture, and pressure, may predispose to a skin reaction, as well as preexisting irritation or inflammation of the skin.[127]

Diagnosis and Treatment. Diagnosis of contact dermatitis is based on patient history, physical examination, and a patch test. Important items in the history include (*a*) condition onset; (*b*) previous episodes; (*c*) initial site of involvement; (*d*) history of skin allergies; (*e*) recent activities that may have resulted in exposure to an irritant or allergen; (*f*) change in medications, socket, socks, soap, or cleansing agent for the socket, or any of those; and (*g*) all materials contacting the residual limb. Contact dermatitis should present in a recognizable pattern where the area of skin involved corresponds geographically to the inciting contact irritant or allergen (see Figure 4-65). A patch test evaluates the suspected agent. Using a standard size patch, the agent is attached to normal skin. The patch is left in place for 24 to 72 hours and, in some cases, up to 5 days, after which the patch is removed and the skin examined. Skin is reexamined for up to 5 weeks in case there is a delayed reaction. Even with a careful history, physical examination, and patch testing, the offending agent may be difficult to identify. This is especially true in allergic contact dermatitis where the refractory period and incubation time makes identification of the offending allergen confusing. Offending agents to keep in mind are the materials used in making sockets or liners. Additionally, residual limb socks and cleansing materials may be the offending agent.

Treatment consists of removal of the causative agent. Additionally, dermatitis treatment with topical steroids, cold compresses, aspirin, antihistamines, and antipruritic medications may be beneficial. In pruritic cases, scratching may lead to secondary infection, requiring antibiotic agents.[127]

Residual Limb Pain: Intrinsic Causes

Ischemia. Ischemia may present with intermittent claudication recurring at a set distance.[126] The amputee may have pallor and soft tissue breakdown revealed on examination of the residual limb.[128] Doppler, $TcPO_2$ and xenon 133 vascular studies can assess for ischemia.

Ischemia may be caused by dysvascular disease or may result from excess vascular compression by the socket. An excessive popliteal bulge in the PTB-TCS, or Scarpa's triangle in the quadrilateral socket, can result in ischemia.[128]

Initial treatment in the dysvascular patient consists of conservative measures. If soft tissue breakdown is present, appropriate wound care and discontinuance of weight bearing in the prosthesis is usually indicated. Once healing has occurred, a gel socket or appropriate liner is needed. In some cases, a below-knee bypass prosthesis may be utilized if the gel socket is unsuccessful.[128] If conservative measures fail, revision or revascularization should be considered.

If ischemia is caused by excess vascular compression by the prosthesis, socket modification is required. The popliteal bulge can be eliminated.[128] In the quadrilateral socket, Scarpa's triangle pressure can be decreased or replaced with an NSNA socket with reduced pressure over the femoral artery.

Ectopic Bone. Development of bone spurs may result in localized pain, which may become worse with prosthetic use. The amputee may even be unable to tolerate pressure from the socket. Ectopic bone results from periosteal stripping of retained bone either by the original trauma, or by surgical procedure.[126] Ectopic bone may also occur from retained periosteum in the residual limb.[14] Radio-

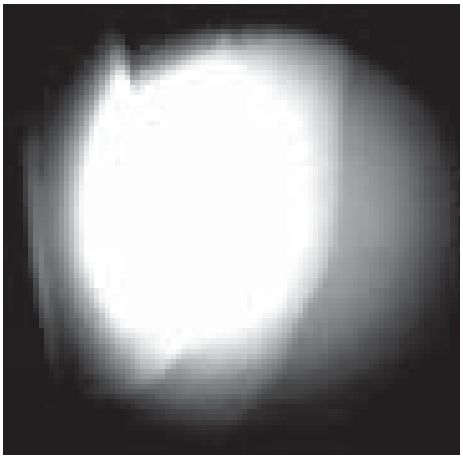


Fig. 4-66. Ectopic bone on plain x-ray.

graphs readily show the ectopic bone (Figure 4-66). Ectopic bone development may be minimized or possibly prevented by not disturbing the periosteum.[126] Once symptomatic ectopic bone is present, initial conservative management is warranted; a socket relief is tried.[126,128] If unsuccessful, a soft liner with a cutout for a gel pad insert over the bony prominence may be helpful. If conservative measures fail, surgical revision is considered. Only symptomatic spurs should be removed.[126]

Excess Fibular Length. When the fibula is longer than the tibia, an amputee may present with pain that is worse on weight bearing. Examination will reveal a prominent fibula longer than the tibia, and there may be soft tissue breakdown at the distal fibula. Radiographs will confirm the diagnosis. Conservative treatment consists of socket modifications, soft liners, or distal pads. If unsuccessful, a revision may be necessary.[126]

Inadequate Tibial Beveling. Inadequate tibial beveling can result in bursal development or pain and soft tissue breakdown over the distal anterior tibia. Treatment consists of socket modifications to relieve pressure over the region or utilization of a liner. A soft foam liner with a cutout for a gel pad over the distal tibia can be used. If conservative methods fail, surgical revision may be necessary.

Hypermobile Fibula. In addition to pain, amputees may complain of symptoms secondary to pressure on the peroneal, tibial, or sural nerves. Examination will reveal an excessively mobile fibula. The hypermobile fibula results from traumatic disruption of the interosseous membrane and the proximal tibiofibular joint. Treatment in symptomatic individuals is fusion of the proximal tibiofibular joint.[126]

Unbalanced Myodesis in Above-Knee Amputation. The amputee may complain that distal, anterolateral residual limb tenderness is worse when wearing the prosthesis. A physical examination may reveal the tenderness on palpation. Skin inspection may reveal ulceration. The problem results from an unbalanced myodesis of the adductor muscles with femoral drift anterolaterally through the soft tissues. Treatment consists of socket relief at the bony prominence. Alternatively, the socket may be built up anteriorly and proximally, thereby reducing pressure over the painful area. If conservative measures fail, surgical revision with adductor myodesis may be necessary.[126]

Neuroma. Individuals with a symptomatic neuroma often present with sharp, shooting pain.[36] Symptoms are brought on or worsened by prosthetic wear or weight bearing. Examination will reveal a positive Tinel's sign with tingling discomfort[36,126] and pain reproduction with direct palpation over the symptomatic neuroma.

Neuromas normally develop after nerve transection and may generate pain when mechanically irritated. Less commonly, a neuroma may become a spontaneous pain generator.[36] If a neuroma becomes adherent to scar located in weight bearing regions or in areas of socket pressure, it is subjected to increased mechanical irritation with subsequent pain generation.

Neuromas located by MRI will reveal hetergenous ovoid structures of intermediate intensity surrounded by a rim of low signal intensity on T1 images. T2 images demonstrate ovoid structures of increased signal intensity intermingled with strand-like areas of low intensity surrounded by a low signal intensity rim.[129]

Singson and associates[129] postulate that the hetergenous ovoid structures represent low signals from collagen matrix and intermediate to high signals from cellular nerve fascicles. They further postulate that the rim of low intensity signal represents collagen tissue. MRI may also differentiate neuroma from scar tissue, abscess, osteomyelitis, and hematoma as causes of residual limb pain.[129] Anesthetic nerve blocks or a neuroma injection can determine if a neuroma is the cause of residual limb pain. Injections are not only diagnostic, but may provide therapeutic analgesia.

The best treatment for symptomatic neuromas is prevention. Avoidance of neuroma formation in the wound scar, weight bearing location, or socket pressure point should be considered at the time of surgery. Nerves should be sharply transected under

tension to allow retraction into healthy muscle, which provides protection from mechanical irritation or pressure with prosthetic use.

Initial conservative management of symptomatic neuromas consists of socket modifications to decrease pressure or shear. Pressure may be decreased with socket reliefs, total contact sockets, or liners. Shear may be decreased with a nylon sheath and optimal suspension to minimize pistoning. A TENS unit trial is performed. Also, a trial with anticonvulsant medications, such as carbamazepine or phenytoin, may be concomitantly tried or used alone.[36] If the neuroma becomes refractory to socket modifications, and if temporary anesthetic injection of the neuroma relieves the pain, Davis[36] recommends chemical obliteration of the nerve with CT-guided phenol injection of the neuroma. However, Friedman[14] states that chemical obliteration is of no benefit. If conservative management fails, surgical revision may be necessary. The neuroma is resected and moved to a deeper site by transection under tension and retraction into muscle. Another method consists of burying the nerve end in bone,[126] although Friedman[14] believes this procedure has no benefit.

Reflex Sympathetic Dystrophy. Reflex sympathetic dystrophy (RSD) is a symptom complex that may occur after major or minor trauma, including amputation.[130] It may occur in any age group. Major symptoms are pain, swelling, and tenderness in an extremity. Physical examinations may reveal edema, tenderness, contractures, mottling, and dusky red or blue color. There may be skin atrophy, or increased or decreased skin temperature, nail growth, hair growth, and sweating. The symptoms and signs are partly dependent on the stage of RSD. RSD is divided into three stages:

1. Stage I (acute phase) may consist of pain, local edema, local increased temperature, increased blood flow, joint stiffness, increased hair growth, and increased nail growth. This stage lasts for a few weeks to several months.[131]
2. In stage II (dystrophic phase), there is decreased hair growth, nail growth, and local temperature. Additionally, muscle and subcutaneous atrophy begins and nails become brittle. The skin may be pale or cyanotic. This stage may last 3 to 6 months.
3. In stage III (atrophic phase), contractures, marked muscle wasting and subcutaneous atrophy occur, with the skin developing a glassy appearance.[131]

Diagnosis of RSD is mainly clinical. Other disorders that cause pain must be eliminated from the differential diagnosis. Kozin[132] developed a classification to help in the diagnosis of RSD. The probability of having RSD was divided into *definite, probable, possible,* and *doubtful* groups. The *definite* group exhibits pain, edema, vasomotor, and sudomotor changes in the involved extremity. The *probable* group exhibits pain, vasomotor, and sudomotor or edema, but not both, in the involved extremity. The *possible* group exhibits vasomotor or sudomotor changes. The *doubtful* group exhibits pain only.

Diagnostic tests mainly include radiographs, bone scans, and sympathetic blocks. Radiographs may demonstrate patchy osteopenia in the involved limb after 6 weeks.[131] Prior to 6 weeks, radiographs may be normal. Three-phase bone scans with technetium 99m methylene diphosphonate are reported as abnormal in 83% of individuals with definite RSD.[132] In stage I, bone scans reveal increased velocity, blood pooling, early fixation, and delayed fixation. In stage II, there is increased early fixation and delayed fixation with normalization of velocity and pooling. In stage III, there is decreased velocity and blood pooling with normalization of early and delayed fixation.[133,134]

Response to anesthetic sympathetic blockade is supportive of the diagnosis. However, nonresponsiveness does not preclude the diagnosis. Additionally, radiographic and bone scan findings are not entirely specific to RSD. The diagnosis is clinical with supportive diagnostic tests.

Prevention is the key, because once RSD develops, it may be very difficult to treat. Early mobilization is the mainstay in prevention. Once RSD develops, early physical therapy and occupational therapy should be initiated. Active and passive range-of-motion exercise of the involved extremity is performed. Modalities such as heat, cold, or TENS units may be tried for local pain control to help promote function or allow exercise to proceed. Desensitization therapy with contrast baths and friction massage may be started.

Tricyclic antidepressants such as amitriptyline may be used for analgesia. Sedative effects may improve sleep. Also, if depression is present, these medications will be of benefit. If this regimen is unsuccessful, a series of anesthetic sympathetic blocks may be tried. If improvement occurs, blocks may be periodically continued. If no improvement occurs after three to five blocks given daily or every other day, then sympathetic blockade is stopped.[132] Oral prednisone may be tried with 2- to

4-day intervals at dosages of 60 to 80 mg, 40 to 60 mg, and 30 to 40 mg in four divided doses.[133] This is followed by tapering as follows: 2- to 3-day intervals of 40, 30, 20, 10, and 5 mg given each morning and then discontinued. Kozin and associates[133] studied 64 patients with RSD and reported good results with an oral prednisone bolus in 90% of those with RSD and a positive bone scan.

Other medical treatments have included nitroglycerin, nifedipine, phenoxybenzamine, prazosin, propranolol, and intranasal calcitonin.[135] If the problem becomes chronic, a multidisciplinary pain approach is necessary. Treatment goals should be improved function and quality of life.

Other Medical Causes. Amputees may suffer from medical conditions that affect the general population. Degenerative arthritis or other rheumatologic disorders may present with symptoms in the residual limb. These conditions should be considered in the differential diagnosis of residual limb pain.

Referred Causes. In addition to local causes, conditions referring pain into the residual limb are in the differential diagnosis of residual limb pain. Radiculopathy has been reported as a cause of residual limb pain in an amputee.[136] Diagnosis may become difficult secondary to inability to test sensation, strength, or reflexes for a particular neurologic level because of the amputation. Electrodiagnostic studies and radiographic imaging may be required. Residual limb pain has been reported[137] after epidural anesthesia. The pain occurred in the residual limb at the time of epidural anesthesia. With increased anesthetic medication given epidurally, the pain subsided. However, the pain returned postoperatively. A TENS unit was helpful in reducing the pain, and complete pain resolution occurred in 3.5 hours after onset. Other referred causes in the differential diagnosis include spinal stenosis, facet syndrome, piriformis syndrome, and myofascial pain syndrome.

Residual Limb Pain: Extrinsic Causes

Extrinsic causes of residual limb pain refer mainly to residual limb socket interface problems. These problems result from poor socket fit or alignment. Poor prosthetic fit is the most common cause of residual limb pain.[36]

Localized Increased Pressure. A poorly fitted prosthesis with increased pressure may cause focal pain. Examination of the residual limb often will reveal abrasions, ulceration, or callosities. Increased pressure over a bony prominence may result in bursal development.[126,128] In these cases, pain is worsened with prosthetic use. Upon removal of the prosthesis after ambulating, prolonged erythema may be present. Treatment consists of socket relief or, if unsuccessful, fabrication of a socket.

Bursal Enlargement or Inflammation. A socket with increased pressure, or with inadequate suspension with increased shear over a bony prominence, may result in development, enlargement, or inflammation of a bursa. The amputee will complain of pain during prosthetic use. Examination will reveal signs of localized increased pressure or shear and a tender, fluctuant mass is palpated. Usually, the bursa is warm and erythematous. Treatment consists of correcting the cause and symptomatic treatment of the bursitis. If the bursa developed from increased pressure or poor suspension, a socket relief is made or suspension is corrected, respectively. Symptomatic treatment involves pain relief and antiinflammatory measures. In most cases, symptoms are relieved with cessation of prosthetic irritation. Local ice treatment over the inflamed bursa may be helpful; in some cases, a corticosteriod bursal injection may be required.

Loose Socket. A loose socket may cause pain over bony prominences or skin breakdown.[126,128] The above-knee amputee often presents with pubic ramus and distal pain. The below-knee amputee may present with pain at the hamstrings, inferior patellar pole, fibular head, and distal residual limb, which is worsened with prosthetic ambulation.[128] Examination after ambulation often will reveal areas of increased pressure or shear. The loose socket may occur with residual limb volume changes from generalized weight loss, local muscle atrophy, or normal residual limb maturation. Treatment consists of proper education and use of stump socks to provide an optimal prosthetic fit. Socket modifications, a new socket, or liner may be necessary.

Bell Clapping. Bell clapping results from distal residual limb shrinkage and presents with poorly defined residual limb pain and choking.[126] With ambulation, the residual limb strikes the anterior socket wall during swing phase, and choking occurs from proximal constriction. This may be precipitated by use of stump socks to improve distal fit. However, because the proximal residual limb has not proportionately changed, the addition of extra stump socks causes proximal constriction.

Often, careful questioning can reveal a history of residual limb changes with pain on prosthetic use. The amputee may complain of a loose socket distally with the residual limb hitting the socket walls with ambulation. Physical examination will

reveal a conical residual limb with signs of distal edema, skin irritation, and proximal constriction. When bell clapping is suspected, a xeroradiograph can be obtained to evaluate socket fit. A xeroradiograph is a special radiograph that provides a clear picture of the socket and soft tissue interface. With bell clapping, xeroradiography of the residual limb in the socket demonstrates the proximal constriction and distal socket looseness and confirms the clinical diagnosis.

Treatment requires socket modification. Posterior filling of the socket to eliminate the distal looseness may help.[126] If unsuccessful, or socket modifications are impractical, a new socket should be fabricated.

Choking. Choking results in proximal constriction and distal edema. The amputee may complain of pain. There may be skin breakdown. Treatment consists of socket modification or refabrication to provide total contact without excess proximal constriction.

Phantom Limb Sensation

Phantom limb sensation is defined as any sensory phenomenon except pain, referred to an absent limb or portion of a limb. After amputation, 80% to 100% of amputees experience phantom sensations at some time in their lives.[138] A recent study revealed that within the first 24 hours postoperatively, about one third of new amputees experience phantom sensations. The percentage who experienced phantom sensation at 8 days, 6 months, and 2 years postoperatively were 84%, 90%, and 71%, respectively.[139]

While a wide variety of sensations are described, phantom sensations may be divided into three categories:

1. Kinesthetic sensations are those related to the phantom limb posture, length, and volume.[138,140] The phantom limb may be perceived as behaving just like a normal limb, such as bending at the knee with sitting.[35] Eight days postoperatively, normal volume and length were perceived in 48% and 55% of amputees, respectively.[138]
2. Kinetic sensations are sensations of movement. Both willed and spontaneous movement may be perceived as occurring.[138,140] Willed movements are often simple flexion and extension movements of a phantom foot or hand. The incidence of kinetic sensations at 8 days, 6 months, and 2 years are reported as 36%, 37%, and 24%, respectively.[138]
3. Exteroceptive sensations are surface sensations such as touch, temperature, pressure, and pruritus. Amputees may report a wide variety of sensations, such as itching, tingling, and heat. In one study,[139] the incidence of having only exteroceptive sensations were 13% and 14% at 8 days and 6 months postamputation, respectively.

Phantom sensations often undergo telescoping. Telescoping is the perceived shortening of the phantom limb. Often, more distal portions of the limb are perceived to remain with disappearance of the more proximal.[140] Hence, an above-knee amputee may experience telescoping with a phantom foot perceived directly at the end of the residual limb. Telescoping is usually completed in one year and occurs in 25% to 75% of cases.[138] Usually, only a painless phantom shortens; conversely, phantom pain attacks may perceptually lengthen a phantom limb.

Phantom limbs often undergo fading. Fading refers to a change in the frequency and intensity of phantom episodes. Approximately 70% of amputees have marked phantom sensations immediately postoperatively. After 10 years, only 29% of amputees experience marked phantom sensations.[138]

There is no specific treatment for phantom sensations, which may be regarded as a normal occurrence after amputation. However, the experience may be frightening to the new amputee who is not educated regarding this phenomenon. Some amputees may think they are becoming insane. To avoid psychological discomfort, preoperative education regarding phantom sensations should be provided. Additionally, having experienced amputees relate their own phantom sensation experiences is beneficial.

Phantom Limb Pain

Phantom limb pain is defined as pain in an absent limb or portion of a limb. Phantom limb pain must be differentiated from phantom sensation and residual limb pain. Problems with the definition are differences in pain tolerance, threshold, and individual interpretation. Furthermore, past studies have not always differentiated residual limb pain from phantom pain and phantom limb sensation, thereby creating problems in evaluating the incidence and treatment of phantom pain.

The incidence of phantom limb pain ranges from 2% to 97%.[140] In a survey of 5,000 American veteran amputees with 55% responding, 78% reported

phantom limb pain.[141] Another study evaluated the incidence of phantom limb pain at 1 week, 6 months, and 2 years and found the incidence of phantom pain was 72%, 65% and 59%, respectively. Duration and frequency of phantom pain episodes decreased with time, with 21% experiencing pain daily, but none constantly at 2 years.[138] Phantom pain episode durations are usually seconds to hours and rarely last weeks to months.[142] Jensen and Rasmussen[138] speculate that 5% to 10% of amputees have severe, persistent phantom limb pain. While phantom pain may persist, some individuals have spontaneous remission.[140]

Phantom pain tends to localize distally.[138,140] All types of painful stimuli have been reported, although at 6 months postoperatively, most individuals with phantom pain reported a burning, squeezing pain.[143] A minority reported a painful distorted position similar to the position prior to surgery.[138] The perceived pain can be intermittent or continuous. A variety of factors can modify the pain. Factors making the pain worse include yawning, micturition, fatigue, sleeplessness, anxiety, weather changes, pain from other body sites, stimulation of another body part, heat, cold, and a poorly-fitted prosthesis.[138,140,142,143] Factors mitigating the pain include mental distractions, rest, emotional pleasure, massage, elevation of the residual limb, electrical stimulation, cold, heat, and a well-fitted prosthesis.[138,139] The presence of preamputation pain correlating to phantom pain is controversial.[140,143] The incidence of phantom pain reported as being similar to preoperative limb pain ranges from 12.5% to 79%.[144] Jensen and colleagues[143] prospectively found 36% of amputees had phantom pain similar to their preoperative pain. At 2 years from amputation, 10% had phantom pain similar to preoperative pain.[143] Additionally, long-term residual limb pain has correlated with an increased risk for phantom limb pain.[143] Factors identified as having no significant effect on the development of phantom limb pain in adults include site and level of amputation, cause of amputation, sex, age, and civilian vs military etiology of amputation.[139,142,145] Furthermore, psychopathologic personalities or psychiatric abnormalities are not the etiology of phantom pain.[146]

Pathophysiology. The pathophysiology of phantom limb pain is unknown. Current theories have not adequately explained all the observed phenomena seen in phantom pain patients. Current theories may be divided into peripheral, spinal cord, supraspinal, and neuromatrix.

The peripheral theory postulates spontaneous discharges from neuromas traveling through the somatosensory system to the brain.[35] The impulses may be interpreted as phantom sensations or pain. Various observations have suggested a peripheral role. Phantom limb sensation may be modulated by residual limb manipulation. Phantom pain has been temporarily abolished by local residual limb anesthesia. Residual limb revisions or neuroma resection may transiently decrease phantom pain. Tapping of neuromas may increase phantom pain.[138] Additionally, axons in the neuroma generate spontaneous impulses. There is abnormal sensitivity to mechanical and chemical stimuli.[140] However, treatments aimed at peripheral solutions have not given long-term relief. Neuroma resections and dorsal rhizotomies have not been successful in permanent relief, which suggests more proximal structures are involved in phantom pain generation.

Changes in the spinal cord may play a role in phantom pain. After nerve transection, changes take place in the dorsal horn. There is atrophy of primary afferent terminals, postsynaptic inhibition, and changes in concentrations of neuropeptides.[138] Decreased postsynaptic inhibition by loss of afferent fibers may lead to pain enhancement at the spinal level.[36] Dorsal horn neurons that have lost afferent input may begin to respond to nearby intact afferents, resulting in an expanded receptive field. An expanded receptive field is thought to explain stimulation of the residual limb, which modifies phantom sensation or pain.[138] Additionally, phantom pain or sensation may be related to spontaneous discharges from dorsal horn neurons that have lost primary afferent input.[35] While dorsal horn changes may have a role in phantom pain, these changes cannot adequately explain the onset of phantom limb pain in a low thoracic (T-11) paraplegic with complete sensory loss who underwent leg amputation. Supraspinal areas may play a role in phantom pain. Nociceptive specific neurons exist in the cortex, and the plasticity that occurs in nociceptive neurons in the periphery and spinal cord are postulated to ascend centrally to nociceptive and antinociceptive systems.[138] Observations suggesting a central role have been described. Bursting activity in thalamic neurons was demonstrated in a paraplegic suffering from pain in regions innervated below the level of complete spinal cord injury.[35] Additionally, thalamic stimulation has mitigated phantom pain in some individuals. These observations suggest a thalamic role. The parietal lobe may also be involved, as in one case, a right hemisphere lesion resulted in disappearance of phantom pain. Supratentorial areas are further postulated to play a role secondary to the need for in-

tegration of complex afferent input and the wide variety of sensations and pain described in phantom phenomena.[138] However, ablative treatments of the thalamus and cortex have not been successful in treating phantom pain.[35]

Melzack[35] has a newer theory to explain phantom sensation and pain. He hypothesizes there exists in the brain a network of neurons that responds to sensory stimulation based on previous sensory experiences and generates a perception of the body and its limbs. Melzack terms the neuron network as the neuromatrix and based on the report of phantom sensations in congenital amputees, he postulates that the neuromatrix is genetically determined and "prewired" before birth. For example, the existence of a phantom hand in a congenital amputee would suggest that the neuromatrix was prewired with the body having a hand, although physically the hand was congenitally absent. Sensory phenomena are interpreted not only by the pure sensory impulses through the somatosensory system, but also emotionally and on past experiences to the same or similar phenomena.

The wide interpretation of sensory phenomena suggests the neuromatrix is influenced by experiences and consists of more than the somatosensory system. Melzack[35] states that the neuromatrix is composed of at least three parallel systems: (1) somatosensory, (2) limbic, and (3) cortical. The limbic system provides emotional and motivational responses. The cortex, with probable involvement of the parietal lobe, provides recognition of the body as one's own. Support for parietal lobe involvement are cases of neglect of the hemiparetic body in persons with right parietal lobe cerebrovascular accidents. The right parietal lobe infarct patient may not recognize the left leg as self or not shave the left side of his face. Conversely, in the amputee with phantom limb sensation, the neuromatrix may still have a body concept that includes the amputated leg.

The generated pattern providing the body image and as one's own is termed the neurosignature. The pattern that is "prewired" to give the body image is influenced by experience,[35] which may influence the strength of synaptic connections. The pattern of connectivity among the neurons of the neurosignature is affected by which neurons are involved, the number of synapses, and the types and strength of the synapses.[35]

Normally, afferent input would enter the neuromatrix. The neuromatrix would place its neurosignature on the input along with the integration of the sensation, perception, and emotional response. This information travels to another part of the brain for transformation into a conscious experience.[35] In phantom sensation or pain, the neurosignature still incorporates the amputated limb as part of one's own body. Spontaneous impulses from transected nerve axons, dorsal horn neurons, or thalamic neurons may enter the neuromatrix, resulting in a wide array of conscious sensory interpretations. Pain may occur from strong synaptic connections resulting from pain prior to amputation. Severe pain continuing to the time of amputation has been associated with phantom pain.[144] Pain may also occur as the neuromatrix fires in impulse bursts from the loss of usual sensory input from the amputated limb. The bursts may create a burning sensation. Furthermore, the neuromatrix may send impulses for the amputated limb to move. The lack of response may result in more frequent, stronger impulses perceived as cramping or shooting pain.[35]

The neurosignature may change as neurons in the neuromatrix previously associated with the amputated limb reassociate with other synapses. The changed pattern may explain "fading" of the phantom limb.[35] The neuromatrix and neurosignature theory provides a plausible explanation of phantom pain and sensation but requires further research to develop and test the hypothesis.

Treatment. Overall treatment of phantom limb pain has been unsuccessful for long-term relief. In the treatment of over 8,000 amputees with phantom pain, Sherman[147] reported that only about 7% of them received some benefit from treatment. Problems in evaluating treatment have arisen secondary to research studies not differentiating residual limb pain from phantom pain, and other study design flaws.[140] Current treatments consist of a variety of methods that may be used alone or in combination. Sherman, Sherman and Gall[37] reported that their surveyed care providers prescribed 50 different treatment methods.

Medical. Ideally, the selection (and use) of a medication is based on knowledge of how the pharmacologic characteristics of the medication will affect the pathophysiology of the disorder. Unfortunately, since the pathophysiology of phantom limb pain is unknown, there is an ambiguous direction in pharmacologic treatment with many agents rarely exceeding the effects of placebo administration.

Nonsteroidal antiinflammatory drugs, (NSAIDs) the most commonly used analgesics in chronic pain,[140] are usually tried first.[148] Based on the benefit in arthritic patients whose pain is made worse with changes in barometric pressure, NSAIDs may be useful in the treatment of phantom limb pain that is worsened by weather changes.[147]

Narcotics are not recommended in the treatment of phantom limb pain except in very limited circumstances, because they usually result in increased dosage requirements, increased dependence, poorer control, and increased depression.[140] But low dose narcotic agents, in combination with an antidepressant, may be helpful in increasing function.[148] Patient selection is based on refractoriness to other treatments, no drug dependence behavior, no past history of drug dependence, and increased function with narcotic treatment. Sedative/hypnotic medications have no role in the treatment of phantom pain, as they are habit forming and may increase depression.[140]

Anticonvulsants, based on membrane stabilizing properties, have been used in the treatment of phantom pain.[148] Most commonly, carbamazepine has been used with a 22% to 77% success rate. Other agents tried include phenytoin, valproate, and mephenytoin.[140] Anticonvulsants may be useful for a cramping, shooting pain.[148]

Tricyclic antidepressant medication has been used based on an analgesic serotonergic mechanism.[149] Serotonin is postulated as having a central pain inhibitory mechanism.[148] Additionally, the antidepressant effects are beneficial for those individuals who are concomitantly depressed.

Neuroleptics, such as butyrophenone, phenothiazines, and benzamides have been used. Frequently, chlorpromazine has been used. Neuroleptics are postulated to alter centrally the projection and interpretation of pain stimuli.[148]

Sympathetic beta-blockers such as propranolol and atenolol may be given. Propranolol at 40 mg/d has been used.[140] These medications are hypothesized to centrally increase serotonin concentrations.[148] Beta-blockers may be beneficial for a burning, throbbing pain.[147]

Baclofen is a gamma aminobutyric acid agonist and has been shown to depress trigeminal spinal nucleus activity in cats, and has been used successfully in the treatment of trigeminal neuralgia. In phantom pain, baclofen may be useful alone, or in combination with phenytoin or propranolol.[148]

Mexiletine, a sodium channel blocker and cardiac antiarrhythmic, has been reported to provide relief from phantom pain. Davis[36] reports an 87% success rate in significantly improving phantom pain in 45 patients.

Intravenous calcitonin has met with success in treating phantom pain. Jaeger and Maier,[150] in a double blind, crossover study, obtained greater than 50% relief of early postoperative phantom pain in 19 of 21 patients, and complete relief in 16 of 21 patients treated with intravenous calcitonin. At 1 year postamputation, 8 of 13 surviving patients had greater than 75% pain relief. Side effects were transitory and included headache, vertigo, nausea, vomiting, enhanced phantom sensation, drowsiness, and hot or cold flashes. The mechanism of pain relief is unknown. Jaeger and Maier postulate that a central, sertonergic mechanism exists and conclude that intravenous calcitonin may be beneficial in the early postoperative relief of phantom limb pain.

Local Anesthetic Blocks. Local anesthetic blocks are mainly used as a diagnostic tool to evaluate for neuromas, sympathetically mediated pain, and pain from referred sources. Trigger point injection for myofascial pain syndrome with radiation into the phantom extremity may be helpful. For phantom pain resembling RSD symptoms, a sympathetic block may be helpful.[138,147]

Surgical. Neuroma resection is performed only for symptomatic neuromas. It may give temporary relief for approximately 3 weeks until the neuroma regrows with subsequent return of symptoms.[140] Neuroma resection is not done to alleviate phantom limb pain. The indications were previously discussed under Residual Limb Pain: Intrinsic Causes.

Dorsal root entry zone (DREZ) lesioning is a new method. The procedure may utilize selective thermocoagulation or electrocoagulation of the substantia gelatinosa. Saris, Iacono, and Nashold[151] performed DREZ on 22 patients and had good results in 36%. For 9 patients with phantom pain alone, good results were obtained in 6. Five of 6 patients with root avulsion had good results. Poor results were obtained in those with phantom pain and residual limb pain or residual limb pain alone. DREZ will require further investigation before conclusions regarding its efficacy in phantom limb pain can be determined.

Two sites of stimulation have been used in deep brain stimulation: (1) the periaqueductal and periventricular gray and (2) the lateral thalamic and internal capsule. Periaqueductal and periventricular gray stimulation is postulated to decrease pain by increased endorphin release. This site of stimulation has not been effective for long-term relief with chronic deafferentation pain.[148] Lateral thalamic and internal capsule stimulation has resulted in satisfactory pain relief in some patients.[140] This site has been used along with TENS unit stimulation.[148] Further study is needed to evaluate the effectiveness of this method.

Dorsal cord stimulation is based on the gate theory of pain relief. This method has resulted in an immediate 80% success rate, which dropped to

20% after 1 year.[148] Further study is needed. Ablative procedures that have been tried include dorsal rhizotomy, anterolateral chordotomy, thalamotomy, and cortical resections. Overall, these procedures have not been successful.[138,140,147] Ablative procedures are not recommended in the treatment of phantom limb pain.

Psychological. Hypnosis has been utilized in chronic pain, but its efficacy is unknown.[148] Multidisciplinary pain clinics that utilize an operant behavioral approach have not usually been necessary for the treatment of phantom pain.

Biofeedback requires prolonged training and has not been widely used. Biofeedback may be useful for a cramping phantom pain associated with increased muscle tension.[147] A valuable technique used in conjunction with other treatments is relaxation. Relaxation techniques may be helpful for phantom pain made worse with stress or increased muscle tension.

Preoperative education helps in preventing maladaptive behavior and decreases patient stress.[152] Preoperative education should include discussion of the preoperative, operative, postoperative, rehabilitative, and prosthetic processes. Potential complications should be explained. Postoperative pain, phantom sensation, and phantom pain issues and management should be discussed. Often, an experienced amputee screened by the multidisciplinary team may provide the patient with valuable education and insight.

Phantom pain is not due to a psychologic disorder. Any psychotherapy for the patient with phantom pain should be for preexisting psychologic disorders. Psychotherapy is not used for phantom pain alone.

Other. Range-of-motion exercises and massage of the residual limb may provide temporary relief. Additionally, the use of heat or cold modalities may provide temporary relief.

Acupuncture may provide pain relief by increasing endorphins or serotonin.[148,153] The successful use of acupuncture along with TENS and electroacupuncture to decrease phantom pain has been described.[153] However, the relief may be only temporary.[36,142] Further trials are needed to establish acupuncture's efficiency.

TENS has good success up to 6 months, but only 25% of those treated have relief at 12 months.[140] The main complication related to TENS is allergic reactions to electrode pads attached to the skin. TENS trials may require use of different electrode placements to achieve analgesia. Electrodes may be tried on the residual limb or contralateral limb.[138] As TENS has minimal complications, a trial should be given.

Vibration or percussion of the residual limb has been tried in the past and may be effective. These methods are not often used today. Early prosthetic fitting and ambulation have been reported to decrease phantom pain.[58] Additionally, rigid dressings have also been reported to reduce phantom pain.

Prevention

Overall, treatment has not been very successful; therefore, the prevention of phantom pain is an important measure. Bach and associates[154] controlled pain for 3 days prior to surgery by using a lumbar epidural blockade with bupivacaine or morphine. With this they found a deceased incidence of phantom limb pain. Another method used was insertion of a catheter into the nerve at the time of surgery, which provided pain relief postoperatively by continuous nerve sheath blockade. With this method, the patients in the study experienced no phantom pain.[155] Both of these studies had small sample sizes, which suggests further study is needed on the efficacy of these methods. However, pain control in the preoperative period to prevent phantom pain appears useful.

Treatment Summary

Phantom pain may be a difficult problem to treat in some amputees. The unknown pathophysiology and myriad treatments makes treatment decisions confusing and difficult. As any one treatment has not met with overwhelming success, it is necessary to try a variety of treatments or treatment combinations before a satisfactory result is found for an individual patient. Additionally, because of low success rates, initial treatments should have low morbidity, and treatments that may result in permanent deficits should be avoided. Furthermore, total treatment of the amputee optimizes overall outcome, which may influence chronic phantom pain problems. Early comprehensive multidisciplinary rehabilitation results in better acceptance and management of phantom pain and higher functional outcomes.[36] Additionally, comprehensive treatment may be helpful in prevention of phantom pain. The following guidelines may be helpful in the prevention and management of phantom pain.

Preoperative education is provided when possible. A multidisciplinary team approach to provide comprehensive treatment is utilized. Preoperative pain control is instituted to decrease the risk of de-

veloping phantom pain. If not contraindicated, an IPOP or rigid dressing is utilized. Normal postoperative residual limb pain is treated; and if pain continues, it must be established whether the pain is residual limb pain, phantom sensations, phantom pain similar to preoperative pain, phantom pain, or referred pain. Residual limb pain and referred pain causes are important to identify because treatment is different for each and often has a higher success rate. Range-of-motion exercises, residual limb massage, and desensitization are often helpful. The prosthesis or rigid dressing must fit properly. A TENS trial should be initiated. Pharmocologic therapy starts with an NSAID, and if phantom pain is similar to preoperative pain, the same agents that were successful in the preoperative pain management of the patient may be used. For other cases of phantom pain, carbamazepine or a tricylic may be started. Additionally, other agents may be tried dependent on the type of pain. Mexiletine and IV calcitonin may hold promise, but further studies are needed. For those with phantom pain resembling RSD symptoms, a sympathetic block may provide relief when the above treatments are unsuccessful. The multidisciplinary treatment team must meet and discuss how pain is impacting on functional gains and quality of life issues. Psychologists need to assess for depression, which frequently occurs in individuals with chronic pain, and utilize psychological techniques previously discussed to assist phantom pain control. A log should be kept regarding phantom pain episodes and factors modulating the pain. The log is analyzed for modulating factors to determine efficacy of interventions.[147] In limited circumstances, a narcotic along with an antidepressant may be used, but only if other measures have failed and the earlier-stated indications and contraindications are followed. Ablative surgical procedures should be avoided. Surgical procedures such as dorsal column stimulation and DREZ require further study before conclusions regarding their efficacy can be reached. Usually, multidis-ciplinary pain clinics are not required, except in cases when phantom pain is chronic, unresponsive to standard treatment, and influenced by environmental entities.

THE MULTIPLE AMPUTEE

The amputee with multiple amputations poses challenges to the rehabilitation team. It is important for military rehabilitation professionals to be cognizant of the special needs of these casualties. At Fitzsimons General Hospital during the Vietnam War, over 500 soldiers with major amputations were treated, with 342 sustaining loss of part of a leg and 44 with loss of both legs.[57] Three were triple amputees and 18 of the 44 had bilateral transfemoral amputations. Brown[156] describes these multiple amputees as complicated casualties often with concomitant loss of vision, fractures, and systemic infections. All of these casualties sustained their wounds as a result of high-explosive or high-velocity missile injuries. This report by Brown and the subsequent discussion by Commander Donald Rohren of the Oakland Naval Hospital (described in Brown's paper) provides an excellent insight into military rehabilitation of the multiple amputee.

The traumatic battle casualty who subsequently loses one or more limbs was described as demonstrating an initial shock and sense of relief that he remained alive following his wounding.[156] This was followed by manifestations of depression, anxiety, and hostility. These multiple amputees required substantial multidisciplinary rehabilitation care, which included a physician, prosthetist, physical therapist, and an occupational therapist. These casualties frequently required revision of their residual limbs. Thirty-four of the 88 required skin grafting, and 48 of the 88 required definitive revisions. There were 12 knee disarticulations and 8 of those required revisions to an above-knee level.[156] Seven stumps had persistent drainage that required sinus tract excisions, and 4 stumps had bone spur formation that required excisions. These figures demonstrate that many war-injured amputees require multiple surgical procedures in order to obtain a healed, painless, and functional residual limb.

Brown[156] reported that due to the residual limb problems in his series of bilateral leg amputees, prosthetic fitting and training were often delayed for weeks or months. Therefore, rehabilitation efforts focused on strengthening and maintenance of joint range of motion. Twice-a-day exercises to condition remaining muscles for ambulation were instituted.

At the earliest possible time, prostheses were fitted and ambulation training was begun using crutches and parallel bars. Brown[156] felt that for the bilateral transfemoral amputee, "stubby prostheses" were optimal first devices. These short, rigid prostheses with no knee joints are advantageous in

the early training of amputees, particularly with respect to development of balance.

Functional activities were vigorously addressed. Community ambulation and automobile use were taught. In addition, a skiing program was incorporated into the rehabilitation treatment plan. Over 100 of the amputees who were treated skied during 1968 and 1969 using adaptive skiing aids. These war-injured casualties developed confidence and a sense of accomplishment through pursuit of this activity. In addition, other recreational activities, such as swimming, scuba diving, and water skiing were available.[156] The Fitzsimons General Hospital amputee rehabilitation program stressed treatment of the amputee as a whole individual with the goal of returning to an optional level of function in many functional and vocational areas.

In Brown's report,[156] Rohren discussed the Fitzsimons amputee care, contrasting it with amputee rehabilitation at the Oakland Naval Hospital. Rohren felt that the focus of amputee rehabilitation should be on the gait training and exercise, and he, therefore, felt that allowing amputees time off for recreational training detracted from optimal basic rehabilitation training, and thus prolonged their rehabilitation. Rohren echoed the complexity of the war injured amputee. In addition, he reported that convalescent leave impeded optimal stump wrapping and resulted in excessive weight gain, leading to prolonged rehabilitation.

Dunlap[157] reported a case of a combat wounded, bilateral leg amputee who sustained a right transfemoral amputation and a left hip disarticulation. A long rehabilitation course was required for ambulation training. The difficulties in fitting the amputee with two prostheses were described.

Canty[158] described amputee care during World War II at the United States Naval Hospital, Mare Island, Vallejo, California. This hospital was the first Armed Service Amputation Center established. Over 2,500 amputees were treated and rehabilitated with a reported 90% success rate. The rehabilitation program began with proper stump conditioning by means of surgical procedures, stump wrapping, and exercises. Physical therapists began bed exercises early in the casualty's course of rehabilitation. Occupational therapists provided the soldier with a variety of arts, skills, and hobbies during recuperation. Chaplain support and recreation departments also supported the casualty. Group support was provided by round table discussions, which gave the amputee valuable psychological support. As the casualty improved, aggressive physical training, including swimming, was stressed. Gait training with a prosthesis progressed from posture and balance training to walking. Prevocational training, driving, and dancing and various sports and games were introduced into the rehabilitation program, facilitating optimal adjustment to the new disability. Competition between amputees in ambulation was encouraged, which built a spirit of competition and improved functional outcomes. Canty[158] stated that a prosthetic device must be aligned and fitted properly so that the amputee can wear it without discomfort. Prostheses must also be light, strong, durable, economical in cost, and cosmetically acceptable. Canty also reported a case of a naval pilot who lost a leg, was rehabilitated, and returned to flying duty in the forward area. After the war this amputee was discharged from the service, following which he successfully operated his own commercial airline.

Ambulation for the bilateral leg amputee has been extensively addressed in the literature for the older dysvascular amputee.[159–165] Traumatic bilateral leg amputees have a better outcome in terms of ambulation in general than do elderly dysvascular amputees.[161] Kerstein and associates[164] found that elderly dysvascular amputees with bilateral amputations required an average 30 weeks of rehabilitation, but that 50% of bilateral transfemoral amputees eventually walked, although usually only for short distances and with ambulatory aids. Hamilton and Nichols[166] reported the need for inpatient rehabilitation for these patients. The younger traumatic bilateral amputee is more likely to ambulate; however, the energy cost of ambulation is much higher than for their able bodied counterparts. For the bilateral transfemoral amputee, "stubbie" prostheses are used initially with the feet set in a wider stance to provide a wider base of support.[159]

In the case of a quadruple amputee,[167] ADL training along with special wheelchair drive adaptations were required. This individual was able to become an independent ambulator with prostheses and achieved independence in all ADLs, including driving a car.

In summary, the war injured bilateral lower limb amputee can usually achieve a higher level of ambulatory independence than can older, dysvascular amputees. During an intense, prolonged war, multiple amputees must be anticipated. These soldiers present more difficult rehabilitative needs, and frequently require a prolonged course of inpatient rehabilitation, often due to other coexistent problems, such as nerve injuries, fractures, and so forth.

VOCATIONAL OUTCOMES OF AMPUTEES

The complete rehabilitation of an amputee requires the achievement of all functional goals, so that when possible, the amputee will assume an expected societal role that involves productive work. This is particularly important for the war-injured soldier who will have many productive years remaining after injury.

Statistics regarding amputees who return to active duty are not readily available, but a review of data from a U.S. Army Physical Evaluation Board over a 9-year period (1981–1989), revealed that only 2.3% of all amputees returned to active duty. Historically, during times of prolonged major conflict, amputees were utilized to perform many non-combat tasks. In World War II, amputees were sometimes trained in prosthesis fabrication and utilized in military hospitals.[3] The British Royal Air Force retained amputees on active duty because they found that it was more costly and time consuming to retrain aircraft mechanics and crewmen than it was to retain amputees.[168,169]

The literature concerning vocational outcomes of war-injured amputees is limited.[170–172] In a follow-up study[171] of amputees from the Vietnam War, it was found that when comparing the social and vocational outcomes of these amputees to those of noninjured Vietnam veterans, the amputees fared less well. The amputees showed twice the unemployment rate, earned less money, held more blue collar jobs, and obtained fewer college degrees than their noninjured counterparts. These results underscore the need for emphasis on vocational rehabilitation. Steinbach[170] described the Israeli experience in the rehabilitation of war injured amputees and pointed out the importance of vocational counseling as soon as possible after the injury. He also reported that 96% of their amputees at discharge had vocational plans with 28% returning to their previous jobs. Unfortunately, the percentage who returned to active duty was not specified. Ryan and colleagues[172] conducted a follow-up study of World War II amputees who had been treated by naval physicians. These authors followed 200 amputees and found that 78% were working or pursuing higher education. They again pointed to the need for addressing vocational issues while the injured soldier convalesced at a military hospital, including driving instruction.

The civilian experience relates similar findings and also highlights intervention strategies for improving vocational outcome. The literature[173,174] suggests that amputees do have higher unemployment rates than their able-bodied counterparts. Only a small percentage of amputees return to their previous jobs.[173] The reasons for reduced vocational outcomes were address by Sheikh[175] in a study of limb injuries, including amputations. Surprisingly, Sheik found that the exact type of limb injury (fractures, amputations, or soft tissue injuries) had little if any effect on vocational outcome. However, variables such as motivation, low level of disability, short duration of unemployment, a vocational retraining program, and low unemployment in the general population, strongly influenced return to work. Some of these variables can potentially be modified through appropriate rehabilitation. Millstein et al[49] in their review of 1,010 Canadian amputees, found that 87% of lower limb amputees returned to work. Unilateral amputees were more likely than multiple amputees to return to work. Most of these Canadian amputees were casualties of work related accidents. They found that younger ages, comfortable and routine prosthesis use, and provision of vocational services were associated with return to work. Phantom pain and residual limb pain, along with multiple amputations, negatively impacted on return to gainful employment. Helm and colleagues,[176] in their series of amputees, found that prosthetic fit and pain were important variables affecting amputee function. The above authors, and others, strongly support early vocational intervention.[177–179] Brown[179] notes that simulated work tasks coordinated by occupational therapists and other rehabilitation professionals can help amputees develop skills that will be used in pursuing alternative careers. Part-time return to duty, if this is possible during convalescence, can also be advantageous.[180,181]

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