Chapter 9

SPECIAL SURGICAL CONSIDERATIONS FOR THE COMBAT CASUALTY WITH LIMB LOSS

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INTRODUCTION

The operative treatment of the combat casualty with limb loss is challenging, but can also be immensely rewarding. The previous chapter discussed general surgical principles to guide early treatment, prevent complications, and optimize outcomes. This chapter discusses special surgical considerations for specific subgroups of amputees, with emphasis on late complications and patient complaints. Although no individual amputee will (hopefully) require operative intervention for all of the complaints, complications, and issues discussed herein, this chapter may serve as a guidepost in the long-term surgical management of the combat-related amputee.

EVALUATION OF THE LESS-THAN-SUCCESSFUL AMPUTEE

Even highly functioning posttraumatic amputees continue to suffer from perceived physical limitations and pain. Smith et al[1] retrospectively reviewed a large cohort of transtibial amputees, finding that short form 36 (SF-36) health status profile scores were significantly decreased from published normal aged-matched scores in the categories of physical function and role limitations because of physical health problems and pain. Similarly, Gunawardena and associates[2] found that differences in profiles for combat-injured soldiers with unilateral transtibial amputations were largest in scales sensitive to physical health as compared to uninjured, age-matched controls. More proximal levels of amputation and problems with the residual limb and sound leg were significantly associated with poor physical and mental health scores.

When considering the myriad potential causes of amputation-related disability, it is critical to remember that, regardless of how well the operative surgeon perceives the technical success of the surgery, a painful prosthesis will not be used by the patient.[3] To resolve this problem, a critical and systematic approach to the identification of residual disability, both real and perceived, is essential in the evaluation of amputees.

History

As in much of medicine, an adequate and complete history is the first step in the evaluation process. Patient age, comorbidities, and histories of original injury, infection, and revision operative procedures should be explored and documented in appropriate detail. A history of recent trauma or progressively increasing pain should be sought. Daily prosthetic usage, recreational activities, age of the prosthesis, and frequency and types of adjustments should be noted. Pain, perhaps one of the most nebulous areas in all of medicine, is by far the most common presenting problem for amputees. Nonetheless, elucidation of the intensity, onset, and character of the pain is often revealing of underlying cause. Medications, doses, and utilization patterns should be reviewed and discussed.

Numerous types of postamputation pain have been reported. However, three main categories are generally accepted: (1) phantom sensations, (2) phantom limb pain, and (3) residual limb or "stump" pain. Phantom sensations are defined as nonpainful sensations referred to the missing limb. These are estimated to be present in 4% to 20% of congenitally absent limbs and in 53% to 100% of traumatically or surgically removed limbs. Within the limb, sensations of tingling, itching, pins and needles, or numbness can occur. Additionally, "super-added" phenomena such as the sensation of wearing a ring or sock may be present. The phantom limb may "telescope" in size over time, leaving a relatively small area of foot or digits perceived on the stump. These sensations are generally more of a nuisance or curiosity than an overt problem and usually stabilize within the first year following amputation.[4]

Phantom limb pain is nociceptive afferent pain from the amputated limb. The quality of phantom limb pain varies but is generally described as either a burning or throbbing sensation, or a discomfort ranging from a mild ache to excruciating and intolerable pain.[5] Phantom limb pain occurs on some level in as many as 50% to 80% of amputees. Symptomatic neuroma may present with neuropathic pain of similar characteristics, but can frequently be localized and distinguished based on symptom onset, exacerbations, and physical examination.

Residual limb or stump pain is discomfort within, localized to, and identified with the residual limb itself. Although invariably present in the early postoperative period, chronic stump pain generally exhibits a characteristic dull and nagging nature. It has been reported in 6% to 76% of amputees and is not thought to be related to the central neural axis, but rather to organic issues within the residual limb itself.[4] Localized stump pain can be caused by skin disorders, delayed healing, infection, prosthetic fit and alignment issues, or fracture. Hirai et al[6] noted that residual limb problems were seen in about 37% of lower extremity amputees, and identified specific patterns of stump pain associated with different levels and methods of lower extremity amputation, including abnormal keratosis in Syme amputation, equinus deformity in Chopart

amputation, reduced muscle power in transfemoral amputation, and knee joint dysfunction in transtibial amputation.

Physical Examination

Surgeons should attempt to develop a systematic approach to examination of a residual extremity that is efficient, complete, and reproducible to avoid overlooking potential problems. In general, examination should proceed gradually from benign maneuvers remote from the source of pain toward direct palpation of the source of discomfort to avoid "guarding" by the patient. Specifically, both passive and active range of motion of adjacent joints should be measured and recorded. Hip and knee flexion contractures are well-known problems associated with lower extremity amputation and may cause a functional limb length discrepancy and resulting problems. Stability, especially of the ankle, knee, shoulder, and elbow joints must be assessed with appropriate stress testing and provocative maneuvers. Strength of major muscle groups should be evaluated and documented as well as a complete sensory examination. Painful neuromas can sometimes be palpated directly, and reproducible symptoms can often be elicited during percussion testing for Tinel's sign.

The patient should be asked to don and doff the prosthesis under direct observation and point with a single digit to specific areas of discomfort or skin breakdown. Brief observation of static standing and ambulation in the prosthesis is essential to evaluate gait abnormalities and malaligned or malfunctioning prosthetic components. Hoagland et al[7] evaluated 251 veterans with major traumatic amputation-related problems. They found that approximately half of all patients had socket problems that caused or contributed to their symptoms. Among this group, 59% of the transtibial and 78% of the transfemoral prostheses had inadequate socket fitting. Improper shaping of socket margins was the most frequently observed deficiency. Moreover, 41% of transtibial and 22% of transfemoral residual limbs demonstrated signs of mechanical skin irritation or skin breakdown. Faulty suspension and alignment, in addition to improper socket fit and construction, contributed to these problems. Excessive stiffness of solid ankle cushion heels was the most common prosthetic foot problem and contributed to gait abnormalities. Socket-related skin complications are less frequently observed in upper extremity amputees, but prosthesis fit and utilization should be evaluated in these patients as well. One of the most important components of patient rehabilitation is the ability to consult with a prosthetist frequently and make prosthetic modifications as needed to ensure proper fitting and pressure relief. A more complete discussion of prosthetic alternatives and available modifications is presented elsewhere in this text (Chapters 20–24).

Skin disorders are frequent complaints among amputees due to the intimate and confined nature of the limb within the socket. Skin is challenged by both shear and loading forces delivered by the prosthesis to the residual limb during ambulation or prosthetic use. 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 or an inadequate soft tissue envelope is present, chronic and recalcitrant skin changes may develop. Some of the more common skin disorders include verrucose hyperplasia, epidermoid inclusion cysts, contact dermatitis, stump edema, Marjolin's ulcers, and, infrequently, squamous cell carcinoma related to chronic infection. Skin disorders are usually easily identified on visual inspection of the limb.

Similarly, surgical scars may be symptomatic. The optimal surgical scar is linear and avoids bony prominences, the cut end of bone, and socket pressure points. Although ostensibly less of an issue with modern prosthetic liners and sockets, the scar or scars should ideally not lie directly over the terminal residual limb because of these problems. Unfortunately, achieving this scar position is not always possible or practicable in the setting of a posttraumatic or combat-related amputation. Nonetheless, the optimal scar should be freely moveable, soft, pliable, and insensitive. Scar adhesion to bone, in particular, renders the scar immobile and increases the risk of skin breakdown due to excessive shear forces at the skin-liner interface. The adherent scar thus often breaks down, necessitating discontinuance of the prosthesis until healing occurs. Frank wound dehiscence or inflammation, warmth, and persistent redness not relieved by rest and elevation around surgical scars usually heralds underlying infection and should be evaluated with routine laboratory testing of the white blood cell count with differential, erythrocyte sedimentation rate, and C-reactive protein, at a minimum.

Plain radiographic examination of the residual limb is simple and inexpensive and can reveal many problems unique to the traumatic blast-injured amputee. Posttraumatic or age-related arthritis in adjacent joints may be present. Fracture within the residual limb following subsequent trauma or minor falls has been noted by several authors.[8,9] Additionally, heterotopic ossification (HO) and bone spur formation complicate a large percentage of combat-related amputations and can be a disabling source of localized pain.[10] Likewise, nonunion of an attempted

bone-bridging distal tibiofibular synostosis can be a potential source of continued pain. Both of these phenomena are discussed in greater detail in subsequent sections of this chapter.

Weight-bearing radiographs taken in the prosthesis can be extremely beneficial for analyzing complications related to myodesis failure and residual limb control or occult soft tissue envelope deficiencies. Xeroradiography is an excellent technique in evaluating the fit and alignment of extremity prostheses. With these tools, the degree of contact achieved and attendant pressure problems, if any, can be precisely determined.[11] More elusive problems thought to be associated with gait-related dynamic interface within the prosthesis can be further investigated in a gait laboratory or using videofluoroscopy, if available.[12]

Magnetic resonance imaging (MRI) has increased in popularity to aid in identification of inflammation-related pathology including bursitis, localized soft tissue inflammation, and bone marrow edema.[13] It is a sensitive tool for evaluation of infection and has demonstrated some utility in evaluation of neuroma formation in amputees.[14] Local lidocaine and steroid injections can be both diagnostic and therapeutic in evaluating and treating these frequently encountered problems.

HETEROTOPIC OSSIFICATION

HO is the formation of lamellar bone in nonosseous tissue. Although infrequently reported in previous modern conflicts, known reports of HO in combat-related amputations date back to World War I[15] and the US Civil War.[16] Because of its apparently increased prevalence following injuries sustained in the recent conflicts in Iraq and Afghanistan, HO is now recognized as a common and not infrequently problematic development in the residual limbs of traumatic and combat-related amputees.[10]

HO formation is thought to require cellular elements capable of osteogenesis, an inciting event, and an environment supportive of bone formation.[17] The most accepted theory about this dysplastic process regards mesenchymal stem cells present in muscle, periosteum, and soft tissue as the cells of origin, with the inciting event in these cases being a blast injury or combat-related trauma.[18] It is now clear that traumatized residual limbs represent a very conducive milieu for this process. Although, as will be discussed, the timing of various putative causative factors and prophylactic measures varies, the nucleus of this metabolic cascade lies at the point of injury. Indeed, clinically evident HO can develop very rapidly following injury (Figures 9-1 and 9-2), and ectopic bone due to any cause is reliably present and detectable in some quantity within 2 months of the instigating stimulus onset, although further growth and maturation may continue thereafter.[19,20]

At least 36% of all combat-related amputees from the current conflicts have radiographically proven HO in their residual limbs. The prevalence jumps to an astounding 63% when only limbs with adequate radiographic follow-up are assessed.[10] Although this latter figure likely represents a degree of selection bias, because patients with palpable or symptomatic lesions are more likely to have follow-up radiographs performed, the actual prevalence likely approaches or exceeds 50%. The scope of the clinical problem is therefore vast and not merely a topic of academic discussion.

Proven and statistically significant risk factors for HO formation in residual limbs of traumatic and combat-related amputees include a final amputation within, rather than above, the initial zone of injury (ZOI) and a blast (vs blunt, sharp, or even high-velocity gunshot) mechanism of injury (MOI). However, HO may also develop due to other, non-blast MOIs (Figure 9-3). Final amputation level within the initial ZOI also appears to be predictive of HO magnitude and severity.[10] In addition to these proven risk factors, a number of other potential causative or confounding factors for

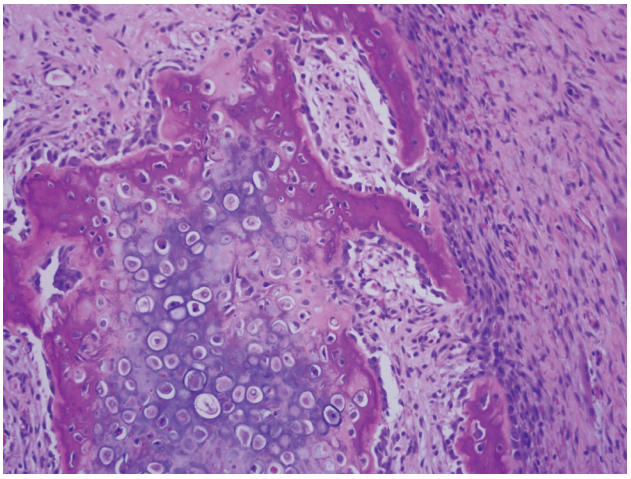

Figure 9-1. Photomicrograph (hematoxylin-eosin stain; original magnification 20) of a specimen resected from the brachialis muscle of a transhumeral amputation at the time of definitive revision and closure just 15 days after injury. Abundant enchondral heterotopic ossification formation is evident immediately adjacent to normal skeletal muscle.

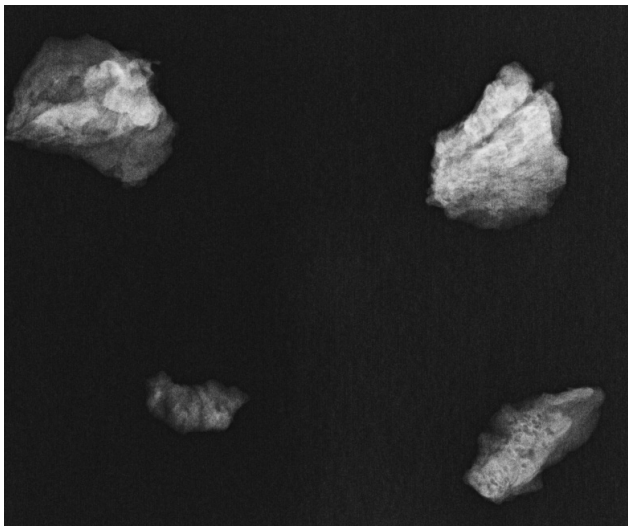

Figure 9-2. Radiograph of resected heterotopic ossification specimens from the soleus muscle belly of a transtibial amputee at the time of definitive amputation and closure 20 days after injury. Although wound vacuum-assisted closure and pulse lavage exposure have been theoretically implicated as potential causes of the apparently increasing prevalence of heterotopic ossification in modern combat-related amputees, the deep superficial compartment of this patient's leg was protected from direct exposure to these devices. The patient underwent elective transtibial amputation for an unreconstructable soft tissue defect associated with a type-IIIB/C tibia fracture after free tissue transfer failed.

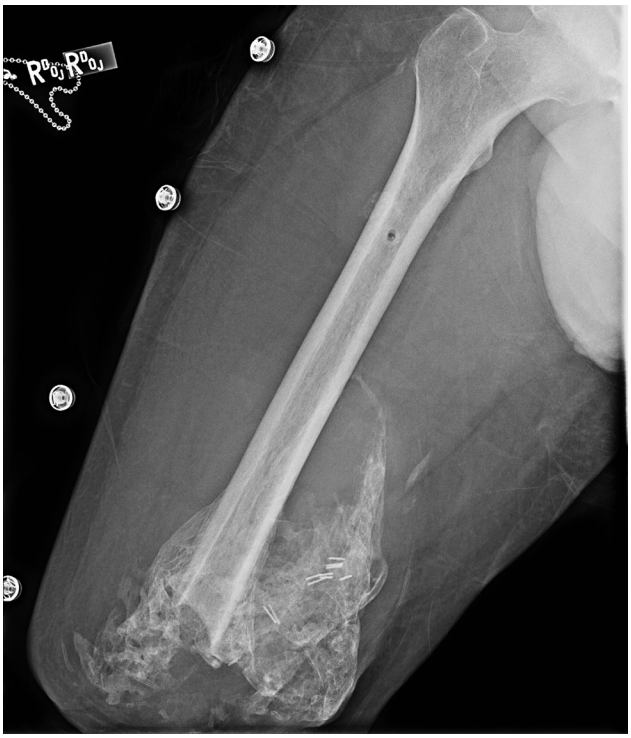

Figure 9-3. Anteroposterior radiograph of a right transfemoral amputation with severe, symptomatic heterotopic ossification following a crush injury sustained in a motor vehicle accident. The patient underwent excision of extensive heterotopic ossification with surgical revision of his residual limb with an excellent clinical result.

the high recent prevalence of HO in residual limbs have been proposed or anecdotally reported. Chief among these is the potentially greater survival of otherwise grievously injured combatants afforded by modern body armor, rapid evacuation and treatment, and medical advances as compared to historical conflicts.

Other potential risk factors for ectopic bone growth within residual limbs include subatmospheric pressure dressings, moderate- to high-pressure pulsatile lavage irrigation systems, occult traumatic brain injury, chronic low-grade local infection, preinjury nutritional supplement use by allied combatants, and other as yet undetermined geographic environmental factors. With the data currently available, none of these has been definitively shown to increase the risk of HO formation in residual limbs.[10] However, such confounding variables, most notably the severity of initial injury to the limb and other body systems, are difficult to adequately control for in statistical data analysis. Further study of these factors is warranted and ongoing.

A wide variety of suppositional prophylactic agents and modalities to prevent HO have been studied, with varied levels of clinical and laboratory evidence of efficacy, in other patient populations with or at risk for HO. The only modalities definitively proven to prevent HO occurrence are nonsteroidal antiinflammatory drugs (NSAIDs) and local external beam radiation therapy.[20–23] Local radiation therapy within the requisite time frame (24–72 hours of injury) is logistically infeasible in a combat environment, irrespective of concerns about irradiating open wounds and resulting local immunosuppression and inhibition of wound healing, as well as initial uncertainty about the final level of amputation. NSAIDs also have undesirable effects on platelet function, fracture healing, and the renal and gastrointestinal systems. However, in patients with essentially isolated amputations who are putatively able to systemically tolerate this modality, early prophylaxis is reasonable and should be continued for at least 2 and as long as 6 weeks postinjury.

Other proposed prophylactic modalities include vitamin K antagonists, corticosteroids, colchicine, and calcitonin.[24–27] Independent of concerns about coagulopathy, immunosuppression, and other untoward side effects, however, currently available evidence does not

support the routine use of any of these agents in the combat-injured amputee. The only agent that has been evaluated for late prophylaxis is the older bisphosphonate etidronate sodium.[28] Enthusiasm for this agent is tempered by frequent symptomatic esophagitis, inhibition of concomitant long-bone fracture healing, and the potential for late "recurrence" of HO after discontinuation of therapy due to delayed mineralization of transiently inhibited ectopic bone. Some long-term benefit may be gained with this modality, however. If bisphosphonate therapy is pursued, etidronate should be used. Newer agents have not been evaluated in relation to HO treatment, and would likely be less efficacious due to greater selectivity and inhibition of osteoclasts, as opposed to the osteoblast suppression desired in HO prophylaxis.

After HO is established within a residual limb, asymptomatic lesions do not require treatment. Particularly in asymptomatic patients in whom the radiographic HO is not palpable, repeated reassurance should be given that the lesion is not a true tumor, no treatment is required, and that asymptomatic HO seldom causes discomfort associated with prosthetic fitting. In dedicated rehabilitation centers where many amputees have HO and some of these have undergone excision, such discussions are critical to avoiding unnecessary and potentially complicated surgery.

The initial treatment of all symptomatic amputees with HO is conservative. The authors have found HO excision with or without amputation revision to be fraught with wound-related and infectious complications. Because of these complications, an exhaustive attempt at nonoperative treatment is indicated prior to excision. This consists of brief periods of rest and activity modification concurrent with adjustments to pain medications, evaluation for alternate causes of residual limb pain (as discussed in the preceding section), and serial prosthetic alignment, socket, suspension, and liner modifications. Using this approach, most patients with symptomatic lesions can be treated conservatively. Of recent combat-related amputees with known HO, nearly 85% were asymptomatic or had been successfully treated conservatively, with only about 7% of all amputees requiring surgical excision of HO.[10]

Once conservative measures have been exhausted and surgery is planned, however, further new socket fitting and prosthesis component changes should be delayed until after the procedure; virtually all patients undergoing HO excision require entirely new sockets postoperatively. Indications for operative intervention include exposed bone, continued skin and soft tissue breakdown, and localizable pain, all of which should be proven refractory to local wound care and/or repeated prosthetic modifications preoperatively. Patients contemplating an excisional procedure should be counseled that the incidence of wound-related and infection complications requiring additional surgery may approach 25%.

Radiographically, HO may be graded in severity as mild, moderate, or severe based on whether the ectopic bone occupies less than 25%, 25% to 50%, or over 50%, respectively, of the cross-sectional area of the terminal residual limb on plain radiographs.[10] Severe HO is more difficult to excise, requires more extensive surgery for complete excision (including frequent formal myodesis and amputation revision), and is more likely to demand creative soft tissue reconstruction to achieve adequate coverage of the residual limb. However, the shape and depth of heterotopic lesions may be a more critical factor in determining which lesions become symptomatic and require excision (Figures 9-4 and 9-5).

The timing of HO excision has previously been a matter of substantial debate, with many advocates for delayed excision of HO to prevent unacceptable local recurrence rates.[29] The authors have found assessment of historical markers of HO maturity such as bone scan activity and serum alkaline phosphatase to be unhelpful and unnecessary. Plain radiographic evidence of maturity is somewhat helpful (stable, mature cortical rind and no change in appearance on radiographs taken at least 1 month apart), but principally because mature, mineralized bone is technically easier to marginally but completely excise than its softer, cartilaginous precursor. With frequent utilization of adjunctive secondary recurrence prophylaxis (ie, radiotherapy and/or NSAIDs), good results have been obtained, with no clinical recurrences to date, in operations performed as early as 3 months postinjury. The authors therefore advocate excision as soon as required in patients with HO symptoms refractory to conservative measures, which generally take 3 to 4 months to exhaust. At a maximum, 6 months appears to be a more than adequate observation interval from injury to excision for surgeons desiring a more conservative approach.

Preoperative planning and detailed patient counseling are critical to ensuring optimal outcomes following HO excision from residual limbs. In addition to the potential for wound complications, any primary or contingency plans for myodesis takedown, residual limb shortening, or formal revision of the amputation concurrent with the excisional procedure should be discussed with patients preoperatively. All of these factors may affect both subsequent patient function and the postoperative rehabilitation schedule. Although direct data to support secondary HO recur-

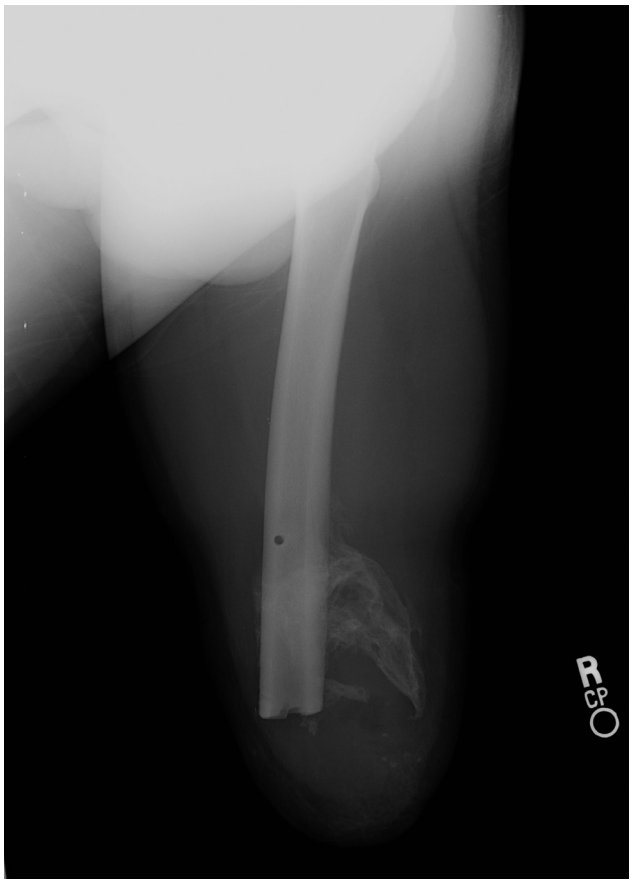

Figure 9-4. Anteroposterior radiograph of a left transfemoral amputation demonstrating moderate heterotopic ossification with a prominent, symptomatic distal-lateral spike of ectopic bone. The patient's symptoms were refractory to repeated prosthesis modifications, and he subsequently underwent heterotopic ossification excision through a direct lateral approach without myodesis takedown.

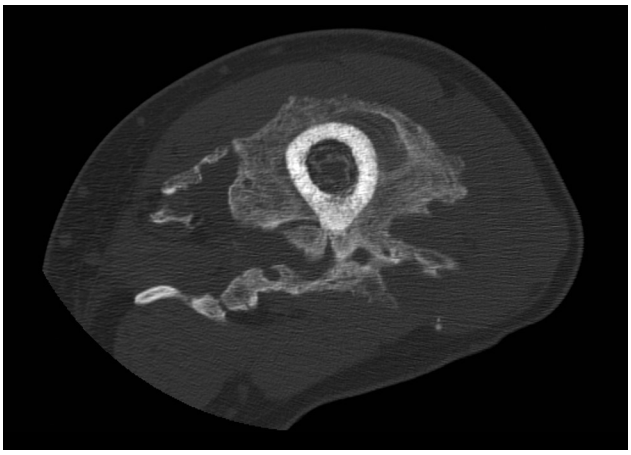

Figure 9-5. Axial computed tomography scan of a left transfemoral amputee with diffuse heterotopic ossification about his terminal residual limb. Although the patient's preoperative symptoms were greatest laterally, he desired compete excision of the heterotopic ossification. This required complete myodesis takedown and revision amputation concurrent with the heterotopic ossification excision.

rence prophylaxis are lacking due to a nearly absent control group, the authors advocate routine use of radiotherapy and/or NSAIDs postoperatively based on the potential residual limb compromise that may occur if repeat excision is required. This portion of the postoperative plan should also be discussed with the amputee preoperatively, emphasizing the importance of compliance with, and reporting of side effects related to, postoperative NSAID use.

For relatively uncomplicated cases, orthogonal radiographs of the residual limb are all that is required. For larger, serpentine ectopic bone lesions and those that approach or envelope critical neurovascular structures, preoperative computed tomography scans with coronal, sagittal, and (ideally) three-dimensional reconstructions can be helpful for both preoperative planning and intraoperative reference (Figure 9-6). Overlying split-thickness skin grafts should be excised concurrently with the HO excisional procedure when practicable. However, soft tissue coverage is often difficult after extensive HO resection, and the majority of any concurrent soft tissue resection should be performed after the HO has been removed. In patients with focal, localizable symptoms or for whom complete excision would require revision with extensive limb shortening or loss of a functional joint level, partial excision of only the most symptomatic HO is a reasonable approach. No evidence indicates that partial excision of HO predisposes the patient to recurrence of the excised portion. A plan for the exact sequence of events during the excisional procedure, including soft tissue coverage and closure as well as the potential need to shorten the residual limb, is helpful in avoiding unsuspected problems.

The authors attribute the relatively high incidence of postoperative infections and wound-related complications to compromised soft tissue envelopes, potentially latent chronic infections, and the frequent culture-positive nature of excised HO specimens. Given the high incidence of postoperative infection and wound-related complications, relatively short-term (~2 weeks) postoperative empiric and subsequently culture-specific antibiotics should be administered, in addition to routine empiric preoperative prophylaxis. Tissue from each resected HO specimen should be sent to microbiology for culture analysis. To further minimize complications, wounds should be irrigated

thoroughly following excision, meticulous hemostasis achieved, and layered closure performed over a surgical drain.

Postoperatively, drains should be removed at the bedside generally within 72 hours as indicated by drainage output. Dressings should be changed daily starting on postoperative day 2, and patients should be transitioned back to compressive shrinker stockings as soon as feasible. Sutures should be removed at 2 to 3 weeks postoperatively. For patients with focal excisions and limited dissection, prosthetic fitting and wear may recommence as soon as wound status and comfort allow, in some cases even prior to suture removal. When formal myodesis and amputation revision has been performed, prosthetic rehabilitation should follow a standard protocol and progression similar to, but slightly accelerated from, that utilized for new amputees. New radiographs of the residual limb should be obtained immediately postoperatively, again at 2 to 3 months to assess for possible HO recurrence or myodesis failure, and as clinically indicated thereafter.

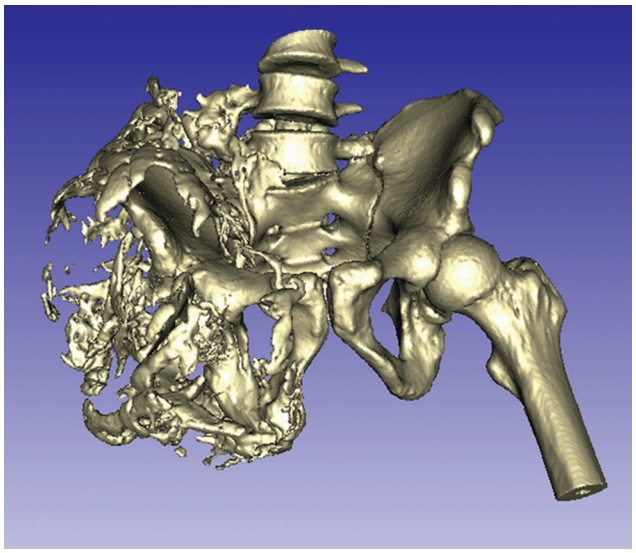

Figure 9-6. Three-dimensional computed tomography scan reconstruction of an amputee with a blast-related right hip disarticulation through the initial zone of injury complicated by severe, diffuse heterotopic ossification.

NEUROMA

Neuroma formation in amputation surgery is inevitable—all transected nerves form neuromas. Currently no technique has been convincingly proven to prevent or ameliorate this process. However, not all neuromas are symptomatic. Persistent symptoms associated with neuromas have been reported in approximately 20% to 30% of amputations,[30,31] and the majority of these can be managed without revision surgery. A discreet area of pain in the vicinity of a palpable nodule and the presence of Tinel's phenomenon are clear indicators of the presence of a symptomatic neuroma. Evaluation of the residual limb with routine radiographs may provide useful information if HO or retained metallic fragments are near the neuroma, but computed tomography or ultrasound rarely provide any information that cannot be determined by a good history, examination, and standard radiographs. Careful evaluation of fine cut MRI scans can occasionally be helpful in identifying neuromas that are otherwise difficult to localize.[14] Prosthetic socket modification is usually sufficient to relieve pressure causing persistent pain from a symptomatic neuroma. However, in recalcitrant cases a diagnostic injection of a local anesthetic at the point of maximal tenderness may help verify the diagnosis as well as provide some prognosis for improvement if surgical excision becomes necessary.

A neuroma that is diagnosed and found to be resistant to all nonoperative measures is best treated with early resection to avoid the development of a "pain generator" and changes in the central neural axis that may result in chronic, refractory pain.[32] The first surgical intervention to remove a painful neuroma is usually the most effective. Tupper and Booth[33] found that in the treatment of 232 neuromas, 65% of patients improved following the first surgery, while only 13% showed improvement following a second operative procedure. Many of the principles outlined in the preceding chapter's section on managing nerves during amputation surgery apply to neuroma surgery. A clean, sharp transection of the nerve proximal to the neuroma, with moderate tension applied, will allow the nerve to retract into the proximal soft tissues. If the surgeon decides to implant the freshly cut nerve end into a local muscle, it is imperative to avoid any tension on the nerve and place the implant in an area free from scar and socket pressure.

Nerves that traverse a relatively superficial anatomic course deserve specific mention. Superficial radial nerve neuromas should be resected so that the remaining nerve end is well beneath the brachioradialis muscle.[34] For neuromas of the peroneal nerve, the surgeon should consider a higher level of resection in the thigh to better insure that the nerve end is beneath the hamstring muscles, while the sural nerve should be allowed to retract deep to the gastrocnemius or into the distal popliteal fossa. When excising a symptomatic neuroma of the sciatic nerve in transfemoral amputees, it is important to remember not to excessively shorten

the nerve, which may lead to pain with sitting and is often recalcitrant to repeated attempts at surgical revision. As mentioned previously, pulsatile, throbbing pain, particularly at rest, usually indicates a neuroma in proximity to a blood vessel. Revision surgery for this problem involves separation of the nerve and blood vessel, repeat ligation of the vessel, and a well-performed traction neurectomy insuring that the nerve is no longer in proximity to the pulsing blood vessel. Adherence to these principles, both conservative and operative, will ensure acceptable relief for the vast majority of amputees with symptomatic neuromas.

MYODESIS FAILURE AND LACK OF SOFT TISSUE PADDING

In response to an increasingly active amputee population, modern amputation techniques emphasize appropriate and durable bone covering as well as anatomic muscle and soft tissue stabilization. In addition to proper socket fit and training, the success and longevity of residual limbs, especially in a young, active population who place supraphysiologic demands on their residual limbs, depend heavily upon the adequacy of this muscular and soft tissue stabilization. Myodesis failure and loss of soft tissue padding are two potential complications facing modern amputees and may contribute significantly to long-term healthcare costs.[35] Thus, it is critical that the treating physician be familiar with the signs and symptoms associated with failure of one or both of these important physiologic constructs.

The approach to the painful or ill-functioning prosthetic limb is multidisciplinary. Close consultation among the patient, orthopaedist, physiatrist, and prosthetist is required to help determine which conditions may respond to socket modifications and which may require further evaluation and surgical treatment (as described in the first section of this chapter). To address failure of myodesis, failure of myoplasty, or loss of soft tissue padding, history and physical examination, weight-bearing radiographs (in and out of the socket), and gait analysis are often successful at identifying the problem.

Myodesis Failure in Transfemoral Amputation

Myodesis of the adductor magnus to the residual femur is critical to restoring proper mechanical alignment and control of the lower extremity.[36,37] Failure to achieve adequate myodesis or catastrophic subsequent rupture of the construct results in a 70% decrease in adduction strength due to a shortened effective movement arm of the weaker adductors longus and brevis (Figure 9-7).[38] The femur, pulled into abduction by the relatively unopposed abductors, can no longer be held in anatomic alignment, even with aggressive socket modifications (Figure 9-8).[37,39–41] The resulting problems, often debilitating, include residual limb pain and ulceration as well as a less-efficient gait cycle, leading to increased energy expenditure during ambulation.[42]

Patients may complain of anterolateral residual limb pain or ulceration despite socket modifications. Subjective weakness in the residual limb, or a decrease in gait velocity, with or without fatigue, often accompanies the discomfort. In highly functional amputees, history may reveal a previously well-functioning limb and well-fitting prosthesis prior to an uncontrolled fall or hyperabduction injury. This may indicate a catastrophic failure of the myodesis. An exaggerated side lurch or a circumduction gait is noticeable as the patient compensates for an inadequate adductor mechanism.

Physical examination may reveal a flexed and abducted residual limb, as well as a bony prominence anterolaterally. An "adductor roll" may be present above the socket line medially, caused, in part, by the retracted adductor musculature. Strength and isometric testing would reveal weak adduction and extension, without a palpable contraction of the adductor longus or hamstring muscle bellies. Radiographic evaluation including weight-bearing anteroposterior and lateral radiographs of the residual limb would reveal an excessively flexed and abducted femur within the soft tissue envelope of the residual limb.

Once the diagnosis of myodesis failure or insufficiency has been made, it is important to assess the amputee's level of functioning before committing to an elective surgical revision. Sedentary or otherwise low-demand patients without ulceration may respond to socket modifications and continue to function adequately despite an insufficient adductor mechanism.[39,40] Most patients, however, may not respond adequately to socket modifications and may desire to achieve (or return to) a higher level of functioning. These amputees require a timely revision procedure to restore proper anatomic alignment to the residual femur.

In these situations, revision or reconstruction of the adductor mechanism should be performed as soon after diagnosis as possible. Scarring and retraction of the adductors and hamstrings can make delayed repair more difficult. Also, some evidence suggests that within a residual limb, retracted muscles atrophy over time, losing up to 60% of their cross-sectional area (and thus the majority of their contractile strength), compared to muscles in which the length-tension relationship

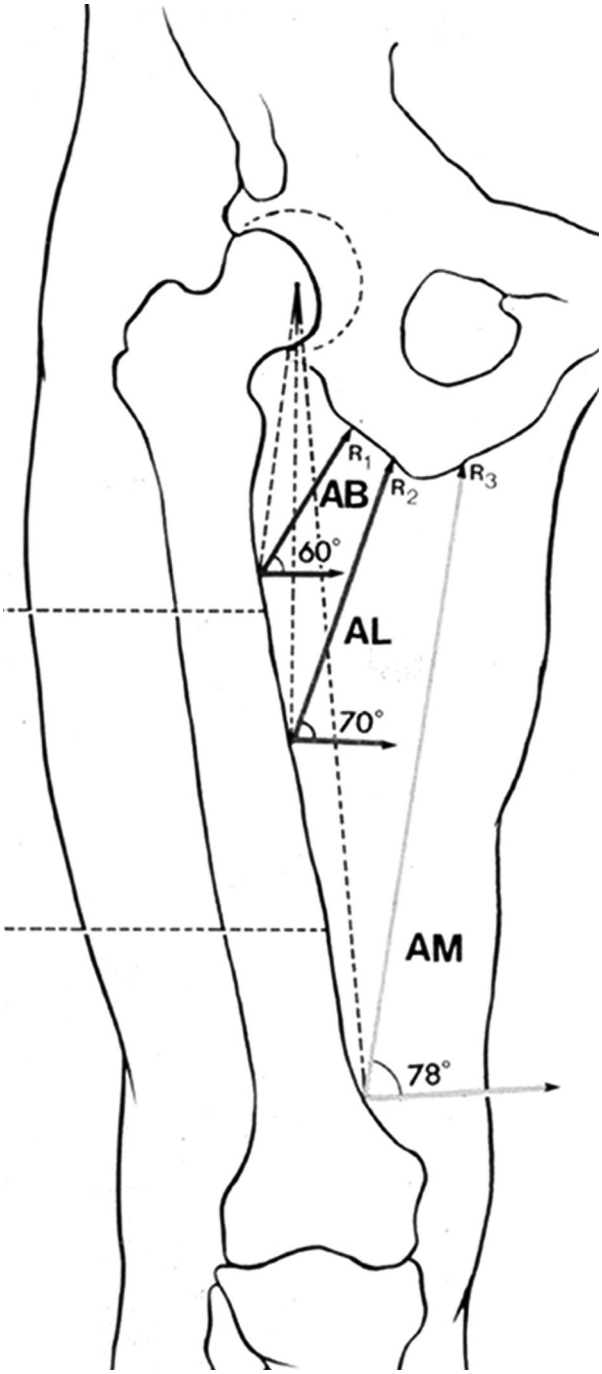

Figure 9-7. Diagram of the resultant forces of the adductor muscles. The relative insertion sites of the adductors are indicated. Progressive shortening of the residual femur results in increasing weakness in adduction as a result of progressive loss of adductor function.
AB: adductor brevis
AL: adductor longus
AM: adductor magnus
Reproduced with permission from: Pinzur MS, Gottschalk FA, Pinto MAG, Smith DG. Controversies in lower-extremity amputation. *J Bone Joint Surg Am*. 2007;89:1118–1127, Figure 7.

was preserved.[43–45] Early rather than delayed repair of the adductor mechanism is therefore preferred to maximize potential restoration of the residual femur to anatomic alignment, as well as to minimize the difficulty of the reconstruction.

Repair of the insufficient adductor mechanism is technically demanding and consists of meticulous identification of the adductor magnus and hamstring tendons. Previous incisions should be used, and the development of flaps minimized. If adequate tendon length is present, the myodesis is performed in much the same way as a primary transfemoral amputation. The authors recommend the technique described by Gottschalk[38] as outlined in greater detail in the previous chapter. If the adductor and medial hamstring tendons are insufficient for this task, femoral shortening may be required and the patient should be counseled accordingly. In severe or unique cases, reconstruction of the adductor mechanism using soft tissue autograft, allograft, or xenograft may be necessary. Metal vascular clips may be attached to the adductor mechanism near its new insertion in an effort to provide a radiographic indicator of myodesis integrity.

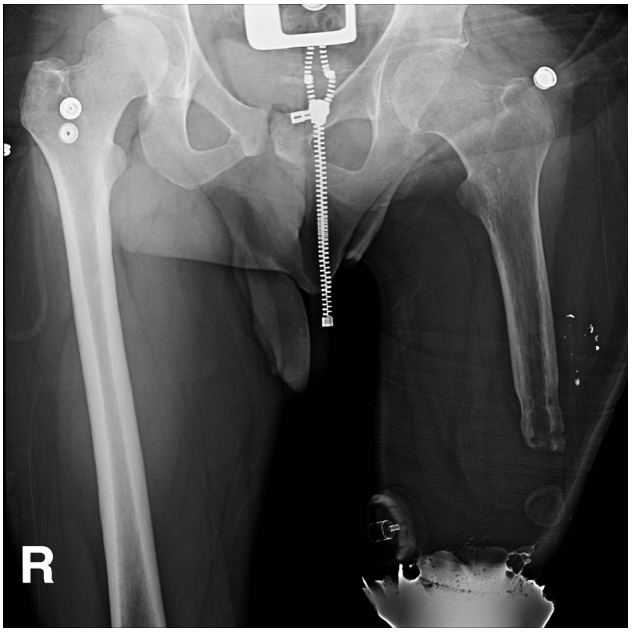

Figure 9-8. Standing anterior-posterior radiograph of a transfemoral amputee in his prosthesis demonstrating failure of the adductor magnus myodesis. Due to the resulting deficiency in adductor strength, the residual femur is pulled into progressive abduction, altering the alignment of the residual femur versus the normal mechanical axis in the contralateral sound limb femur, producing a less efficient gait, and causing a focal pressure point against the distal lateral socket, which was a source of the patient's discomfort.

Prolonged adductor pain is common in patients who have undergone revision myodesis. Adequate early pain control with judicious use of muscle relaxants and abduction precautions to protect the myodesis repair is important. Likewise, close consultation with a physical therapist in addition to the prosthetist is critical. After adequate early healing of the wound and myodesis, early rehabilitation should focus on active adduction and extension exercises before a return to prosthetic fitting and rehabilitation.

Inadequate myoplasty or soft tissue padding in the transfemoral amputation is rare, but can be a source of pain and disability. Although most cases result from an inadequate adductor myodesis as discussed above, some can be caused by failure of the quadriceps myoplasty itself. This can often be appreciated clinically via new anterior distal prominence of the residual femur as well as hypermobility of the anterior residual limb skin with active quadriceps contraction. Additionally, traumatic and combat-related amputees may have a paucity of healthy and robust residual limb soft tissue due to appropriate early efforts to maintain maximal residual limb length in the setting of a broad ZOI. Short of revision with substantial shortening of the residual limb or free tissue transfer, both operative options of last resort, reconstructive alternatives may be quite limited in this setting. Fortunately, socket modifications can succeed in improving symptoms in the majority of cases, and it is thus important to maximize the benefits of nonoperative therapy prior to surgery. Revision of the quadriceps myoplasty is unlikely to be successful, especially in a high-demand patient, if the adductor myodesis is inadequate. Therefore, it is important to assess these two structures thoroughly and concurrently.

Myodesis and Myoplasty Failure in Transtibial Amputation

Myodesis and/or myoplasty within the transtibial amputation provides the residual limb with a durable end-bearing muscle mass. Standard posterior (Burgess-type) flaps are perhaps the most durable and employ a myodesis technique.[46,47] Sagittal, skew, and free flaps provide end-bearing bulk by myoplasty alone, or a combination of myoplasty and myodesis.[48–51] The so-called "fishmouth" flap is used in rare cases to salvage bone length when the posterior musculature is inadequate. It is formed by two equal anterior and posterior fasciocutaneous flaps that provide little or no muscular coverage over the distal tibia suitable for end-bearing. For this reason it is not routinely used, but reserved for salvage cases only.

Loss of durable end-bearing musculature in the transtibial amputation causes pressure-related pain with prosthetic wear. Patients may complain of anterior residual limb pain or present with skin breakdown and ulceration. History may reveal a previously well-functioning limb and well-fitting prosthesis prior to a fall onto the residual limb, which may indicate an acute failure of the myodesis or myoplasty.

Physical examination will reveal a prominent anterior and distal tibia. Depending on the type of flap used, retraction of the posterior musculature or a rent in the skew flap myodesis will be palpable. As with any amputation revision, nonoperative management including socket modifications may result in a functional and painless limb and should be exhausted preoperatively. For the same reasons listed above, however, most young, active amputees may not respond adequately to socket modifications and may desire a higher level of function and residual limb durability. This subset of patients requires a timely revision procedure to restore durable end-bearing muscle to the distal tibia. For overt myodesis failure presenting acutely, particularly if occurring relatively early in the soldier's initial rehabilitation, immediate operative repair without a trial of nonoperative treatment is reasonable.

Revision of the transtibial myodesis or myoplasty is challenging. In the acute setting, a simple myodesis or myoplasty repair may be possible; however, retracted posterior compartment muscles are often scarred and difficult to mobilize. Shortening of the residual tibia and fibula is almost always necessary to ensure an adequate, durable myodesis. Care must be taken, however, to avoid overtightening the myofascia of the posterior compartment, which may cause a knee flexion contracture and predispose the patient to early failure of the (revision) myodesis. The anterior bevel of the tibia should also be revised, if needed, and the myodesis performed with stout nonabsorbable sutures. It is important to note that the lateral gastrocnemius undergoes far less atrophy than its medial counterpart, and may contribute a more robust construct to the repair.[52,53] Myoplasty repair, if indicated, may be performed with long-lasting absorbable suture, and consideration should be given to augment the repair with a myodesis technique to prevent recurrence.

As in most amputation revision surgery, previous incisions should be utilized and the development of flaps minimized. Although the development of a knee flexion contracture is undesirable, residual limb rest with the knee in slight flexion for a few days postoperatively is reasonable to permit the muscles to adapt to their new resting length and minimize tension on

the myodesis. Early rehabilitation should then focus on gentle passive knee extension and active-assisted knee range-of-motion exercises.

Myoplasty Failure in Transhumeral Amputation

In contrast to lower extremity amputations in which the myodesis and myoplasty form a durable end-bearing pad, myoplasty techniques of the arm serve to stabilize the musculature and contain the residual humerus within the soft tissue envelope. Additionally, for high-demand amputees utilizing myoelectric prostheses, stable myodesis may be required for optimal residual limb and terminal device control.

Failure of the myoplasty is often characterized by the insidious onset of symptoms; catastrophic (or acute) failure is rare. Patients may complain of a painful snapping sensation with range of motion or pressure-related pain with prosthesis wear. Physical examination may reveal a painful bursa overlying an area of inadequate myodesis; however, palpating a defect (rent) in the myoplasty is the key to diagnosis.

As with any amputation revision, nonoperative management must be exhaustive, including socket modifications, local wound care (if necessary), and prosthesis rest. Those amputees who do not improve with nonoperative management require surgical repair. In the authors' experience, higher demand amputees are more likely to fail conservative management for these issues, which should be a consideration when selecting patients for surgery as well as timing the surgery.

Repair of the myoplasty should be performed as soon as possible to minimize the effect of muscular contraction and scarring. The myofascia should be repaired with a mild amount of tension to restore the muscle bellies to resting length and tension. This ensures a maximum myoelectric signal generation for applicable prostheses.[54] Shortening of the humerus is occasionally required, depending on the timing of the repair and general condition of the remaining soft tissues. As with other amputation revisions, previous incisions should be used, and the development of flaps minimized. Postoperative care and rehabilitation are similar to those in primary transhumeral amputations.

Myodesis and Myoplasty Failure in Transradial Amputation

Myodesis in the transradial amputation serves a similar purpose to that performed in a transhumeral amputation. Anterior and posterior muscle flaps are used to contain the residual radius and ulna within a durable, stable myofascial construct. Failure of the myoplasty is rare at this level but is characterized by a prominent distal radius or ulna. As in the transhumeral level, patients may also complain of a painful snapping within their residual limb as well as pressure-related pain with prosthesis wear. Physical examination will indicate an area of inadequate myoplasty and may reveal an overlying painful bursa. Once again, identifying a palpable rent in the myoplasty or new focal area of prominent bone is the key to diagnosis.

Nonoperative management, including socket modifications, local wound care (if necessary), and prosthesis rest will likely provide symptomatic relief and should be exhausted prior to surgery. Those amputees who do not improve with nonoperative management require surgical repair. Again, as with all cases of suspected myodesis or myoplasty failure, conservative options should be pursued expeditiously to minimize muscle retraction and scarring in those cases requiring revision surgery. The myofascia or tendons should be repaired while keeping the muscle bellies at resting length and tension to maximize distal bone stability, residual limb control, and myoelectric signal generation.[54] Shortening of the radius and ulna is sometimes required because more muscle mass is available proximally; however, progressive loss of residual forearm length directly correlates to a decrease in forearm rotation.[55] This must be kept in mind when planning to shorten a transradial amputation, and the patient must be counseled accordingly. For more distal transradial amputations, retracted tendons can often be mobilized sufficiently via proximal dissection so that shortening is not required. Neuromata, if present, may also be addressed during the revision surgery. As with other amputation revisions, previous incisions should be used, and the development of flaps minimized. Postoperative care and rehabilitation are similar to those in primary transradial amputations.

OSTEOMYOPLASTIC TRANSTIBIAL AMPUTATION: THE ERTL PROCEDURE

In 1939 Janos Ertl[56] published a technique for transtibial amputation revision for problematic residual limbs, which he developed treating World War I amputees in Hungary. In 1949 he published his experience treating 6,000 amputees following World War II.[57] His original technique calls for raising periosteum from the medial aspect of fibula with attached cortical chips and suturing it to the lateral tibial periosteum. A similar flap of periosteum is raised from the anteromedial tibia. The distal tibia and fibula are then cut at the same level, taking care to carefully bevel the tibial crest and round off all cortical edges. The tibial periosteum is

then sutured to lateral fibular periosteum. Anteriorly and posteriorly, the edges of the two periosteal flaps are sutured together, forming a tube of periosteum with opposed "cambrial" surfaces and viable bone chips. With time, a synostosis forms between the two bones, with a broad, smooth surface (Figure 9-9). Ertl felt this allowed end bearing in the socket, reducing pain and improving function. He also proposed that, by sealing the medullary canal, "normal bone physiology" was restored.

The procedure continues to have proponents in Europe.[58] In the United States, two generations of Ertl descendants have been proponents of the elder Dr Ertl's techniques.[59] During the Vietnam War, the technique was utilized at Valley Forge General Hospital, the Army's amputee center at the time, for revision of problematic transtibial amputations.[60] Deffer, Moll, and LaNoue[60] reported a case series of 155 patients, giving their opinion that the technique allowed more reliably successful total-contact fitting in their young, active, patient population. In cases of short residual limb length, they successfully utilized free autograft, iliac crest, and rib to form the bone bridge. Pinto and Harris[61] advocated the use of a fibular segment to form the distal tibiofibular synostosis, noting that approximately 7 cm of tibia must be resected to harvest an adequate amount of tibial periosteum. They advocate leaving the adjacent viable lateral compartment muscle attached, performing a closing wedge osteotomy to swing the fibular segment into a slot in the lateral tibial cortex, so the healing will more closely approach fracture healing.

Although the Ertl procedure has many proponents, most of the published literature on the subject consists of case series. A recent review of that literature found a single controlled outcome study.[62] Pinzur and associates[62] reported on 32 consecutive patients with modified Ertl transtibial amputations for a variety of diagnoses, compared to a historical "control" group of 17 transtibial amputees who had been treated by the classic Burgess technique and who were considered to be highly functional. A validated outcome instrument, the prosthetics evaluation questionnaire, measuring "quality of life and functional demands in patients with lower extremity amputations," was administered to the Ertl group at an average of 16.3 months and to the Burgess group and an average of 14.7 years. The Ertl group scored better in ambulation ($P = 0.037$) and frustration ($P < 0.001$) and lower in appearance ($P = 0.025$). The results in the other six domains were similar between the two groups. The authors conclude that bone-bridging "may enhance patient-perceived functional outcomes." No randomized or blinded studies

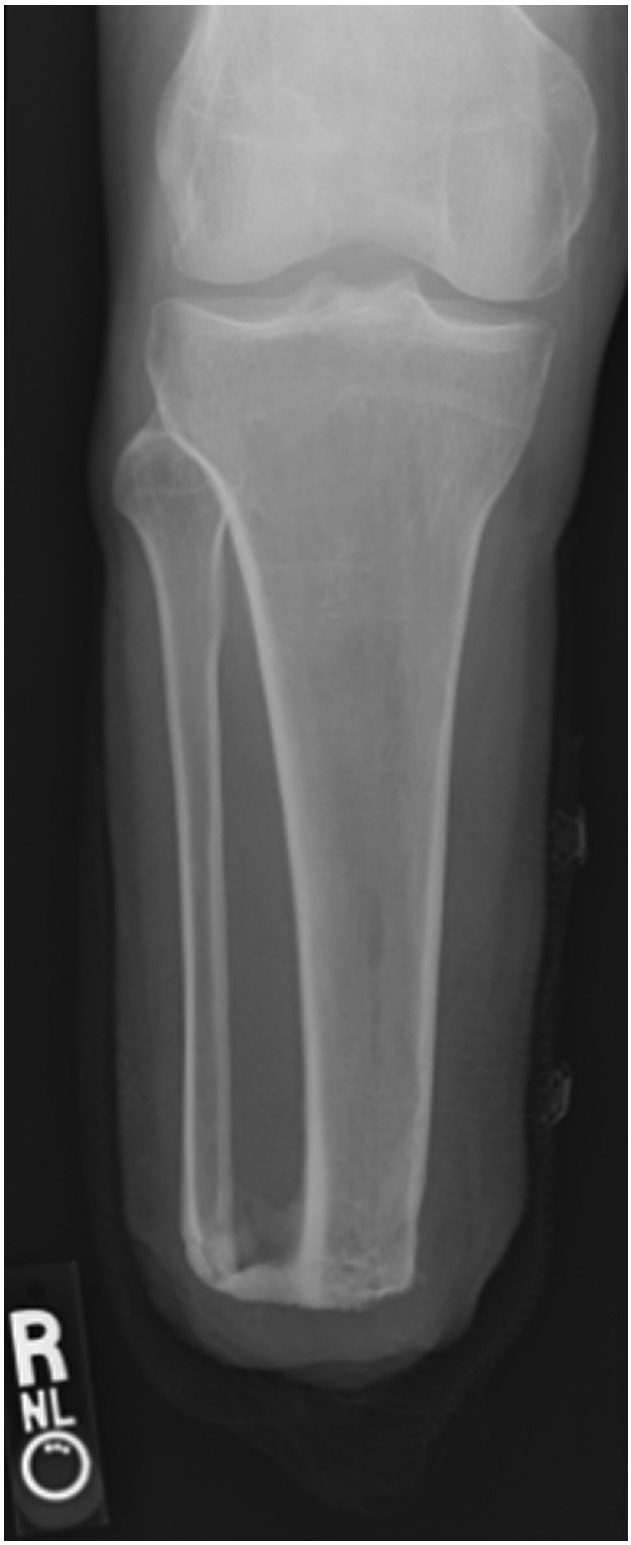

Figure 9-9. Anterior-posterior radiograph after healing of a classic osteomyoplastic transtibial amputation utilizing the classic Ertl technique with strips of tibial and fibular periosteum.

have been performed assessing function or outcomes.

The osteoplastic transtibial amputation technique has been performed on a limited number of amputees from the current wars in Iraq and Afghanistan. Because the current practice is to perform length-preserving amputations in the ZOI, fibular instability due to rupture of the interosseous membrane is not uncommon. There is a general consensus among military orthopaedic surgeons that synostosis is strongly indicated in this clinical situation. A variety of techniques have been used, with roughly an even split between the closing wedge technique and the use of a free segment of autograft fibula. In the latter case, the segment should be relatively short, because a narrower distal tibiofibular distance and osteoplasty length is thought to maximize osseous stability and be less likely to cause a symptomatic osseous prominence. The graft can be stabilized via one of several techniques. Often, a single 3.5-mm cortical screw is placed through the lateral fibular cortex, through the medullary canal of the graft segment, and through one or two cortices of the tibia (Figure 9-10). The graft can also be secured via intraosseous sutures utilizing devices designed for anterior cruciate ligament graft or syndesmotic stabilization (Figure 9-11). Alternatively, drill holes can be made in both the distal tibia and fibula and the graft secured with heavy, nonabsorbable suture in a fashion resembling a myodesis (Figure 9-12).

If available, the periosteum of the anteromedial tibia, which is invariably thick and easily raised, is then

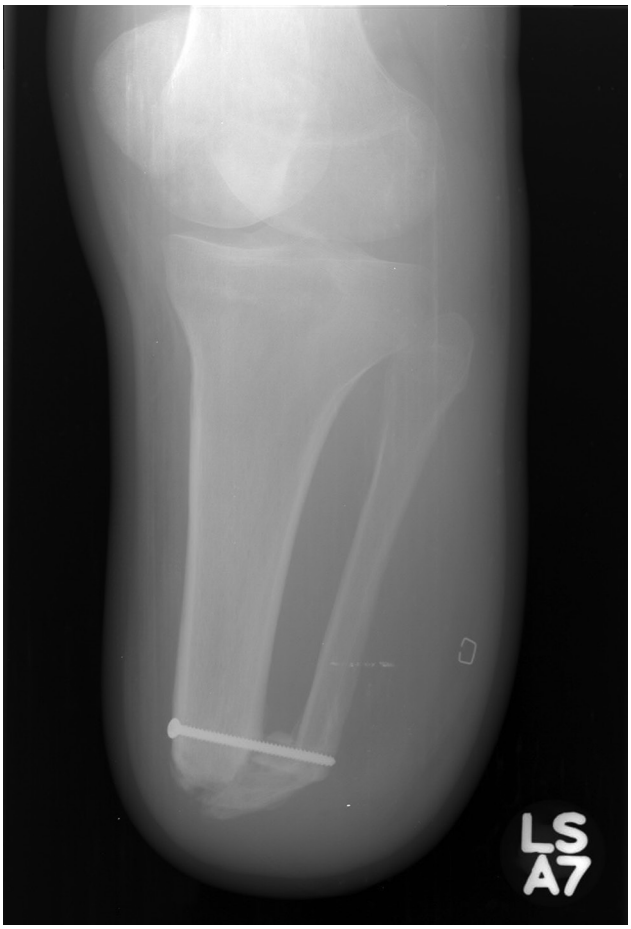

Figure 9-10. Postoperative anterior-posterior radiograph demonstrating a distal tibiofibular synostosis in a transtibial amputation secured with a 3.5-mm cortical screw.

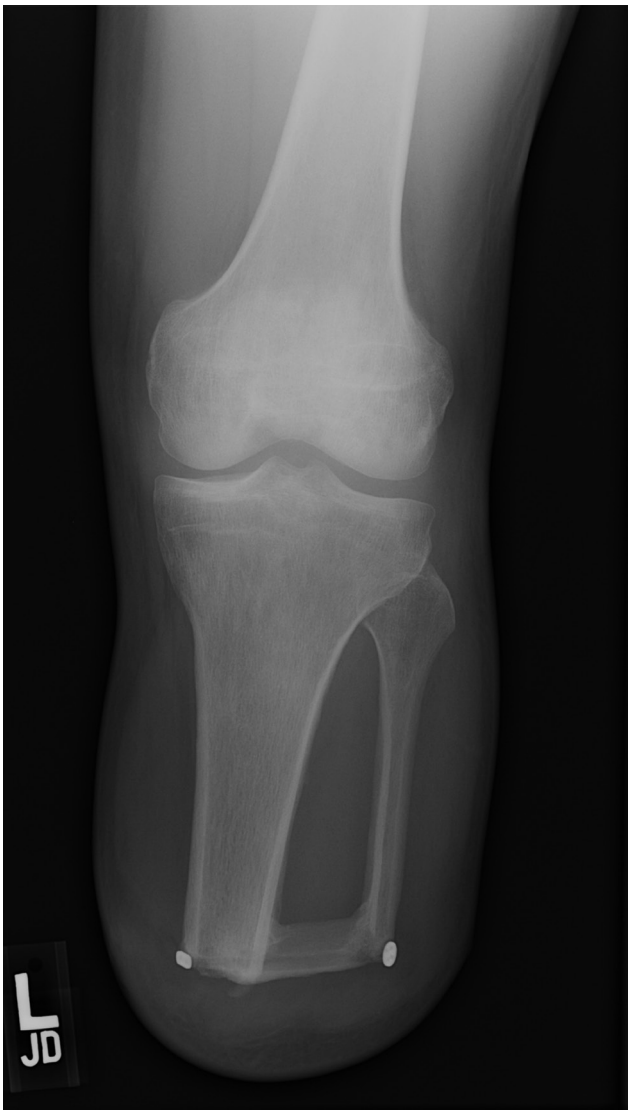

Figure 9-11. Anterior-posterior radiograph demonstrating a healed distal tibiofibular synostosis in a transtibial amputation secured with an intraosseous suture technique.

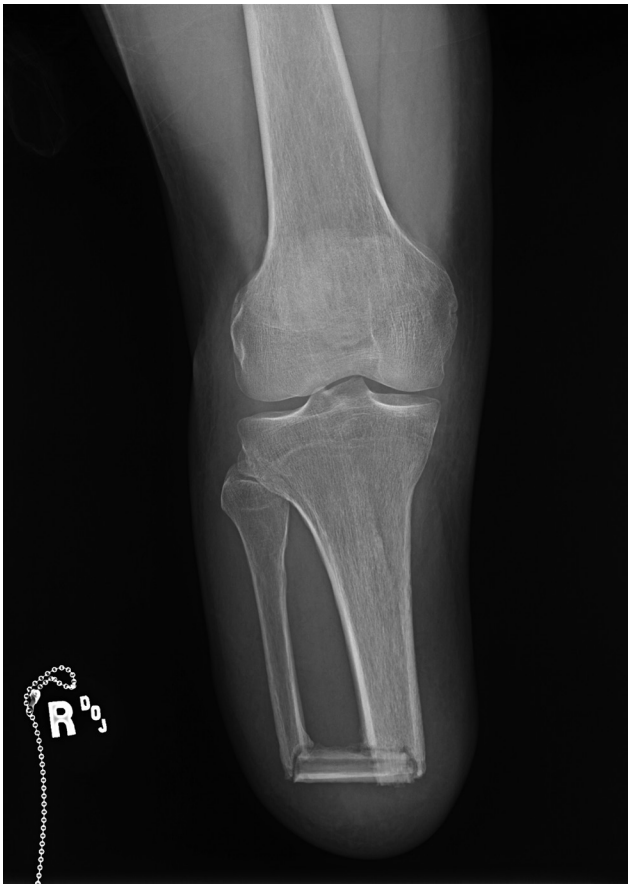

Figure 9-12. Anterior-posterior radiograph demonstrating a distal tibiofibular synostosis in a transtibial amputation utilizing fibular autograft and tibial periosteum and secured with tranosseous heavy, nonabsorbable sutures at both graft junctions. Early postoperative remodeling and healing is evident in this image obtained 8 weeks postoperatively.

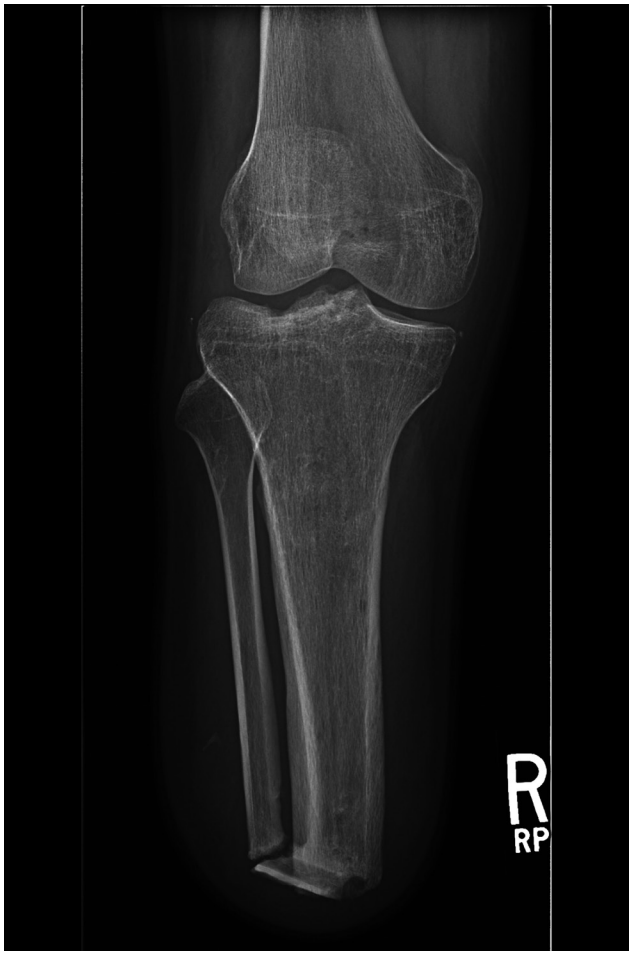

Figure 9-13. Anterior-posterior radiograph demonstrating a nonunion of a distal tibiofibular synostosis at nearly 1 year postoperatively.

sutured over the cut end of the tibia and to the lateral fibular periosteum. This speeds graft incorporation, and extensive remodeling of the synostosis has been noted over time, with its distal profile becoming gradually rounded off in both the anteroposterior and lateral planes. The authors have not noted any frequent problems with graft incorporation when viable periosteum was unavailable, as is the case in most revision cases; although nonunions do occasionally develop (Figure 9-13), they are infrequently symptomatic. Occasionally percutaneous screw removal had to be performed when the screw head became prominent due to osseous remodeling. In revision cases without evidence of latent infection and in which both fibular autograft and tibial periosteum are unavailable without excessive residual limb shortening, use of tricortical iliac crest autograft or fibular allograft may be considered. Finally, as an alternative source of local autograft, the surgeon may perform a partial tibial osteotomy, hinged distally and utilizing a segment of lateral tibial cortex as graft, while maintaining the overall length of both the tibia and fibula.

The use of the Ertl technique in other clinical situations remains controversial. Because of the risk of infection, many surgeons are reluctant to leave a devascularized fibular segment or a metal implant at the time of delayed primary closure of an amputation through the ZOI. Concern for infection is less in revision surgery above the ZOI, such as transtibial amputation following failed salvage of severe hindfoot injury. The patient with a painful residual limb, who on physical examination has pain with manipulation of the fibula or progressive splaying of the fibula on serial radiographs, may also benefit from synostosis. That said, the surgeon must exercise care to identify and address other causes of lateral residual limb pain,

such as peroneal neuroma, or run the risk of a failed outcome and persistent symptoms despite the achievement of radiographic synostosis. Because of the lack of a convincing body of evidence for the superiority of the Ertl over the Burgess technique, synostosis is performed on the basis of surgeon preference and training. Studies are currently in progress that will examine both subjective and objective results comparing the two techniques using outcome instruments such as the SF-36, gait analysis, and videofluorscopy of the residual limb-prosthesis interface, which may provide an evidence-based choice of operative technique.

Much anecdotal advocacy for the Ertl appears on the Internet and in the prosthetic business community.[63] Several patients have requested that highly functional Burgess amputations be revised to Ertls based on this promotional material, including patients successfully running long distances and playing cutting sports. The authors feel these requests are based on limited information, and strongly discourage them. Nonetheless, some patients have found civilian surgeons willing to revise their residual limbs following retirement from active duty.

In summary, the osteomyoplastic transtibial amputation offers the theoretical benefit of allowing distal end bearing, and is definitely indicated acutely in cases where the interosseous membrane has torn and the fibula is unstable. As a revision procedure, it is also useful in cases where fibular hypermobility can be identified as a pain generator. No strong evidence in the literature, however, shows a significant improvement in outcome over amputation without synostosis in patients with a stable fibula. Studies are underway that may further clarify this controversy.

MANAGEMENT OF BURNS AND SKIN GRAFTS

Burn-Related Amputations

Burn injuries may occur due to chemical, electrical, or flash fire-type mechanisms.[64] Burns sustained in combat-related injuries, with or without associated amputation, typically result from fires or thermal injuries secondary to conventional or improvised ordinance and thus fall into the latter category. Burns from volatile compounds such as white phosphorus or actual chemical weapons fortunately remain absent from the present battlefield environment.

In the present conflicts, approximately 5% of all major injuries requiring evacuation from theater have been amputations.[65] A similar proportion of amputees have had concomitant burn injuries, with burns involving the residual limb in nearly 75% of cases. Roughly 6% of patients requiring burn center treatment were amputees, and the proportion of burn patients with multiple limb amputations has not been significantly different from that of amputees without burns. The average burn size has been 40% of total-body surface area (TBSA) involved in the burn amputee group, as compared to 16% TBSA in the entire burn cohort.

In contrast to most combat-related amputations, which often occur as a direct result of the inciting trauma or during early surgical management, nearly 45% of burn-related amputations are ultimately performed at the definitive treatment facility due to early (15%) or late (30%) burn-related complications. Amputees with burn injuries have demonstrated a greater mortality rate (24%) than their nonamputee burn patient counterparts (6%). Thus, burns in the combat-injured amputee complicate treatment and rehabilitation and are associated with higher mortality. Half of the amputations were complete in theater, while 6% had unreconstructable fractures, and 9% required amputation due to progressive ischemia from required vasopressor support. In the delayed amputation group, 21% required amputation due solely to the severity of the burn. The remaining 9% had complications of infection or nonunion. These rates are in direct contradistinction to the available civilian literature on burn-related amputations: the rate of amputations among burn unit patients at civilian centers is 1% to 2%, with the vast majority of these amputations being performed in delayed fashion[66] and burns being more likely to result in multiple limb amputations.[67] Multiple studies have demonstrated a survival benefit to amputation in the management of severe burn patients.[68,69]

Initial in-theater management of the combat-related burn patient with or without amputation follows basic advanced trauma life support and burn protocols. Appropriate early and subsequent attention must be paid to hypothermia, volume resuscitation, electrolyte imbalances, coagulopathy, infection, associated inhalational injuries, and tissue necrosis that may result in sepsis or renal failure.

Surgical principles followed for burn amputees are similar to those recommended for all combat-related amputations, with initial open management and length preservation. In the absence of ongoing sepsis and/or hypotension requiring vasopressors, which may result in additional tissue necrosis and ischemia, tissue viability is generally clinically evident within 4 to 7 days following injury.[64] This time frame coincides with the average arrival time at definitive treatment facilities in the present conflicts. Thus, advanced techniques of tissue viability assessment, such as nuclear medicine

scans, have not been routinely required in the authors' experience. Amputees with burn injuries require, in general, a substantially greater number of operative procedures during their initial hospitalization than their counterparts without burns.

Myodesis at the time of definitive treatment is typically performed. One particularly useful technique is to utilize extra-long muscle and/or skin flaps to cover bone and other structures, preserving length and even amputation levels. Even when the entire medial face of the tibia was exposed, a carefully designed very long posterior flap extending down to the plantar foot can preserve a transtibial level (Figure 9-14). Heroic attempts to salvage residual limb length or functional joint levels are indicated in some instances, particularly in multiple limb burn amputees who otherwise would be less likely to achieve independent function and ambulation.[66] The results of such procedures can be extremely gratifying.[70] However, flap coverage is best performed late, after tissue viability, physiologic status, and residual limb wounds have stabilized; flap failure has been significantly associated with early coverage in burn patients.[71] Eventual skin grafting of residual limbs is routinely required in most patients with burns, and in most cases resulted in a functional residual limb[72] (Figure 9-15).

Most of the civilian medical literature discussing amputations secondary to or associated with burn injuries is limited to case reports or small case series, many of which address electrical injuries. There is general agreement that amputee rehabilitation and prosthetic fitting is complex and frequently delayed secondary to additional surgeries, concomitant medical problems, open wounds and wound instability, edema,

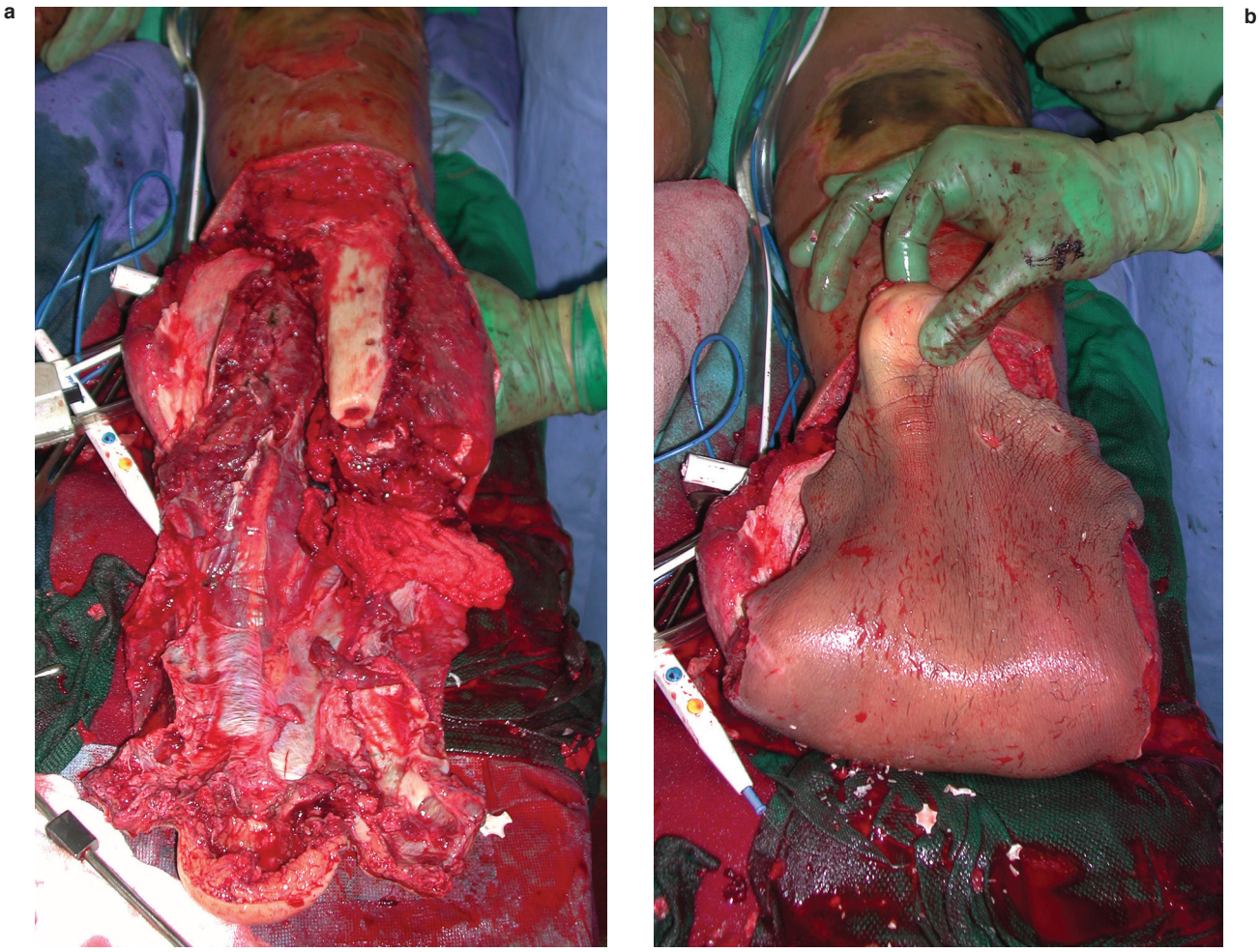

Figure 9-14. Intraoperative photographs of a transtibial amputation with burns of the residual limb. An extra long posterior flap was utilized to compensate for inadequate anterior soft tissue coverage, avoiding the need for a skin graft and salvaging an extremely functional final residual limb length.

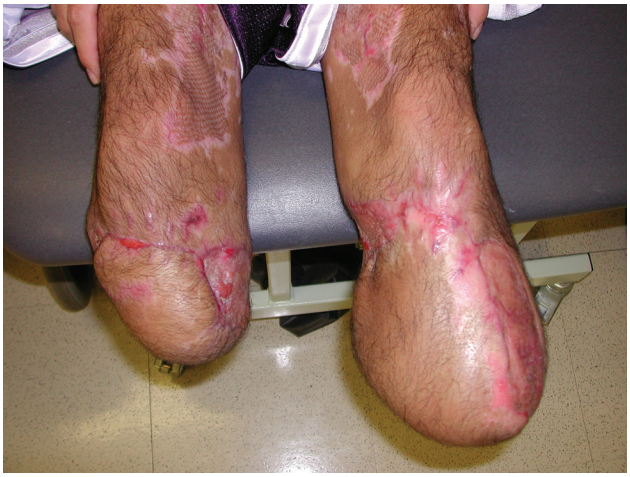

Figure 9-15. Clinical photograph of a healed bilateral transtibial amputee who presented with extensive burns of his residual limbs. Relatively long posterior flaps were utilized, minimizing the need for split-thickness skin grafting. The required skin grafts, which healed uneventfully and functioned well, were not placed over osseous prominences near the terminal residual limb, areas of relatively greater direct pressure and shear forces.

the need for skin graft maturation, hypertrophic and often painful scarring on the residual limb, and joint contractures.[66,68,72,73] The average time to prosthetic fitting of burn amputees in the authors' experience has been over 110 days, or nearly two to three times that of most nonburn amputees. Additionally, burn amputees who had larger burn surface injuries (> 40% TBSA) had a slightly higher average time to prosthetic fitting than burn amputees with less involvement. Due to lower shear forces placed on the residual limb at the skin-prosthesis interface, upper extremity burn amputees without rate-limiting concomitant injuries may be candidates for accelerated prosthetic fitting, training, and rehabilitation.[74]

Skin Grafts

When practicable, skin grafting of residual limbs is best avoided. Although satisfactory results can be achieved in most cases with the techniques described, concerns about chronic and recurrent complications ranging from minor patient discomfort to skin breakdown and ulceration or frank graft failure remain. Split-thickness skin grafts (STSGs) placed over terminal residual limbs or directly over bony prominences are particularly problematic. Current silicone liners, however, have decreased the rate of complications associated with skin grafting of the residual limb. In patients with adequate residual limb length, modest shortening to achieve adequate native myofasciocutaneous coverage is warranted. However, in many cases, the need for skin grafting cannot be avoided without substantial residual limb shortening or functional joint levels. Furthermore, most combat-related amputees have soft tissue and/or osseous injuries proximal to their residual limb, making shortening or revision to a more proximal level an even less appealing alternative.

When necessary, the authors advocate slightly thicker than typical STSGs (12–16 thousands of an inch) to maximize final residual limb soft tissue durability. With adequate wound bed preparation, including the absence of active infection or nonviable tissue and evidence of early healing granulation tissue formation, failure of these grafts has not been a problem in our experience. However, thicker STSGs may not be possible in burn patients with large TBSA involvement, in whom repeat donor site harvest is sometimes necessary.

Full-thickness pinch grafts can be useful to cover small areas, particularly over the terminal residual limb, but are more prone to early graft necrosis and failure than split-thickness grafts; when utilized, full-thickness grafts should be liberally perforated with a no. 15 blade in order to prevent seroma or hematoma accumulation and subsequent graft separation and failure. In patients undergoing skin grafting at the time of definitive amputation, skin that would otherwise be discarded can sometimes be harvested from the terminal limb or revised viable skin flaps.

Every effort should be made to place grafts over viable underlying muscle, both to ensure graft survival and maximize ultimate function via adequate soft tissue padding. Grafts placed directly on fascia or periosteum, even when "successful," are frequently problematic in the long term. The utilization of creative, atypical myofascial flaps and, occasionally, free flaps, is critical to avoid these problems. When such flaps are not possible, bioartificial dermal substitutes can be useful in restoring soft tissue contour or substituting for the absent native dermis.[75,76] Placed in areas of exposed tendon or bone or otherwise inadequate soft tissue coverage, the grafts should be allowed to incorporate and mature with regular dressing changes for a period of 10 to 21 days, followed by planned, delayed STSG. Grafts can also be layered at 10- to 14-day intervals in an effort to restore normal surface contour to particularly cavitary defects.[76] Treatment with this method is time consuming and can be costly, but the authors have had generally favorable results in a few amputees and a number of nonamputee combat-injured service members.

Myriad conventional graft bolstering techniques have been described in civilian settings. However,

when feasible, the authors advocate placement of subatmospheric pressure dressings (VAC; KCI, San Antonio, Tex) to cover STSGs for the first 4 to 5 days postoperatively. Although military medical treatment allows managing these dressings in an inpatient setting in most cases, due to associated injuries, ongoing inpatient rehabilitation, or social concerns not often present in civilian trauma (as well as the general absence of third-party pressure to accelerate discharge), portable units are now available for outpatient use. Numerous series have demonstrated increased graft survival with VAC use compared to conventional techniques.[77–79]

After initial graft healing, careful transition to conventional shrinker compression stocking use can be initiated at 2 to 3 weeks postoperatively. A supplemental dressing beneath the shrinker is generally used initially to protect the graft and cover peripheral areas of ongoing granulation and healing by secondary intention. Prosthetic fitting and, in particular, use are delayed until more definitive graft maturation has occurred. Utilizing this and similar techniques, most amputees requiring skin grafting of their residual limbs can ultimately be fit with and operate a functional prosthesis.[72]

Late wound problems after skin grafting are best managed early and aggressively (albeit nonoperatively) via local wound care, transient activity modification, and prosthetic modification. Problematic grafts can often be treated with late excision and primary closure with adjacent fasciocutaneous advancement after early soft tissue healing and swelling subsidence, or concurrently with excision of symptomatic HO and salvage of redundant native skin. In other cases, catastrophic graft failures following multiple grafting attempts or as a result of prosthesis wear, in addition to patients chronically dissatisfied with their residual limb function or discomfort, may require discussion of more aggressive alternatives including tissue expanders, free tissue transfer, or residual limb shortening or revision to a more proximal level.

JOINT CONTRACTURES

Lower Extremity Contracture

Contracture is a potential complication of any amputation including the lower extremity. Although very uncommon in traumatic amputees, severe contractures may be seen in amputees with neurological injury or vascular disease. Significant contracture can challenge prosthetic fitting and limit functional return. Contractures may also be associated with decubitus ulcers and complicate seating and patient positioning. For these reasons, prevention and aggressive management of contracture are very important in the rehabilitation of war-related amputee care.

Contractures in amputees are caused by many factors. The resulting change in limb length sometimes allows one muscle group to dominate, due to injured, inefficient, or absent antagonist muscle groups, leading to contracture formation. Such a situation is observed in midfoot and hindfoot amputations, when a fixed equinus deformity develops because of unopposed pull of the gastrocsoleus complex, or in a transtibial amputee who developes a knee flexion contracture because of excessive pull of the hamstrings. Contractures are often also exacerbated by delayed prosthetic fitting and mobility training. In addition, pain can often inhibit range of motion of joints and contribute to contracture formation. In the hip, problems are often encountered with prolonged seating or semirecumbent positioning, with shorter residual limbs being at greater risk for contracture development.

The presence of injury proximal to the level of amputation may also be a cause of contracture. In the transtibial amputee, injury to the knee or the distal femur may cause quadriceps scarring, HO, and limited motion in flexion, leading to an extension contracture. Standing is not impaired, but the limitation of flexion makes sitting more difficult in a vehicle and limits high-level function such as running. In these situations, a quick connecting coupler to the prosthetic limb can be a simple solution to facilitate sitting.

The treatment of contracture should be initiated at the time of surgical amputation. It is recommended that midfoot and hindfoot amputation undergo lengthening or tenotomy of the Achilles along with preservation or tenodesis of the tibialis anterior and the peroneal musculature.[80] Similarly, in transfemoral amputees, the myodesis of the adductor and hamstring in adduction and extension reduces the risk of a hip flexion and abduction contracture.[81]

Following surgery, dressings and patient positioning assist in preventing contracture. Hindfoot amputations should be splinted in maximal dorsiflexion. Transtibial amputees should be instructed to initiate active knee extension and range of motion exercises and avoid placing pillows under the knee, producing a flexed resting posture. The transfemoral amputee should be instructed on periodic prone lying, and active hip adduction and extension exercises. For patients unable to tolerate or participate in these activities, periodically lying completely flat in bed and placing a light sandbag on the residual limb to facilitate passive hip extension is an effective preventative measure for supine patients.

Rigid dressings for transtibial amputation have been advocated not only for maintenance of extension but also for edema and pain control.[82,83] The use of rigid dressings was fairly standard in the treatment of war amputees in the Vietnam era. However, in the authors' experience, soft dressings have been very effective in the postoperative management of combat-related amputations and permit regular wound monitoring. In compliant traumatic amputees with appropriate therapy, it has been our experience that amputees have not developed flexion contractures of the hip or knee. Dynamic splinting may be effective in transtibial flexion contracture if the tibial segment is long enough to allow such a device. Another option is to adapt the prosthetic socket in flexion to accommodate the contracture and facilitate mobility and progression with rehabilitation.[64,84]

Generally, surgery is not required in the management of contracture following amputation surgery. Appropriate surgical technique at the time of amputation surgery followed by diligent therapy and patient instruction will generally prevent this complication. In a hindfoot amputation equinus contracture, revision to a transtibial level can be an effective solution. Additionally, consideration can be given to converting a transtibial amputation to a through-knee or transfemoral level when other means of knee contracture treatment have failed.[84,85] However, every effort should be made to save the knee, which has a significant impact on functional recovery. The authors' experience with knee arthrofibrosis release and quadricepsplasty has been generally satisfactory in a few young, motivated amputees. Gas-sterilized custom sockets with attached shafts can be useful intraoperatively to assist in knee manipulation under anesthesia after contracture release (Figure 9-16). In the hip, contracture up to 25° can be accommodated by the socket. In the hip, as in the knee, a surgical release is difficult, requiring extensive dissection. In these instances, consideration may be given to a femoral corrective osteotomy to improve prosthetic function.

Burn amputees with extensive burns on their limbs represent a separate category of patients with distinct complications.[86] When a skin graft is required, contracture develops slowly, often despite appropriate therapy and positioning.[66,73,87] These contractures may respond to plastic procedures to release the scarred skin but may also require release of contracted muscle-tendon units. When other factors such as very delicate skin grafts make prosthetic wear unlikely, such methods should be avoided.

All patients with contractures should undergo exhaustive conservative attempts to increase motion and function prior to considering operative intervention. Postoperatively, amputees undergoing any contracture release require early mobilization and aggressive physical therapy to maintain and maximize operative gains. Toward this end, indwelling regional anesthesia catheters, continuous passive motion machines, and static and dynamic splinting can be particularly useful. When combined with an appropriately motivated patient, satisfactory results can be achieved in most cases through nonoperative and, in carefully selected patients, operative treatment of contractures. However, it cannot be overemphasized that the primary and most important contracture treatment in combat-related amputees is prevention.

Figure 9-16. Intraoperative photographs of manipulation under anesthesia of a transtibial amputee following knee extension contracture release and quadricepsplasty utilizing a sterilized custom socket. Satisfactory motion was achieved and maintained postoperatively through aggressive rehabilitation.

Upper Extremity Contracture

Among combat-injured personnel with upper extremity amputations, symptomatic contractures are rare. In the absence of additional risk factors, no amputees from the current conflicts have required surgical management or significant modification of prosthetic devices, to the authors' knowledge. Exceptions to this include burn patients, whose injuries may lead to contractures of the elbows and shoulders, patients with concomitant ipsilateral intraarticular elbow fractures, and patients developing HO about the elbow adjacent to short transradial amputations.

In the evaluation and treatment of upper extremity amputees with contractures, decision-making is determined by the condition and function of the terminal limb, the involved joint, and the individual patient's associated injuries as well as his or her real and perceived functional limitations. Consideration for contracture release in burn patients with contracted amputations should be based on the experience gained in the treatment of burn patients without amputations. This may involve capsular release, excision of HO, plastic management of contracted skin (Z-plasty, expanders, and tissue transfer).[88–90] Wound-healing complications are common and often only modest improvements in function are observed.

When HO is limiting functional motion around the elbow, with or without associated fracture, surgical excision and release can be undertaken after conservative measures have been exhausted. A waiting period of 3 to 6 months is recommended to permit initial HO and wound maturation, but longer waiting periods are not necessary.[10,91–93] Typically, at least this much time will transpire while conservative modalities are pursued, patients adapt to their new lives as amputees, functional limitations that cannot be overcome or compensated for become evident, and most patients would even contemplate an additional, elective surgical procedure. The authors advocate standard techniques of scar revision/excision and circumferential capsular release with simultaneous HO excision, followed by postoperative radiotherapy and/or NSAIDs, with aggressive physical therapy.[91–93] Some evidence shows that results of elbow contracture release may be superior in patients with HO compared to those with non-HO posttraumatic fibrosis.[94]

Symptomatic functional loss of shoulder range of motion has not been a frequent problem in the authors' experience, particularly for amputations distal to the elbow. Some patients with short transhumeral amputations likely have markedly decreased shoulder range of motion secondary to a protracted time course of restricted mobility because of multiple surgeries or adjacent soft tissue injury. However, this is seldom if ever bothersome to the amputee; most transhumeral amputees who use functional prostheses seldom use them for overhead activities. For amputees with symptomatic loss of shoulder motion, we recommend standard arthroscopic releases followed by manipulation under anesthesia, soft tissue envelope permitting.[95] Patients in whom the shoulder girdle tissues are too compromised to permit arthroscopy would ostensibly be at dramatically increased risk of wound complications if an open procedure were attempted. Open release should therefore be reserved for patients with a reasonably intact shoulder soft tissue envelope and who fail an attempt at arthroscopic release and manipulation, due to extraarticular causes (eg, subscapularis contracture).

As with most complications, primary treatment of amputation-associated upper extremity contractures is prevention via early motion and therapy as soon after injury as soft tissue and osseous injuries permit. Unique considerations in upper extremity amputation contractures include compromised soft tissue envelopes, which may limit soft tissue healing and durability after operative treatment; shortened lever arms, which may make early passive and active-assisted therapy more difficult; and the patient's desire to return to early prosthetic fitting and use after surgery. Postoperatively, aggressive physical therapy and early return to regular prosthetic use is necessary to maintain operative gains and maximize ultimate patient function. Modalities such as indwelling postoperative nerve catheters, continuous passive motion, and static or dynamic splinting remain relatively unproven with regard to efficacy but can serve as useful adjunctive rehabilitation measures, particularly for patients in whom postoperative pain is too great or motivation too little.

MARQUARDT HUMERAL OSTEOTOMY

Successful prosthesis use by the unilateral transhumeral amputee is by no means guaranteed, despite the availability of the most advanced prosthetic technology and occupational therapy services. Many patients find single-limb strategies for activities of daily living preferable to using a transhumeral prosthesis, be it body-powered, hybrid, or myoelectric. Additionally, many transhumeral amputees who are regular prosthesis users utilize their prostheses only for very specific tasks, and may wear their limbs only for an hour or two per day, a couple of days per week. Among the common reasons cited by patients for low prosthetic use are prosthetic weight and limited functional range of motion. Many suspension systems utilize shoulder

caps that are hot and uncomfortable and can chafe and restrict motion. Likewise, suction suspensions on cylindrical residual limbs have limited resistance to torque in the axial plane.

In 1972 Marquardt[96] published a case report of a pediatric patient utilizing a new technique in which a distal angulation osteotomy was performed. He noted improved suspension with unrestricted shoulder motion and improved rotational control in flexion and abduction, giving a much larger functional range for prosthetic use. In 1974 Marquardt and Neff[97] published a case series of adults and children who had undergone the procedure, noting that, in addition to improved motion and control, the incidence of terminal overgrowth in pediatric patients was reduced by the procedure. With the angulation osteotomy, therefore, transhumeral amputation acquired most of the beneficial attributes of elbow disarticulation—without the limitations of external-hinge elbow units needed to keep relative arm and forearm length normal in the disarticulation patient.

The authors have used this technique in selected combat-related amputees. The ideal candidate is a successful prosthetic user who is dissatisfied with a shoulder cap suspension, or who needs greater range of motion or improved rotational control for specific desired bimanual tasks. Most of these transhumeral patients have undergone "length-preserving" amputations closed with nontraditional flaps, and an appropriate portion of the initial closure is utilized. The procedure is performed as a revision only. The risk of placing fixation hardware in these initially highly contaminated wounds is considered too high to be justified until the wound has declared itself and a rehabilitation problem has been identified. Utilizing a portion of the wound closure scar, a 5-cm portion of the distal humerus is exposed. Concomitant revision procedures such as neuroma or HO excision are performed as appropriate. A 70° wedge is then cut anteriorly, with the posterior periosteum preserved as a hinge, if possible. The osteotomy is then closed and fixed with a single 3.5-mm cortical screw placed in compression from distal to proximal (Figure 9-17). (This represents a deviation from Marquardt's original technique, which was performed through a separate posterolateral incision and fixed from proximal to distal.)

Postoperative management includes edema prevention, initially with figure-of-eight elastic wraps, and progressing to a stump shrinker as soon as the patient tolerates application. The patient is transitioned to a Silastic (Dow Corning Corporation, Midland, Mich) liner at about 2 weeks postoperatively. Prosthetic wear is resumed after 3 weeks to allow for early osteotomy healing. The authors have not encountered any problems with nonunion or loss of fixation by resuming

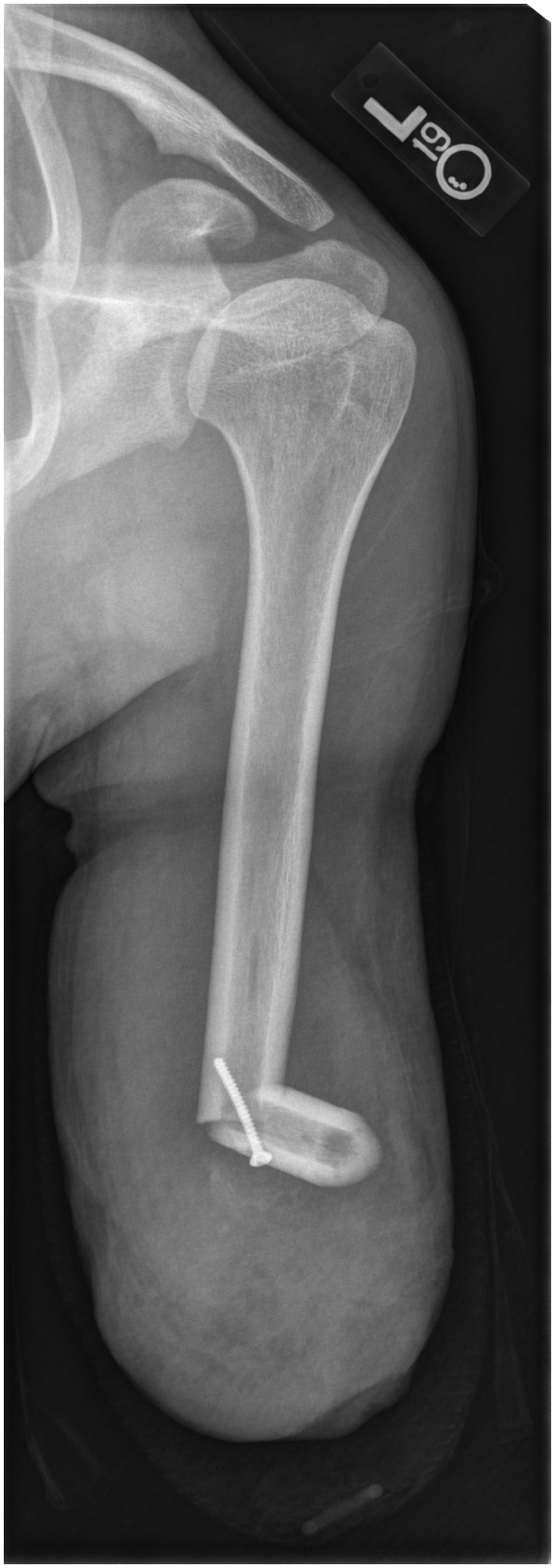

Figure 9-17. Anterior-posterior radiograph of a transhumeral amputee with a healed Marquardt angulation osteotomy.

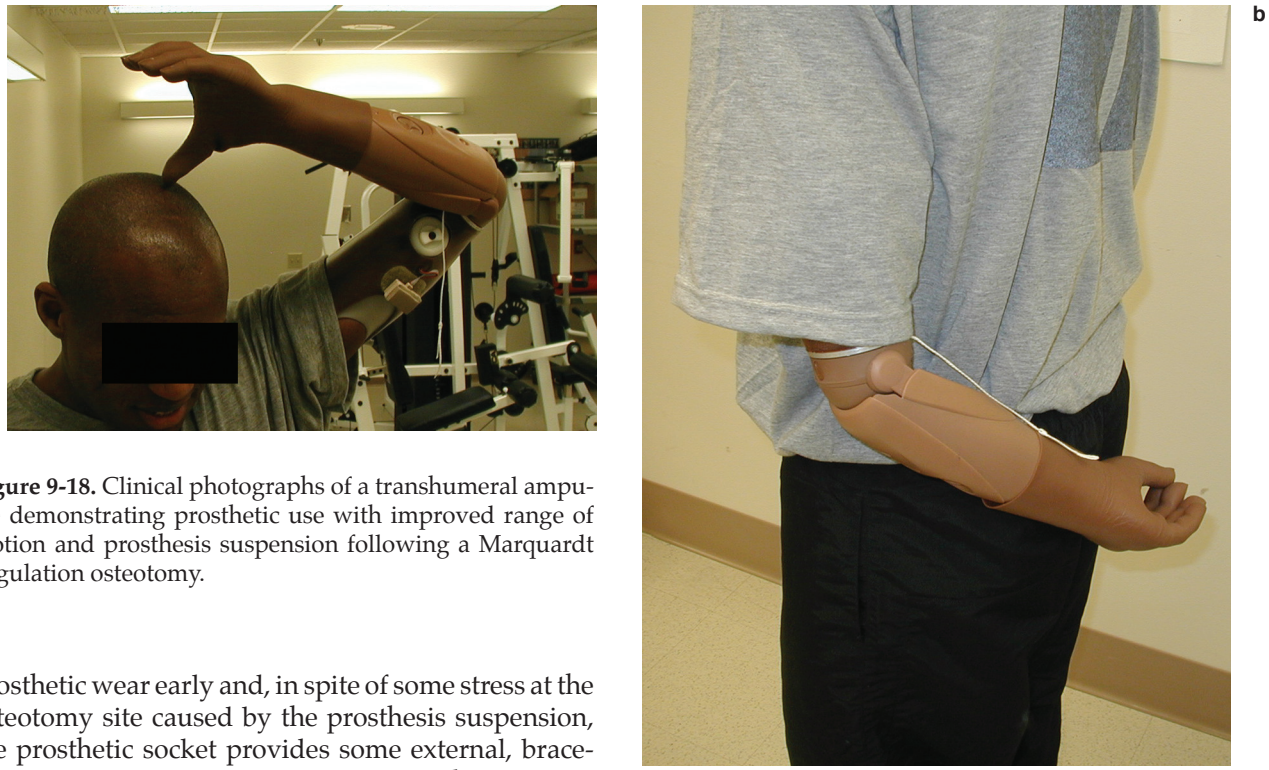

Figure 9-18. Clinical photographs of a transhumeral amputee demonstrating prosthetic use with improved range of motion and prosthesis suspension following a Marquardt angulation osteotomy.

prosthetic wear early and, in spite of some stress at the osteotomy site caused by the prosthesis suspension, the prosthetic socket provides some external, brace-like support. An unexpected benefit is that patients universally perceive a decrease in the weight of their prosthesis (Figure 9-18). We attribute this to the decrease in shear forces on the residual limb soft tissues. The weight of the prosthesis appears to be transferred to the bone, which is better able to tolerate it than the patient's often compromised soft tissues and skin.

Although the best suspension solution for the transhumeral amputee may be direct skeletal attachment (osseointegration), the Marquardt angulation osteotomy is a useful technique for certain patients until the difficulties of the prosthesis/skin interface and loosening associated with osseointegration are resolved.

KNEE INSTABILITY

The open, length-preserving amputation technique advocated in this textbook, with amputation frequently carried out through the ZOI, is sometimes associated with ligamentous injury to adjacent joints. Two recurrent clinical situations have presented in high-demand transtibial amputees that require ligament reconstruction or repair: (1) anterior cruciate ligament (ACL) deficiency and (2) the short residual limb with an unstable fibula. Although both can be successfully treated with standard surgical techniques, making the correct diagnosis can be challenging. In ACL deficiency, symptoms of "giving way" may be masked by problems with prosthetic fit, weakness, or gait training. The length of the residual limb may make it difficult to perform a Lachman maneuver, and make a classic pivot shift test nearly impossible to perform. Retained ferrous fragments may preclude or obstruct MRI. The symptomatic unstable fibula can be confused with other causes of lateral residual limb pain, such as peroneal neuroma. Careful physical examination, evidence of fibular splaying on plain radiograph, and peroneal nerve block in the thigh will assist in the diagnosis.

In the authors' experience, high-demand transtibial patients with ACL-deficient knees have not been satisfied with prosthesis modification, incorporating polyaxial hinges in the socket similar to current sports braces used to treat ACL-deficient athletes nonoperatively. Single-bundle ACL reconstruction, however, has had good results. Allograft bone-tendon-bone, Achilles, or tibialis posterior tendons are preferable in reconstructing the ACL-deficient knee in the transtibial amputee, rather than using autograft bone-tendon-bone or semitendinosis/gracilis from the ipsilateral or contralateral knee. Both lower extremities have frequently been severely injured, and the slight delay in incorporation of allograft outweighs the additional insult of autograft harvest. These patients are fitted with hinged, double-upright socket extensions fab-

ricated by prosthetists to protect the reconstruction for 12 weeks postoperatively, allowing early return to prosthetic use. Full weight bearing without ambulatory aides is allowed at 12 weeks, and running and cutting activities are permitted when the quadriceps and hamstrings are within 85% of the contralateral side by Biodex (Biodex Medical Systems, Shirley, NY) testing, usually at about 5 to 6 months.

Patients with extremely short transtibial amputations have achieved high-level functioning: many with amputations 2 or 3 cm distal to the tibial tubercle are runners, and several patients with these short transtibial amputations who have a contralateral transfemoral amputation are able to run and play cutting sports. The function achieved by these young men and women defies conventional wisdom, and speaks volumes about their courage and tenacity.

Some patients with short transtibial amputations, however, have painful, unstable residual fibulas. Frequently, this can be elucidated on physical examination or on plain radiographs. A residual fibula shorter than 5 cm should raise the suspicion that insufficient interosseous membrane remains for fibular stability. Patients with longer residual limbs who have fibular instability can be treated with revision to an Ertl-style amputation with a synostosis between the distal tibia and fibula, but this technique is not easily done in patients with short residual limbs. These patients respond well to fibular excision with repair of the posterolateral corner. In this procedure, the lateral collateral ligament (LCL) and biceps femoris tendon insertion are elevated as a sleeve and fixed to the lateral tibia with a screw and washer at the tibial facet of the proximal tibiofibular joint, after excision of the articular cartilage. The repair is protected for 6 weeks with a custom clamshell brace before range of motion and active strengthening against resistance are resumed.

If fibulectomy of a very short residual fibula is performed early in a patient's postinjury treatment to facilitate soft tissue closure and prosthetic fitting, the authors advocate securing the released biceps tendon and LCL to the isometric point on the residual tibia with periosteal sutures, suture anchors, or drill holes through bone. However, several early patients in whom this was not performed have not experienced symptomatic instability as a result. For amputees presenting with late LCL/posterolateral corner instability after early fibulectomy, allograft reconstruction using conventional techniques, securing the graft to the residual tibia via a biotendodesis screw, is a reasonable approach.

Elbow or shoulder instability above transradial or transhumeral amputations has not been a common problem in upper extremity amputees. Stiffness of these joints is a more common complaint, due to adjacent fractures, frequent proximate soft tissue injury, and the difficulty of performing early range of motion exercises above an often open or otherwise compromised residual limb. However, in the event that these issues are encountered, standard open and arthroscopic-assisted reconstructive techniques would be indicated.

INFECTION

Despite aggressive medical and surgical care (including serial debridements, judicious use of antibiotics, and local wound adjuvant therapies), as many as 20% to 40% of combat-injured amputees may develop deep infection requiring inpatient care or surgery following attempted definitive revision and closure.[10,98,99] Specific recommendations on point-of-injury care, antibiotic therapy, serial debridements, and the timing and technique of definitive closure for infection prevention are discussed in Chapter 8, General Surgical Principles for the Combat Casualty With Limb Loss. Additionally, combat casualties frequently become malnourished in the postinjury setting because of limited oral intake and high metabolic demands. Nutrition has been repeatedly demonstrated to play a critical role in the wound-healing potential and immunocompetence of diabetic and dysvascular amputees,[100] and the importance of adequate and supplemental nutrition cannot be overemphasized in the care of combat-injured personnel as well.

Given the demonstrated high incidence of early and/or late infectious complications in combat-related and traumatic amputations, appropriate counseling on patient expectations is critical. The probability and likelihood of infection requiring further antibiotic and/or operative treatment should be discussed with patients and families *before* an infection develops so that the psychological and physical setback of an infection, should one develop, is preemptively tempered. Similar to the portrayal of the amputation itself as a reconstructive procedure (rather than an ablative procedure or necessarily a failure of salvage treatment), viewing infection in this setting as an unfortunate but frequently necessary step in the rehabilitative process can prevent both patient and clinician from becoming unnecessarily discouraged.

Once an infection develops, important treatment information can be inferred from both the timing and apparent chronicity of the process. Infections in residual limbs should thus be classified as early (< 6

weeks from closure) or late, and further classified as acute or chronic. The latter distinction is influenced by the duration and type of symptoms or a history of prior infection with the same organism, and frequently this determination cannot be made until after the initial operative debridement permits direct inspection of deep tissues and operative cultures. Acute infections typically present with more fulminant collections of purulence and wound drainage, whereas chronic infections are generally less virulent and may involve well-formed abscesses or slow, gradual destruction of deep tissues or bone. Early infections typically result from bacteria already present and active within the residual limb at the time of definitive closure. Late infections may result from reactivation of a latent process dormant in the deep tissues for long periods, hematogenous seeding of persistent or new fluid collections, or extension of cutaneous infections aggravated by prosthetic wear (eg, cellulitis or folliculitis). Most early infections are acute and most chronic infections are late, but this is not always the case. The timing and chronicity of the infection, as well as the virulence and antibiotic susceptibility of the organism or organisms, are important in determining the need for operative irrigation and debridement, as well as the duration and type of antibiotic therapy. All types of residual limb infections may require one or more operative debridements, but relatively shorter durations of antibiotic therapy are typically required for early, acute infections.

The history and physical examination of a patient with an infected residual limb should include reassessment of mechanism and ZOI, history of prior infections, chronologic relationship with wound closure and prosthetic use, and systemic symptoms, as well as recent exposures, procedures, and antibiotic use. In the authors' experience, most patients with early or acute infections present with a febrile history, but (as is the case in chronic osteomyelitis)[101] fever is less reliably present in late, chronic infections. Patients with focal pain and swelling and symptoms associated with a recent change in activity or prosthesis should have bursitis included in their differential diagnosis. This distinction is important because the treatment of bursitis, particularly aseptic bursitis (discussed in greater detail in the following section), differs substantially from that for abscesses and deep wound infections.

When infection is present, most patients present with an erythematous, swollen, and painful residual limb, with difficulty or inability to tolerate prosthesis wear. The presence or history of a draining sinus should be noted and is strongly suggestive of chronic deep infection (Figure 9-19). Likewise, the presence, quantity, and quality of recent incisional wound drainage should be assessed and noted (Figure 9-20). Any palpable fluid collections should be assessed for size, location, tenderness, transillumination, and fluctuance. Routine culture of sinus tracts or draining incisions is not advocated because the results of these cultures are frequently polymicrobial and unreliably indicative of the actual infecting organism.[101,102] If complete evaluation (including laboratory values and imaging studies) is strongly suggestive of infection versus bursitis, bedside aspiration of small palpable fluid collections under sterile conditions is reasonable in the rare instance that this may obviate the need for operative intervention; however, in most cases abscesses should be treated surgically, and multiple operative tissue cultures are preferred to bedside aspirates even under optimal circumstances.

All patients should undergo laboratory evaluation consisting, at a minimum, of blood cultures, complete blood count with manual cell differential, and inflammatory parameter (Westergren erythrocyte sedimentation rate and C-reactive protein level) assessment. Orthogonal radiographs of the residual limb should be obtained with particular attention to soft tissue swelling, osseous changes or new interval bone destruction, and HO. Although the relationship

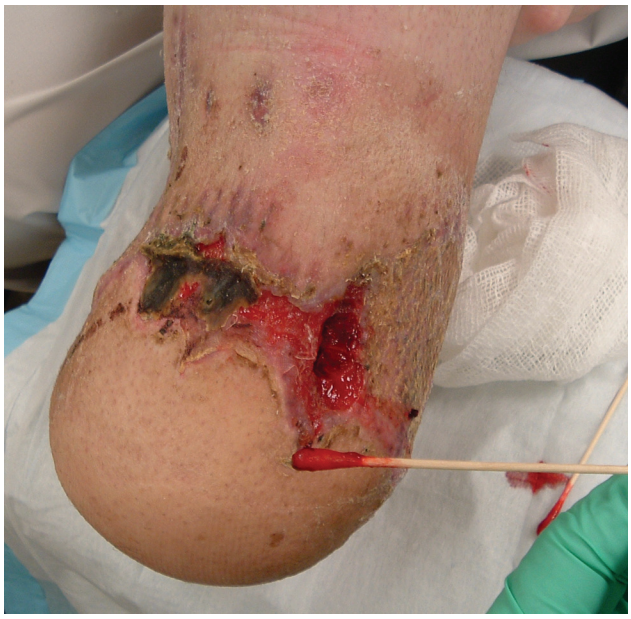

Figure 9-19. Clinical photograph of a transtibial amputation complicated by superficial skin necrosis, eschar formation, and a large draining sinus that probed to bone. The limb was salvaged with serial irrigation, debridements, and vacuum-assisted closure dressing changes followed by delayed split-thickness skin grafting after the excised sinus tract had granulated appropriately.

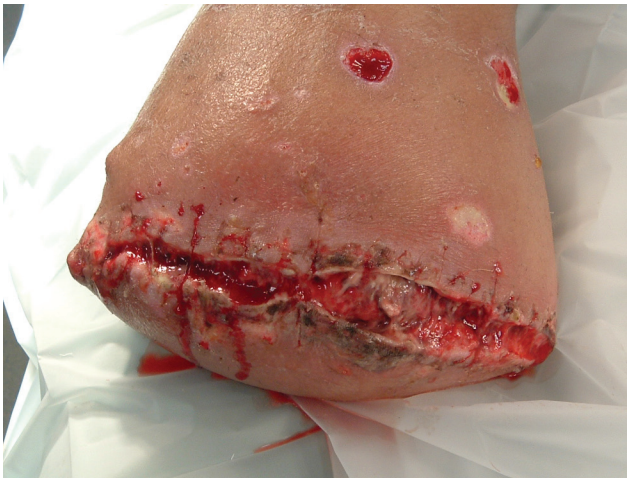

Figure 9-20. Intraoperative photograph of a bilateral transtibial amputee with a deep infection of the right residual limb. Abundant purulence and necrotic tissue is present along the incision line, which dehisced following intraoperative suture removal. The infection was eradicated with two irrigation and debridement procedures with concomitant antibiotic-bead and vacuum-assisted closure dressing use followed by closure over a drain and 2 weeks of parenteral antibiotic therapy.

with infection remains unclear, a high percentage of resected HO specimens from combat-related amputations are culture-positive.[10,102] Advanced imaging modalities are not frequently required, but in patients with equivocal findings, MRI, ultrasound, and indium-111 tagged white blood cell scans can provide useful information.[13,103–105] Isolated technetium-99 three-phase bone scans can remain positive for a prolonged period following revision and closure and may never return to normal in residual limbs due to osseous stress reactions from prosthesis wear,[103] and therefore are generally less helpful in the absence of a paired indium scan.[104,105]

Most residual limb infections should be initially managed with hospital admission. For patients without abscess, fluid collection, or overt wound drainage or draining sinuses, initial treatment should consist of parenteral antibiotics, elevation, adjacent joint and complete prosthetic rest, and continued use of compressive shrinker stockings. Operative intervention should be withheld pending failure to appropriately respond to these conservative measures. Toward this end, patients should be kept non per os (NPO) after midnight for the first 1 or 2 days of admission pending treatment response. This can assist in expediting operative treatment when required, and patients responding appropriately can resume a normal diet without missing any meals following reassessment on early morning rounds.

Patients with active drainage or fluid collections generally require early operative exploration with formal tissue cultures and thorough irrigation and debridement. In these instances, to maximize culture accuracy and yield, empiric antibiotic therapy should be withheld until operative tissue cultures are obtained. When possible, prior surgical incisions and scars should be utilized, but draining sinuses should be excised and some superficial abscesses distant from other incisions are best managed with a direct longitudinal approach, local anatomy permitting. All purulent material and nonviable tissue should be removed and the wound should be thoroughly irrigated. Mixed data regarding the efficacy of gravity, bulb syringe, and pulsatile lavage irrigation preclude a recommendation of a specific irrigation technique,[106–108] which remains a matter of surgeon preference.

Although some patients can be adequately treated with a single irrigation and debridement, closure over a surgical drain, and subsequent systemic antibiotic therapy, the authors prefer a staged approach for most patients. Wounds should be managed in a provisional closure or open fashion, and a return to the operating room for a second look planned. This is performed 2 or 3 days following the initial procedure and permits reassessment of compromised tissue and overall wound status after operative culture speciation and antibiotic susceptibilities have been completed, permitting appropriately tailored subsequent antibiotic therapy. Consultation with an infectious disease specialist is helpful in deciding which antibiotic to use, as well as in determining duration of therapy and monitoring for side effects of antibiotic treatment. Patients who are systemically ill or have locally aggressive infections may require early return to the operating suite within 24 hours. Likewise, patients with ongoing tissue destruction on repeat irrigation and debridement may require further serial irrigation and debridement procedures until the infection is controlled.

In addition to narrowing the antibiotic spectrum while avoiding undertreatment of resistant organisms, a staged approach to infection management may also allow for judiciously less aggressive initial debridement in patients with marginal soft tissue coverage or preexisting suboptimal residual limb length. As a general rule, patients and limbs are best served with eradication of infection via aggressive debridement. In rare instances substantial shortening of the residual limb or even revision to a higher level may be required to both control infection and permit reconstruction of an adequate soft tissue envelope to allow high-demand prosthetic use. Issues of possible limb shortening should be carefully discussed with the patient preoperatively.

A number of local wound adjuncts are available to assist in the staged management of infected residual limbs. Developed in World War I, Dakin moist-to-dry dressing changes are useful for provisional wound management in patients with superficial wounds and others able to tolerate frequent bedside dressing changes. The solution has strong antimicrobial properties without excessive untoward effects on healthy patient tissues, and has been used to good effect in both recent and historical combat-related wounds.[109,110] In some cases of small, superficial abscesses, healing by secondary intention with serial Dakin dressing changes is a reasonable course of action. Subatmospheric pressure VAC dressings encourage vascular ingrowth and granulation tissue formation while removing excess fluid from the wound, reducing soft tissue edema, and preventing excessive soft tissue retraction. These devices also obviate the need for frequent dressing changes and have been utilized with good temporizing and, in some cases, definitive wound management results in both the authors' experience and in the recent open fracture literature.[111–113]

Antibiotic-impregnated polymethylmethacrylate beads achieve supratherapeutic bacteriocidal local antibiotic concentrations with minimal systemic effects and have been utilized with good success in both arthroplasty and fracture-related infections.[114–116] The beads may be placed deep to VAC dressings, in open wounds under an occlusive dressing, or inside provisionally closed residual limbs. A relatively large number of heat-stable antibiotics have been utilized successfully with bone cement, allowing microbe-specific local therapy. Finally, silver-impregnated antimicrobial dressings may be utilized alone or in combination with the aforementioned techniques. These dressings have been repeatedly demonstrated to have good local antimicrobial properties,[117,118] but reports of their use are lacking in the orthopaedic literature. In the authors' experience, antibiotic-bead–associated exudate and silver residue may need to be irrigated from the wound at the time of the repeat procedure prior to wound assessment. Each of these modalities, used appropriately, may putatively assist in the local control of infection in residual limbs. Although useful in infection control, they should not be viewed as a substitute for adequate debridement, voluminous irrigation, and systemic antimicrobial therapy.

Regardless of the adjuvant wound treatments used, it is prudent to provisionally tag critical structures (eg, released myodesis tendons, skin, and muscle flaps) with monofilament suture and secure them near their intended final locations between staged infection control procedures. This prevents excessive retraction, fibrosis, and scarring, which may make definitive revision and closure of the infected residual limb difficult or impossible days or weeks later. Maintaining as much residual limb length as practical following infection treatment is desirable, but when necessary, freshening the terminal bone end with an oscillating saw and redrilling myodesis holes is useful in achieving satisfactory coverage and closure. Skin closure of previously infected wounds should be performed with nonabsorbable monofilament suture over a closed suction drain and a compressive dressing applied. Drains should be left in place for 1 to 3 days depending on quantity and quality of output and then removed at the bedside. Dressings should be changed daily starting on postoperative day 2, and wound status closely monitored for evidence of recurrent infection. Patients should be transitioned back to compressive shrinker stockings as soon as wound drainage, patient comfort, and edema permit. Sutures should be removed at 2 to 3 weeks postoperatively, after adequate initial wound healing has been achieved and infection-related swelling has subsided. Patients can then be allowed to gradually resume prosthetic fitting, wear, and rehabilitation. Close clinical follow-up is required for several weeks up to and after the completion of systemic antibiotic therapy to monitor for recurrence of infection. As noted, the duration, type, and route of long-term antibiotic therapy are best determined in consultation with an infectious disease specialist.

BURSITIS

Bursitis is a common and likely underreported problem in the residual limbs of amputees with functional pain, especially that which waxes with prolonged prosthetic use and wanes with subsequent rest.[13,119] It can be a disabling and recalcitrant problem in residual limbs, and its treatment can be a matter of great frustration for patient, prosthetist, and physician alike. By definition, synovial (or true) bursae are formed in utero over tendinous or osseous areas of friction or dissimilar motion. In contrast, adventitious bursae develop postnatally within superficial connective tissues in response to chronic pressure, irritation, and friction. This latter group accounts for the majority of bursae within residual limbs. When these bursae are serially exposed to external stresses that exceed the physiologic tolerance of the involved tissues, they may become inflamed and bursitis results. In the residual limbs of amputees, the majority of symptomatic lesions develop in the subcutaneous tissues, but deep bursitis can develop between a patient's myodesis and the

adjacent terminal bone end as well.

Fluid collections are exceedingly common in the early postoperative period following elective amputation or definitive revision and closure of open residual limbs.[120] The majority of these collections undergo biologic resorption and resolve spontaneously. Prior to initiation of regular prosthetic training and rehabilitation, these perioperative collections are unlikely to represent bursae and should be considered hematomas, seromas, or abscesses until proven otherwise. After initial prosthetic fitting and rehabilitation have commenced, a bursa may develop under any area of increased friction or pressure within or near the edge of the prosthetic socket.

Treatment of bursitis begins with prevention. Amputation and wound closure techniques are discussed elsewhere and are therefore beyond the scope of this section. However, bursitis may develop due to either inadequate or redundant mobile soft tissue coverage of a terminal residual limb or bony prominence. Hence, both should be avoided. Likewise, problems with prosthetic alignment, fitting, padding, or suspension may incite or aggravate bursitis and require due diligence on the part of both patient and prosthetist to avoid inadequate prosthetic modifications. Once formed, asymptomatic bursae should be considered part of a normal adaptive physiologic response and do not necessarily require treatment, but socket and liner modifications may be considered to reduce friction in these areas and decrease the potential for bursitis to subsequently develop.

Potential conundrums in bursitis management begin with the frequently difficult diagnosis. The chief differential diagnoses in symptomatic patients include aseptic bursitis, septic bursitis, abscess, and cellulitis. Aseptic bursitis is thus notoriously difficult to distinguish from infection.[121–123] The medical history should include focused questioning about recent changes in activity or wear of the prosthesis or to the prosthesis or liner itself. The duration of symptoms, presence of any constitutional symptoms or fever, and relationship of these to prosthetic wear should be elucidated.

On physical examination, the degree of tenderness, fluctuance, erythema, transillumination, and relative cutaneous warmth[122] of the affected site can be helpful in distinguishing aseptic, mechanical bursitis from septic bursitis or abscesses. A complete blood count with manual cell differential and inflammatory parameters may provide reassurance on the diagnosis of aseptic bursitis or, conversely, guide more aggressive diagnostic and therapeutic modalities for a probable infectious process. Orthogonal radiographs of the residual limb should be obtained, with attention to cystic degeneration of bone, bone spurs, or HO deep to the symptomatic bursa. Advanced imaging modalities (including ultrasound, MRI, and technetium-99 bone scans) have been advocated.[13,119] However, the appreciation of a fluid collection with adjacent edema is expected, and reciprocal osseous changes may occur in the absence of a septic process; therefore, the utility of these studies in cases of suspected bursitis is limited in the absence of a florid deep infection or overt osteomyelitis.

Diagnostic or therapeutic aspiration should be performed only if sufficient clinical suspicion of septic bursitis or abscess persists following the initial evaluation. There is little evidence that aseptic bursitis outcomes are improved with aspiration alone, and the potential exists for cutaneous fistula formation or bacterial contamination and creation of iatrogenic septic bursitis. Aspiration should therefore not precede more conservative measures in aseptic bursitis patients. At minimum, Gram stain, bacterial cultures, and cell count with differential should be sent from any aspirate.[123,124] If adequate fluid is obtained, additional studies worthy of consideration include aspirate protein, glucose, and lactate dehydrogenase, with corresponding serum levels. Confirmed cases of septic bursitis or abscess should be managed with empiric and subsequently culture-specific antibiotics. The determination of initial intravenous versus oral treatment is predicated upon the severity of the infection and the patient's clinical status. However, when in doubt, initial intravenous therapy with conversion to oral treatment following a positive clinical response is reasonable. The decision to proceed to the operating suite for formal irrigation and debridement of septic bursitis depends on the adequacy of the aspiration and the initial response to antibiotic treatment. Frank abscesses generally require operative intervention for adequate treatment and evacuation.

For cases of suspected aseptic bursitis, initial treatment is conservative and should generally not include antibiotic therapy. Although complete resolution of inflammation and symptoms may require a prolonged period, failure to see tangible early and stepwise improvement within a few days should alert the clinician to a possible underlying infectious process and prompt further evaluation. Conservative treatment should consist of complete prosthetic rest and the required activity modifications, continued compression stocking wear, elevation, ice, and nonsteroidal antiinflammatory medication. Concurrently, investigation should continue in an effort to identify and modify any prosthesis- or activity-related inciting factors. Failure to do so will result in probable and predictable future recurrence of bursitis. Toward this end, particular attention should be paid to relieving pressure and

friction over the involved area and prevention of limb pistoning. As symptoms become quiescent, prosthetic wear may gradually be resumed.

For patients with recurrent or refractory aseptic bursitis, further treatment is required. Invasive treatment should be considered only after repeated and exhaustive efforts at prosthetic modification have been completed. Although the results of injection or operative treatment of bursitis are frequently gratifying, the potential complications can be disastrous.[121,123–126] The success of aspiration in aseptic bursitis has been demonstrated only when utilized concurrently with other conservative measures,[123] and only anecdotally noted in amputees.[119] Conversely, corticosteroid injection, while found effective in a small randomized trial of olecranon bursitis patients,[125] may result in atrophy of overlying fat and soft tissue, which is particularly undesirable in amputees with suboptimal soft tissue coverage. Steroid injection is therefore advocated only in patients with a robust soft tissue envelope, and simple aspiration should be the initial invasive treatment of others. Complications of aspiration and injection include tissue atrophy, iatrogenic infection, needle track fistulas, and recurrence of bursitis.

Operative treatment of aseptic bursitis is even more contentious. The difficulties in treating nonamputees with more typical olecranon and prepatellar bursitis have been well documented. Amputees must eventually resume prosthetic wear and, in spite of the benefit of prosthetic modifications, place direct pressure and/or shear on their previously symptomatic sites. This complicates treatment further and may predispose amputees to recurrences in spite of initially successful treatment. Therefore, the authors do not advocate surgical bursectomy for aseptic bursitis in the absence of concurrently modifiable external (eg, prosthesis or activity) or internal (eg, bone spur or HO excision) factors. Regardless of operative technique, completeness of excision, and avoidance of complications, failure to identify and address these factors will reliably lead to early symptomatic recurrence.[121]

Once operative drainage and bursectomy are considered, a preoperative plan should be formulated accounting for the location of the bursitis, the patient's soft tissue envelope, and preexisting surgical incisions, scars, and skin grafts. In contrast to abscess drainage, incisions directly over the involved bursa are ill-advised. Such incisions violate already compromised soft tissue in an area of known chronic irritation and stress, and may be more prone to chronic drainage as well. Therefore, the patient's prior incisions should be utilized when practicable, avoiding skin grafts and flaps if possible. If the local anatomy renders this approach infeasible, a longitudinal incision adjacent to, but not immediately overlying, the involved bursa is recommended. A complete bursectomy should be performed without causing undue damage to uninvolved tissue, and the use of a surgical drain strongly considered. Using these techniques in nonamputees, most authors report favorable results in over 90% of patients,[123,124,126] but wound drainage problems and recurrences in up to 27% and 22% of patients, respectively, have been reported.[121] Endoscopic bursectomy has been reported with limited favorable results but cannot be advocated for routine use in amputees on the basis of the available evidence.[127]

SKIN PROBLEMS

The traumatic amputee who becomes a successful prosthesis user is likely to face lifelong challenges at the skin-prosthesis interface. The skin is subject to many stresses and factors unique to an enclosed and superficial environment. Modern socket liners and suspension have made tremendous progress toward eliminating many of these challenges. However, the surgeon is occasionally called to address issues ranging from wound healing to infections, and even flap failure early in the rehabilitation process. Late sequelae can also occur, such as verrucous hyperplasia, epidermoid cysts or suture abscesses, contact dermatitis, chronic drainage, and even the unlikely development of squamous cell carcinoma after many years of draining sinus tracts or chronic irritation from the prosthetic socket.[128] Most of these conditions, and even more transient problems like hyperhidrosis, terminal limb edema, callus formation, folliculitis, hidradenitis, and fungal infections, can be successfully managed nonsurgically by a skilled team including the therapist, prosthetist, physiatrist, dermatologist, and surgeon.

When the combat amputee eventually undergoes definitive wound closure, it is nearly universal to experience terminal edema. While routine management includes carefully applied dressings and subsequent shrinker appliances, this edema generally resolves once the patient begins socket wear. Whenever a socket is removed for prolonged periods of time edema can return and must be managed accordingly. Over the first several months edema generally stabilizes to a steady state and rarely requires treatment. Similarly with socket wear, issues like hyperhidrosis and maceration improve with hygiene, stump sock use, and, infrequently, topical application of drying materials. The treating physician should regularly monitor for fungal infections or contact dermatitis associated with

chronic maceration or reaction to chemicals associated with socket manufacture.

Another condition often associated with prosthetic fit, underlying vascular injury, or chronic bacterial infection is verrucous hyperplasia (Figure 9-21). Verrucous hyperplasia, in keeping with its nomenclature, has a wart-like appearance, often in areas of limited socket contact. While the condition poses superficial hygienic challenges, and pain when associated with skin breakdown, it is best managed with shrinker socks, or socket modification that equalizes the contact pressures throughout the limb.

Chronic conditions that often require surgical intervention are not common. One such condition is an epidermoid cyst, a pocket or invagination of keratin-producing cells, either as a result of overgrowth at the margin of the original amputation incision, or from the original wound closure. These cysts present as localized masses, intermittently draining or painful, and should be excised when recurrent.

Another condition, related to chronic recurring draining fistulae or sinus tracts but reported in amputees with recurrent skin breakdown, is squamous cell carcinoma or Marjolin's ulcer. This condition typically presents years or decades after the original trauma, and is always heralded by a new-onset painful, often malodorous, ulceration at the site of a recurrent sinus tract.

Finally, many combat amputees lack adequate soft tissue coverage to permit closure of native myofascial layers and skin over their terminal residual limbs. Techniques to avoid this problem, including length-preserving initial amputation, subatmospheric pressure dressing use, skin traction, and creative skin flap creation, were discussed earlier. Nonetheless, some patients require split-thickness skin grafting to achieve definitive closure and coverage. Particularly in the lower limb, these grafts may not physiologically withstand high-demand prosthesis use (Figure 9-22). For this reason, somewhat thicker than typical split-thickness skin grafts are advocated. Although the treatment process is lengthened by this intervention and the authors have only anecdotal experience in amputees, in cases of profoundly deficient subcutaneous tissue, dermal substitutes, commonly utilized in burn patients, can be a useful means to achieving an increased thickness of collagenous tissue between prosthesis liner, skin, and bone.[75] Patients experiencing recurrent breakdown of necessary skin grafts are best managed with a truly exhaustive series of conservative measures, including activity, liner, and prosthesis modification. In rare instances, edema subsidence or underlying HO excision may permit delayed skin graft excision and closure with native skin. Some patients, particularly transfemoral amputees with relatively

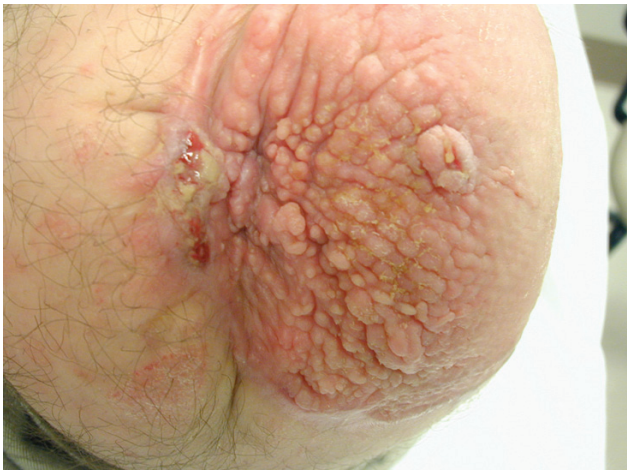

Figure 9-21. Verrucous hyperplasia in a 22-year-old soldier, 18 months after definitive prosthesis. Note the maceration and fissuring within the invaginations.

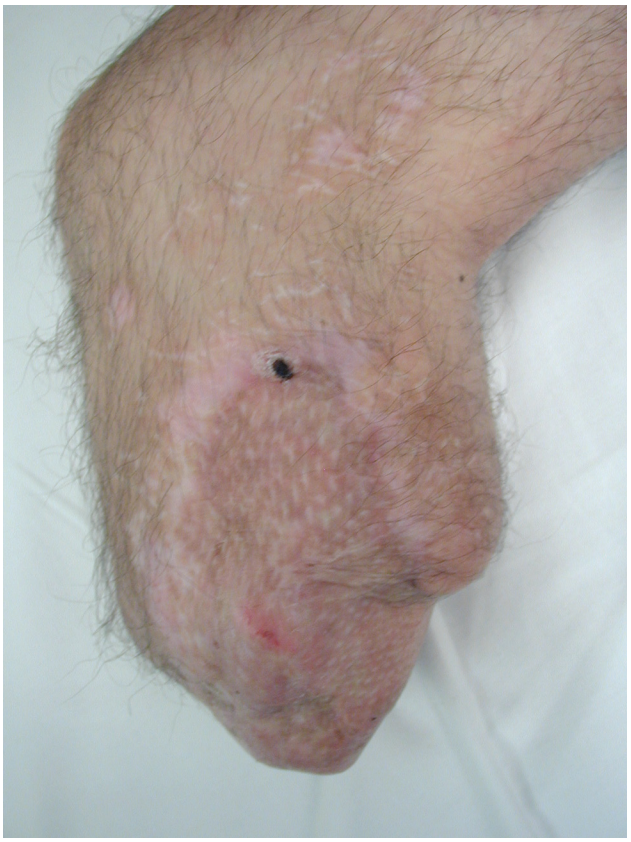

Figure 9-22. Clinical photograph of a transtibial amputee with recurrent skin breakdown of a terminal split-thickness skin graft complicated by underlying heterotopic ossification.

more adjacent soft tissue, may benefit from plastic surgery consultation and tissue expander use. However, most cases requiring operative treatment will ultimately require free tissue transfer, residual limb shortening, or even revision to a higher level.

Skin conditions are common and require awareness and management with a multidisciplinary approach. Although the majority of these conditions can be successfully managed without surgery, the surgeon may encounter them in the normal postoperative phase and must be prepared to recognize them to direct appropriate management.

CONCLUSION

The surgical management of the combat-related amputee, and amputations in general, remains an elusive and constantly evolving art and science. This chapter and the previous one represent a summary of both the best available published evidence on specific techniques and the sum of the authors' combined clinical experiences in managing hundreds of amputees from the current conflicts in the global war on terrorism. Although specific techniques, such as osseointegration and target nerve transfer or reinnervation, as well as the development of newer and better modern prosthetics, may alter the art of amputation management in future years and conflicts, the general principles described are intended to guide the treating surgeon in making the best operative (and nonoperative) treatment decisions possible for each uniquely complex case and patient. Adherence to these often timeless and proven techniques and principles, coupled with creative thinking, a current knowledge of the available literature, and frequent consultation with experienced peers, will help to ensure the optimal results for both surgeon and patient.

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