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CHAPTER 40. Lower Extremity

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INTRODUCTION

Lower extremity injuries represent the primary cause of more than half of all hospitalizations for trauma. Their frequency, severity, and costs emphasize the impact of those injuries on society.[1,2] Lower extremity fractures may be caused by either low- or high-energy forces and occur both in isolation and as multiple injuries. The mechanism of injury defines the specific individual fracture pattern. Typical trauma mechanisms include blunt versus penetrating trauma, low-energy versus high-energy forces, twisting, bending, or crushing forces. Significant lower extremity injuries compromise functional outcome and can lead to long-term pain, abnormal gait, degenerative joint disease, chronic infection, and limb loss.

Dislocations of the hip, knee, or more distal joints, as well as displaced fractures, may cause pressure on nerves, vessels, or skin, resulting in permanent deficits. Delay of more than a few hours in reducing a dislocated hip significantly increases the risk of avascular necrosis of the femoral head. Displaced intracapsular femoral neck fractures also have a high risk of avascular necrosis, which can be lowered by urgent reduction and fixation. In young patients, this injury may appropriately be considered as an “ischemic surgical emergency.” Failure to recognize an undisplaced fracture of the femoral neck may result in its displacement, with a much greater likelihood of poor outcome. Open fractures of the lower extremities are true emergencies, requiring a timely surgical treatment to minimize the risk of infection and limb loss.

The wide prevalence of safety belt usage and mandatory airbags in vehicles leads to an increased number of survivors of high-energy crashes, who consequently suffer from a higher severity of lower extremity injuries. Any trauma victim involved in a high-energy trauma mechanism may have associated potentially life-threatening injuries to the head and torso. Thus, the initial evaluation of lower extremity fractures must focus on the patient as a whole, and not focus exclusively on the injured limb.[3–5] The concept of “damage control orthopedics” (DCO) was established based on the principle that prolonged early definitive treatment of long bone fractures can be detrimental for severely injured patients who are in unstable physiological conditions.[6,7] In these patients, the early mitigation of the “lethal triad” of persistent metabolic acidosis, hypothermia, and coagulopathy represents the prime goal for survival.[4] The controversial concept of “limb for life” entails the early amputation of a mangled lower extremity in critically injured patients with the aim of increasing the likelihood of survival. The ideal timing and modality of long bone fracture fixation in multiply injured patients, particularly in presence of severe head or chest trauma, represents another controversial topic of debate related to the care of lower extremity injuries.[3,8]

A relatively recent concept in lower extremity fracture care is that the majority of fractures can be treated entirely or in part with minimally invasive fixation. The evolution of techniques for percutaneous reduction and fixation of fractures, coupled with technological adaptation of fracture implants, has completely revolutionized fracture fixation.[9] While intra-articular fractures usually require some form of open reduction to restore articular congruity, most diaphyseal and metaphyseal lower extremity fractures can be treated with minimally invasive surgery. The decreased blood loss, lowered risk of infection, and increased rate of healing likely have positive implications for the injured patient with lower extremity fractures.

HISTORICAL PERSPECTIVE

Orthopedic surgery has developed through the need to alleviate pain, correct deformity, and restore function following fractures. Evidence of splinted fractures and the first successful amputations dates as far back as the fifth Egyptian Dynasty, about 4,500 years ago. The *Corpus Hippocrates* described the principles of traction, countertraction, and external fixation. Surgeons have built on these past foundations with the advancement of technology. In England, Thomas described the traction splint that still bears his name. In France, Malgaigne described the external fixator, and Delbet reported use of a weight-bearing cast for tibial fractures. In the United States, Buck described skin traction, while Steinmann in Switzerland and Kirschner in Germany introduced skeletal traction. Another German, Küntscher, made many contributions to modern intramedullary nailing. In Austria, Böhler established hospitals devoted to the care of injuries and published a comprehensive text on fracture surgery. Lambotte, a Belgian, is the father of modern internal fixation, which was advanced further by his countryman, Danis, who demonstrated that rigid fixation could result in direct bone healing without callus formation. The Swiss-based “Arbeitsgemeinschaft für Osteosynthesefragen” or “Association for the Study of Internal Fixation” (AO/ASIF) was founded in 1958 by a group of Swiss surgeons to produce and disseminate a system of fracture care based on stable fixation with preservation of soft tissue, active motion, and functional rehabilitation.[10] This association has earned itself a worldwide reputation as an international authority in the treatment of trauma through its continuing research and development of instrumentation. Further advances continue, with emphasis on indirect reduction techniques, closed or minimally invasive fracture fixation, and stable but less rigid fixation that promotes rather than suppresses indirect, callus-dependent healing of bone.[9]

At about the same time in the Soviet Union, Professor Ilizarov, working in the Siberian town of Kurgan, developed and refined the concept of distraction osteogenesis, permitting healthy de novo bone to be created in vivo through distraction with a ring external fixator system with Kirschner-type wires. His work led to significant advances in the use of external fixators as definitive treatment for a variety of traumatic injuries and post-traumatic complications.

The increasing ability of orthopedic surgeons to obtain early fracture stability with relatively low complication rates has led to improvements in postinjury rehabilitation. Rehabilitation concepts have changed from the prolonged rest suggested by Thomas to the present emphasis on rapid restoration of skeletal stability that allows for prompt mobilization of injured extremities and patients. Early weight bearing is encouraged, whenever possible to promote bone healing and overall physiological restoration. Detailed knowledge of a patient’s musculoskeletal injuries, his or her treatment, and his or her response is crucial for appropriate decision making in both the acute and late phases of care. Therefore, the orthopedic surgeon should ideally be directly involved from the trauma bay to the entire recovery process.

PATHOPHYSIOLOGY AND BIOMECHANICS

Fractures occur when the applied load to the bone exceed its load-bearing capacity. Fracture patterns relate to bone strength and the forces that cause the injury. Young, active individuals have strong bone. Children’s bones can undergo plastic deformation and may bend without breaking. Elderly, osteoporotic individuals have diffusely weak bone. Focal bone defects may weaken a bone so significantly that it fails under a load that would normally pose no problem, resulting in a pathologic fracture. Such pathologic fractures may be due to tumor, infection, or dysplasia, as well as more generalized conditions that severely weaken bone, such as osteoporosis. The amount of energy that produced a given fracture is suggested by the patient’s history and the fracture pattern. Comminution (the presence of more than two fracture fragments) implies a higher-energy injury that will produce multiple fracture lines. Displacement and the extent of local damage to soft tissue also reflect the amount of absorbed energy. Spiral fractures are produced by indirect, torsional forces. Less local soft tissue damage is generally present, but a very comminuted spiral fracture may have required such force that each fracture fragment acted as a high-velocity "internal missile," producing significant damage in the surrounding tissues. Transverse fractures are caused by directly applied forces. A wedge or "butterfly" fragment is often seen on the side of the bone where the fracturing force was applied as a result of local compression, while the opposite cortex fails transversely in tension.

MECHANISM OF INJURY

Obtaining a thorough patient history provides the physician with useful information to begin forming a list of differential diagnoses in his or her mind prior to radiographic examination of the patient. The history should specify the mechanism of injury, provide information regarding the severity of the applied forces, and alert the physician to associated injuries, illness, or medically relevant problems. While an accurate history may be difficult or impossible to obtain initially in a seriously injured patient, more details should always be sought and reconfirmed as the patient improves or more information becomes available. The history may be particularly helpful in managing open fractures by providing information on the following: the identification of the source and extent of contamination, the time elapsed from the moment of injury, and whether bone was initially protruding from an extremity wound.

A history inconsistent with the extent of injury suggests either a pathologic fracture or the possibility of abuse. A normal child, particularly under 2 years, should not fracture his or her femur while playing, even roughly, with a friend or parent. An elderly patient will not normally sustain a hip fracture from turning over in bed. Although pathologic fractures should be suspected in a patient with known malignant or metabolic disease and can be preceded by local pain, fractures may occur in completely asymptomatic patients as the initial presentation of an underlying disorder. In a young child, multiple fractures at various stages of healing are pathognomonic of child abuse, the diagnosis and appropriate management of which may be lifesaving. The report of pain or impaired function of an extremity requires careful evaluation to exclude a fracture or injury to a joint, nerves, muscles, or vascular structures.

CLINICAL ASSESSMENT

Examination according to the Advanced Trauma Life Support (ATLS®) protocol provides a systematic method of thoroughly examining the trauma patient and minimizing missed injuries.[4,11] In addition, the importance of continuous detailed documentation of the physical findings cannot be overemphasized. Assessment of patient progress may suffer due to a lack of reexamination and thorough documentation. Local tenderness at a fracture site may be masked or completely absent in a severely injured patient. Deformity, swelling, or both almost inevitably occur with fractures or dislocations of the lower extremity, although swelling may be delayed, especially if the patient arrives in a hypovolemic state. Truly occult fractures are rare indeed. Displaced long bone fractures result in shortening, malrotation, or angulation. Immediate reduction and splint placement reduces pain and blood loss, and often restores circulation to a pulseless extremity. The diagnosis of a joint dislocation is established by a thorough clinical exam in conjunction with conventional x-rays. Dislocations typically assume characteristic positions, and may be masked by associated fractures. Intra-articular injuries usually cause a hemarthrosis unless the joint capsule is disrupted, in which case more diffuse soft tissue swelling occurs about the joint. Instability or abnormal motion when stressing the joint may be difficult to elicit if the region is tender, but is particularly important and useful in the anesthetized patient. Immediate relocation of a dislocated joint is warranted especially when circulatory compromise is apparent.

RADIOGRAPHIC DIAGNOSTICS

As per ATLS® protocol, an anteroposterior (AP) chest and pelvis, and adequate lateral cervical spine radiographs are indicated early in the evaluation and resuscitation of the injured patient during the primary survey.[4,11] X-rays of injured extremities are of much lower priority and fall into the secondary survey. The obviously injured extremity should be dressed and stabilized with a splint. Resuscitation of the patient should never be delayed or interrupted for x-rays of the extremities. X-rays can be taken after urgent surgical treatment for other life-threatening problems. In the unstable patient, care should be concurrent and not contiguous, implying that x-rays and fracture stabilization can occur concomitantly in the operating theater or resuscitation bay with lifesaving maneuvers such as laparotomy or thoractomy. If adequate extremity radiographs can be obtained without delaying other essential aspects of the evaluation and treatment of the trauma patient, they can be valuable in making the initial care plan.

Extremity x-rays should show both AP and lateral views of the entire bone in question. If the need for surgical treatment has been determined, further views may be better obtained in the operating room under anesthesia or after traction has realigned and separated the fracture fragments sufficiently to improve visualization. There is an ongoing debate related to the importance of obtaining prereduction radiographs for joint dislocations. In general, any joint dislocation should be reduced as soon as possible, in order to avoid strain on associated structures, including vessels and nerves. For this reason, some physicians argue that x-rays of dislocated joints should never be obtained under any circumstance. The opposite point of view is based on the notion that some injury patterns are not amenable to closed reduction, and that such in vain manipulations and reduction maneuvers may increase the risk of inducing or exacerbating the severity of associated injuries. A reasonable guideline for the acute management of joint dislocations is to reduce dislocated joints in anatomic locations that are not frequently associated with neurovascular injuries without prereduction x-rays (e.g., ankle fracture–dislocations), and to obtain x-rays in all cases of more "at-risk" anatomic locations, such as the knee or hip joint. Postreduction x-rays must be obtained in all cases, to ensure anatomic joint reduction and to design a final treatment plan for the individual injury patterns.

Certain complex articular fractures are best visualized with computerized tomography (CT) scans. If a patient is hemodynamically stable and requires other CT studies, extremity CTs may be obtained at the same time. Early involvement of the orthopedic surgeon ensures proper x-rays and avoidance of unnecessary diagnostic studies.

ASSOCIATED INJURIES

►Vascular Injuries

A high "level of suspicion" for a significant associated vascular injury, in conjunction with a thorough clinical exam (**Table 40-1**), should help in the guidance of the acute management of joint dislocations. Any pulse deficit or measurable reduction in arterial pressure index (API), before or after manipulation, must be considered evidence of a vascular injury. The accuracy of pulse examination alone for the detection of an arterial injury is very low. The five clinical "hard signs" of an arterial injury (**Table 40-1**)[12] are present in more than two thirds of all dislocations with an associated significant vascular injury and are of paramount importance in the clinical guidance for decision making related to the acute management concept (i.e., the operative exploration vs. further diagnostics/angiography vs. clinical observation).[12–14] In presence of a "hard sign" of arterial injury, operative exploration with or without intraoperative ("on-table") arteriogram is indicated. The majority (>95%) of arterial injuries occur in proximity to the site of the fracture or joint dislocation. Delay in diagnosis or worse, observation alone, can result in limb loss. The use of "soft signs" to detect occult vascular injury is less clear (**Table 40-1**). The yield of arteriography in the setting of clinical "soft signs" is very low and the lesions that are typically identified are nonocclusive lesions: intimal flap, contusion, spasm, and pseudoaneurysm. The natural history of these lesions is benign and self-limiting, and they rarely require surgical repair.

TABLE 40-1 Clinical Signs for Determining the Likelihood of a Significant Vascular Injury Associated with Lower-Extremity Fractures and Dislocations

"Hard Signs"	"Soft Signs"
Active or pulsatile hemorrhage	Asymmetric extremity blood pressures
Pulsatile or expanding hematoma	Stable and nonpulsatile hematoma
Clinical signs of limb ischemia	Proximity of wound to a major vessel
Diminished or absent pulses	Peripheral neurological deficit
Bruit or thrill, suggesting AV fistula	Presence of shock/ hypotension

The presence of a "hard sign" of an arterial injury warrants an immediate surgical exploration with the option of an on-table angiography. In contrast, the "soft signs" are less specific in predicting a significant arterial extremity injury. In exclusive presence of a "soft sign," such as an asymmetric ankle–brachial index, the recommended further diagnostic workup includes an angiography or CT angiography.

The neurovascular status may be difficult to assess clinically in a severely injured patient. Therefore, a high level of suspicion is required for identifying and treating potentially catastrophic vascular injuries. Capillary filling is not, by itself, adequate clinical evidence of an intact proximal vascular flow. Distal pulses may be present after a significant arterial injury. Perhaps the most familiar arterial injury in the lower extremity involves the popliteal artery in association with knee dislocations or periarticular fracture. Late thrombosis of an initially nonocclusive injury may result in limb loss. Frequent assessment of pedal pulses is required for such patients. Any alteration of pedal pulses requires assessment, at least with Doppler pressure measurement. Assessment of ankle systolic blood pressure is an important adjunct to the physical exam. Pressure below 90% of that in the arms or the opposite leg requires prompt evaluation by a vascular surgeon. Doppler sonography or contrast arteriography may be considered if pulses decrease, but should not delay consultation with a trauma surgeon. Risk factors for limb loss include delayed surgery, arterial contusion with consecutive thrombosis, and, most importantly, failed revascularization.

An arterial injury in combination with an orthopedic injury, such as a traumatic joint dislocation or fracture–dislocation, requires a coordinated approach by the acute care surgery and orthopedic teams. The use of a temporary arterial shunt to restore limb perfusion and minimize tissue ischemia in the management of complex extremity injury is an emerging concept in DCO surgery (**Fig. 40-1**). Both civilian and military experiences demonstrate temporary vascular shunting as a useful adjunct in successful limb salvage. Tanner and colleagues reported 100% early limb preservation following temporary vascular shunts placed in forward combat surgical centers with 96% of shunts remaining patent until arrival to a facility where definitive arterial reconstruction could be performed. Arterial repair is completed by autologous repair of the vessel when indicated. Time to revascularization is of utmost concern since delays in excess of 8 hours after injury carry a risk of amputation in excess of 80%. In contrast, successful operative vascular repair within 8 hours of injury yields excellent rates of limb salvage.

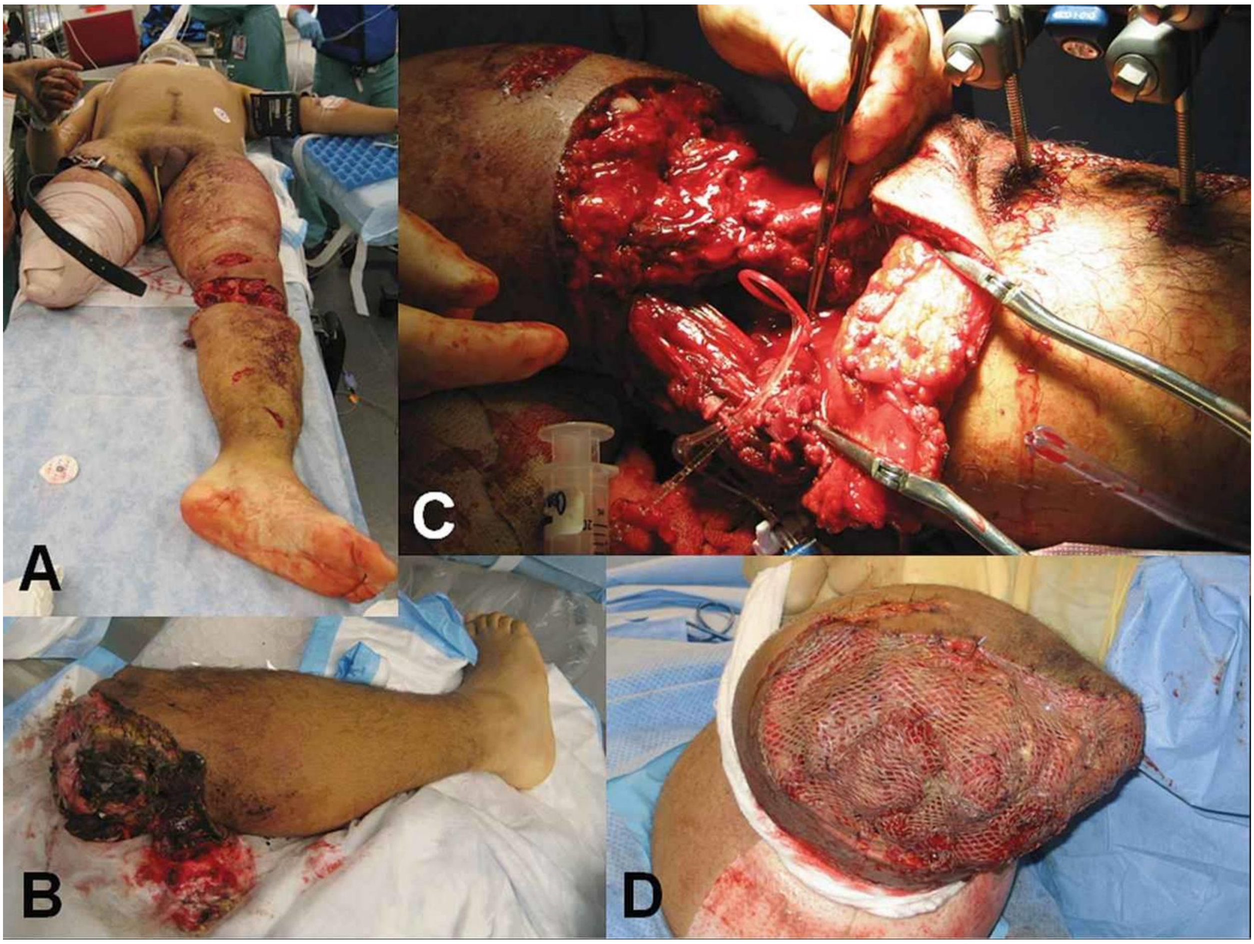

FIGURE 40-1 Limb salvage procedure in a 35-year-old male patient who was involved in a high-speed motorcycle collision. The patient sustained right-side traumatic lower leg amputation (**A** and **B**) and a contralateral type IIIC open traumatic "floating knee" injury, with a combination of a displaced intra-articular distal femur fracture and a comminuted proximal tibia fracture. On presentation to the emergency department, the left lower extremity was dysvascular, pulseless, with a pathologic ankle–brachial index (ABI) of 0.5. The patient was immediately taken to the operating room for spanning external fixation of the left knee and vascular repair. Intraoperative shunting was performed to reconstitute temporary blood flow distal to the SFA (**C**). Successful vascular repair was performed with a saphenous vein graft from the contralateral side. The amputated residual limb on the contralateral side was debrided and successfully closed by a split-thickness skin graft within 2 weeks (**D**). The patient recovered well from his injuries and was able to ambulate without support within 3 months using a custom-made above-knee prosthesis for the right residual limb, and functional rehabilitation on the left lower extremity.

► Nerve Injuries

The neurological status of the extremity should be documented before any definitive treatment, whenever possible. The neurological examination, like the vascular examination, may be unreliable in the severely injured patient or extremity. Stocking hypoesthesia may be due to acute ischemia, direct nerve injury, or psychogenic mechanisms. Absent sensation restricted to the isolated sensory area of a peripheral nerve suggests injury to that nerve. Impaired motor function may be caused by pain and instability, a peripheral nerve injury, or a spinal cord injury. Peripheral nerve damage is associated with certain lower extremity injuries. Posterior dislocations of the hip may injure the sciatic nerve, most often its peroneal component. Knee dislocations or equivalent injuries may injure the common peroneal and/or tibial nerves in the popliteal fossa, a possible clue to an associated arterial injury. Pressure from a splint or cast may also injure the peroneal nerve as it encircles the neck of the fibula at the knee.

Most peripheral nerve injuries associated with traumatic joint dislocations are due to shearing mechanisms (“neurapraxia”) and most commonly resolve without the need for surgical exploration and/or repair. Typical locations include the axillary nerve for shoulder dislocations, the ulnar nerve for elbow dislocations, and the sciatic nerve for posterior hip dislocations. A peripheral nerve injury is assessed by clinical examination. The incidence of peripheral nerve injury in extremity trauma is very low, around 1–2%. Early nerve conduction studies within 6 weeks after trauma can aid in defining the extent and prognosis of injury. A delayed nerve repair should be performed at that time, if complete nerve injury is confirmed. However, successful repair, for example, by grafting with autologous peripheral nerve tissue, is rarely successful in elderly or comorbid patients, and the indication is therefore restricted to the pediatric population and to young and healthy adults. The sural nerve is the most common donor site for autologous nerve grafting.

► Injury Combinations

Awareness of typical combinations of lower extremity injuries aids diagnosis and may decrease the risk of missing important injuries. One mechanism can produce several injuries. An unrestrained passenger in a head-on motor vehicle collision may strike his or her knee against the dashboard, sustaining a patellar fracture or injury to knee ligaments, depending on the point of impact. The force indirectly applied along the femur then dislocates the flexed hip, concurrently producing a posterior wall acetabular fracture and/or fracture of the femoral head. The association between femur fractures and pelvic or acetabular fractures is so strong that careful review of a pelvic x-ray is mandatory for all patients with femoral shaft fractures. Patients who fall from a height and land on their feet may have both calcaneal fractures and injuries to the thoracolumbar spine—another “classic” combination. Patients with fractures of the femoral shaft may have associated fractures of the femoral neck, either obvious or undisplaced and occult. The trauma surgeon should be aware of the association of ruptures of the thoracic aorta with pelvic fractures and of the frequently observed multiple injuries seen with “floating knees” (simultaneous ipsilateral femoral and tibial fractures), which also have a high incidence of associated injuries to soft tissue at the knee joint. Isolated fibular fractures may be associated with traction injuries of the peroneal nerve or with ligamentous disruptions of the knee or ankle. While fractures are often distractingly obvious on x-rays, injuries to joints such as subluxations and even dislocations may easily be overlooked unless one is suspicious.

► Joint Dislocations

A “joint dislocation” describes the complete separation of at least two articular surfaces of adjacent bones, by which the functional contact between those articular surfaces is lost. In contrast, the term "joint subluxation" defines the partial disruption of articular surfaces, in which some functional contact within the joint remains. The direction of displacement of the distal bone involved in the joint determines the type of displacement. For example, a "posterior knee dislocation" describes a state in which the tibial head is displaced posteriorly to the femoral condyles. Traumatic joint dislocations represent frequent orthopedic injuries, which can be successfully treated by simple closed reduction maneuvers and early functional aftercare in most cases. Most traumatic joint dislocations do not require surgical fixation, except in the case of associated fractures ("fracture–dislocation") or multiligamentous joint instability. Care must be taken in the case of complex fracture–dislocations, which may require a primary open reduction and fixation. Extensive closed reduction maneuvers may lead to complications related to associated neurovascular injuries. A high level of suspicion must be raised for associated vascular injuries that may lead to a detrimental outcome with delayed limb loss, if missed during the first few hours after trauma. Patients "at risk" are mainly young individuals with high-energy trauma mechanisms, particularly in case of traumatic hip or knee dislocations. However, minor trauma mechanisms, such as simple mechanical falls, do not preclude from a significant vascular injury. The clinical assessment by "hard" and "soft" signs of vascular injury (**Table 40-1**), including the determination of blood pressure gradients on the extremity, will help in the guidance for decision making on timing and modality of treatment. The presence of clinical "hard signs" mandates immediate surgical exploration and repair, with optional "on-table" angiography, if needed. Urgent assessment and treatment, generally without exceeding 6–8 hours of ischemic time, is of crucial importance for successful limb salvage. Associated nerve injuries are managed nonoperatively and will resolve in most cases.

SOFT TISSUE INJURIES AND COMPARTMENT SYNDROME

Soft tissue injuries to the lower extremity are critical in the decision making for the timing and modality of fracture fixation, particularly in high-energy tibial fractures (**Fig. 40-2**). Tense swelling and increasing pain is typical of compartment syndrome, which must be suspected in every injured lower extremity.[15,16] Impaired sensory or motor function in the setting of compartment syndrome is a late presentation and correlates compartment necrosis. Compartment syndromes typically develop several hours or more after injury, before or after treatment has begun, and may be related to a cast or dressing that has become tight as the enclosed limb swells. Immediate release of such a constricting dressing aids diagnosis and may be therapeutic. Compartment syndrome is most effectively diagnosed by an experienced examiner and remains primarily a clinical diagnosis. Intracompartmental monitoring with arterial lines or specialized "compartment monitors" can be helpful in the obtunded patient. In the awake patient, unremitting pain and a tense or swollen limb should be assumed to be compartment syndrome. Patients with suspected compartment syndrome should be taken to the operating room immediately and undergo fasciotomy of all compartments (three in the thigh, four in the tibia, nine in the foot). Partial fasciotomies, or the use of limited incisions, in general are not appropriate in the trauma patient. Quantification of soft tissue injury severity has been attempted by many investigators. Tscherne emphasized that the severity of injury depends largely on the extent of damage to soft tissue in both closed and open fractures. The Oestern/Tscherne classification focuses on categorization of the soft tissue injury[17] (**Table 40-2**). Open fractures require urgent surgical treatment for debridement and fracture stabilization. Closed fractures with high-energy soft tissue damage also require urgent stabilization as well as close monitoring for compartment syndrome.

FIGURE 40-2 Critical soft tissue injury in a 43-year-old patient who sustained a high-energy proximal tibia fracture after a motorcycle crash. Fracture blisters developed within 24 hours of injury. The critical soft tissue conditions mandated a staged treatment concept by initial spanning external fixation and delayed conversion to internal fixation once the tissue swelling had subsided and the fracture blisters had healed. Despite the high-energy injury pattern and critical soft tissues, this patient did not develop a compartment syndrome and had an uneventful long-term recovery.

TABLE 40-2 Hannover Classification System for Soft Tissue Injuries, According to Tscherne and Oestern

Score	Description	Example
0	No soft tissue injury, indirect trauma mechanism, simple fracture pattern	Indirect torsion fracture of the tibia
I	Superficial skin abrasion, skin contusion by internal pressure of fracture fragments	Unreduced fracture–dislocation of the ankle
II	Deep soft tissue contamination, skin contusion by direct force, impending compartment syndrome, complex fracture pattern	Bumper injury to the lower leg
III	Severe soft tissue contusion with skin necrosis, myonecrosis, degloving injury, acute compartment syndrome, comminuted fracture pattern	High-energy rollover trauma

OPEN FRACTURES AND THE "MANGLED LIMB"

Open fractures should be quickly assessed on arrival of the patient in the emergency room. The wound should be covered with a sterile saline dressing and only examined in the operating room in order to avoid further contamination and soft tissue damage. Extensive exploration or manipulation of exposed bone should not be attempted in the emergency department. Bleeding, even from amputation wounds, can almost always be managed with a pressure dressing. A tourniquet should be reserved for uncontrollable hemorrhage from penetrating lower extremity injuries.[18] A "mangled extremity" defines a severely injured limb secondary to trauma in which there is a significant risk of amputation as a potential outcome. More specifically, a functional limb is composed of the following critical elements: skin and subcutaneous tissue, blood vessels, muscles and tendons, bones, joints including cartilage and ligaments, and peripheral nerves. Irreparable injury to one or more elements may significantly impair the function of a limb and lead to disability. A mangled extremity, the most severe form of injury, encompasses significant injury to multiple elements critical to limb function.

In the event of multiple injuries, hemorrhagic shock, prolonged delay to definitive care, and/or risk of death, amputation may be the preferred option: "limb for life concept." Once the patient responds to resuscitative efforts, the extremity is carefully examined during the secondary survey. Evaluation focuses on signs of arterial injury, extent of soft tissue and bone injury, and degree of contamination. A search for "hard signs" and "soft signs" (**Table 40-1**) of arterial injury is essential since both civilian and combat experiences demonstrate that the risk of limb loss correlates with a delay in revascularization beyond 6 hours. The risk of limb loss is further increased in the setting of ischemia with associated major venous, soft tissue, and muscle injury.[19] Since a significant percentage of injuries, particularly those involving the distal extremity and the major joints, are missed during the initial trauma evaluation, repeated exams are essential, especially as the patient's recovery permits more cooperation. At least one "tertiary" survey is an important part of each significantly injured patient's diagnostic evaluation.

Grading systems for open fractures have been proposed by Gustilo et al., among others[20] (**Table 40-3**). Despite a significant interobserver variability and limitations related to the wide spectrum of open fracture types covered in three categories, the Gustilo classification is very practicable and therefore well accepted among orthopedic surgeons. Newer classification systems, such as the *Ganga Hospital Score*from India,[21] attempt to overcome the shortcomings from the Gustilo classification by increasing the number of categories and correlating the total score with a guideline for treatment. As such, the *Ganga Hospital Score* for open fractures will mandate treatment protocols including the "Fix and close" protocol, "Fix, Bone Graft and Close" protocol, "Fix and Flap" protocol, or the "Stabilise, Watch, Assess and Reconstruct" protocol.[21]

TABLE 40-3 Classification of Open Fracture Types, According to Gustilo et al.

Type	Description
I	Clean wound <1 cm, inside-out perforation, little or no contamination, simple fracture pattern
II	Skin laceration >1 cm, surrounding soft tissue without signs of contusion, vital musculature, moderate to severe fracture instability
III	Extensive soft tissue damage, wound contamination, exposed bone, marked fracture instability due to comminution or segmental defects
IIIA	Adequate soft tissue coverage of the fractured bone
IIIB	Exposed bone with periosteal stripping
IIIC	Any open fracture with associated arterial injury requiring vascular repair

All open fractures require urgent surgical treatment to reduce the risks of infection, soft tissue damage, and ongoing bleeding. In the emergency department, the wound is kept covered with a sterile dressing, pressure is applied as necessary to control bleeding, and the limb is splinted. Tetanus prophylaxis and systemic antibiotics are given. Generally, a first-generation cephalosporin is used for 24–48 hours following wound closure. For more severe wounds or contamination, additional coverage is added (e.g., an aminoglycoside or third-generation cephalosporin for grade III open fractures, or high-dose penicillin for "barnyard" injuries with risk of clostridial contamination).

As soon as the patient's condition permits, radiographs of the injured limb are obtained. Operative care of the open fracture must fit appropriately into the care of the patient's other problems. This should be done in an operating room with general or regional anesthesia. Debridement should preferably be performed within 6 hours of injury, unless more time is required for resuscitation of the patient or for treatment of injuries that pose a greater threat to life or limb. Longer delays likely increase the risk of infection. After thorough debridement of devascularized muscle, fascia, subcutaneous tissue, skin, and bone, removal of all foreign material, and copious irrigation, wound care is enhanced by appropriately chosen fracture fixation. Generally, this involves screw and/or plate fixation for joint fractures, intramedullary nails, or external fixators for diphyseal fracture. Intramedullary nails in the tibia and femur can safely be placed in reamed fashion, even in open fractures. However, in multiply injured, concern for marrow extravasation and subsequent development of systemic inflammatory response syndrome (SIRS) has led to the use of unreamed, small-diameter nails, temporary external fixators, or reamer–irrigator–aspirator (RIA) systems to decrease marrow embolization.[22,23]

After fracture fixation, the open fracture wound, extended as required for debridement and fixation, is left open initially, under a sterile moisture-retaining dressing. Recent randomized studies indicate that there may be a role for primary closure in well-debrided open injuries. Antibiotic-impregnated methylmethacrylate beads placed in large or contaminated wounds may significantly reduce the risk of infection. Severe open fracture wounds mandate a return to the operating room within 24–48 hours to assess the adequacy of debridement and to further debulk potential bacterial contamination. Delayed primary closure, generally after 3 or 4 days, reduces the risk of wound infection. Unless the local tissues are intact enough to permit delayed suture closure, or split-thickness skin grafting, open wounds often require muscle flaps, either swung locally or brought in from a distance with microvascular anastomoses.[24,25] Severe open fractures often require bone grafting to gain union. While bone grafting may be essential, it should be postponed until the wound is securely healed, as the risk of infection is increased if bone grafting is performed at the time of initial open fracture surgery or at delayed closure of the wound (**Fig. 40-3**).

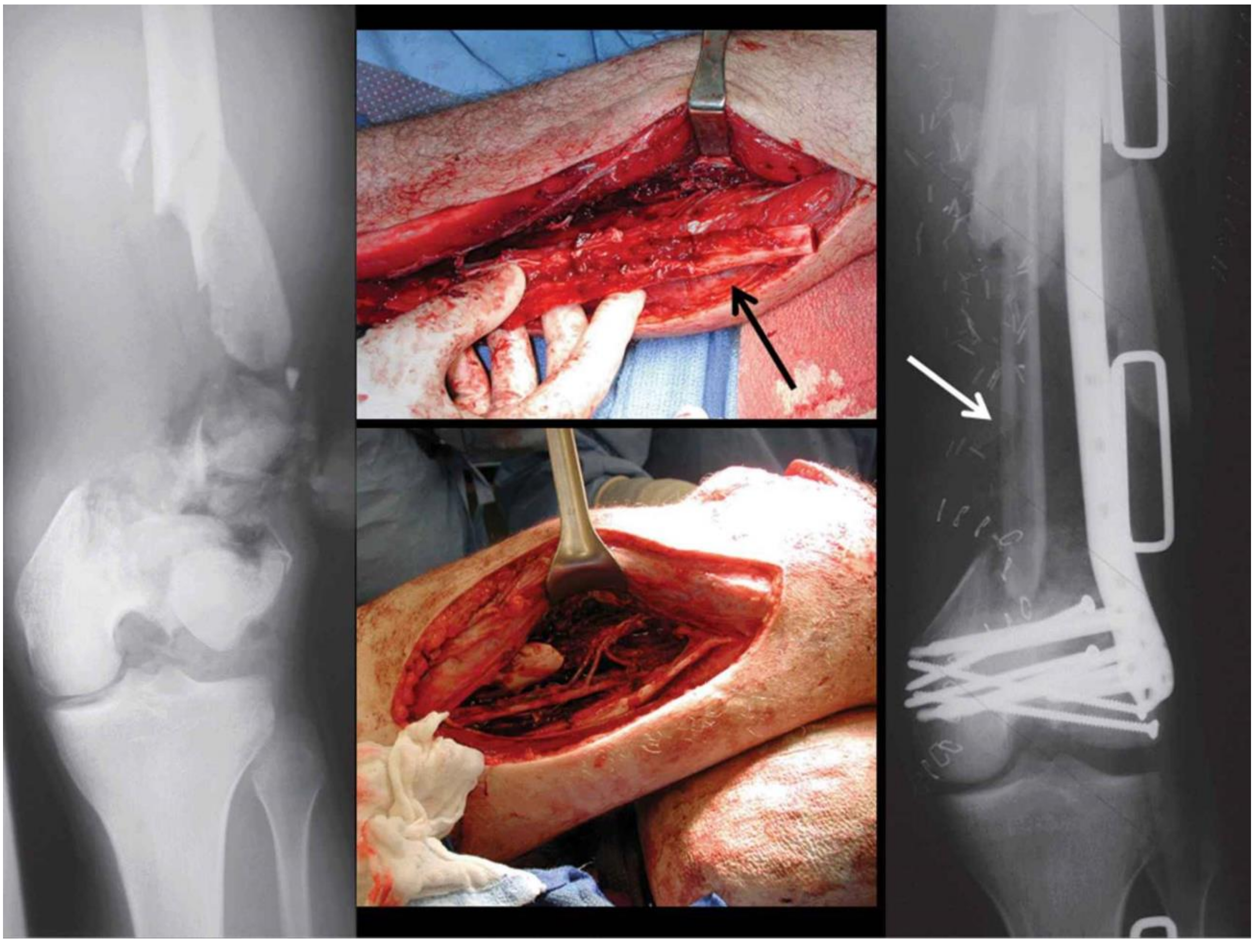

FIGURE 40-3 Free microvascular fibula transfer (arrows) for early bone grafting of a comminuted distal femur fracture with significant bone loss.

CURRENT CHALLENGES AND CONTROVERSIES

► Long Bone Fractures

The large volume of musculoskeletal tissue in the lower extremities, including the pelvis, increases the potential systemic effects of lower extremity injuries. Bleeding and accumulation of extracellular fluid may cause hypovolemia and contribute to systemic hypotension.[26] Several units of blood can be lost into severely injured thighs, and preoperative blood loss associated with a single femur fracture is up to 1,500–2,000 mL. A crushing wound of the lower extremity releases intravasated debris (e.g., bone marrow), myoglobin, related muscle breakdown products, and various inflammatory mediators. The release of these substances may cause fat embolism and adult respiratory distress syndrome (ARDS), acute renal failure, and multiple organ failure (MOF).[23,27,28] Life-threatening infections such as clostridial myonecrosis or necrotizing fasciitis can rapidly develop in the tissues of the lower extremities. While proper early operation may prevent these, immediate recognition and treatment are vital to the salvage of any patient who develops such an infection.[29]

As demonstrated by Tscherne, Bone et al., Trentz and coworkers, and others, prompt surgical treatment for severe extremity injuries benefits the whole patient.[5,30,31] Early fracture stabilization reduces the systemic effects of fractures, including SIRS, sepsis, MOF, and ARDS. Early stabilization reduces pain and the need for analgesic medication, and promotes mobilization of the patient with attendant benefits to the respiratory and gastrointestinal systems. While fracture fixation is particularly beneficial for the patient with injuries to the lower extremity and pelvis, "damage control" procedures should be undertaken if the patient is in shock, coagulopathic, hypothermic, or has an actively developing traumatic brain injury.[3,4,32–34] The concept of DCO emphasizes rapid provisional skeletal stabilization with simple external fixators, followed by delayed definitive fixation when the patient is stable and the inflammatory system is less primed, usually at 5–10 days postinjury.[4,6,7,32,35] While controversy exists concerning the utility of orthopedic damage control in specific patient subsets, the concept of rapid, minimally invasive fracture fixation has been found safe and cost-effective.

A significant body of research has shown that the timing and type of fracture fixation may be critical in specific patient subsets. Intramedullary instrumentation of the femoral shaft can affect circulating neutrophil cell membranes causing surface receptor changes known as "priming" or "activation." The "primed" neutrophil when "activated" releases mediator and cytokine substances that alter endothelial membrane permeability throughout the body, resulting in systemic inflammatory syndrome and fluid entering the alveoli.[36] All of these changes are part of the "second hit" phenomena in which the damage of the initial trauma (first hit) is augmented by further damage from a second "hit."[4] The second "hit" may be caused by secondary procedures such as prolonged surgery with blood loss or instrumentation of the femoral canal. The initial approach to fracture care in the polytraumatized patient must take into account these physiological realities. However, the clinical implications of neutrophil changes and mediator release have not been directly correlated with clinical outcome, in part because of the large cohort numbers required to achieve statistical significance for such a study.

Fractures, whether isolated or in polytrauma, have far-reaching implications for the patient. The results of a "fracture" often depend more on damage to the soft tissues of the limb than on the isolated bony injury. Thus, accurate evaluation of an extremity injury requires assessment of the following: (a) skin and subcutaneous tissue; (b) muscles and tendons; (c) bones; (d) joints, including ligaments and articular cartilage; (e) arteries and veins; and (f) peripheral nerves. Acute as well as final functional outcome will depend on treatment of the entire spectrum of injury.

► Limb Salvage versus Amputation

One of the most challenging decisions involved in the care of an injured patient is whether or not to attempt salvage of a severely injured limb.[37] Although every appropriate effort should be made to preserve functional and anatomic integrity, for some severe lower extremity injuries, an amputation and prosthesis may be more effective for the patient than a limb that is still attached but is of limited use. In the acute phase, the decision to amputate will depend primarily on the immediate condition of the patient and the feasibility of stabilizing/revascularizing the injured limb (Fig. 40-1). If the limb is initially salvaged, then further decisions must be made regarding the desirability of maintaining the salvage effort, which usually involves multiple further operations. Key factors in this decision process include the patient status, the level of potential amputation, as well as the wishes of the patient in those cases in which he or she is cognizant. In all situations involving a decision between limb salvage and amputation, the two primary concerns are (a) the systemic consequences of either alternative for the patient and (b) the likelihood of achieving a functional limb versus the problems associated with limb salvage (time involved, duration of disability, medical risks, socioeconomic costs, number of operations and hospitalizations, etc.).[2,38,39] If a limb is severely injured, it is rare that either amputation or salvage will completely restore function.

In those cases in which the patient is hemodynamically unstable and revascularization cannot be accomplished without increasing the chance of death, amputation is the only choice. In these cases a guillotine-type amputation is appropriate, but every effort should be made to preserve length and coverage options. In particular, efforts to preserve the potential for a below-knee amputation (BKA) by preserving any viable distal muscle and/or skin will improve the patient's outcome.[40] Free tissue transfers, rotational flaps, and skin grafts can all be used effectively to improve length and provide a durable, useful stump. Many surgeons are unaware that skin grafting of well-padded stumps is feasible and highly successful. Similarly, latissimus dorsi free flaps, combined with skin grafts, preservation of vascularized heel pads, and turndown procedures, using vascularized portions of bone from the zone of injury, can effectively preserve a BKA despite severe soft tissue loss. Unfortunately, in many cases, the decision to amputate is made in the middle of the night, without opportunity for consultation with experienced salvage surgeons. Multidisciplinary decision making in these severe cases may provide increased reconstructive options whether the limb is salvaged in entirety or amputated.

The level of amputation greatly impacts future function. Proximal amputations have greater functional impairment and are often less satisfactory then prosthetic alternatives. Prosthetic replacement of the foot and ankle is highly functional. A through- or above-knee amputation, however, requires a prosthesis that requires more energy for ambulation and is less functional than one used after a BKA. Thus, every reasonable effort is appropriate to preserve the patient's own knee joint and enough proximal tibia (at least 10 cm below the joint) to provide for good prosthetic fitting. Prostheses for very proximal femoral amputation levels, hip disarticulation, or hemipelvectomies are rarely functional for ambulation; therefore, efforts are also appropriate to preserve an adequate above-knee amputation level.

The classic injury requiring a decision of amputation versus salvage is an open tibial fracture, with arterial injury (Gustilo type IIIC). Gregory et al. have defined a mangled extremity as one with significant injuries to three of the following four components: integument, bone, nerve, and vessel.[41] Some element of subjective assessment of severity is inevitably involved in the evaluation of severe limb injuries. Several predictive scoring systems have been proposed to aid decisions about limb salvage. These necessarily require consideration of multiple factors. Unfortunately, none of these scoring systems reliably predict the need for amputation and, while they suggest which limbs may be salvaged, they do not correlate with functional outcome.

Variables that must be considered in the decision for limb salvage are both systemic and local. The severity and duration of shock, the severity of other injuries (Injury Severity Score [ISS]), the patient's age, and preexisting medical conditions are crucial. Important features of the extremity injury include duration of ischemia, causative mechanism, fracture pattern, location of vascular injury, neurological status, condition of the foot, and muscle viability following revascularization. The patient's occupation and subjective desires merit consideration. One limb injury scoring scale is the “mangled extremity severity score” (MESS) developed by Johansen et al.[42] Such scales were originally described for open type IIIC injuries, but their use has been extended by other investigators to complex lower extremity trauma. A total MESS of 7 or more suggests the need for primary amputation, since limbs with such scores rarely are salvaged successfully. The sensitivity and specificity of the MESS, however, have not gone unquestioned. Bonanni et al. have critically reviewed the MESS score, comparing it with three similar indices.[43] Applying these scores to 58 lower extremities with salvage attempts, they found that none of the scores had a predictive value significantly better than chance in determining which limbs would be successfully salvaged. Bosse et al., in a large prospective multicenter study of patients with severe injuries to the lower extremity, demonstrated that current severity scores of limb injury cannot be used to effectively predict the need for amputation and functional outcome of the patient.[44,45] They also found that patients with tibial nerve injury did not necessarily have a dismal outcome with salvage and that the 2-year outcome differences between amputation and salvage patients was minimal.[46]

► Replantation

Technically, replantation is possible for complete and subtotal lower extremity amputations. However, given the current near impossibility of lower extremity nerve regeneration in adults, the functional outcome is questionable. In general, only cleanly separated traumatic amputations in young individuals without significant systemic risk factors, including smoking, deserve consideration for replantation. Revascularization in the face of severe neuromuscular injury may result in a viable but painful, dysfunctional limb. Consultation with an experienced replantation team is essential. Preservation of the amputated part is according to the same principles for upper extremity replantation. Care must be taken to not jeopardize the patients’ life in lower extremity replantation and revascularization. Reestablishment of blood flow after a period of prolonged hypoxia can have a toxic effect, causing systemic inflammation and MOF. Consideration should be given to rapid external fixator and arterial shunt placement to “buy time” and permit an overall reassessment of the patient and of the desirability of reattachment of the limb.

MANAGEMENT OF COMMON FRACTURES AND DISLOCATIONS

► Acetabular Fractures

Fractures of the acetabulum are articular injuries with profound implications for the long-term function of the hip joint. Successful open reduction and internal fixation (ORIF) of displaced acetabular fractures significantly improves the prognosis of these potentially devastating injuries and permits early mobilization of a patient who might previously have been managed with many weeks of skeletal traction and bed rest (**Fig. 40-4**). Judet and Letournel’s seminal work has led to our current classification, understanding, and management of acetabular fractures. Oblique x-rays and CT scans are used to classify the acetabular fracture, to assess displacement and need for surgical treatment, and to determine the best surgical approach. There are multiple surgical approaches to the acetabulum including the Kocher-Langenbeck, the ilioinguinal, the extended iliofemoral, the modified iliofemoral, the Stoppa, the triradiate, and combined anterior/posterior and percutaneous. The surgical approach is dictated by the fracture pattern and the overall condition of the patient. A complete three-dimensional understanding of the fracture is essential for formulating a preoperative surgical plan. Preservation of soft tissue attachments is needed to promote healing and avoid osteonecrosis. Vital neurovascular structures must be protected. A precise anatomic reduction must be achieved and fixed stably, generally with screws and plates, which must not encroach upon the articular surface. Intraoperative fluoroscopy has become a valuable tool for ensuring appropriate placement of orthopedic hardware around the acetabulum. Minimally invasive percutaneous screw fixation represents a challenging but valid alternative to open reduction with internal fixation in minimally displaced fractures or in patients with significant risk for wound complications or a “second hit” insult related to extensive surgical procedures (**Fig. 40-5**). Complications and poor results become less frequent with increasing experience of the acetabular surgeon. Acetabular fracture surgery remains among the most challenging procedures in orthopedics. These difficult and dangerous reconstructive surgeries should generally be done in specialized centers to ensure that each patient receives optimal treatment.

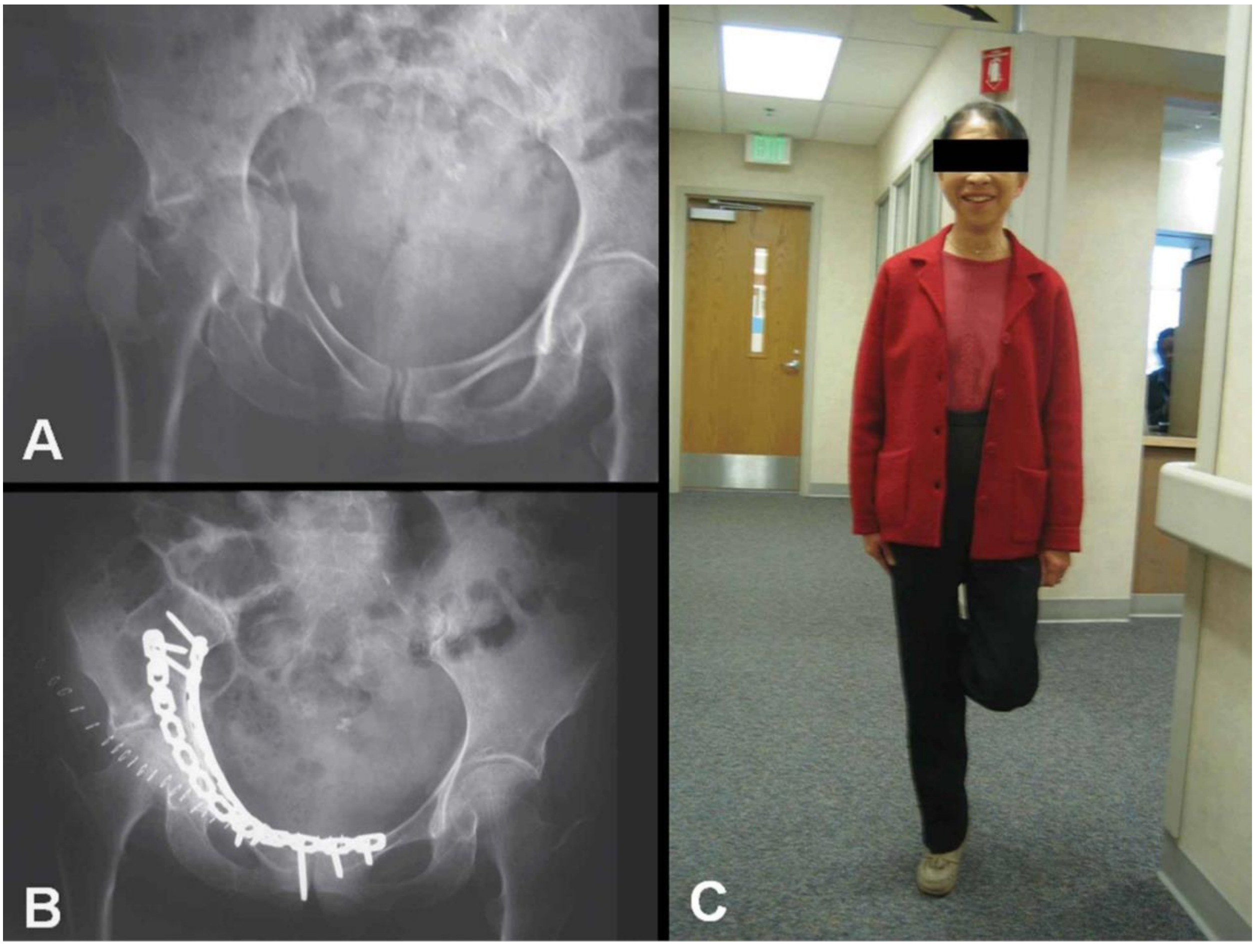

FIGURE 40-4 A 74-year-old lady with severe osteoporosis who sustained a displaced right acetabular fracture after a fall (**A**). The fracture was treated by angular-stable bridge plating with two anterior locking plates (**B**). Conventional, nonlocking screws and plates have a high risk of failure in osteoporotic cancellous bone. The patient is fully weight bearing on the right side, 3 months after surgery (**C**).

FIGURE 40-5 Polytrauma patient with combined pelvic ring and acetabular fracture. Due to the high-risk constellation in this patient, all fractures were treated by closed reduction and percutaneous cannulated screw fixation.

Acetabular fractures in osteoporotic individuals pose special problems. Comminution is often so severe and bone quality so poor that conventional fixation techniques are doomed to failure. In these instances, total hip arthroplasty with specialized acetabular reconstruction devices allows improved fixation and early weight bearing of the elderly patient. Because the femoral head is removed in total hip arthroplasty, extensile or combined exposures may not be required, and operative morbidity may be reduced.

Acetabular fractures are usually closed injuries, without need for immediate operation. If surgery is delayed for 3–5 days, operative bleeding is reduced, and preoperative planning may be improved. Patients with pelvic and acetabular fractures have a significant risk of thromboembolic complications. Intermittent venous compression devices, anticoagulation with fractionated or low-molecular-weight heparin, and insertion of retrievable inferior vena cava filters for high-risk patients are all appropriate strategies for these injuries.

► Hip Dislocation

Posterior dislocations of the hip result from direct blows to the front of the knee or upper tibia of a sitting patient, most typically an unrestrained passenger in a motor vehicle (**Fig. 40-6**). A fracture of the posterior wall of the acetabulum occurs if the leg is more abducted and pure dislocations occur if the leg is adducted at the time of impact. The typical appearance of a patient with a posterior hip dislocation is with a hip that is flexed, adducted, internally rotated, and resistant to motion. This appearance may be lacking if a significant fracture of the posterior wall exists. An associated sciatic (often peroneal component alone) nerve palsy must be checked for. Anterior dislocations are rarer (5%) and are due to forced abduction and external rotation, which are also the characteristic deformity. An AP pelvis x-ray usually shows obvious signs of a hip dislocation or fracture–dislocation. Additional views may be needed, however, to assess adequately the proximal femur where an associated fracture of the head or neck may be present. A CT scan is required after reduction of a dislocated hip to assess its adequacy and the integrity of the acetabulum, as well as to exclude intra-articular bone fragments. Fractures of the femoral head occasionally occur with hip dislocations. They must be recognized and treated appropriately.

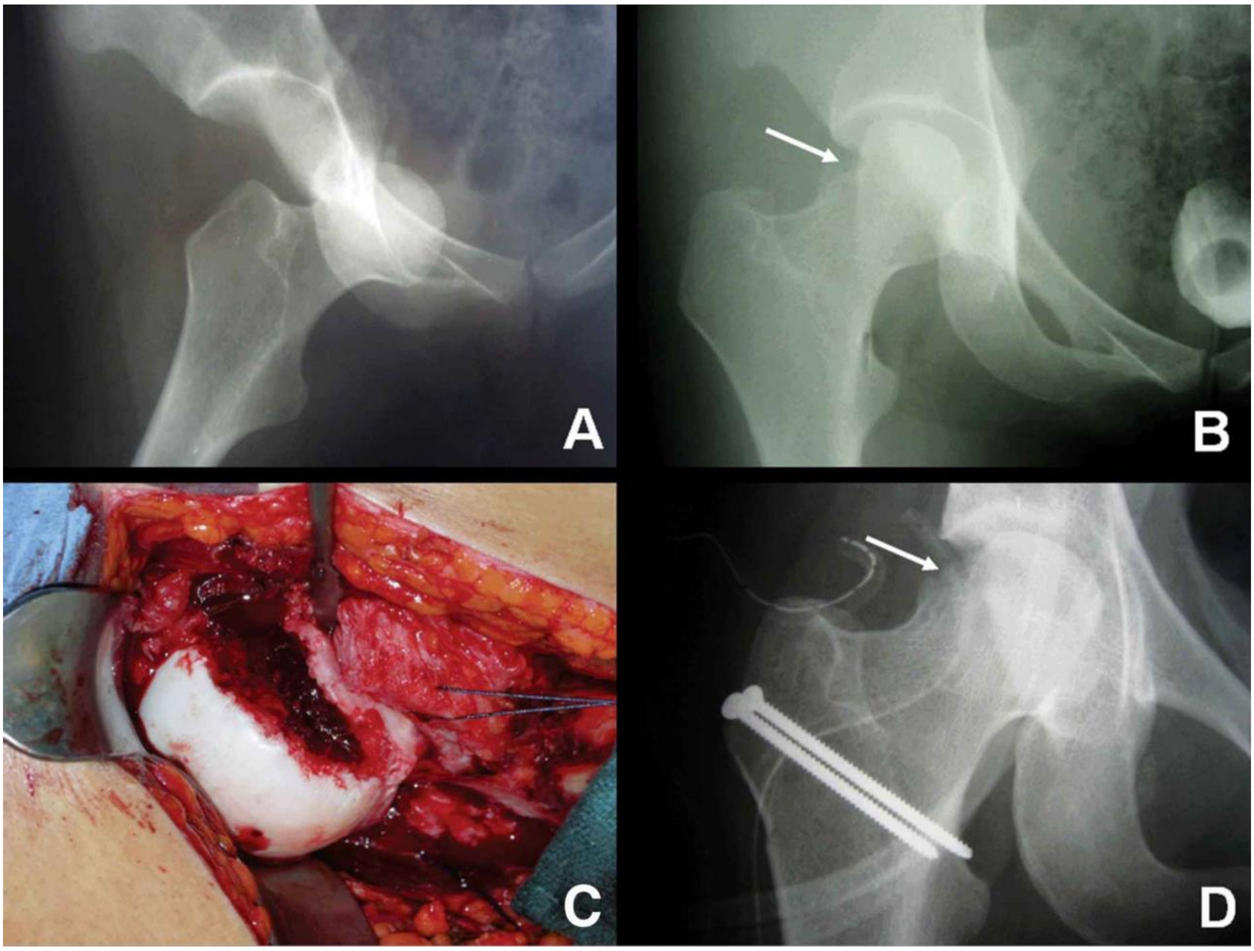

FIGURE 40-6 Traumatic posterior hip dislocation in a 25-year-old woman who sustained a high-velocity motorcycle accident (**A**). After closed reduction, a traumatic defect of the femoral head is seen on the AP x-ray, classified as a Pipkin type II fracture (**B**, arrow). A trochanteric Ganz osteotomy was performed with a surgical hip dislocation to assess and repair the defect (**C**). Postoperative x-ray shows the partially filled defect by an osteochondral autologous graft (**D**, arrow).

Dislocations of the hip are painful dramatic injuries that demand immediate reduction. Improvised splinting in situ with pillows or folded linen is unsatisfactory when compared with prompt reduction for pain relief. After initial x-rays, reduction can be done with intravenous analgesia, but may be gentler and easier for both patient and surgeon with general anesthesia and muscle relaxation. A rapid reduction (under 6–8 hours if at all possible) is crucial to minimize the risk of avascular necrosis of the femoral head. This disastrous complication results in destruction of the hip joint, with arthroplasty or arthrodesis almost always needed. Stability of the hip joint is usually restored by adequate reduction of pure dislocations, but the reduced joint must be checked for stability. Acetabular wall fractures of any significant size can result in instability, which, if present, is an indication for surgical repair within a few days after injury.

A stable, concentrically reduced dislocation of the hip usually becomes comfortable within a very few days. While applying weight to the hip in an unstable position (e.g., getting up from a low chair or toilet or getting into or out of a car) must be avoided until soft tissue healing has occurred, most patients can get out of bed and ambulate as soon as they can move and control their leg. Skeletal traction is required only for unstable hips, which will usually require surgery. Long-term outcome of hip dislocations includes an acknowledged significant risk of osteoarthritis, as well as some stiffness and limping that may never resolve. Avascular necrosis, the risk of which increases dramatically (from about 2% to 15%) if initial reduction is delayed more than a few hours, usually appears during the first year, with essentially all cases evident within 3 years after injury.

► Fractures of the Proximal Femur ("Hip Fractures")

Hip fractures represent the most common major injury in the elderly and are associated with a high rate of morbidity and mortality. The peer-reviewed literature reports a 1-year mortality of patients with hip fractures in the range of 14–47%. The currently largest prospective study assessing the outcome of surgery for hip fractures in more than 16,000 elderly patients reported a 30-day mortality of 8–17% and 120-day mortality of 21–38% in different age groups.[47] A time delay of >4 days from injury to surgery was shown to increase the 30-day mortality significantly. Patients with hip fractures who had a comorbidity requiring preoperative medical workup had 2.5 times the risk of death within 30 days, compared with patients without comorbidities that delayed surgery.[48] The prevention of hip fractures includes the dietary and medical management of osteoporosis, the prevention of falls by physical exercises, and the use of hip protectors in selected patients. While there is a consensus that the treatment of hip fractures consists of a surgical management almost exclusively, the timing and modality of fracture fixation depending on fracture pattern and patient age remains an ongoing topic of debate.[49] Hip fractures represent an important socioeconomic factor due to the increasing life expectancy. The worldwide prevalence of hip fractures is estimated to be around 4.5 million and is associated with unacceptably high morbidity and mortality rates.[47,49] Of note, these numbers are estimated to double by the year 2040, thus placing an enormous burden on global health care systems. While young patients sustain hip fractures due to high-energy trauma, the predominant mechanism in elderly patients is a same-level fall in conjunction with poor bone quality. Postoperative geriatric care is required in about 75% of all cases and 6-month mortality in this cohort has been shown to be around 20–30%.[47,48,50]

Measures to prevent falls, to reduce their consequences, and to prevent and treat osteoporosis are essential if we are to reduce the tremendous socioeconomic consequences of these injuries in the older population. In contrast, proximal femur fractures represent a rare entity in young patients and are usually the consequence of high-energy trauma.[49] These patients are often severely injured and associated injuries to pelvis, abdomen, and chest are common. Early surgical fixation of proximal femur fractures is important in order to reduce the incidence of post-traumatic complications.[51] Patients with displaced proximal femur fractures usually have significant pain and obvious physical abnormalities, typically shortening and external rotation of the injured limb, with an inability to move the leg significantly because of hip pain, usually felt in the groin. Occasionally, hip fractures are undisplaced. These may be occult with pain and tenderness but no radiographic findings. The distinct anatomic regions of hip fractures that are typically distinguished radiographically include femoral neck fractures (intracapsular/extracapsular), trochanteric (pertrochanteric/intertrochanteric), and subtrochanteric fractures.

The location of a hip fracture has important implications for treatment and outcome. In all cases, the goal of surgical treatment is to stabilize the bone sufficiently to allow mobilization of the patient, to minimize the risk of destruction of the hip joint, and also to restore normal anatomic shape of the proximal femur. This is important for normal hip function, which is crucial for most activities of work and daily living. Preoperatively, light skin traction, as with a padded Buck's traction boot, or skeletal traction for more unstable injuries is appropriate for immobilizing hip fractures until surgery. Traction is not essential for elderly patients with low-energy hip fractures. Nonambulatory patients with osteoporotic bone quality are occasionally best treated nonoperatively.[52]

► Femoral Neck Fractures

Femoral neck fractures are classified into (1) displaced versus nondisplaced, (2) stable versus unstable, and (3) intracapsular versus extracapsular (basicervical) fractures.[49] The extent of displacement is classically described by the Garden classification. However, more recent validation studies have revealed that the interobserver accuracy of the Garden classification is very poor, particularly for differentiation between types 1 and 2, and between types 3 and 4.[53] The Pauwels classification was originally described to determine fracture patterns that may warrant a primary valgus (Pauwels) osteostomy, based on the fracture angle/obliquity. Similarly to the Garden system, the Pauwels classification has a poor clinical applicability due to the lack of adequate fracture angle determination on preoperative x-rays, related to the external malrotation of the distal fragment.[54]

The comprehensive AO/OTA classification was recently revised and expanded.[55] This system classifies trochanteric fractures as 31-A, and femoral neck fractures as 31-B types. The AO/OTA subtypes correlate with the extent of instability. While a 31-B1 type corresponds to a nondisplaced, valgus-impacted femoral neck fracture, the 31-B2 type reflects a transcervical or basicervical type, while the 31-B3 type classifies displaced subcapital fractures (Garden type 4).

While nondisplaced, valgus-impacted femoral neck fractures (Garden and Pauwels type 1) are widely managed nonoperatively in Europe, the general practice in the United States tends toward operative fixation of all femoral neck fractures, independent of the aspects of stability and displacement. This fairly aggressive modality is possibly coguided by medicolegal aspects, aside from biomechanical considerations. The choice of implant for fixation of hip fractures is mandated by the fracture pattern (classification) and by associated parameters, such as bone quality and individual patient characteristics. For displaced femoral neck fractures, the widely accepted consensus is that patients under 60–65 years of age should be treated by anatomic reduction and internal fixation.[49,51,56] The ideal treatment for patients over 75–80 years of age is a prosthetic replacement.[57,58] In the group of patients between 65 and 75 years, the treatment modality must be guided by individual patient characteristics, including medical comorbidities, ambulatory status, and the apparent biological/physiological age.[49] The "classic" fixation modality of intracapsular femoral neck fractures consists of three cannulated large-fragment screws (6.5 or 7.3 mm) that are placed percutaneously, in a triangular fashion, with the base of the triangle cephalad. Only one screw is placed at the calcar in order to avoid a potential stress raiser by two screws at the lateral cortex, which may lead to a delayed subtrochanteric fracture. The screws must be placed in a parallel and well-spread fashion, in order to achieve fracture compression and adequate buttress of the posteromedial and posterolateral cortices. It is of crucial importance to place the screws orthogonal to the fracture line and to ensure that the threads of the screw heads are completely engaged across the fracture line. For this reason, short-threaded screws with 16 mm threads are usually preferred over screws with 32 mm threads. While adequate fracture healing can usually be achieved in AO 31-B1 and -B2 fractures treated by cancellous screw fixation, the vertical obliquity of 31-B2.3 and -B3 patterns (Pauwels type 3) has been associated with a high rate of malunion and nonunion, despite an excellent primary reduction and adequate fixation[59] (**Fig. 40-7**). Extracapsular (basicervical) neck fractures may alternatively be fixated by a gliding hip screw/plate device, preferentially with an additional antirotation screw proximal to the hip screw (6.5 or 7.3 mm cannulated lag screws).

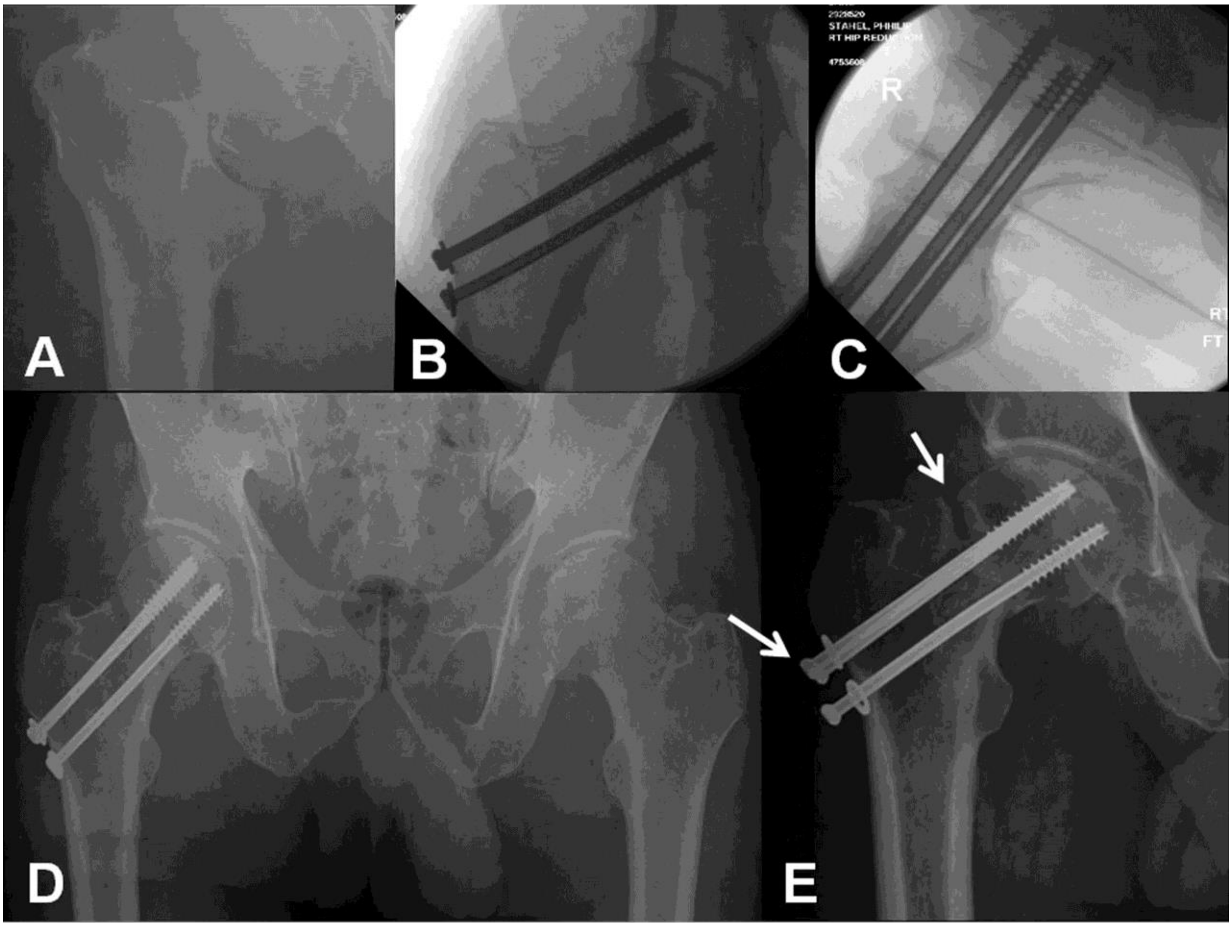

FIGURE 40-7 Displaced vertical femoral neck fracture (Pauwels type 3) in a 65-year-old male patient who fell 6 ft from a tree (**A**). Anatomic reduction was achieved on a fracture table, with lag screw fixation using three 7.3 mm cannulated screws in an inverted triangle pattern (**B** and **C**). Despite anatomic reduction and adequate fixation (**D**), the fracture collapsed into varus and the patient developed a nonunion at 6 months (**E**). The *arrows* point out the nonunion and the lateral protrusion of the screws. This complication emphasizes the inherent instability of Pauwels type 3 fractures and the rationale for a primary joint arthroplasty in elderly patients with displaced femoral neck fractures.

Regarding the issue of anatomic versus valgus reduction, recent clinical studies have suggested that in younger patients (age <60 years) an anatomic reduction leads to better long-term results in Pauwels type 1 and Garden type 2 fractures, whereas a valgus reduction is recommended for Pauwels II/III and Garden III/IV type fractures due to the increased risk of a secondary loss of reduction[59,60] (Fig. 40-7). Displaced femoral neck fractures are associated with a high risk of nonunion and avascular necrosis of the femoral head, where the blood supply runs along the neck in extraosseous retinacular vessels that are torn or kinked by displaced fractures. The expanding intracapsular hematoma may contribute to further hypoperfusion through compression of the nutrient vessels. These complications are so serious for younger patients that most orthopedic traumatologists consider fracture of the femoral neck in a young person to be a surgical emergency. Urgent anatomic reduction, decompressive capsulotomy, and secure fixation of a displaced femoral neck fracture provide the best opportunity for salvage of the patient's own hip joint.[51] Extra-articular femoral neck fractures are less cumbersome to treat than intracapsular fractures and are not generally associated with the above-mentioned complications, such as post-traumatic avascular necrosis. The method of choice for stabilization of these fractures is a sliding hip screw/plate device and early functional rehabilitation with full weight bearing.

The treatment of choice for elderly patients (>80 years) or for patients with an according biological/physiological age consists of a primary arthroplasty.[58,61–63] This modality has been shown to be more efficient clinically, with regard to the incidence of complications and long-term outcomes, and more cost-effective from an economic point of view.[57,58,64] Although hip fracture fixation is more cost-efficient in the early phase, this initial advantage is eroded by significantly increased costs related to subsequent rehospitalizations for failure of fixation and associated complications.[49,57] The question of whether to choose a total hip arthroplasty over a hemiarthroplasty for elderly patients with displaced femoral neck fractures remains a topic of debate. The pertinent literature suggests a trend toward a more favorable outcome in patients with a total hip replacement, compared with those with a hemiarthroplasty.[49,57,58]

► Trochanteric Fractures

Trochanteric fractures are located distal to the femoral neck and are generally categorized into displaced versus nondisplaced and stable versus unstable fracture patterns.[65] These basic classification modalities are helpful in clinical decision making. The AO/OTA classification defines trochanteric fractures as the 31-A type.[55] The stability of trochanteric femur fractures is determined by the integrity of the medial cortex. As such, 31-A1 types are considered stable fractures with an intact lesser trochanter/medial buttress, while the A2 and A3 types are considered unstable fractures. The 31-A2 type corresponds to the classic “three-part fracture,” with a fracture of the medial cortex and a variant multifragmentary component.[65] The 31-A3 type classifies the most unstable trochanteric fractures, such as the “reverse obliquity” pattern (31-A3.1) and the classic “intertrochanteric” transverse fracture pattern (31-A3.2). The A3 types are defined by a breach in the lateral femoral cortex that is associated with a higher risk of failure after surgical fixation.[66] The AO/OTA classification for trochanteric fractures appears very reliable in clinical practice for guiding the optimal treatment and implant choice. Trochanteric fractures are an unequivocal entity of surgical management. A topic of ongoing debate is the question of whether to use a sliding hip screw/plate device as opposed to an intramedullary nail with cephalic interlock for trochanteric fracture fixation. While the implant choice may be guided by individual surgeons’ preference, some biomechanical aspects must be taken into consideration. The stable 31-A1 pattern with intact medial buttress is considered the classic indication for a sliding hip screw/plate fixation (**Fig. 40-8**). In contrast, the highly unstable 31-A3 types, particularly the “reverse obliquity” pattern, represent a contraindication for a sliding screw device and an indication for a cephalomedullary nail, respectively[66] (**Fig. 40-9**). A similar biomechanical aspect accounts for any trochanteric fracture with an associated fracture of the lateral femoral wall. In this regard, the integrity of the lateral femoral wall has been shown to represent a key predictor of reoperation secondary to failure of fixation.[66] Thus, fractures with a compromised lateral femoral wall are considered a contraindication for a sliding hip screw/plate construct. The most frequent trochanteric fracture pattern, the 31-A2 type (e.g., the classic three-part fracture), may be stabilized by either a cephalomedullary nail or a gliding hip screw/plate device, leading to similar outcomes reported in the peer-reviewed literature.[67]

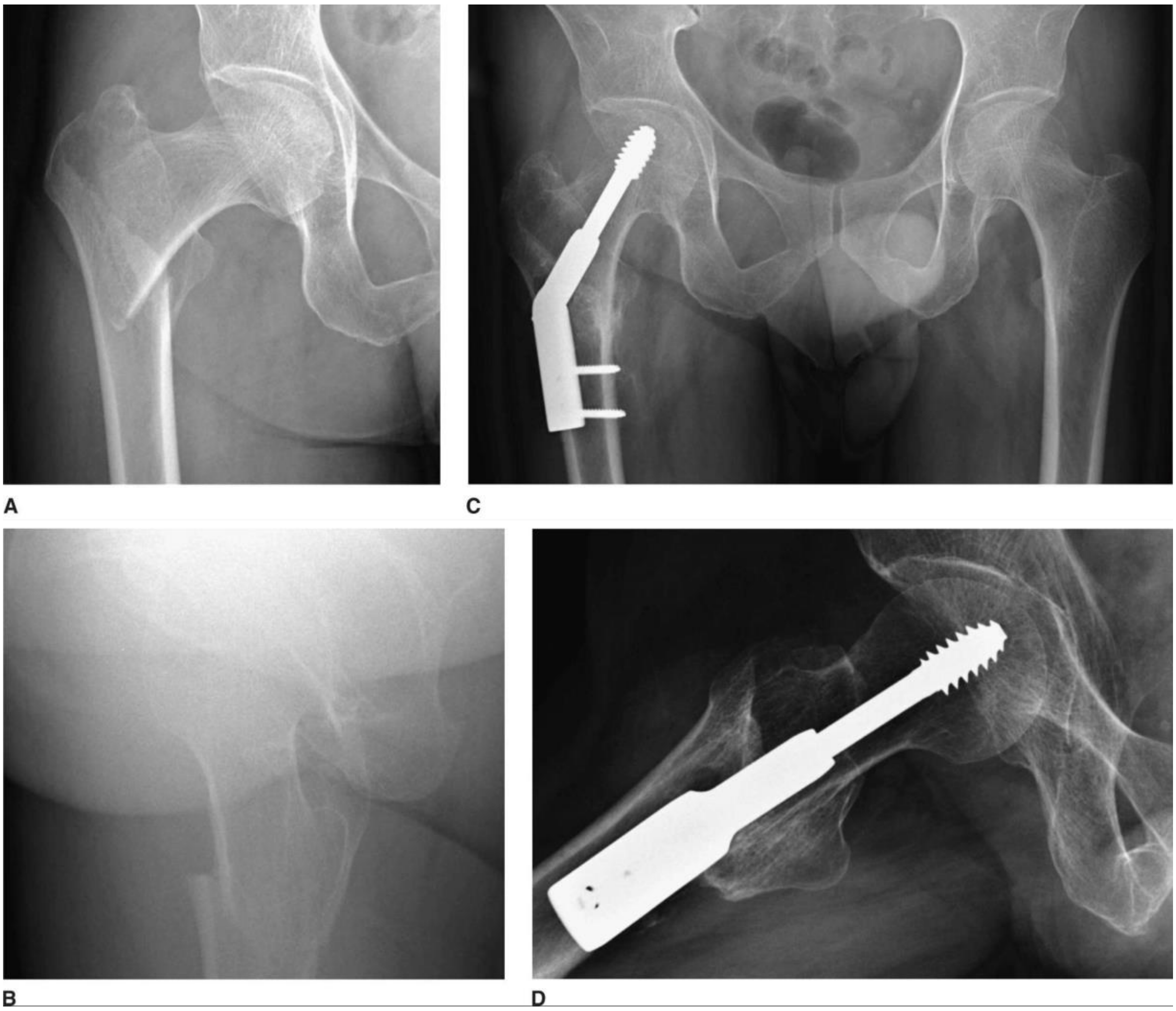

FIGURE 40-8 Trochanteric femur fracture (AO/OTA type 31-A2.1) in a 51-year-old construction worker who sustained a fall from a ladder (**A** and **B**). The fracture was treated by closed reduction and fixation with a gliding hip screw/plate device. X-rays taken at follow-up after 4 months show a healed fracture in anatomic position (**C** and **D**).

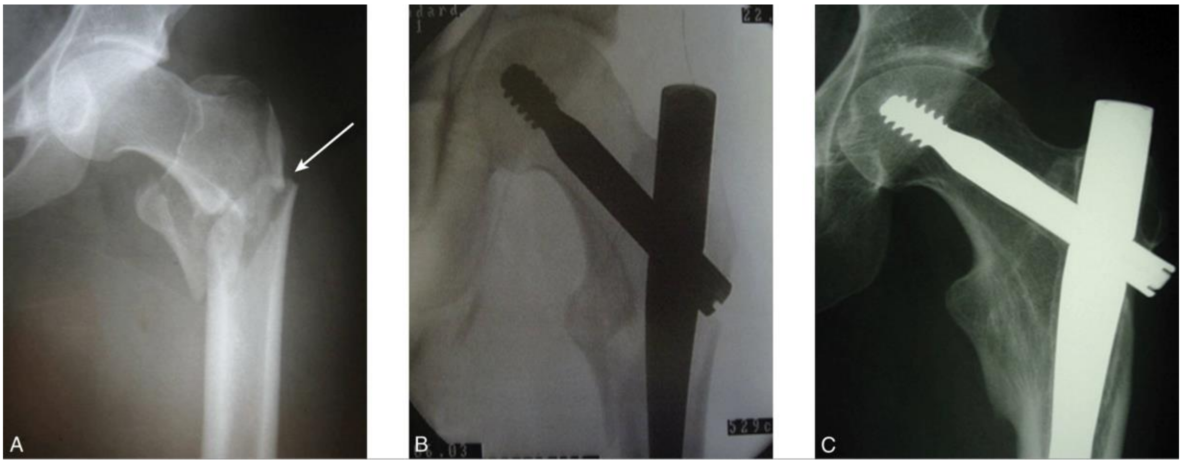

FIGURE 40-9 Highly unstable trochanteric femur fracture in a 20-year-old female medical student who was involved in a motor scooter crash. The unstable fracture pattern (A3 type) with a breach to the lateral wall (arrow in **A**) mandates fixation with a cephalomedullary nail (**B**). The fracture healed uneventfully with full weight bearing within 6 weeks (**C**). The nail was removed after 1 year due to symptomatic hardware.

Fixation is, naturally, more tenuous in osteoporotic bone. The fracture is initially reduced with the aid of a fracture table and image intensifier fluoroscope. Occasionally, actual open reduction is required in order to correct a varus malreduction. Overall, the "cutout" rate of the femoral neck screw with requirement for revision surgery lies below a 10% margin in the literature. A key aspect for maintaining implant fixation and fracture reduction is defined by a "tip–apex distance" of <2.5 cm, which is calculated as the cumulative distance from the tip of the hip screw to the apex of the femoral head in AP and lateral x-ray views.[68] Above the cumulative distance of 2.5 cm, the risk of failure due to femoral neck screw cutout was shown to be significantly increased. Thus, aside from a perfect anatomic reduction, the adequate femoral neck screw placement in both planes (AP and lateral) represents a crucial parameter for a successful outcome after fixation of trochanteric hip fractures. With modern internal fixation devices properly applied, union is typically achieved within 3 months, with acceptable alignment and a low incidence of fixation failure, for all categories of trochanteric fractures. Newer-generation implants aimed at reducing the incidence of failure due to cutoff of the femoral neck screw by replacing the screw with a twisted blade, or by the use of modern angular-stable plates.[69] While biomechanical testing has suggested an improved cutout resistance of these new implants, prospective clinical trials that provide a scientific evidence for the superiority of new-generation plates and nails, compared with conventional implants, are still lacking.

► Subtrochanteric Fractures

Subtrochanteric fractures are classified as a 32-X.1 region by the AO/OTA classification,[55] as opposed to the 31-X type of classification for the trochanteric and femoral neck fractures. In young patients, subtrochanteric fractures result from high-energy forces, typically motor vehicle crashes and falls from heights, and usually extend into the femoral shaft. In accordance with the high-energy trauma mechanism these young patients are usually severely injured and the traumatic impact is associated with severe soft tissue injuries and bleeding. In contrast, the subtrochanteric fracture pattern in older patients is different due to the usual low-energy mechanism of injury, similar to osteoporotic trochanteric fractures. Subtrochanteric fractures, a less frequent variety of hip fracture, still represent challenging injuries because of frequent failures of surgical fixation. Significant advances in understanding of fracture healing and of fixation techniques have improved the management of these fractures. Each of the typical modalities for osteosynthesis of subtrochanteric fractures has its pitfall. When treated by closed reduction and intramedullary nailing, the proximal fragment is difficult to reduce adequately and tends to malreduce in varus position and anteflexion. Often, this problem is overcome intraoperatively by additional cerclage wires, which however may contribute to impaired periosteal blood supply to the fracture. On the other hand, the exact anatomic reduction by ORIF technique uses a 95° angular blade plate remains challenging. Such operative techniques that fully expose the fracture and devascularize bone fragments may produce a "nicer x-ray," but interfere significantly with fracture healing and thus lead to delayed union with loosening or fatigue failure of fixation. The location of a subtrochanteric fracture is important for choosing fixation. If there is a large enough proximal femoral segment to insert a long intramedullary nail, this type of fixation is preferred. If the lesser trochanter is intact, a standard proximal interlocking configuration can be used. If the lesser trochanter is involved, the usual proximal locking screw has insufficient anchorage, and a cephalomedullary ("reconstruction-type") nail is used instead, with locking screws inserted proximally into the femoral head. If the fracture involves the nail entry site, special care is required for intramedullary fixation. A blade-plate or screw-plate device, with indirect reduction technique, may be easier and more reliable.

Although technically demanding, indirect reduction techniques with blade-plate or screw-plate devices can leave the fracture site undisturbed and yield predictable healing without bone grafting or high risk of fixation failure. The key to such procedures is that they maintain the soft tissue envelope around the fracture site, thus providing an improved biological environment for healing. This concept was recently advanced by the introduction of angular-stable locking plates for the proximal femur, which can be applied in a less invasive technique and do not compress the bone, thus leaving periosteal vascularization intact.

► Rehabilitation of Patients with Hip Fractures

For all patients with hip fractures, the goals of surgery include maximal restoration of function, maintaining low morbidity and mortality, while rapidly mobilizing the patient out of bed. Modern surgical techniques usually achieve these ends. Elderly patients may not be able to limit their weight bearing. Therefore, hemiarthroplasty, which offers greater mechanical stability than fracture fixation of osteopenic femoral neck fracture, may be the more appropriate treatment for these intracapsular fractures. Although today's hip screw devices generally permit weight bearing for patients with intertrochanteric fractures, significant osteoporosis or comminution may require protection until fracture consolidation has occurred. In young patients, limited weight bearing is generally easy with crutches and is routinely advocated initially. Early rehabilitation thus typically involves teaching the patient to do transfers and gait to the point of documenting safe ambulation with crutches or walker. Range-of-motion and strengthening exercises are routine. Depending on the injury and operative treatment, the patient may need to avoid certain activities such as loading the significantly flexed hip or crossing the legs in a way that might lead to prosthetic dislocation. Nutritional supplementation, prophylaxis against deep vein thrombosis, monitoring and managing intercurrent medical and psychiatric problems, and, in some cases, formal geriatric rehabilitation programs are also beneficial for patients with hip fractures.

Early stability of a repaired fracture depends on the quality of reduction, and of fixation, as well as bone density. These factors cannot be assessed by radiographic appearance alone and are not constant from patient to patient. No one is in a better position to judge them than is the surgeon who did the original fixation. Unless union occurs within a reasonable period, any fracture fixation implant will inevitably fail. For subtrochanteric fractures, this may take 6–9 months or more. For these reasons, the operating surgeon remains an essential part of the patient's rehabilitation team and should direct graded progression of weight bearing and resumption of activities while maintaining personal follow-up.

► The Future of Hip Fracture Care: Geriatric Fracture Centers

Geriatric fracture centers have recently emerged as a new modality for a standardized comanagement of elderly patient with hip fractures, between orthopedic surgeons, hospitalists, and geriatricians. The model is based on the principle that shorter times to surgery will result in less time to develop iatrogenic complications related to prolonged bed rest and unfixated fractures.[70] Standardized order sets and protocols are used at each stage of patient care, and discharge planning is already initiated at the time of admission. Frequent communication between the comanaging attending physicians will improve patient care and reduce the incidence of perioperative complications. A recently published retrospective analysis from this program showed that the comanagement of elderly patients with hip fractures and associated comorbid conditions by geriatricians and orthopedic surgeons, based on a standardized protocol of care, leads to shorter times to surgery, fewer postoperative infections and overall complications, and a shorter length of hospital stay, compared with a center with standard level of care in absence of a geriatric fracture management service.[70] Based on these promising early findings, the implementation of geriatric fracture centers should likely be promoted as a new cornerstone for the acute management and rehabilitation of elderly patients with hip fractures.

► Fractures of the Femur Shaft

Femoral shaft fractures invariably represent severe injuries due to high-energy trauma and are associated with a significant blood loss of up to 1,500–2,000 mL. Thus, an isolated femur shaft fracture alone can be the cause of a traumatic hemorrhagic shock. Most patients, however, suffer severe associated injuries to the torso, pelvis, and soft tissues. Thus, every femoral shaft fracture must be appraised as a highly critical, potentially lethal injury pattern. Early fixation of femur fractures is essential, in order to avoid or reduce the incidence of complications such as fat embolism syndrome, and ARDS.[71] Furthermore, early fracture fixation pays tribute to the intrinsic load to the patient by reducing stress and pain, which represents an important cardiovascular risk factor and may contribute to secondary deterioration of traumatic brain injuries due to increases in intracranial pressure.[3,4,32,35,72,73]

Intramedullary nailing of a femoral shaft fracture was performed for the first time by the German surgeon Gerhard Küntscher in November 1939. Despite the revolutionary innovation introduced by this new "biological" osteosynthesis, intramedullary nailing of long bone fractures has fallen into oblivion for several decades and had its "renaissance" only in the late 1980s by the introduction of solid and cannulated nails. Currently, the concept of closed reduction and fixation with a reamed interlocked intramedullary nail represents the "gold standard" for the treatment of femoral shaft fractures (**Fig. 40-10**). This procedure is associated with about 99% union rates in the literature, a low complication rate, and the possibility of early functional aftercare with weight bearing. Intramedullary nailing provides generally reliable fixation for any femoral fracture with sufficient intact bone proximally and distally. Interlocking screws were adopted to improve control of comminuted fractures. Intramedullary reaming permits use of a larger-diameter nail with larger-diameter locking bolts. Small femoral medullary canals may not permit insertion of an implant with sufficient strength and durability to avoid the risk of fixation failure. As a result, reaming has generally been recommended as a routine. Awareness of intravasation of reaming debris (fat, bone marrow fragments, inflammatory mediators, etc.) has led to concerns that their embolization to the lung might increase the risk of pulmonary complications and induce ARDS.[74] Clinical trials and experimental animal studies in recent years have ended the decade-long debate on the clinical relevance of reaming the intramedullary canal as opposed to using unreamed femoral nails.[75,76] The current consensus implies that the reaming procedure does in fact not increase the risk of intraoperative and postoperative pulmonary complications.[22,23] Thus, the reamed interlocking nail represents the current standard of care for femoral shaft fractures.

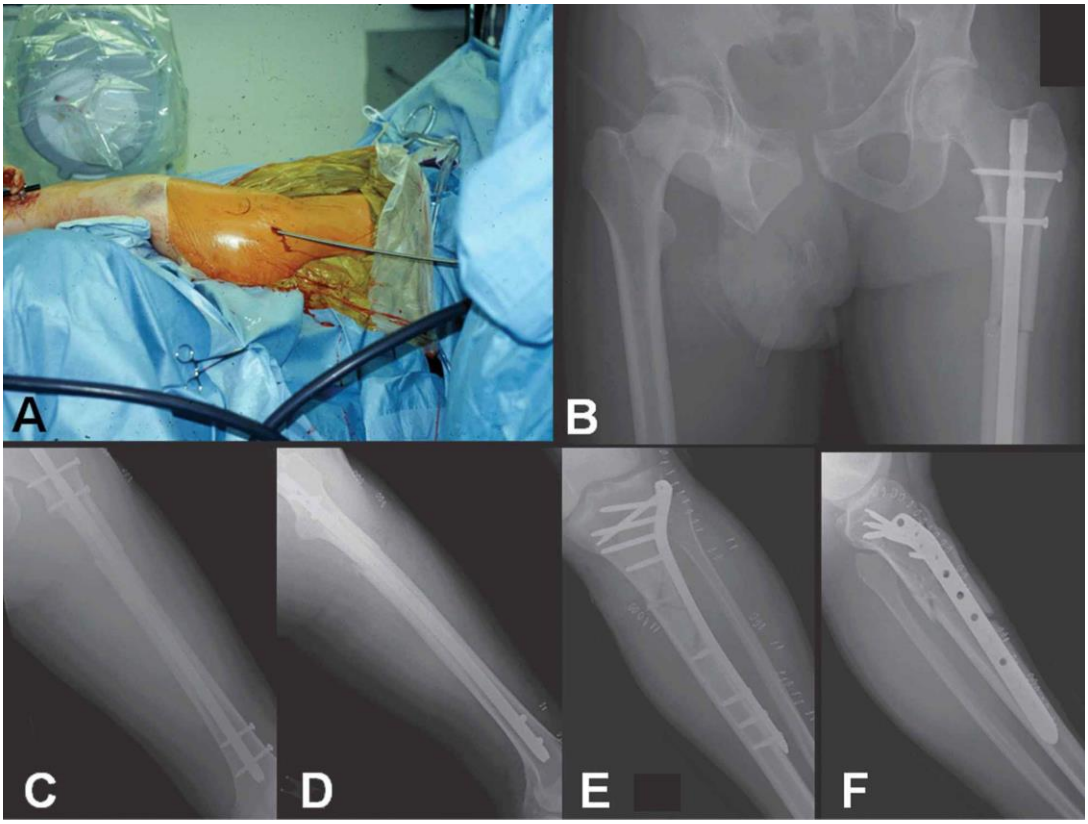

FIGURE 40-10 "True" percutaneous femoral nailing technique by the use of a cannulated femoral nail that is reamed through a small 1 cm proximal skin incision (**A**). This 51-year-old polytraumatized patient sustained a transverse femur shaft fracture (AO/OTA 32-A3) that was treated by closed reduction and stabilization with an interlocked cannulated femur nail (**B–D**) and an ipsilateral, comminuted meta-diaphyseal proximal tibia fracture (AO/OTA 41-A3.3) that was stabilized by a minimally invasive locking plate (**E** and **F**). Both measures are considered "biological" techniques since they spare the soft tissue envelope by the use of minimally invasive skin incisions.

Further controversy exists on the optimal entry point of intramedullary nails (piriformis vs. trochanter). While the piriformis entry poses a theoretical risk of avascular necrosis due to iatrogenic injury to the nutrient artery, and for an iatrogenic femoral neck fracture due to an incorrect entry point (too anterior and too medial), clinical trials have failed to prove a benefit in outcome for the femoral nails with a trochanteric entry point.[77] A newer generation of trochanteric femoral nails has improved the design with regard to a more anatomic bending radius of 150 cm (as opposed to 120 cm in conventional nails) and a 6° angle of the proximal nail segment that allows insertion through the major trochanter. Future clinical studies will have to determine the potential benefits of these new implants, compared with the conventional piriformis nails, with regard to outcome.

Severely injured polytrauma patients (ISS >17) as well as patients with a concomitant chest trauma (AIS for chest wall or lung injury >2 pt) or significant head injury (GCS <13) should be treated by the DCO procedure, as described in a previous paragraph. This implies an early fracture fixation by closed reduction and external fixation, followed by conversion to an intramedullary nail during the "time window of opportunity" between days 5 and 10 after trauma. A few highly critical patients with head or chest injuries and persisting morbidity due to increased intracranial pressure or ventilatory problems may be candidates for a minimally invasive "biological" plating of femur shaft fractures.[78] This modality strictly avoids any potential second hits to the injured brain or the pulmonary endothelium due to the intramedullary insertion of femoral nails.

Intramedullary nailing has been demonstrated to be a safe treatment modality also for open femur fractures (types I, II, and IIIA). Patients with severe open femoral shaft fractures (types IIIB and IIIC) need individualized decisions about fixation techniques. Preferably, external fixation represents a safe modality for early stabilization of these severe open injuries, followed by conversion to an internal fixation (nail or plate) at the time of definitive soft tissue coverage.

► Fractures of the Distal Femur

The osteosynthesis of supracondylar (AO/OTA type 33-A) and transcondylar distal femur fractures (type 33-C) has represented a significant challenge for a long time, due to high complication rates. A problem unique to these fractures is the loss of fixation of the distal femoral fragment, particularly in osteoporotic bone, by the use of conventional implants, such as the condylar buttress plate. Both the conventional plate osteosynthesis and intramedullary nailing procedures were associated with high rates of primary or secondary loss of reduction, malunions, nonunions, and infections. The recent emphasis on more “biological” approaches with minimally invasive techniques in conjunction with the development of angular-stable implants that allow the percutaneous placement of locking head screws has resulted in improved outcomes.[79] These include increased union rates without the need for additional bone grafting and decreased rates of infection and loss of reduction by the use of minimally invasive or less invasive locked plating techniques or retrograde intramedullary nails (**Fig. 40-11**).

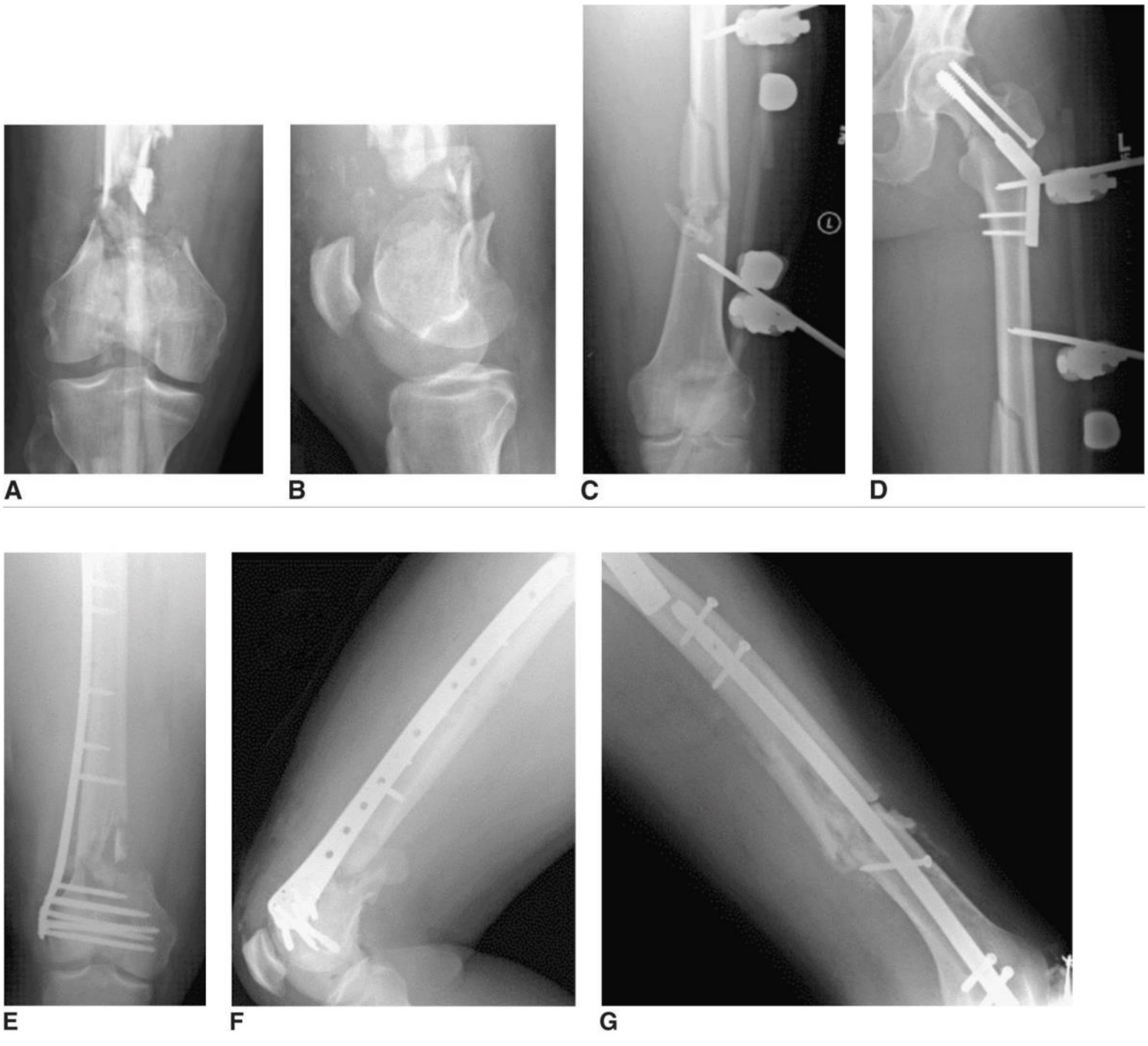

FIGURE 40-11 A 40-year-old dentist who sustained bilateral femur fractures (**A–D**) after a high-energy motorcycle crash, with a nondisplaced left extracapsular femoral neck fracture (AO/OTA type 31-B2.1), an ipsilateral femur shaft fracture (32-B1.2), and a proximal pole transverse patella fracture (45-C1.2). The injury on the right side consisted of a distal femur fracture with a comminuted metaphysis and an intra-articular split (33-C2.3). The femoral neck fracture was closed reduced and fixed with a dynamic hip screw (DHS) and an anti-rotation screw on day 1 (**D**), whereas both femur fractures were stabilized by external fixation for "damage control." Five days later, the patient was taken back to surgery for conversion to a minimally invasive locking plate on the right side (**E** and **F**) and a retrograde femur nail on the left side (**G**). This latter procedure was chosen due to the impossibility of using an antegrade nail related to the proximal DHS. The bilateral femur fractures showed progressive callus formation within 5 months after injury (**H** and **I**) and the left femoral neck fracture was healed at this time (**J**). The patient was ambulating with full weight bearing bilaterally and a free range of motion of both knee joints.

Generally accepted principles of management for articular fractures include anatomic reduction and fixation of the articular surface, with sufficiently stable fixation to permit immediate active and/or passive motion of the joint, and delayed weight bearing until the articular surface has recovered and the fracture has healed sufficiently. A classical implant developed in the 1960s by Maurice Müller in Switzerland is the 95° condylar blade plate that provides sufficient stability for treatment of distal femur fractures[80–82] (**Fig. 40-12**). However, the technique of blade plating requires a high level of skill and experience and may result in failure if not applied properly (**Fig. 40-13**).

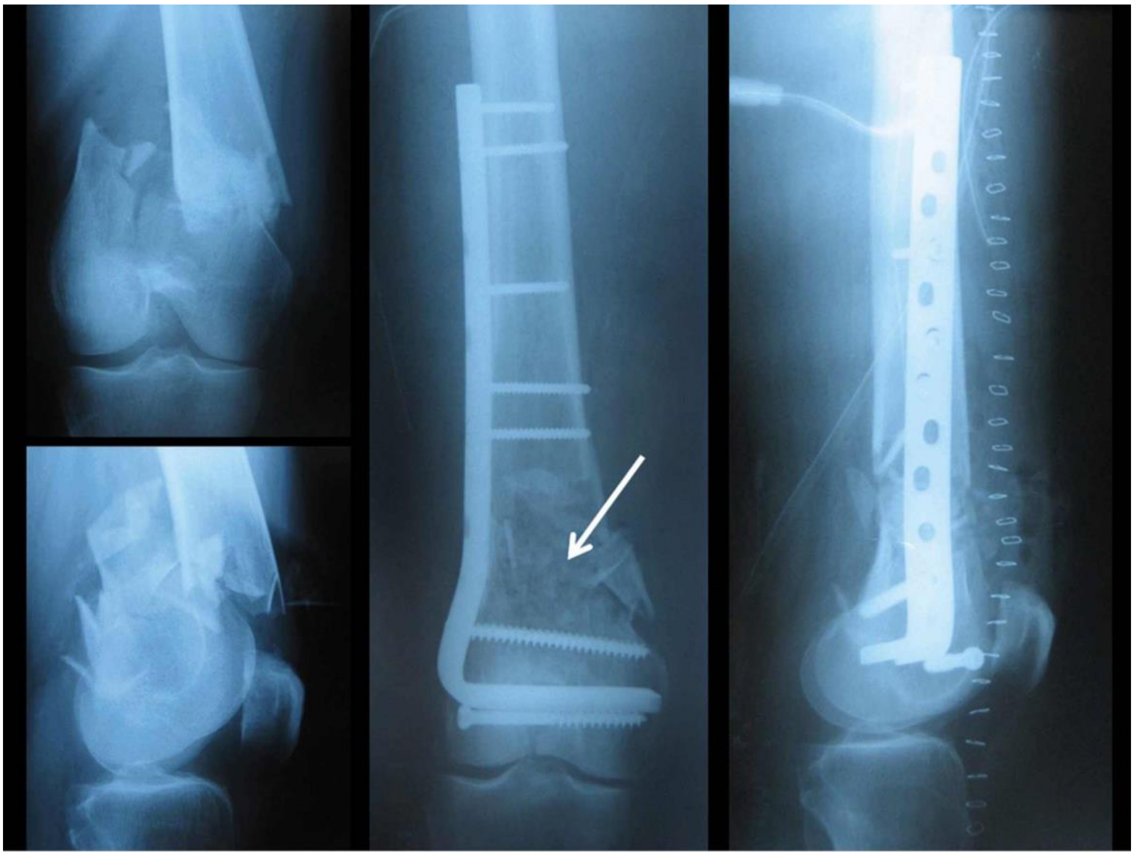

FIGURE 40-12 “Classic” use of a 95° angular blade plate and lag screw fixation of a simple intra-articular and comminuted metaphyseal distal femur fracture (AO/OTA type 33-C2), with primary bone grafting of the metaphyseal bone loss (arrow).

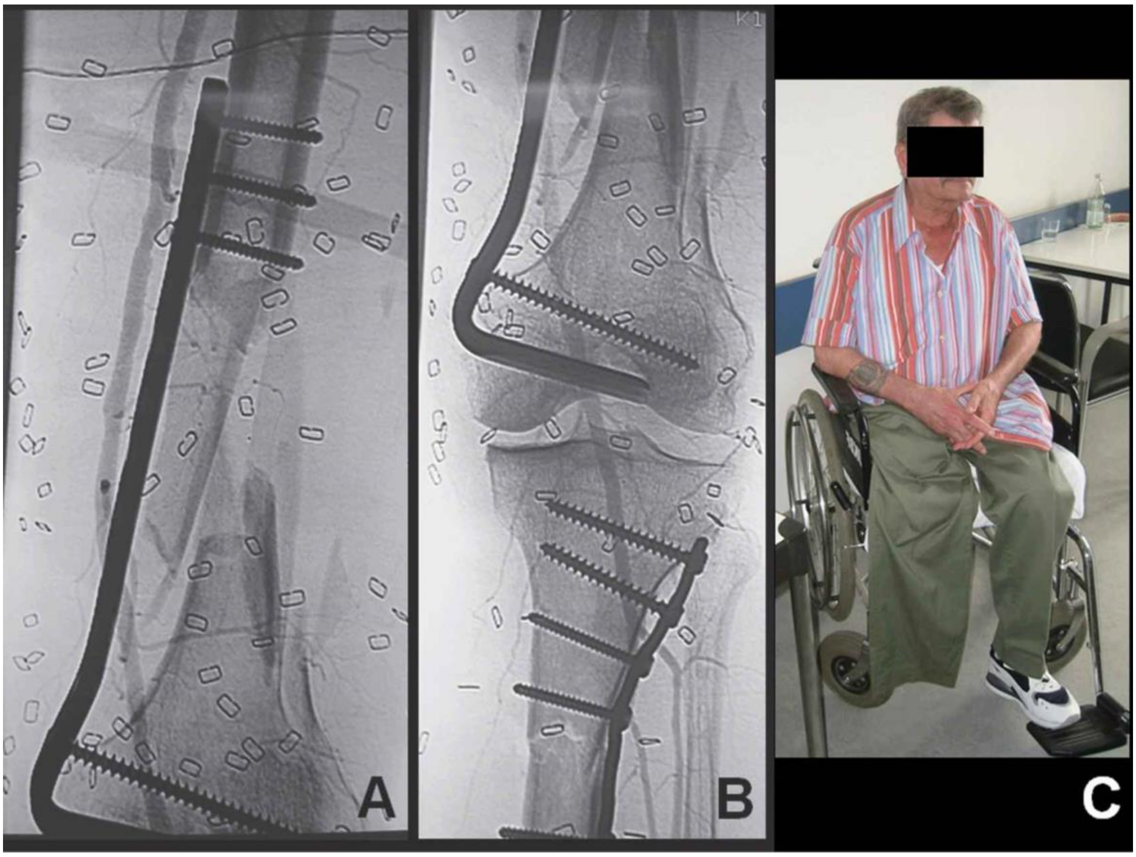

FIGURE 40-13 Wrong technique of plating for an open (Gustilo–Anderson grade IIIB) distal femur shaft fracture in a 55-year-old patient with an ipsilateral proximal tibia fracture and a "floating knee." The 95° condylar blade plate—which is designed for lateral insertion for fixation of distal femur fractures—was applied medially through the open wound, leading to a nonreduced fracture and an acute vascular compromise of the femoral artery, as revealed by the postoperative angiography (**A** and **B**). Inadequate intraoperative decision making in conjunction with an inappropriate surgical technique led to chain of complicating events that ultimately resulted in an above-knee amputation of the injured extremity (**C**).

Partial intra-articular fractures of the femoral condyles (AO/OTA type 33-B) are usually treated by open reduction and internal screw fixation, in order to ensure anatomic reduction of fractures of the articular surface. A typical example is the "Hoffa fracture" that corresponds to a coronal split of the femur condyle (B3 type). Extra-articular components in C-type fractures can often be managed by indirect reduction techniques to restore proper alignment of the articular segment to the limb, relying on proper use of specialized, minimally invasive or less invasive implants, such as the new-generation locking plates.[83]However, these new-generation locking plates have been associated with an increased rate of complications related to difficulty of hardware removal, particularly in the case of cold-welded locking head screws.[84]

Much interest has developed in retrograde intramedullary nail fixation for distal femoral fractures.[85] These nails are inserted in a minimally invasive fashion via the knee joint, into the intercondylar notch of the distal femur, and across the fracture site (Fig. 40-11). Fractures of the articular surface must be reduced and fixed first, with precautions to avoid displacement or interference with hardware as the nail is inserted and its distal and proximal locking screws are placed. Retrograde femoral nail techniques and implants are still evolving. Operations to fix distal femoral fractures can pose formidable technical challenges, especially for the surgeon who does not frequently treat such injuries, with one of the major pitfalls being a malreduction of the distal fragment in varus/valgus or retrocurvatum. However, with appropriate application, this technique is suitable for all fractures of the distal third of the femoral shaft including highly unstable bicondylar fractures without damage to the soft tissues and the knee joint. The primary aim of all surgical techniques applied for fixation of distal femur fractures consists of an early functional rehabilitation, preservation of knee joint range of motion, and an uneventful fracture healing.

► Patella Fractures

Patellar fractures usually result from a direct blow to the flexed knee. Displaced transverse fractures lead to a loss of continuity of the extensor mechanism, which produces extension of the knee both by pulling through the patella (via quadriceps tendon proximally and patellar ligament distally) and through the medial and lateral patellar retinacula. Nonoperative treatment is recommended for undisplaced fractures with a clinically intact extensor mechanism, that is, in those cases where the patient can raise the fully extended leg against gravity. In contrast, a surgical treatment by ORIF is generally indicated in cases with a compromised extensor mechanism as well as in displaced fractures with an incongruity of the articular surface. Depending on the exact fracture type, location, and the amount of comminution, repair may involve ORIF by lag screws and tension banding, and rarely by primary partial or total patellectomy. In all cases, the patellar retinacula must be repaired. Treatment of a patellar fracture should allow early range of motion of the knee, but weight bearing on the flexed knee must be prevented until healing is sufficient to tolerate the powerful tensile stresses produced by the quadriceps muscle. The usual postoperative concept consists of mobilization with touchdown bearing for 4–6 weeks and early limitation of knee flexion to about 60°, with progressive increase in the range of motion to about 90° until the fracture is consolidated.

► Knee Dislocations and Ligamentous Injuries

Knee dislocations may involve either the patellofemoral or the tibiofemoral joints. Lateral patellar dislocations typically occur in adolescent females with a genu valgus alignment. True tibiofemoral dislocations are much less common and generally require significant injury forces, although occasionally they are caused by a simple slip and fall. They are important to recognize because of extensive ligamentous disruption and risk of associated neurovascular injuries. A high level of suspicion for these associated vascular injuries is mandatory when evaluating a patient with a tibiofemoral dislocation and the potential for limb loss due to a missed blunt injury to the popliteal artery must be kept in mind (**Table 40-1**).

Patellar dislocations are usually lateral and involve indirect stresses applied by the patient pivoting on or forcefully extending a flexed knee in valgus. A hemarthrosis or effusion soon develops. Recurrent patellar dislocations are not infrequent, because anatomic abnormalities are often predisposing factors. The dislocated patella is palpable laterally, although it may have been reduced by straightening the knee for immobilization or x-ray. Closed reduction, if necessary, is obtained by passively extending the knee, flexing the hip to relax the rectus femoris, and applying medially directed pressure to the patella. Immobilization for 4–6 weeks allows healing of the medial retinacular tear that typically accompanies an initial dislocation, although acute repair of the medial patellofemoral ligament may be considered. Recurrent dislocations should be evaluated for elective surgical reconstruction.

Complete knee dislocations usually produce obvious deformity and difficulty moving the involved joint, as well as a radiographically evident dislocation, usually anteriorly or posteriorly, but sometimes medially or with rotation to any quadrant. Multiligamentous injuries in the knee with similar neurovascular concerns may be present without obvious deformity on exam or x-rays. It is often stated that these injuries are dislocations that have spontaneously reduced. Knee instability may be due to a purely ligamentous injury or may involve both ligament disruption and a fracture of the proximal tibia, typically a marginal avulsion (so-called Segond fracture or Moore type III fracture–dislocation) or a fracture of the medial tibial condyle (Moore type I fracture–dislocation).[86] Gross instability of the knee in more than one direction is the key diagnostic finding. With a torn articular capsule, hemarthrosis may be absent. With time, however, periarticular swelling is usually evident. Instability of the knee should always be considered when a patient presents with evidence of acute distal neurovascular compromise. A knee dislocation should be reduced as soon as possible after recognition. This can usually be done by traction and gentle manipulation in the emergency department.

The early recognition of an associated popliteal artery injury is crucial, which has been described in 14–34% of all cases with traumatic knee dislocations. While a complete arterial disruption may be obvious early after trauma due to clinical signs of peripheral ischemia, an incomplete dissection or intimal injury by stretching forces may be missed. Intimal tears can lead to delayed thrombosis and secondary limb ischemia in spite of the absence of apparent early clinical evidence for a vascular injury. Due to the often asymptomatic nature of blunt popliteal injuries, the amputation rate for blunt vascular trauma is about three times higher than that after penetrating injuries and lies in the range of 15–20%. Thus, a high index of suspicion is required for blunt popliteal injuries in all cases of knee dislocation and defined diagnostic algorithms should help establish an accurate diagnosis early on. Any pulse deficit or measurable reduction in ankle–brachial Doppler-assisted API, before or after manipulation, should be considered evidence of a vascular injury. This includes the reported absence of pulses at the accident site even when pulses return to normal after reduction of the knee dislocation. Based on large meta-analyses in the literature, the accuracy of pulse examination alone is very low, yielding a sensitivity of only about 79% for the detection of an arterial injury.[12,87] The five clinical “hard signs” for an arterial injury, which are present in about two thirds of all cases, are outlined in Table 40-1.

In cases of a suspected arterial injury, either an (on-table) arteriography or a surgical exploration is mandatory, since observation alone will have detrimental consequences for the patient. Injuries to the peroneal or tibial nerve, with motor and/or sensory impairment, may be associated with an arterial occlusion. Such neurological lesions also interfere with recognition of ischemic pain due to arterial occlusion or an acute compartment syndrome.

A popliteal artery injury associated with dislocation of the knee is repaired in the operating room with both vascular and orthopedic surgeons present. Adequate reduction and stabilization of the knee dislocation is required, and external fixation is well suited for provisional stabilization. A simple external fixator, connecting two self-drilling pins in the femur to two similar pins in the tibia with a bridging bar anterior to the knee, can be applied so rapidly that it will not delay arterial repair. It can readily be adjusted to allow intraoperative motion of the knee, should that help with vascular repair, and furthermore provides a nonconstricting splint for postoperative immobilization and protection of the vascular graft. With regard to ligamentous injuries, the currently favored concept of treatment consists of an early, but not immediate, surgical repair. While the incision for arterial repair must be chosen by the vascular surgeon, consideration should be given to the exposure required for secondary ligamentous repair and whether or not this might safely and appropriately be combined with the emergency vascular repair. Trauma teams that treat these relatively rare injuries may manage them more effectively by developing collaborative protocols for knee dislocations with concomitant injuries to the popliteal artery. Below-knee four-compartment fasciotomy is routinely advisable after popliteal artery repair in order to avoid a secondary compartment syndrome due to ischemia–reperfusion injuries.

Ligamentous and meniscal injuries without dislocation of the knee may occur in multiple trauma patients or as isolated injuries. Hemarthrosis, swelling, pain, tenderness, and impaired motion of the joint are typical findings. If a knee cannot be examined initially because of adjacent fractures, ligamentous stability must be assessed as soon as those fractures are stabilized. Associated knee injuries are not uncommon with femoral or tibial fractures and particularly when both are present in a so-called floating knee. Inability to passively extend the knee suggests a mechanical block, usually a meniscal tear, whereas instability indicates a ligamentous injury. Both knees should be examined for comparison, because individuals have different amounts of intrinsic laxity. Initial examination of the knee requires x-rays to rule out associated fractures. Aspiration of a tense hemarthrosis under sterile conditions can relieve pain. Complete evaluation may also require arthroscopy or magnetic resonance imaging (MRI) to identify ligamentous or meniscal injuries, but such studies are rarely needed emergently. Although many acute ligamentous injuries of the knee can be treated nonoperatively, major reconstructions may be required to restore function. Accurate diagnosis of ligamentous injuries is crucial for planning appropriate treatment. Relatively infrequent disruptions of the posterolateral ligamentous complex should be repaired within the first 2 weeks. Isolated ruptures of the medial collateral ligament do well with nonoperative management in a hinged knee brace. Delayed reconstruction is often advisable for disruptions of the cruciate ligaments, unless avulsed with a bone fragment, for example, in combination with Moore-type fracture–dislocations of the tibial head.

► Fractures of the Tibia

Proximal Tibia

Proximal tibia fractures are differentiated as extra-articular metaphyseal fractures (AO/OTA 41-A type), intra-articular tibial plateau fractures (41-B/41-C types and Schatzker classification), and fracture–dislocations (Moore classification). While the typical split-depression-type fractures (Schatzker types I–III) of the lateral condyle are usually due to low-energy, indirect valgus stress mechanisms of injury, the more severe bicondylar fractures (Schatzker types V and VI) and fracture–dislocations (Moore types I–V) are mainly due to direct high-energy forces with significant soft tissue compromise and a risk for acute compartment syndrome.[86] Those fractures are inherently unstable, difficult to reduce and stabilize, and associated with a high rate of complications, such as malreduction, secondary loss of reduction, infections, and nonunions. Isolated fractures of the medial condyle (Schatzker type IV and Moore type I) are more rare and often require special approaches for adequate reduction and stabilization, for example, by a direct posterior approach[86] (**Fig. 40-14**).

FIGURE 40-14 Bilateral complex tibia fractures in a 52-year-old lady who sustained a collision as a car driver against a truck. She sustained a severely comminuted tibial pilon fracture on the right side (AO/OTA 43-C3; **A** and **B**) as well as a contralateral, unstable bicondylar tibial head fracture (Schatzker type V; **E** and **F**). Both injuries were initially immobilized in an external fixator due to the critical soft tissue conditions. Once the soft tissue swelling subsided within 10 days, the fractures were converted to internal fixation. The bicondylar tibial head fracture was stabilized through a direct posterior approach with a posterior antiglide plate and completed by a lateral buttress plating with a locking plate (**C** and **D**). The pilon fracture was stabilized by initially fixing the fibula for correct length and rotation and by open reduction of the articular part of the pilon fracture with two lag screws and minimally invasive osteosynthesis with a locking plate (**G**–**I**). The patient recovered well without postoperative complications and was non-weight bearing bilateral for 10 weeks.

For the accurate diagnosis of a tibial plateau fracture, routine x-rays of the knee should be complemented by a CT scan with 2D reconstruction, in order to allow an adequate planning of surgical approaches and fixation strategies. Undisplaced proximal tibial fractures can usually be treated with early motion and touchdown weight bearing in a hinged knee brace for 6–12 weeks. The need to stabilize a severely injured limb, especially in a multiply injured patient, can be met initially with a spanning external fixator. Significant deformity of the articular surface, instability, and/or displacement are frequent indications for surgical treatment. To be successful, this must achieve stable fixation and early motion of an anatomically reduced articular surface. Unless these goals can be met, the results of surgery are typically worse than those of nonoperative care. The recent availability of angular-stable locking plates has enabled less invasive approaches and diminished the requirement for primary bone grafting of metaphyseal defects. For example, intra-articular fractures of the lateral plateau (Schatzker types I–III) are nowadays frequently treated by less invasive procedures, whereby the adequacy of articular reduction is intraoperatively assessed by arthroscopic or fluoroscopic control.

Tibial Shaft

Fractures of the tibial shaft range from low-energy, indirect torsional injuries that do well with nonoperative treatment to severe high-energy fractures with severe soft tissue damage and a high incidence of acute compartment syndrome.[88] The amount of energy absorbed by the leg is suggested by the radiographic appearance of a fractured tibia. The severity of the soft tissue injury, whether open or closed, is most important for the overall outcome of tibial shaft fractures. For example, the presence of severely crushed soleus and gastrocnemius muscles makes a plastic coverage of an open tibia fracture by a local rotational flap impossible. The soft tissue envelope on the medial border of the tibia is very thin; thus, minor open fractures may have major therapeutic implications for covering the exposed bone, ranging from skin grafts to local or free microvascular flaps, to a lower limb amputation.

Compartment syndromes develop frequently in tibial shaft fractures due to direct compression forces. They are especially common if the soft tissues have been crushed or if a period of ischemia has occurred. The initial symptom is leg or ankle pain out of proportion to the physical signs and exacerbated by passive motion of the ankle and toes. Indurated swelling of the calf and, occasionally, the foot is noted. Hypesthesia of the foot and reduced motor strength are due to ischemia of the muscles and nerves within the calf compartments and represent late signs of a (missed) compartment syndrome. Skin perfusion and distal pulses remain intact until late in the evolution of compartmental syndromes, since the obstruction, within the involved spaces, is to capillary rather than arterial flow. The diagnosis is made clinically. Measurements of intracompartmental pressures are required in obtunded or comatose patients and to rule out compartment syndrome in unclear or borderline cases. The treatment for an acute calf compartment syndrome is immediate decompression by a four-compartment fasciotomy, which is performed with medial and lateral incisions.

Timing and treatment modalities for tibial shaft fractures are dependent on the severity of injury and associated problems. Limb-threatening complications such as open fractures, vascular injuries, and compartment syndromes require immediate surgery. In absence of such complications, a provisional closed reduction and application of a long leg cast provide initial immobilization. In tibial shaft fractures of minor severity and dislocation, closed treatment is the method of choice.[89] Weight bearing begins as tolerated in the long leg cast, proceeding to a patella tendon bearing short leg cast or brace, as soon as patient comfort and stability of the fracture permit. Although this approach can succeed with more severe tibial shaft fractures, it is often associated with delayed union, deformity, and prolonged disability. Surgical fixation, which provides better control of alignment and allows motion of the foot and ankle, as well as the possibility of earlier weight bearing, is more appropriate for these injuries. Intramedullary reamed nailing is the fixation of choice.[88] The indications for intramedullary nailing are increasingly expanding to more proximal and distal metaphyseal fractures due to the availability of new-generation interlocking nails that allow three-dimensional interlocking in very proximal and distal areas of the tibia (**Fig. 40-15**). One of the important risks of extending the indication for tibia nails to the proximal and distal metaphysis is a malalignment in valgus or varus, unless fractures are reduced adequately, for example, by the use of blocking screws. Reaming of the tibial medullary canal permits use of nails with large enough diameters to provide adequate fixation for most tibial shaft fractures. Such nails have large enough diameters to permit the use of locking screws of adequate strength to ensure definitive control of alignment. The strength and fatigue life of smaller-diameter unreamed nails, and especially of their small-diameter locking screws, is not sufficient for keeping the reduction of tibial fractures throughout their healing period.[90]Thus, the unreamed tibia nail has been associated with a high risk of complications, such as breaking locking bolts, malunion, and nonunion (**Fig. 40-16**). Multiple large clinical trials have demonstrated that both the nonoperative treatment and unreamed nailing strategies have the highest incidence of nonunion and malunion, as opposed to fracture fixation by reamed cannulated nails. The use of blocking ("Poller") screws represents an important intraoperative trick for achieving and maintaining reduction and axial alignment.[88,91,92]

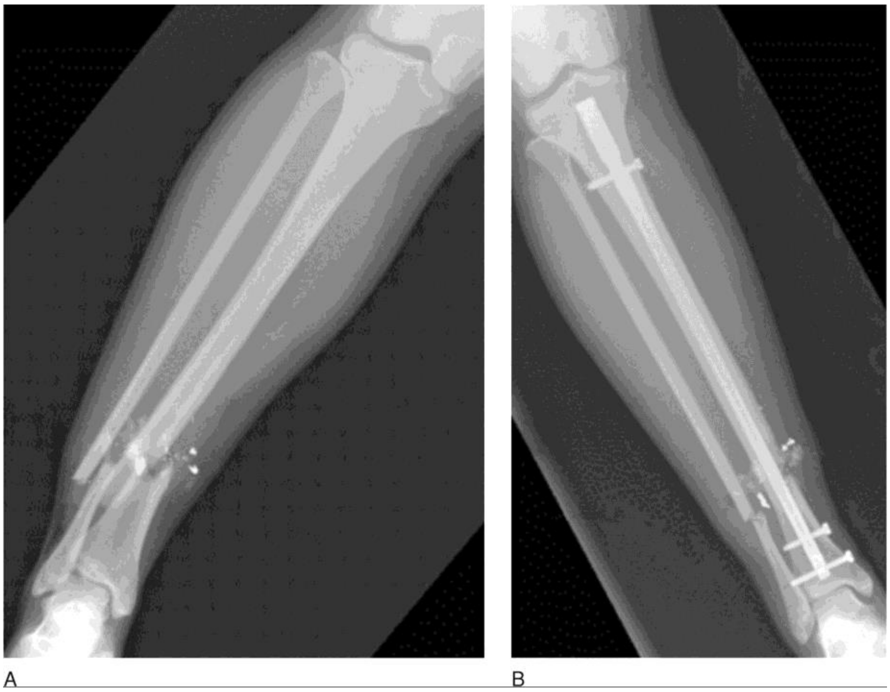

FIGURE 40-15 (**A** and **B**) A 19-year-old girl who was accidentally shot in the right leg as a victim of a drive-by shooting. She was immediately taken to the OR and treated by local wound debridement and intramedullary fixation of her tibial shaft fracture. She did not have any neurovascular injuries. Her postoperative course was uneventful and she was allowed to ambulate with weight bearing as tolerated on the right side. No postoperative infection occurred.

FIGURE 40-16 Varus malunion of a tibia shaft fracture after failure of fixation with an unreamed interlocking tibia nail. This is a typical complication of the first-generation unreamed solid tibia nails due to the thin diameter of the implant and interlocking bolts.

External fixation is still a valuable technique for selected tibial fractures. These include high-energy trauma with significant soft tissue injury, vascular injuries requiring repair, and in the setting of polytrauma patients, as a “damage control” procedure.[4] External ring fixators may furthermore be applied for segment transport in situations with significant bone loss, and for correction of malunions and nonunions. Long-term use of an external fixator (>14 days) is associated with bacterial colonization of the pin tracts and a risk of infection from subsequent intramedullary nailing. Use of an external fixator for only a few days, however, can safely precede intramedullary nailing for definitive management of tibial shaft fractures.

A variety of fixator designs are available, with no clearly established proof that one is better than another. Generally, transfixion pins or wires are used only in the very proximal or distal zones of the tibia, and “half-pins”—screws with long shafts inserted through the subcutaneous anteromedial surface of the tibia—are used to anchor the external fixator frame (**Fig. 40-17**). Leaving the external fixator in place until the fracture is healed helps prevent the typical complication of late loss of alignment, commonly seen with premature removal of the fixator. Early posterolateral bone grafting may be advisable to accelerate union of tibial shaft fractures with primary bone loss.

FIGURE 40-17 Segment transport using an external Ilizarov frame in case of a severely comminuted and contaminated tibial shaft fracture (**A** and **B**). After a proximal corticotomy (**C** and **D**), the bone loss was replaced by means of a distraction osteogenesis, and the distal docking site healed uneventfully (**E** and **F**).

Plate fixation of acute fractures of the tibial shaft is generally reserved for periarticular injuries too proximal or distal for intramedullary nailing.[93] If severe injuries to soft tissue are present, such plating involves a significant risk of sloughing of the incision and/or infection. Techniques of plating that emphasize gentle handling of soft tissues, the avoidance of devascularizing flaps, and use of indirect reduction methods can further reduce the risk of surgical complications of plate fixation.[93] Locking plates that allow less invasive or minimally invasive plating techniques are ideal for bridging comminuted metaphyseal fractures that may be too proximal or too distal for intramedullary nailing techniques.

Pilon Fractures

Tibial pilon (plafond) fractures are highly challenging intra-articular injuries of the distal tibia that are typically caused by axial loading forces with concurrent distortion and of the ankle, leading to a disruption of the tibial articular surface by the twisted and rotated body of the talus. Pilon fractures are classified as AO/OTA types 43-B (partial intra-articular) and 43-C (complete intra-articular) (Fig. 40-14). These fractures typically involve a significant damage to soft tissue, whether or not an open wound is present. Traditional ORIF techniques have a high risk of wound dehiscence and infection, particularly if surgery is performed during the phase of post-traumatic inflammation and soft tissue swelling within the first days after trauma. Clinical studies have clearly revealed an improved outcome of tibial pilon fractures when staged procedures are applied, such as early external fixation and later conversion to ORIF once the soft tissue swelling has subsided.[94] The concept of definitive surgery for pilon fractures involves a standard technique in four “classical” steps, according to Sommer and Rüedi: (1) plating of the fibula for anatomic length of the lower leg; (2) anatomic reconstruction of the tibial articular surface; (3) bone grafting of the metaphyseal gap; (4) buttress plating of the distal tibia. Depending on the degree of comminution, the individual bone quality, and the extent of soft tissue compromise, the postoperative rehabilitation of pilon fractures is either by early functional after treatment or by immobilization in a lower leg cast for about 6 weeks. As for all metaphyseal fractures, weight-bearing status must be restricted to touchdown weight bearing until the fracture is healed, usually for 10–12 weeks.

► Ankle Injuries

Ankle injuries represent overall the most frequent musculoskeletal injuries. The mechanism and severity of injury has been historically classified by the Lauge-Hansen classification system.[95] The ankle is a hinge joint, in which the body of the talus dorsiflexes and plantarflexes within a mortise-like socket formed by the distal tibia (medial malleolus and plafond) and distal fibula (lateral malleolus). Integrity of the mortise is maintained by the ligamentous connections between tibia and fibula, just above the ankle joint (anterior and posterior syndesmosis). Widening of this mortise results in talar instability, which predisposes to post-traumatic arthritis. The lateral malleolus is the prime determinant of talar alignment. Restoration of its proper relation with the distal tibia is "key" to treating malleolar injuries. This may require anatomic ORIF of a displaced lateral malleolar fracture and/or restoration of the disrupted syndesmosis by returning the fibula precisely to its location adjacent to the tibia. Stable, minimally displaced lateral malleolar fractures can be managed nonoperatively with closed treatment, typically with about 6 weeks of immobilization, followed by rehabilitative exercises to restore the range of motion. If the ankle is unstable, it will need to be temporarily fixed with a syndesmotic screw until ligamentous healing is secure, usually for 6 weeks. Patients who require syndesmotic fixation have a significantly worse long-term outcome than patients with ankle fractures and a stable syndesmosis.[96] Medial ankle disruptions may involve the medial malleolus, which should be reduced and fixed, or the deltoid ligament, which need not be repaired if the remainder of the joint is reduced and repaired properly. Several authors have determined that a widened "medial clear space"—under stress exam or gravity stress test—of more than 4-5 mm represents an indication for surgical ankle fracture fixation.[97] The posterior lip of the tibial plafond, the so-called posterior malleolus or Volkmann's triangle, is frequently fractured in malleolar injuries. The designation of a "trimalleolar" fracture implies those injuries that involve the posterior tibial plafond in addition to the medial and lateral malleoli. Large posterior tibial plafond fractures of more than one fifth of the articular surface should be reduced and fixed to avoid posterior subluxation of the talus and/or incongruency of the joint. Malleolar fractures are produced by indirect forces, generally caused by the body's momentum when the foot is planted on the ground in one of several typical positions. Depending on the position of the foot and direction of motion, typical combinations of fractures and ligamentous injuries result, with progressively greater damage and displacement, up to and including talar dislocation. Knowledge of these patterns improves the surgeon's understanding and treatment of such injuries. The basic principle of treatment remains open reduction of displaced injuries, with anatomic reduction and rigid fixation. If significant displacement is present, prompt closed reduction is urgent, while definitive fixation can be delayed, depending on the quality of the individual soft tissue situation. As with pilon fractures, significant swelling is an indication for a delay in surgery to decrease complications with wound healing.[98] Some authors have suggested a staged protocol for complex ankle fractures with significant soft tissue compromise, with initial closed reduction and transarticular pin fixation, followed by delayed ORIF once the soft tissue swelling has subsided.[99] The soft tissue envelope about the ankle and foot is thin, with little muscle coverage. This renders simple lateral malleolar fractures susceptible to significant soft tissue complications, including skin necrosis, wound dehiscence, and infections. Open fractures of the malleoli may require a microvascular free flap transfer due to the bad quality soft tissue coverage and the impossibility of local rotational flap in this distal area of the leg. Recognition and appropriate management of open ankle injuries is essential to minimize complications and avoid adverse outcomes, which may require a BKA. This notion emphasizes again, as mentioned above for the pilon and tibial shaft fractures, the “key” aspect of the soft tissues for uneventful fracture healing.

Ligamentous injuries of the ankle most commonly involve the lateral collateral ligament complex, which provides inversion stability of the talus within the mortise. Inversion of the foot normally occurs at the subtalar joint, between the talus and calcaneus. If forced to the limit, however, the lateral collateral ligament stretches or ruptures, producing the typical “sprained ankle” with lateral pain, swelling, and ecchymosis and tenderness over the injured ligament distal and anterior to the lateral malleolus. Minor ankle sprains can be treated symptomatically, with restricted activities, elevation, ice, and support as needed for comfort. More severe sprains require immobilization and/or crutches for comfort and to decrease the risk of late instability, which is manifested by recurring episodes of “giving way” of the ankle. After a brief period of rest, most injuries to the lateral collateral ligament of the ankle are effectively treated with a functional brace.

Since it is difficult to differentiate a simple distortion from a fracture in the acute phase, due to nonspecific symptoms such as pain, tenderness, and swelling, a precise diagnosis usually requires adequate radiographs. A “true” AP view of the ankle (so-called mortise view) requires internal rotation of about 15–20° to position the joint axis, which runs between the tips of the two malleoli, in a plane parallel to the x-ray film. The mortise view and a lateral view are usually sufficient to adequately diagnose most ankle fractures. Oblique views and foot x-rays may be required to identify more occult or associated injuries, such as a base of the fifth metatarsal avulsion fracture, lateral process of talus (“snowboarder’s injury”), or anterior process of calcaneus fractures.

► Fractures and Dislocations of the Foot

Injuries of the foot typically result from a direct blow or crushing force. Extreme dorsiflexion or plantarflexion and rotation outward (pronation) or inward (supination) can also produce significant bony and joint injuries of the foot. These injuries may be unrecognized or underestimated, especially in a multiply injured patient, and a delay in definitive treatment may compromise outcome (**Fig. 40-18**). Disability due to a significant foot injury is often far greater than that resulting from more dramatic injuries to long bones. Open fractures may result from crushing injuries, which can severely damage the surrounding skin envelope, as well as from lacerations and gunshot wounds.[100] Neurovascular structures and tendons may be involved, and their function must be carefully assessed with any injury. Compartment syndromes occasionally develop due to severe crush mechanisms; however, they are much rarer in the foot than in the lower leg.

FIGURE 40-18 Combined navicular fracture–dislocation and metatarsal I Lisfranc dislocation of the left foot (**A** and **B**) in a severely injured polytrauma patient. The foot injury was treated by open reduction and internal fixation of the navicular fracture with two 2.0 mm mini-AO screws and a 3.5 mm joint-transfixing screw as temporary arthrodesis (**C**). This screw was removed after 3 months and the patient could walk with full weight bearing without pain.

A swollen, tender, or painful foot following trauma should be assumed to be a fracture or dislocation until proven otherwise. Radiographs must be obtained to demonstrate suspected or obvious fractures and to locate possible foreign bodies. Major injuries such as tarsometatarsal dislocations often have subtle x-ray findings, while less severe fractures may be quite obvious. Fractures of the talus and calcaneus result from a direct blow to the plantar surface, usually transmitted through the heel. Undisplaced and extra-articular fractures of the calcaneus can be managed nonoperatively. Improved surgical approaches and fixation techniques, coupled with detailed demonstration of the pathologic anatomy of calcaneal fractures provided by CT scanning, have focused surgical treatment on restoration of the typical post-traumatic varus deformity as well as reconstruction of the frequently involved subtalar articular surface (so-called posterior facette) and the calcaneocuboideal joint. Interestingly, large prospective trials have impressively shown that the nonoperative treatment of displaced intra-articular calcaneus fractures yields similar long-term results as in operative cases where the articular surfaces have been anatomically restored. Furthermore, operative interventions bear a high risk for severe soft tissue complications, since the surgical approach typically dissects through the thin skin envelope over the lateral calcaneus. For this reason, ORIF should be delayed until soft tissue swelling is completely resolved. This may take up to 2–3 weeks for severely displaced and comminuted calcaneus fractures.

Displaced fractures and fracture–dislocations of the talus require precise reduction and rigid fixation with an interfragmentary screw. Displaced talar neck fractures represent a surgical emergency due to the high risk of post-traumatic avascular necrosis. This risk gradually increases with the severity of injury, as graded by the Hawkins classification (I–IV). Post-traumatic arthritis and osteonecrosis may require an ankle fusion in the end stage.

Isolated, minimally displaced or undisplaced metatarsal fractures are treated nonoperatively. Treatment options include a hard-soled stiff shoe and a brace or cast for comfort, with weight bearing allowed as tolerated. Displaced midfoot fractures and dislocations require anatomic reduction, which is best achieved by an open technique. Typical fracture–dislocations at the Lisfranc or Chopart joints require ORIF by temporary arthrodesis, usually with small- or mini-fragment screws for about 3 months. While dislocations of a toe should be reduced promptly, phalangeal fractures generally require little specific treatment. Open fractures of the foot are treated with debridement, repair of critical structures, and fixation of fractures as needed to preserve stability and alignment. Loss of skin at the foot represents a serious problem, which can be addressed in part with skin grafting but may require free tissue transfer or even amputation. Mangling injuries of the toes are usually treated with primary amputation.[100]

LATE COMPLICATIONS

► Nonunion

A diagnosis of nonunion is made when there is failure of complete healing within a 6- to 9-month time period following definitive fracture care. Fractures have different expected time periods of healing depending on the type of fracture and the location. Tibia fractures are relatively slow healing, particularly open fractures. Femur fractures heal more rapidly. Nonunions complicated by bone loss, significant malalignment, or infection are extremely difficult challenges for the patient and surgeon (**Fig. 40-19**). Treatment to gain union may require 2–5 years and numerous revision surgeries.

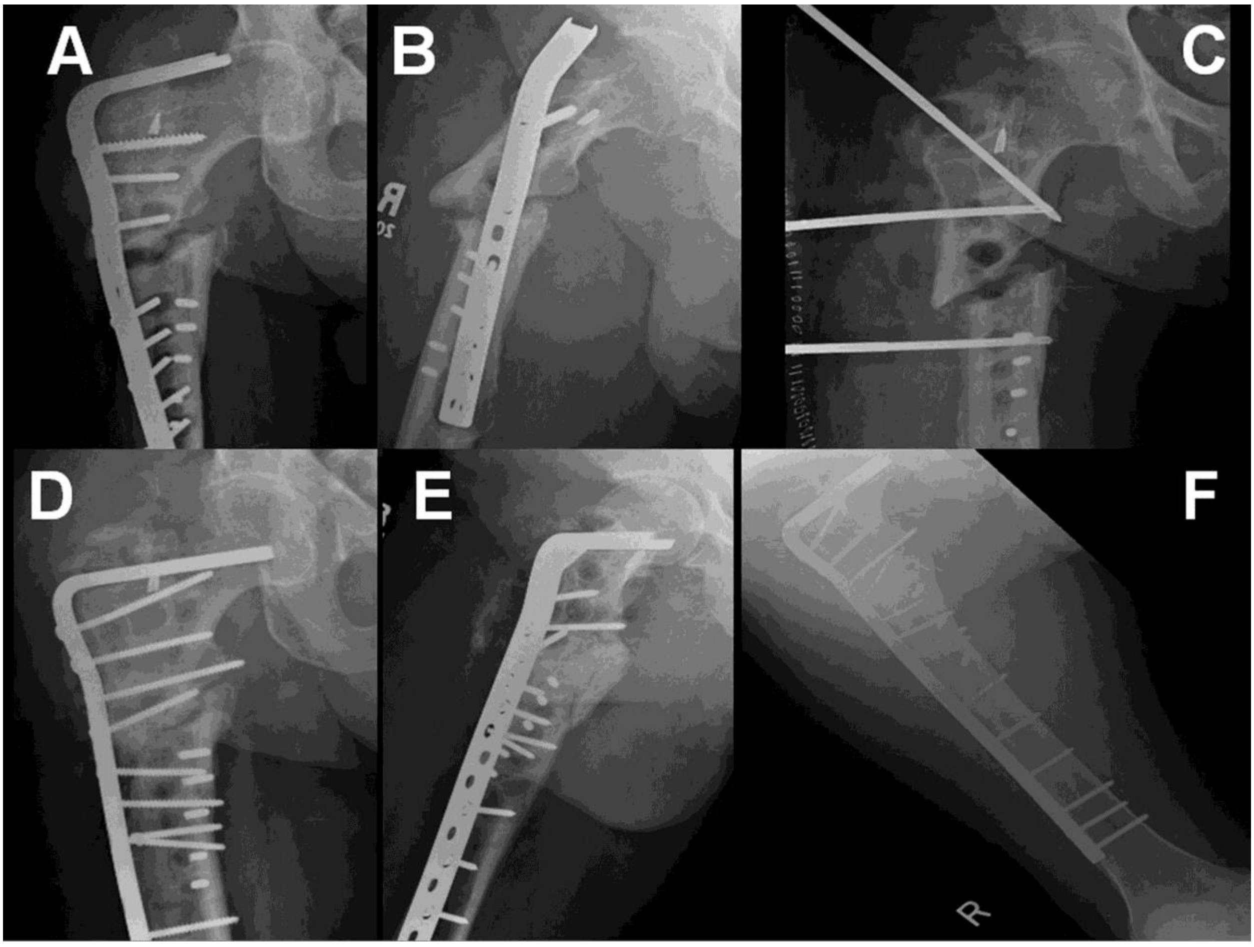

FIGURE 40-19 Salvage procedure of an infected subtrochanteric femoral nonunion after osteosynthesis with a 95° condylar blade plate in a 62-year-old male patient who had been previously treated in an outside hospital 7 years prior to admission. Initial x-rays of the right hip reveal a lack of stability due to placement of the condylar blade outside of the femoral neck, with evidence of failure of fixation and osteolytic changes around the screw holes in the femoral shaft (**A** and **B**). A staged surgical revision was performed, by hardware removal, radical surgical debridement, and external fixation (**C**). Intraoperative tissue cultures revealed growth of *Enterococcus* spp., thus confirming the presence of an infected nonunion. After a 6-week course of i.v. antibiotics, revision blade plating was performed, in conjunction with autologous bone grafting through an RIA harvest from the contralateral femur (**D** and **E**). The fracture was clinically and radiologically healed within 4 months after the last revision procedure (**F**), and the patient was able to ambulate with full weight bearing and minimal residual hip pain.

Nonunions are categorized as hypertrophic, normotrophic, and atrophic. These distinctions are critical in that they describe the underlying cause of the nonunion and therefore point toward correct treatment options. Hypertrophic nonunions are fractures that have failed to heal in spite of a good local blood supply and obvious formation of callus. Mechanical stabilization alone usually produces union in this situation. Normotrophic nonunions show minimal callous formation but no bony resorption. These need mechanical stabilization and some improvement of the local biology, usually by local autogenous bone grafting. Atrophic nonunions show little to no callus formation and have local bone resorption. The atrophic nonunion has poor local blood supply and will require rigid mechanical stabilization, local bone grafting, and in many cases resection of dead bone and flap coverage. If the bone resection is significant, distraction osteogenesis with a ring or monolateral transport external fixator will be necessary. If deformity coexists with a nonunited fracture, both problems should be addressed simultaneously if possible.

► Malunion

Malunion involves shortening, angulation, and/or malrotation following fracture. While some amount of shortening is well tolerated, shortening greater than 2 cm in the lower extremity requires a built-up shoe to equalize leg length for stance and gait. Elective limb lengthening, contralateral extremity shortening, and even amputation are surgical alternatives to a significant leg length discrepancy. A variety of techniques are available using external fixators or specialized lengthening intramedullary nails to regain limb length.

Rotational and angular deformities may be better tolerated in the femur than in the tibia. Varus or valgus deformity may be cosmetically unacceptable and can produce knee and ankle symptoms that warrant corrective osteotomy. Significant deformity may also predispose to progressive osteoarthritis from asymmetric loading of joints. Malunion of hindfoot or metatarsal fractures may result in painful weight bearing, requiring osteotomy for realignment, with or without arthrodesis of adjacent joints.

► Sequelae of Joint Trauma

Stiffness, ankylosis, and contracture may follow an injury to a joint or to the proximal muscles that control it. Direct injury to articular cartilage, joint malalignment, or incongruity increases the risk of post-traumatic arthritis. Significant arthritis leads to pain with weight bearing and eventually loss of normal functional activities, necessitating joint replacement or fusion.

Anatomic reduction and early motion of injured joints provides the best chance of preventing post-traumatic arthrosis. Unfortunately, perfect postoperative reductions do not guarantee perfect functional outcomes. Factors out of the control of the surgeon such as cartilage damage occurring at the time of injury, soft tissue injuries, and postinjury psychological distress have significant impact on the overall outcome.

Flexion contractures of the hip, knee, and ankle may occur in patients who do not perform frequent prophylactic extension stretching exercises of these joints. This is particularly true for intensive care patients who remain intubated for extended periods of time. Equinus ankle contractures predictably develop if appropriate splinting and stretching exercises are not provided for the posterior calf muscles. Flexion contractures of the toes may follow injuries to the leg and foot. Passive toe stretching is required to ensure adequate dorsiflexion for normal gait. Toe clawing is the result of contractures of the leg and/or foot muscles following injury, scarring, traumatic neuropathy, or ischemic contractures from a compartment syndrome. Surgical correction may be required. Prevention of contracture with appropriate splinting and early exercises is more effective than late correction.

Traumatic arthritis may develop in any injured joint. While ankle and subtalar joint arthrosis is usually evident within a year, the hip and knee may require several years before symptoms are significant. Rapid deterioration of the hip joint may be caused by avascular necrosis, typically after delayed reduction of a hip dislocation or a displaced femoral neck fracture. Avascular necrosis eventually results in segmental joint collapse, typically seen in 1 or 2 years after injury. Pain and disability do not always correlate with x-ray findings. Pain with activity is the typical major symptom of post-traumatic arthritis. If symptoms are not too disabling, then conservative measures such as a cane or brace or intermittent use of anti-inflammatory drugs are indicated. Although arthroplasty of the hip or knee is a satisfactory reconstructive procedure for elderly adults with severe symptoms of traumatic arthritis, there is still no uniformly satisfactory procedure for alleviating the condition in the young, vigorous patient.

CONCLUSION

Lower extremity injuries have an enormous impact on the acute and long-term functional outcome of the traumatically injured patients. Advances in orthopedic trauma care center on multidisciplinary cooperation and management, with an emphasis on prudently aggressive stabilization of the multiply injured patient. The plethora of effective techniques and approaches to early stabilization mandates an ongoing conversation between the orthopedic surgeon, general/trauma surgeon, and neurosurgeon regarding the management of individual patients. Clearly, in this day and age, the placement of multisystem trauma patients in splints and traction is suboptimal for most major lower extremity injuries. Whether “damage control” external fixation or definitive minimally invasive fixation is chosen, early aggressive care is part of an optimal management paradigm.

Isolated lower extremity injuries can be devastating with potential loss of life and limb or appear to be relatively benign. Unfortunately, nondramatic injuries such as foot fractures can have lifetime consequences and prevent a patient from returning to his or her work and life activities. Therefore, each injury should be carefully evaluated, thoughtfully treated, and followed long term to insure the best possible physical and psychological result.

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