Injuries to the pelvis and extremities are common, occurring in approximately 85% of patients who sustain blunt trauma. Improper management can have devastating consequences. Major long bone fractures are a sign that substantial force has been applied to the body, and they are frequently associated with torso injuries. Trauma to the pelvis or the extremities can result in injuries that are potentially life-threatening (e.g., pelvic disruption with hemorrhage, major arterial bleeding, and crush syndrome) or limb-threatening (e.g., open fractures and joint injuries, vascular injuries and traumatic amputation, compartment syndrome, and nerve injury secondary to fracture dislocation). In this chapter, we outline the basic knowledge the general or trauma surgeon requires for initial management of injuries to the pelvis, the extremities, or both.

Evaluation and Assessment

INITIAL PRIORITIES

In the surgical management of musculoskeletal injury, the priorities are (1) to save the patient’s life, (2) to save the endangered limb, (3) to save the affected joints, and (4) to restore function; these priorities are pursued in accordance with advanced trauma life support (ATLS) guidelines. The musculoskeletal injury that it is most important to identify during the primary survey is an unstable pelvic injury, which can lead to massive and life-threatening internal bleeding. If manual compression-distraction of the iliac crests elicits abnormal movement or pain, a pelvic fracture is probably present. In this case, a prefabricated splint or sheet wrap is applied around the pelvis to reduce the intrapelvic volume, and the legs are wrapped together to induce internal rotation of the lower limbs. Grossly deformed extremities are reduced by means of manual traction to reduce motion and to enhance the tamponade effect of the muscles. In the initial phase, control of hemorrhage from deep soft tissue lesions and vessel injury is best achieved with direct compression.

During the secondary survey, the rest of the musculoskeletal system is assessed to identify fractures, dislocations, and soft tissue injuries. It is advisable to perform a tertiary survey 24 to 48 hours after admission to detect any missed injuries, especially in multiply injured patients whose condition at admission precluded the completion of a full secondary survey.

IMAGING

Diagnostic imaging usually begins with conventional x-rays. The pelvis is imaged during the primary survey, but x-rays of the extremities typically are obtained only after life-threatening injuries have been corrected and the patient’s general condition is such that the surgeon can afford to spend the time necessary to complete extremity and spine imaging (which is often as long as several hours). Conventional x-rays of the affected limb are guided by the injury mechanism, the history, and the physical examination and are always done in two planes (anteroposterior [AP] and lateral). Long bones should be visualized over their entire length, including the adjacent joints. After reduction of fractures and dislocations, x-rays should be repeated, unless no time is available (e.g., because of the presence of limb-threatening vascular injury).

Computed tomographic scanning is frequently used as an adjunct to conventional x-rays, especially in patients with periartricular fractures and dislocations or pelvic fractures. Axial, sagittal, coronal, and three-dimensional reconstructions allow exact determination of the extent of the fracture and the position of fracture fragments. CT scanning also helps in the process of deciding between operative and nonoperative treatment, and it facilitates preoperative planning when a surgical therapy is adopted. In addition, CT scanning may play a role in detecting bleeding sources in the pelvis, though hemodynamic instability or ongoing blood loss in the presence of a pelvic fracture usually is best managed with immediate angiography rather than CT.

Magnetic resonance imaging can be helpful with complex malunions, soft tissue injuries, and certain fracture types (e.g., scaphoid fracture). Bone scintigraphy and ultrasonography are less frequently employed in the setting of pelvic and extremity trauma. Triphasic bone scanning is primarily used to detect osteomyelitis, avascular necrosis, and malignant lesions, whereas ultrasonography is mostly used to assess soft tissue injuries.

CLASSIFICATION OF INJURIES

Fracture

Of the many existing fracture classification systems, the one that is most frequently used is the system developed by two Swiss organizations, the Association for Osteosynthesis (AO) and the Association for the Study of Internal Fixation (ASIF) [see Figure 1]. The AO-ASIF fracture classification system serves both as a means of documenting fractures (e.g., for research purposes) and as an aid to the surgeon in assessing the severity of the fracture and determining the appropriate treatment.

In the AO-ASIF system, any given extremity fracture can be described in terms of a five-place alphanumeric designation [see Figure 1a]. The first place represents the bone injured. The second represents the segment affected by the injury (proximal, middle or diaphyseal, or distal, with malleolar a fourth category that is sometimes employed). The third represents the fracture type (A, B, or C). In middle-segment long bone fractures, type A refers to simple fractures with two fragments, type B refers to wedge fractures with contact between the main proximal and distal fragments after reduction, and type C refers to complex fractures without contact between the main fragments after reduction [see Figure 1b]. In proximal and distal long bone fractures, type A refers to extra-articular fractures with the articular surface intact, type B refers to partial articular fractures in which there is some articular involvement but part of the articular surface remains attached to the diaphysis, and type C refers to complete articular fractures in which...
the articular surface is disrupted and completely separated from the diaphysis [see Figure 1c]. The fracture types are then further subdivided into three groups (1, 2, or 3), represented by the fourth place, and (mainly for scientific purposes) three subgroups (.1, .2, or .3), represented by the fifth place.

For the fracture types, groups, and subgroups, increasing letter and number values represent increasing severity, as determined by the complexity of the fracture, the difficulty of treatment, and the prognosis. Thus, an A1 fracture is the simplest injury with the best prognosis, and a C3 fracture is the most complex injury with the worst prognosis. For practical purposes, the first four places of the AO-ASIF alphanumeric designation are usually sufficient for treatment planning; the fifth (the subgroup) adds little to the process.

Pelvic ring and acetabular fractures are classified in essentially the same fashion [see Management of Pelvic and Acetabular Injuries, below].

**Soft Tissue Injury**

The type of soft tissue injury present and its extent are determined by the type of insult sustained (e.g., blunt, sharp, or crush), the degree and direction of the force applied, the area affected, and the extent of contamination (if any). With closed injuries, the intact skin prevents direct assessment of the subcutaneous tissues, and as a result, soft tissue injuries are frequently underestimated. In the emergency department, a single inspection is made, and the wound is covered by a sterile dressing; at this point, it may be helpful to take pictures with a digital camera. Exact grading of the soft tissue injury is best done in the operating room by an experienced surgeon who can also decide on a treatment plan.

The system most commonly used for classification of open fractures is the one developed by Gustilo and Anderson, which divides these fractures into three types as follows [see Figure 2]4,5:

1. **Type I:** the wound is smaller than 1 cm and results from an inside-out perforation, with little or no contamination; the fracture type is simple (type A or B).
2. **Type II:** the skin laceration is larger than 1 cm but is associated with little or no contusion of the surrounding tissues; there is no dead musculature, and the fracture type is moderate to severe (B or C).
3. **Type III:** extensive soft tissue damage has occurred, with or without severe contamination, frequently in association with compromised vascular status; the fracture is highly unstable (type C) as a result of comminution or segmental defects. Type
III fractures are further divided into the following three subcategories:

a. IIIA: adequate soft tissue coverage of the bone is still possible.

b. IIIB: extensive soft tissue loss occurs with periosteal stripping and exposed bone; contamination is usually massive.

c. IIIC: an arterial injury is present that requires repair; any open fracture accompanied by such an injury falls into this category, regardless of fracture type.

Closed fractures are less frequently classified according to the type and extent of soft tissue injury, though this does not mean that such injury is not an important consideration with closed fractures. The classification system most commonly used for closed fractures is that of Tscherne, which recognizes the following four grades:

1. Grade 0: soft tissue injury is absent or minor; the fracture type is simple.

2. Grade I: superficial abrasion or contusion is present as a result of pressure applied by the fragment from the inside; the fracture type is simple or moderate.

3. Grade II: deep contaminated abrasions and localized skin or muscle contusion are present as a consequence of direct trauma, possibly leading to compartment syndrome; the fracture type is moderate to severe.

4. Grade III: extensive skin contusions, destruction of musculature, and subcutaneous tissue avulsion have occurred; the fracture is severe and mostly comminuted.

Timing and Planning of Intervention

In multiply injured patients, the timing of operative treatment of injuries to the pelvis and extremities depends both on the condition of the patient and on the particular combination of skeletal and soft tissue injuries sustained [see Table 1]. In such cases, the threshold for adoption of a damage-control strategy [see Damage-Control Surgery, below] to minimize operating time and tissue...
The performance of multiple definitive osteosyntheses is an option only in patients who have been successfully resuscitated (as indicated by stable hemodynamic status without a need for inotropes; absence of hypoxia, hypercapnia, and acidosis; normothermia; normal coagulation parameters; and normal diuresis).

In other cases, the timing and extent of operative treatment of musculoskeletal injuries may be more complex. Generally, if open reduction and internal fixation are indicated, the sooner the operation is performed, the better. With early operation, fracture surfaces are more easily cleaned of blood clots and other material, and reduction is facilitated by the absence of prolonged dislocation and shortening. After 6 to 8 hours, swelling develops, making both the operation and the subsequent closure more difficult and thereby increasing the risk of infection and other wound complications. There are some cases, however, in which it might be preferable to postpone a complex articular reconstruction in order to ensure that the surgical team is optimally prepared. If, for any reason, significant swelling precludes a definitive operation, it is usually safer to stabilize the fracture temporarily (e.g., with splinting or external fixation), then wait 5 to 10 days for the swelling to subside. Temporary stabilization usually allows the surgeon to achieve a reasonable provisional reduction; however, complete joint dislocations are not acceptable. Clinically, sufficient reduction of swelling has occurred when the skin has regained its creases and is wrinkled over the operative site. Early definitive surgery may also be contraindicated when abrasion or degloving injury is present at the fracture site on admission.

Swelling is less of a problem with shaft fractures that will be treated with intramedullary nailing. If, however, it is not possible to perform nailing within 24 to 48 hours after the injury, it is better to postpone the operation for 7 to 10 days; patients operated on between days 3 and 7 are at higher risk for the acute respiratory distress syndrome (ARDS).8,9 If the procedure must be delayed for more than 2 to 3 weeks (e.g., because of sepsis and organ failure), reconstruction of bones and joints will be substantially more difficult. If such delay leads to suboptimal axial alignment and nonanatomic reconstruction of the articular surface, the long-term prognosis will be worse.

Thorough preoperative planning is necessary for any operation done on the musculoskeletal system. Depending on the procedure to be performed, logistical considerations may include availability of the appropriate operating team, availability of the correct operating table, availability of the specific instruments needed, avail-

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**Figure 2** Illustrated is the Gustilo-Anderson classification system for open fractures.
ability of the appropriate implants, and availability of intraoperative imaging. Technical considerations include the operative approach to be followed and the fixation method to be used, which are determined on the basis of an understanding of the extent of the injuries and a detailed knowledge of the anatomy in the area to be exposed. For example, awkward placement of fixator pins could seriously obstruct soft tissue reconstruction if the pins are in the area that should be used for a soft tissue flap. Before operation, the correct operative site is verified (with the patient awake) and marked with a permanent marker pen. A drawing of the planned reduction maneuvers and fixation techniques may be helpful for the surgeon while also serving as an educational tool for the assisting team members. Correct documentation is important for both medical and legal reasons.

**DAMAGE-CONTROL SURGERY**

Immediate and complete care of all fractures, dislocations, and soft tissue injuries may seem the ideal treatment strategy for patients with musculoskeletal injuries. However, this is not always the case. Major trauma leads to a systemic inflammatory response syndrome (SIRS) characterized by increased capillary leakage, high energy consumption, and a hyperdynamic hemodynamic state. Especially in the setting of severe single-organ injury or multiple injuries, the physiologic and immunologic impact of extended surgical procedures on the patient’s general condition can increase the risk of the multiple organ failure syndrome (MODS), ARDS, and other complications. Balanced against this risk is the understanding that early fracture fixation in polytrauma patients is beneficial in terms of mortality and morbidity. Improved understanding of the physiologic response to major trauma over the past decade has led to the approach known as damage-control surgery (DCS) or staged surgery, the purpose of which is to keep the patient from having to deal with the “second hit” imposed by the operation right after experiencing the “first hit” imposed by the initial trauma.

Currently, DCS is widely promoted for management of intraabdominal, vascular, and musculoskeletal injuries. It can be divided into three main phases: (1) a resuscitative phase, (2) an intensive care phase, and (3) a reconstructive phase. The initial focus is on control of bleeding, contamination, and temporary stabilization of fractures; time-consuming reconstructions and osteosyntheses are avoided at this point. At a later stage, when vital functions have been restored, definitive reconstructions are performed during one or more planned reoperations.

The decision whether to employ DCS should be made before the operation to avoid a scenario in which the patient’s general condition of the patient deteriorates seriously during a difficult operation (e.g., a complex femoral nailing procedure) [see Table 2]. An experienced and judicious surgeon will make an appropriate decision about DCS more often than not. If, as sometimes happens despite the surgeon’s best efforts, the patient’s condition does show serious deterioration unexpectedly during operation, the surgeon should immediately choose a bailout option, usually involving external fixation.

As applied to musculoskeletal trauma, DCS begins with debridement of open wounds and irrigation with pulsed lavage (so-called washout). Amputation of the injured limb or limbs is considered if it appears potentially lifesaving [see Management of Life-Threatening or Limb-Threatening Injuries, Mangled Extremity, below]. During the initial debridement, osteochondral

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**Table 1** Time Frames for Operative Treatment of Pelvic and Extremity Trauma*

<table>
<thead>
<tr>
<th>Category</th>
<th>Time Frame (hr)</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Immediate</td>
<td>(Imminent) hemodynamic instability (e.g., pelvic fracture)</td>
</tr>
<tr>
<td>I</td>
<td>Immediate</td>
<td>Neurovascular injury with compromised vitality of extremity</td>
</tr>
<tr>
<td>I</td>
<td>Immediate</td>
<td>(Imminent) compartment syndrome</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Open fractures (increased risk of infection)</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Joint dislocations that cannot be reduced in ED</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Primary stabilization (e.g., external fixation) in multiply injured patients who are hemodynamically stable</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Femoral neck fractures in patients &lt; 65 yr (to prevent femoral head necrosis)</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Long bone fractures (to prevent complications and immobilization)</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Severe soft tissue injury (e.g., degloving caused by rollover accident)</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Closed fractures with compromised skin</td>
</tr>
<tr>
<td>II</td>
<td>Urgent (6–12)</td>
<td>Dislocated talar neck fractures</td>
</tr>
<tr>
<td>III</td>
<td>Semiurgent (12–24)</td>
<td>Femoral neck, intertrochanteric, and subtrochanteric fractures</td>
</tr>
<tr>
<td>III</td>
<td>Semiurgent (12–24)</td>
<td>Closed reduction of fractures in children</td>
</tr>
<tr>
<td>III</td>
<td>Semiurgent (12–24)</td>
<td>Treatment of soft tissue injuries (e.g., to tendons of wrist and hand)</td>
</tr>
<tr>
<td>III</td>
<td>Semiurgent (12–24)</td>
<td>Closed fractures that benefit from early treatment (e.g., to prevent swelling with ankle fractures)</td>
</tr>
<tr>
<td>III</td>
<td>Semiurgent (12–24)</td>
<td>Spine fractures that are unstable or associated with neurologic deterioration</td>
</tr>
<tr>
<td>III</td>
<td>Semiurgent (12–24)</td>
<td>Wound debridement and irrigation or washout</td>
</tr>
<tr>
<td>IV</td>
<td>Semi elective (24–72 hr or delayed)</td>
<td>Achilles tendon ruptures</td>
</tr>
<tr>
<td>IV</td>
<td>Semi elective (24–72 hr or delayed)</td>
<td>Stable spine fractures</td>
</tr>
<tr>
<td>IV</td>
<td>Semi elective (24–72 hr or delayed)</td>
<td>Other fractures</td>
</tr>
<tr>
<td>IV</td>
<td>Semi elective (24–72 hr or delayed)</td>
<td>Revision procedures other than those done for infection</td>
</tr>
</tbody>
</table>

*These time frames are general guidelines and may be modified in accordance with individual patient parameters (e.g., physiologic condition, soft tissue injury, and fracture type) and local preferences.

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**Table 2** Goals of and Indications for Damage-Control Surgery in Management of Pelvic and Extremity Trauma

<table>
<thead>
<tr>
<th>Category</th>
<th>Goals</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control of hemorrhage</td>
<td>Clinical parameters</td>
</tr>
<tr>
<td></td>
<td>Control of contamination</td>
<td>Multiple trauma (ISS &gt; 15) and additional chest trauma</td>
</tr>
<tr>
<td></td>
<td>Removal of dead tissue and prevention of ischemia-reperfusion injury</td>
<td>Pelvic ring injuries with exsanguinating hemorrhage</td>
</tr>
<tr>
<td></td>
<td>Facilitation of ICU treatment</td>
<td>Multiple trauma with abdominal or pelvic injuries and hemorrhagic shock (BP &lt; 90 mm Hg)</td>
</tr>
<tr>
<td></td>
<td>Pain relief</td>
<td>Radiographic findings indicating (bilateral) lung contusion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Femoral fractures in polytrauma patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Polytrauma in geriatric patient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Resuscitation, operation, or both expected to last &gt; 90 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physiologic parameters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Severe metabolic acidosis (pH &lt; 7.20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Base deficit (&lt; –6 mEq/L)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hypothermia (T* &lt; 35° C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Coagulopathy (PT &gt; 50% of normal)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multiple transfusions</td>
</tr>
</tbody>
</table>

ISS—Injury Severity Score PT—prothrombin time
fragments in open joint fractures are retained—provided that they are not severely contaminated—to allow later reconstruction of the joint surface. Dislocations and diaphyseal fractures are reduced and stabilized with simple external fixator frames (if necessary, placed so as to span the adjacent joint or joints), and wounds are provisionally closed. Fixator pins are placed through stab incisions in safe zones. Fractures need not be reduced anatomically under image intensifier control; the only goals at this point are to restore length and align long bone fractures and joints, to reduce contamination, and to enable postoperative wound management in the intensive care unit while definitive treatment is pending. The more complex the fixator frame, the more time-consuming its application usually is. Muscle compartments believed to be at risk for compartment syndrome are widely decompressed. At all times, the operating surgeon must keep the goals of DCS clearly in mind. The main aim of this strategy is not necessarily a nice-looking postoperative x-ray showing parallel fixator pins and a perfectly reduced tibia; rather, it is the survival of the patient in stable physiologic condition. Depending on the severity of the injuries, the reconstructive procedures likely to be performed, and the availability of specialists or subspecialists, consultation with a plastic surgeon during the initial operation may be advisable to optimize operative and logistical planning.6,7

Careful attention must be paid to the logistical aspects of DCS. As soon as the decision for DCS is made, OR personnel should be notified of the type of procedures to be performed and the implants required. It may be helpful to have a dedicated DCS equipment trolley with all the materials and equipment necessary for the first hour.11 Once the patient and the operating team are in the OR, the injuries sustained, the operative plan, and the injuries (known or suspected) that need special attention (e.g., a small pneumothorax) are written down or sketched on a whiteboard so that all persons present in the OR know what is to be done.

During the operation, the surgeon should stay in close contact with the anesthesiologist regarding the condition of the patient and the procedure currently under way. If operative procedures are required in more than one organ system (e.g., laparotomy and external fixation of the femora), they should, whenever possible, be performed simultaneously by multiple teams working together. The end of the procedure should be announced well ahead of time so that the anesthesiologist can take the precautions necessary for transport of a potentially unstable patient and so that the ICU can be notified of the patient’s arrival. In this way, unnecessary waiting times in the OR can be kept to a minimum.

The second phase of DCS is restoration of vital functions in the ICU. This phase is crucial for ensuring that the patient is fit to undergo a second procedure.10 Close cooperation between surgeon and critical care physician is required to outline an aggressive strategy for ventilation, circulatory support, and reversal of hypothermia, coagulopathy, acidosis, and other abnormalities. Administration of large volumes of fluid will be necessary as a consequence of massive tissue swelling and bowel edema. Cardiac monitoring with central venous access should usually be employed. Application of external fixators allows the nursing staff to place the patient in the position that is most suitable for intensive care of head, chest, and abdominal injuries, while still allowing wound inspection and dressing changes as required. During this phase, imaging studies may be performed (or, if already performed, repeated) to allow planning for repeated washouts and definitive reconstructive procedures.

The third phase in the DCS sequence is the performance of one or more planned reoperations. This usually takes place at least 24 to 48 hours after the initial procedure, when the patient is stable and normothermic and has normal or near-normal coagulation parameters.10 Subsequent visits to the OR are used to continue wound debridement and coverage and to exchange external fixators for definitive fixation (e.g., with intramedullary nails).12,13 During these operations, multiple teams can work simultaneously on the repair of abdominal, musculoskeletal, and other injuries. The period from postinjury day 5 to day 10 is often referred to as the window of opportunity for reconstruction of intra-articular or periarticular fractures and of upper-limb fractures.

### Management of Life-Threatening or Limb-Threatening Injuries

#### LIFE-THREATENING PELVIC TRAUMA

Pelvic fractures are frequently associated with significant hemorrhage, not only because of the fracture itself but also because pelvic trauma is often accompanied by serious injuries to other parts of the body (e.g., the chest or the abdomen). Significant arterial hemorrhage is present in approximately 25% of patients with unstable pelvic fractures.4,5,10,14,15 Bleeding from pelvic trauma can be quite severe: as much as 4 L of blood may accumulate in the retroperitoneal space. Whether hemorrhagic shock is associated with certain fracture types remains a matter of debate, but there is certainly a link between the severity of the pelvic injury and the incidence of hemorrhagic shock. Hemorrhagic shock in patients with pelvic fracture strongly influences outcome and necessitates immediate evaluation and treatment.

Hemorrhage may originate either from within the fractured pelvic bones themselves or from torn arteries and veins in the pelvis, which are in close proximity to the bony structures of the pelvis. In particular, the presacral venous plexus and the internal iliac arteries and side branches may be lacerated. The most commonly injured anterior branches of the internal iliac artery are the internal pudendal artery and the obturator artery, whereas the most commonly injured posterior branches are the superior gluteal artery and the lateral sacral artery.16,17

Given that bleeding in pelvic fracture patients can occur in other body compartments besides the pelvis and can be arterial as well as venous, it is of the utmost importance to identify its source and, ideally, determine its nature as soon as possible. This information is crucial in determining what the next steps in management should be (see Figure 3).

The first step after diagnosing a pelvic fracture should be the immediate application of some type of external stabilization device (e.g., a sheet wrap or a device such as the Pelvic Binder [Pelvic Binder Inc., Dallas, Texas]) (see Figure 4).18 The rationale behind this step is that approximating the fractured bones and thereby decreasing the volume of the pelvis may reduce blood loss, particularly from the fractured bones and the lacerated venous plexus. In addition, stabilization may minimize further damage to blood vessels and prevent dislodgment of recent clots. It is doubtful, however, whether this procedure actually reduces arterial hemorrhage to a significant degree.

In hemodynamically unstable patients with clinical signs of a pelvic fracture, the next step (immediately after—or, preferably, while—x-rays of the chest, the pelvis, and the cervical spine are obtained according to ATLS protocols) should be the FAST (focused assessment for sonographic evaluation of the trauma patient) to rule out a significant intra-abdominal bleeding source. If the FAST is negative and no other obvious sources of hemorrhage (e.g., chest or extremities) are found, the pelvis is the most...
Thus, CT is an ideal means of identifying patients who might benefit from angiographic embolization, having a sensitivity and specificity of well over 90%. This technique does, however, require a skilled, experienced, and permanently available interventional radiology service.

Contrast-enhanced CT scanning is extremely helpful in determining the presence of arterial hemorrhage in cases of pelvic fracture, but it can be performed only if the patient is stable enough to undergo the time-consuming transfer to the imaging suite. If a CT scanner is available in the shock room, it may be possible to extend the use of this modality to unstable patients. Extravasation of contrast medium, a large retroperitoneal hematoma, or abrupt cutoff of an artery on CT indicates that angiographic embolization is necessary. Contrast extravasation (so-called contrast blush) is a particularly good predictor of arterial hemorrhage; consequently, it is vital to decide whether the question then arises whether the pelvic hemorrhage is predominantly arterial or venous. An arterial bleeding source in the pelvis is found in 73% of hypotensive patients who do not respond to initial fluid resuscitation.

Little or no intraperitoneal fluid is present

Perform angiography and embolization. Place external fixation device. (Consider retroperitoneal packing as an adjunct.)

Patient has unstable pelvic fracture

Perform noninvasive external stabilization with sheet wrap or prefabricated device (e.g., Pelvic Binder).

Patient is hemodynamically unstable

Obtain x-rays of chest, pelvis, and cervical spine according to ATLS protocols. Immediately afterward (or simultaneously, if possible), perform FAST to rule out intra-abdominal bleeding source.

Patient is hemodynamically stable or has moderate hemodynamic abnormality

Obtain x-rays of chest, pelvis, and cervical spine according to ATLS protocols. Perform contrast-enhanced CT scanning to look for bleeding source.

Large amount of intraperitoneal fluid is present

Perform angiography and embolization. Place external fixation device. If hemodynamic instability persists, perform angiography and embolization.

Pelvic bleeding is identified

Perform laparotomy, and place external fixation device. (Consider retroperitoneal packing.)

No bleeding is identified

Place external fixation device. (Consider retroperitoneal packing.)

Intra-abdominal bleeding source is identified

Perform laparotomy, and place external fixation device. If persistent hemodynamic abnormality is present, perform angiography and embolization. Or (depending on intraabdominal injury type) Perform primary angiography and embolization. Place external fixation device. (Consider retroperitoneal packing.)

Figure 3 Algorithm outlines management of unstable fracture in patients with varying degrees of hemodynamic stability.

likely source of the bleeding. The question then arises whether the pelvic hemorrhage is predominantly arterial or venous. An arterial bleeding source in the pelvis is found in 73% of hypotensive patients who do not respond to initial fluid resuscitation.

Arterial hemorrhage should preferably be treated by angiographic embolization, whereas others favor more liberal use of surgical retroperitoneal packing of the pelvis.

and the performance of embolization strongly influences outcome. Angiographic embolization with gel foam or coils can almost always be performed via the common femoral artery approach, even with a sheet wrap or an external fixation device in place. Success rates exceed 90%, and major complication rates are below 5%. This technique does, however, require a skilled, experienced, and permanently available interventional radiology service.

In patients with unstable fractures, venous hemorrhage is treated with operative placement of an external fixation device. This measure requires specific expertise on the part of the trauma surgeon; in experienced hands, it should take no longer than 20 minutes to perform. Patients with more severe pelvic fractures (e.g., AO-Tile type B and C fractures and higher grades of lateral compression and anteroposterior compression fractures [see Management of Pelvic and Acetabular Injuries, Pelvic Ring, below]) probably benefit most from this procedure. Retroperitoneal packing may be employed as an adjunct to external fixator placement. It is unlikely that external fixation has a significant impact on arterial hemorrhage; consequently, it is vital to decide whether angiographic embolization should precede placement of an external fixation device in the OR.

The optimal strategy for controlling bleeding in patients with life-threatening pelvic injuries remains subject to debate. We favor a prominent role for CT scanning and angiographic embolization, whereas others favor more liberal use of surgical retroperitoneal packing of the pelvis.
OPEN FRACTURES AND SOFT TISSUE RECONSTRUCTION

Approximately 3% to 5% of all fractures and 10% to 15% of all long bone fractures are open. The prognosis after an open fracture is very different from that after a closed fracture; treatment of open fractures is much more complex than treatment of simple fractures or traumatic wounds. The existence of an open fracture means that a great deal of energy has been delivered to the bone to produce soft tissue disruption. Accordingly, it can be inferred that there has been considerable stripping of muscle, periosteum, and ligament from the bone, resulting in relative devascularization, and that varying degrees of contusion, crushing, and devascularization of the associated soft tissues have occurred. All of these events greatly influence the rate of healing, the incidence of nonunion, and the risk of infection (most commonly by *Staphylococcus aureus*, *Enterococcus*, or *Pseudomonas*). As noted [see Evaluation and Assessment, Classification of Injuries, Fracture, above], open fractures are typically classified according to the system formulated by Gustilo and Anderson.4,5,26

Management of open fractures in the ED starts with a detailed history that includes the patient’s medical condition before the injury, the mechanism of injury, and the time elapsed since the injury. A careful physical examination is then performed, with particular attention paid to neurovascular status, muscle function, and the presence or absence of associated injuries. Compartment syndrome [see Management of Life-Threatening or Limb-Threatening Injuries, Mangled Extremity, below, and 7:13 Injuries to the Peripheral Blood Vessels] should be ruled out in patients at risk; as many as 10% of open tibial fractures are associated with compartment syndrome as a result of severe soft tissue injury. If the limb is malaligned, gentle gross reduction should be performed to relieve any vascular compromise. The wound is then inspected, and a sterile dressing is applied. Once this is done, the dressing should not be removed until the patient is in the OR and preparation for operation has begun. The need for repeated inspections by various specialists can be eliminated by taking pictures of the fractured limb with a digital camera. A temporary splint is applied to the limb to relieve pain and prevent further soft tissue injury. X-rays are obtained in two planes, with the adjacent joints included. Antibiotic treatment is started in the ED, and antitetanus measures are instituted according to local protocols.

The goals of treatment are to prevent infection, achieve adequate soft tissue coverage, allow bone healing, and promote early and full functional recovery. The basic principles of management consist of aggressive debridement, open wound treatment, soft tissue and bone stabilization, and systemic administration of antibiotics.4,5 These principles have reduced the formerly high mortality associated with open fractures to acceptable levels.

High-velocity gunshot wounds and open fractures must be approached differently from closed fractures because of the force imparted to the soft tissues. Open fractures call for emergency surgical treatment. Ideally, such treatment should begin within 6 hours of injury; the incidence of infection is directly related to the time elapsed before initiation of treatment. Typically, a second-generation cephalosporin is administered for 48 to 72 hours; prolonged administration is not necessary. For grade III open fractures, gentamicin should be added to cover gram-negative bacteria; for farmyard injuries, which are at risk for contamination with *Clostridium*, penicillin should be added.27,28

The first stage of operative treatment consists of thorough irrigation of the wound with 6 L of normal saline; pulsed or jet lavage

![Figure 4 (a) Shown is initial stabilization of pelvic fracture in a patient with severe head injury, life-threatening unstable pelvic fracture, distal femoral fracture, and proximal tibial fracture. (b) Shown is the same patient after DCS.](image)

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<td>Indications for Angiographic Embolization in Patients with Pelvic Fracture</td>
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<td>Hemodynamic instability; FAST negative for intra-abdominal bleeding source; inadequate response to fluid resuscitation</td>
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<td>Contrast blush on contrast-enhanced pelvic CT scan</td>
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FAST—focused assessment for sonographic evaluation of the trauma patient
RBCs—red blood cells
can be helpful for this purpose. Cultures are ordered at this time. To determine the true extent of the soft tissue damage, it is frequently necessary to enlarge the skin wound. Foreign contaminants, as well as dead bone and other devitalized tissues, predispose to infection and should therefore be removed. It is good practice to perform a routine second-look operation 48 to 72 hours after the initial debridement; debridement should be repeated until the soft tissues appear healthy and clean.

Although grade I open fractures may sometimes be treated in much the same way as similar closed fractures, grade II and grade III open fractures must be surgically stabilized during the second stage of the initial operation. Restoring of the normal anatomy through reduction and stabilization improves circulation; promotes healing of bone and soft tissue; reduces inflammation, bleeding, and dead space; and increases revascularization of devitalized tissue. It also results in earlier mobilization of multiple injured trauma patients and improves their overall status.

Internal fixation is preferred for most open fractures, with plates and screws mostly used for articular and metaphyseal fractures and intramedullary nailing for femoral and tibial shaft fractures. It is not always necessary, however, to achieve definitive fixation in the first operation. In the case of complex fractures for which additional imaging or a specialized operative team is required, a correctly placed external fixator is a safe and sensible option. External fixation as a temporary bridge to definitive fixation is also frequently used for severely contaminated grade III open fractures.

Surgically created wound extensions may be closed; however, the traumatic wound itself should be left wide open. If the wound is small, a portion of the surgical extension should be left open to allow adequate drainage and to prevent the traumatic wound from sealing off prematurely. Every attempt should be made to cover bone, joint surfaces, implants, and sensitive structures (e.g., tendons, nerves, and blood vessels) with available local soft tissue, but such coverage must be achieved without tension. As an alternative to soft tissue coverage, a temporary method of wound coverage may be chosen (e.g., traditional wet dressings, synthetic membranes, allografts, or other skin substitutes).

Because leaving a wound open for prolonged periods increases the risk of infection, skin coverage and soft tissue reconstruction should ideally be achieved within 1 week after the injury. In the case of a grade I or II open fracture for which the initial culture is negative, the wound may be allowed to close by granulation and secondary intention, or the patient may be returned to the OR in 5 to 7 days for delayed primary closure. For larger wounds, split-thickness skin grafts are often required. For grade III open fractures, some type of flap is often required for soft tissue coverage. Amputation in the acute phase should be performed at a safe level by means of a guillotine technique, combined with open wound management.

The functional prognosis after limb salvage is based on the presence or absence of nerve injury and the surgeons’ judgment of whether adequate vascularization, soft tissue coverage and long-term bony stabilization are likely to be achievable. Often, multiple operations must be performed over several months, and even then, the outcome may be uncertain. In patients with limbs at high risk for amputation, the 2-year outcomes after reconstruction typically are about the same as those after amputation. Accordingly, some patients may be better served by early amputation as definitive treatment.

MANGLED EXTREMITY

One of the more difficult decisions for a trauma surgeon is whether to amputate a severely injured or mangled extremity (see 7:13 Injuries to the Peripheral Blood Vessels). The Mangled Extremity Severity Score (MESS) is frequently used as an aid in making this decision, with a score of 7 or higher generally considered an indication for amputation. The final decision whether to amputate or to attempt salvage, however, is based on the individual patient’s overall condition, level of neurovascular function, and expected functional result.

The decision between amputation and salvage does not necessarily have to be made immediately; often, it can wait until the involved specialists have discussed the matter in the hours or days following the initial operation. If a mangled extremity does not pose an acute threat to the patient during the initial resuscitation, it may be best treated with irrigation and debridement (as with open fractures), some form of external stabilization, and temporary soft tissue coverage. Amputation in the acute phase should be performed at a safe level by means of a guillotine technique, combined with open wound management.

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COMPARTMENT SYNDROME

Compartment syndrome is defined as high-pressure swelling within a fascial compartment (see 7:13 Injuries to the Peripheral Blood Vessels). Many physicians still believe, incorrectly, that compartment syndrome cannot develop in conjunction with an open fracture, because the break in the skin provides decompression. This is a dangerous assumption: compartment syndrome occurs in...
Compartment syndrome is suspected

- Clinical findings unequivocally indicate compartment syndrome
  - Perform fasciotomy.
- Clinical findings are inconclusive, or patient is not alert or reliable
  - Measure compartment pressures. In particular, determine difference between diastolic arterial pressure and pressure in involved compartment ($\Delta p$).
  - $\Delta p < 30$ mm Hg
    - Compartment syndrome is considered to be present.
    - Perform fasciotomy.
  - $\Delta p \geq 30$ mm Hg
    - Perform continuous compartment pressure monitoring and serial clinical evaluations.
    - $\Delta p < 30$ mm Hg
      - Compartment syndrome is considered to be present.
      - Perform fasciotomy.
    - $\Delta p \geq 30$ mm Hg
      - Perform fasciotomy.

The key to diagnosis of compartment syndrome [see Figure 5] is to maintain a high level of suspicion in any situation involving an extremity injury where there is a significant chance that this syndrome might develop (e.g., tibial fractures, forearm fractures, and all comminuted fractures associated with severe soft tissue injury). The diagnosis is primarily a clinical one, with the five Ps—pain, pallor, paresthesia, paralysis, and pulselessness—constituting the classic signs. The surgeon should not wait until all these signs are present; the prognosis is much better if they are not. Severe ischemic muscle pain occurs that is unrelieved by the expected amounts of analgesia. On palpation, the compartment is tense and swollen, and passive stretching of the digits of the extremity increases the pain. Paresthesia occurs early and should be actively watched for; paralysis develops when ischemia has caused permanent damage. Pulselessness occurs late and is a relatively rare sign; it has been shown that irreversible damage can occur in a patient who still has palpable pulses.4,5,10,37

Measurement of compartment pressures is also employed in the diagnosis of compartment syndrome. Monitoring can be particularly helpful in patients who are not alert or are difficult to examine.36 There is no agreement on what constitutes the critical pressure threshold for a definitive diagnosis. An absolute value of 30 to 35 mm Hg has frequently been adopted as a diagnostic indicator; however, the evidence suggests that the difference between the diastolic arterial pressure and the pressure in the involved compartment ($\Delta p$) is more important than any particular absolute value. Currently, a diagnosis of compartment syndrome is usually made if $\Delta p$ is less than 30 mm Hg, depending on the clinical signs and the level of suspicion.

If compartment syndrome is suspected, the first step is to remove all circumferential bandages to relieve any pressure. If a plaster cast is present, it should be split, spread, or removed; if necessary, maintenance of reduction should be sacrificed. If the clinical picture does not improve after these measures are taken, then a decompressive fasciotomy is indicated. Fasciotomy is described in greater detail elsewhere [see 7:13 Injuries to the Peripheral Blood Vessels].

PERIPHERAL VASCULAR INJURY

Vascular injuries can result from either blunt or penetrating trauma to the extremities, though the vascular injuries seen in urban trauma centers tend to be caused more often by penetrating trauma. Early diagnosis and prompt multidisciplinary treatment are crucial for successful management. The severity of the vascular injury and the length of the interval between injury and restoration of perfusion are the major determinants of outcome.37,39-42 Diagnosis and management of such injuries are outlined in greater detail elsewhere [see 7:13 Injuries to the Peripheral Blood Vessels].

There has been considerable discussion regarding the optimal order of repair in cases of combined musculoskeletal and vascular trauma—that is, whether fracture stabilization should precede vascular repair or follow it.41 Fracture stabilization facilitates the exposure needed for vascular repair and reduces the risk of subsequent disruption of a fresh arterial repair, but it inevitably takes time to perform. Rapid application of an external fixator is a good alternative for extensive fracture repairs. Insertion of a temporary intraluminal shunt can be valuable and limb-saving when DCS is performed in a patient with severe vascular extremity injury or when a patient has a grossly unstable fracture that must be stabilized before arterial repair is possible.44 Endovascular repair plays a limited, albeit growing, role in the treatment of arterial injuries associated with extremity trauma.45

PERIPHERAL NERVE INJURY

Injury to a peripheral nerve can result in loss of motor function, sensory function, or both; it is the principal factor accounting for limb loss and permanent disability. Because the upper extremities have less muscle and bone mass and more neurologic structures than the lower extremities do, upper-extremity injuries are twice as likely to result in nerve damage as lower-extremity injuries are. Penetrating injuries from cuts or stab wounds that result in a clean laceration of a nerve are amenable to early intervention and repair; penetrating injuries from gunshot wounds are more difficult to assess and manage. Blunt...
injuries result primarily from compression or stretching. Nerve injuries are generally categorized according to the Seddon classification system, which divides them into three types: (1) neurapraxia, (2) axonotmesis, and (3) neurotmesis. Complete recovery from neurapraxia and axonotmesis can usually be achieved, but neurotmesis usually necessitates surgical intervention. How quickly and successfully nerves regenerate depends on several factors, including age, type of nerve (sensory or motor), level of injury, and duration of innervation.

Careful assessment of motor and sensory function is essential for diagnosis. Additional diagnostic information can be obtained by means of electromyography (EMG), MRI, and nerve conduction studies.

In the setting of blunt trauma, surgical treatment is recommended for closed injuries when the injured nerve shows no evidence of recovery either clinically or on electrophysiologic studies done 3 months after the injury. It is also recommended for gunshot wounds without vascular or bony problems; such wounds have relatively good potential for neurologic recovery. For most open injuries (e.g., laceration with neurotmesis), surgical exploration at the earliest opportunity is recommended. If possible, the nerve is reapproximated primarily and the epineurium is sutured, or (sural) nerve grafts are employed.

Physical therapy should be started soon after nerve injury to maintain passive range of motion in the affected joints and preserve muscle strength in the unaffected muscles. Splinting of affected joints may be necessary to prevent contractures and minimize deformities.

CRUSH SYNDROME

Crush syndrome (also referred to as traumatic rhabdomyolysis) is a clinical syndrome consisting of rhabdomyolysis, myoglobinuria, and subsequent renal failure. It is caused by prolonged compression of muscle tissue (frequently in the thigh or calf) and is usually seen in victims of motor vehicle accidents who required a long extrication procedure or in earthquake victims who are rescued from beneath rubble after being trapped for several hours or days. Once released from entrapment, crush syndrome patients are likely to exhibit agitation, severe pain, muscle malfunction, swelling, and other systemic symptoms.

The pathophysiologic process underlying this syndrome begins with muscle breakdown from direct pressure, impaired muscle perfusion leading to ischemia and necrosis, and the release of myoglobin. As long as the patient is entrapped, the ischemic muscle is isolated from the circulation, and this isolation affords some protection against the systemic effects of the released myoglobin and other toxic materials. Extrication and the resulting reperfusion of necrotic and ischemic muscle lead to the second insult, the reperfusion injury. This injury is caused by the formation of toxic reactive oxygen metabolites, which leads to failure of ion pumps and increasing permeability of cell membranes and microvasculature. When large amounts of muscle are involved, the resulting fluid changes can rapidly induce shock. The large quantities of potassium, lactic acid, and myoglobin that are released into the circulation can lead to renal failure, disseminated intravascular coagulation, and circulatory arrest.

Treatment should begin at the time of extrication so as to anticipate the onset of the syndrome. The first step is initiation of I.V. fluid therapy, starting with a 2 L crystalloid bolus and continuing with crystalloid infusion at a level of 500 mL/hr (the dosage must be adjusted in pediatric and cardiac patients). Cardiac monitoring is essential (T waves indicate hyperkalemia). Intravascular fluid expansion and osmotic diuresis, by maintaining high tubular volume and urine flow, may prevent renal failure. Forced diuresis can be achieved by giving mannitol or other diuretics. Alkalization of the urine with sodium bicarbonate (1 mEq/kg I.V. to a total of 100 mEq) is a controversial measure but is recommended by some on the grounds that it should, in theory, reduce intratubular precipitation of myoglobin. If compartment syndrome is suspected, compartment pressures should be measured [see Compartment Syndrome, above].

General Management of Fractures

FIXATION METHODS AND IMPLANT TYPES

Fracture fixation can be accomplished either nonoperatively (by means of external splinting) or surgically. Surgical fixation can be achieved with many different techniques, which yield varying degrees of stability. Screws, metal wires (e.g., Kirschner or cerclage wires), plates, nails, and external fixators have all been used for this purpose. Surgical fixation methods may be broadly divided into techniques of absolute stability and techniques of relative stability.

Treatment of fractures with techniques of absolute stability was widely promoted by the ASIF. Anatomic reduction and achievement of absolute stability by means of interfragmentary compression plating were advised for treatment of articular, metaphyseal, and diaphyseal fractures. This method reduces strain at the fracture site and allows bone healing without visible callus formation (so-called direct bone healing). However, obtaining interfragmentary compression usually necessitates a fairly extensive surgical approach, which disturbs the local blood supply.

Unlike techniques of absolute stability, techniques of relative stability (e.g., intramedullary nailing, use of bridging plates across a comminuted fracture, and external fixation) allow small interfragmentary movements to occur when a load is applied across the fracture site. Such movements can stimulate callus formation and lead to union of the bone in four stages: (1) inflammation, (2) soft callus, (3) hard callus, and (4) remodeling. The various techniques of relative stability (also referred to as splinting or bridging techniques) yield varying degrees of stiffness.

Both biologic factors (fracture healing) and biomechanical factors (strength and stiffness) are important for recovery after a fracture. Over the past two decades, clinical experience and data from basic studies have led to a shift in focus away from the mechanical aspects of fracture treatment and toward the biological aspects. Today, a common practice is so-called biologic osteosynthesis, which means careful handling of the soft tissues to take advantage of the remaining biologic support, coupled with the use of techniques of relative stability to stimulate callus formation. Anatomic reduction is no longer considered a goal in itself, except in the case of intra-articular fractures.

Conventional dynamic compression plates are applied tightly against the bone. Their application can compromise the blood supply and thereby induce partial necrosis of the underlying bone. The presence of avascular tissues may reduce the healing potential and lower the local resistance to infection. To overcome some of these disadvantages, plates with smaller contact areas were developed. This process has culminated in the introduction of locking compression plates (e.g., LCP; Synthes, West Chester, Pennsylvania), which can be regarded as noncontact plates. The LCP is a plate-and-screw system in which the screws are also locked in the plate by means of an extra thread in the head of the screw; thus, the plate is no longer tightly fixed to the bone and the periosteum. Locking compression plates (also referred to as locked internal fixators) are designed in such a way that both conventional dynamic compres-

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sion techniques and bridging techniques can be used, depending on the fracture type. They may be applied via a less invasive approach using closed reduction techniques.\(^4\)\(^,\)\(^5\)

Intramedullary nails are placed within the medullary canal and therefore have the same biomechanical properties in both the frontal and the sagittal plane. They differ from plates in that the latter are attached eccentrically to the bone. Intramedullary nails may be inserted in either an unreamed or a reamed fashion; both techniques have advantages and disadvantages. With unreamed nailing, the nails are inserted without widening the medullary canal. This approach causes somewhat less operative trauma than reamed nailing, but it places some limitations on the diameter and strength of the nail and the locking bolts. If larger-diameter nails (> 9 mm) are needed, the medullary canal must be reamed to accommodate them. Reaming takes time, leads to increased intramedullary pressure, and produces debris that may be embozed in the pulmonary circulation. The clinical consequences of reamed intramedullary nailing have not yet been fully clarified. Current evidence suggests, however, that reamed nailing is associated with significantly lower rates of nonunion and implant failure than unreamed nailing is.\(^4\)\(^,\)\(^5\)\(^,\)\(^1\)

External fixators consist of metal pins (Schanz screws) that are placed in the bone proximal and distal to the fracture and connected outside the skin by one or more rods. Most external fixators are used only on one side of the limb, but in specific instances, multiplanar or circular devices may be used. The stability of the frame depends primarily on the stiffness of the rods, the distance between the rod or rods and the bone (the smaller the distance, the greater the rigidity), and the number, placement, and diameter of the fixator pins. As a general rule, two pins proximal and distal to the fracture are sufficient for fixation of long bone fractures. The main advantage of external fixators is that their use minimizes additional surgical trauma. The main disadvantages are the occurrence of pin-tract infections and the frequent lack of stability for definitive fracture treatment. Appropriate placement of fixator pins requires a detailed knowledge of the cross-sectional anatomy of the injured limb.\(^4\)\(^,\)\(^5\)

**BASIC PRINCIPLES OF TREATMENT**

Although most fractures heal readily with casting, long periods of immobilization with restriction of muscle activity, joint motion, and weight bearing are known to lead to so-called fracture disease, characterized by muscle atrophy, joint stiffness, disuse osteoporosis, and persistent edema. Accordingly, the goals of fracture treatment should include not only the achievement of bony union but also the early restoration of muscle function, joint mobility, and weight bearing.\(^4\)\(^,\)\(^5\)

Currently, there are seven main indications for operative treatment of fractures:

1. Preservation of life (e.g., decreasing morbidity and mortality through fixation of femoral shaft fractures);
2. Preservation of a limb (as with open fractures, fractures associated with vascular injury, and fractures complicated by compartment syndrome);
3. Articular incongruity;
4. Facilitation of early mobilization and rehabilitation;
5. Inability to maintain reduction with conservative treatment;
6. The presence of more than one fracture in the same limb (so-called floating joints); and
7. The presence of additional fractures in other limbs (e.g., bilateral humeral or tibial fractures).

Improved understanding of the biology of fracture repair and the importance of the soft tissues has led to substantial changes in the treatment of diaphyseal fractures. It is now widely recognized that anatomic reduction of each fracture fragment is not always a prerequisite for restoration of normal limb function (see above). For most long bone fractures, radial and ulnar fractures excepted, the most important goal is restoration of the mechanical axis of the limb without significant shortening, angulation, or rotational deformity. Good functional results may be expected even if fracture fragments lying between the proximal and distal main fragments are not anatomically reduced.\(^4\)\(^,\)\(^5\)

In the upper extremity, both plates and intramedullary implants are frequently used for operative fixation of fractures. In the lower extremity, intramedullary nails are generally preferred because they allow early weight bearing, in contrast to plates and screws, which are more susceptible to failure. However, intramedullary nailing may not be suitable for shaft fractures that extend into the metaphysis or the adjacent joint. The treatment plan may also be influenced by the local condition of the soft tissues (e.g., the presence or absence of contusions or wounds), the quality of the bone (e.g., the presence or absence of osteoporosis), and the origin of the fracture (pathologic or nonpathologic).\(^4\)\(^,\)\(^5\)

For intra-articular fractures, alignment alone is insufficient. Anatomic reduction of the articular surface is required to restore joint congruity, and rigid fixation is necessary to allow early motion and thereby prevent the joint stiffness resulting from prolonged immobilization. Impacted osteochondral fragments are elevated, and the resulting metaphyseal defect underneath is filled with cancellous bone or a bone substitute. Fracture fragments may be reduced either via direct exposure or via more limited approaches, with the assistance of an image intensifier an arthroscope, or both. Regardless of which approach is followed, care must be taken not to devascularize bone fragments. Fixation may be achieved with metal wires, screws, and plates. The reconstructed articular surface is connected to the diaphysis with plates or, alternatively, external fixators.\(^4\)\(^,\)\(^5\)

Nonoperative treatment usually consists of application of plasters or (less frequently) traction and may be employed as either temporary or definitive therapy. It reduces the risk of infection and eliminates operative risk, but it also frequently results in a longer time to union, a higher risk of malunion, and a greater likelihood of stiffness of the involved joints. Accordingly, nonoperative management is mostly reserved for extra-articular and minimally displaced fractures.\(^4\)\(^,\)\(^5\)

Autologous bone grafting remains the gold standard for improving and accelerating fracture healing. In recent years, however, various other methods have been developed and evaluated for this purpose. There is some evidence from randomized trials indicating that low-intensity pulsed ultrasonography may shorten the healing time for fractures treated nonoperatively.\(^5\)\(^,\!\)\(^2\)\(^,\)\(^3\) Ultrasound treatment does not, however, appear to confer any additional benefit after intramedullary nailing with prior reaming. The discovery of specific bone growth factors (bone morphogenetic proteins [BMPs]) was an important step forward in the understanding of bone physiology and raised the possibility that these factors could be locally applied to enhance fracture healing. However, clinical trials have not yet determined the most appropriate indications for the use of BMPs in managing specific fractures or nonunions.\(^5\)\(^,\!\)\(^4\)

The indications for implant removal are not well established. There are few definitive data to guide the decision as to whether an implant should be removed or left in place. In general, implants in most adult patients may be left in place; the same is true of implants in the upper extremity. When implants are removed for relief of pain and mitigation of presumed functional impairment
alone, the results are unpredictable and depend on both the implant type and its anatomic location. Implant removal is often technically challenging and may lead to complications such as infection, neurovascular injury, or refracture. Current data do not support routine removal of implants to protect against allergy, carcinogenesis, or metal detection. The decision for or against implant removal is therefore based on individual patient and surgeon preferences, as well as on the clinical circumstances.55,56

Management of Upper-Extremity Injuries

SHOULDER

Fractures of the clavicle are common and are usually caused by falling on the shoulder. Approximately 80% of clavicular fractures occur in the middle third of the bone, 15% in the lateral third, and 5% in the medial third. Dislocation results from traction of the pectoral and sternocleidomastoid muscles. Neurovascular injury is uncommon, but the patient should always be evaluated for such injury nonetheless. Treatment is primarily conservative, employing a collar and cuff or a sling; union rates approach 95%. Operative fixation is indicated only when there is impending perforation of the overlying skin, an associated injury to the subclavian artery and brachial plexus, an ipsilateral scapular neck fracture (so-called floating shoulder), a dislocation greater than 2 cm (a relative rather than absolute indication), or painful nonunion. Fixation methods include plate osteosynthesis and intramedullary osteosynthesis.57

Scapular fractures result from high-energy trauma and are frequently accompanied by life-threatening injuries to the head, the chest, or the abdomen. CT scanning is usually required to determine the fracture pattern. Most scapular fractures can be treated conservatively. Severely (> 40°) dislocated scapular neck fractures and dislocated intra-articular glenoid fractures are treated with open reduction and internal screw or plate fixation.

HUMERUS

Proximal

Fractures of the proximal humerus are common, especially in elderly women. Correct positioning of the four main bony structures of the proximal humerus (the head, the greater tuberosity, the lesser tuberosity, and the shaft) and their muscle attachments is important for a good shoulder function. Consequently, fractures of this segment of the humerus may have significant functional consequences. Damage to the blood supply of the head may lead to avascular necrosis of this part of the bone. Conservative treatment with a sling is preferred for elderly patients with minimally displaced fractures, and early range-of-motion exercises are encouraged. Operative treatment is indicated for patients with displaced two-, three-, or four-part fractures and fracture-dislocations. The optimal fixation method has not been established, but plate osteosynthesis is frequently employed; alternatives include intramedullary techniques and prosthetic replacement.58,59 Rehabilitation usually takes several months, and continuing impairment of shoulder function is a common complaint.

Shoulder (glenohumeral joint) dislocations mostly occur in young persons participating in sports. The size difference between the large articular surface of the humeral head and the small surface of the glenoid renders the shoulder particularly vulnerable to dislocation. The majority (95%) of patients have anterior dislocations, resulting from abduction and exorotation. The relatively few posterior dislocations that occur tend to be difficult to diagnose and are frequently missed initially. A particularly rare and severe type of shoulder dislocation is luxatio erecta, characterized by inferior dislocation of the abducted arm. Injuries associated with shoulder dislocation include injury to the axillary nerve, injury to the labrum (Bankart lesion), and a depression in the humeral head (Hill-Sachs lesion); the last two predispose to recurrence. Radiographs should be obtained in AP, axillary, and Y-scapular views to determine the position of the humeral head and detect any fractures. Treatment consists of gentle and closed reduction. This can usually be done in the ED; if necessary, it can be done under anesthesia. Reduction is followed by immobilization in a sling.5

Dislocations of the sternoclavicular joint are rare, but they are potentially life-threatening when they occur posteriorly (anterior dislocations are far less dangerous). Diagnosis of these injuries is difficult with conventional x-rays; accordingly, CT is recommended when sternoclavicular joint dislocation is suspected. Compression of the mediastinal vessels and trachea can sometimes lead to respiratory and circulatory failure. In such cases, urgent operative reduction, performed with an eye to potential vascular emergencies, is warranted.5,10

Dislocations of the acromioclavicular joint result from falling on the shoulder and are frequently classified according to the system formulated by Tossy. Tossy 1 dislocations (sprains) and Tossy 2 dislocations (subluxations) are treated conservatively with a collar and a cuff. For Tossy 3 dislocations (complete separations), operative treatment may be considered, though the optimal technique remains to be determined and the results of operative fixation are still uncertain.5

Shaft

Fractures of the humeral shaft typically result from direct trauma. Depending on the level of the fracture, dislocation mainly results from traction placed on the deltoid or pectoral muscles. Fractures of the middle and distal thirds of the humeral shaft can result in injury to the radial nerve, which is the most severe functional complication. Most closed AO-ASIF type A1 and A2 fractures can initially be treated conservatively with functional bracing techniques (rather than hanging casts); this approach yields good or excellent results in the majority of cases. Moderate angulation, rotation, and shortening are well tolerated. Generally accepted indications for operative treatment include open fractures, AO-ASIF type B and C fractures, associated vascular injury, multiple trauma, bilateral fractures, combined humeral shaft and forearm fractures (so-called floating elbow), pathologic fractures, secondary radial nerve palsy, and nonunion.60 The standard technique is open reduction and plate fixation; the main alternative is locked intramedullary nailing, either antegrade (entering in the proximal humerus) or retrograde (entering in the distal humerus).61,62 External fixation is employed in the presence of severe soft tissue injuries and in polytrauma patients as part of DCS.

Distal

Fractures of the distal humerus result from falling on the elbow with the forearm flexed. In elderly persons, many of whom are osteoporotic, a fall from a standing position is often sufficient to cause such a fracture, whereas in young patients, high-energy trauma is required. Extra-articular injuries usually have a good prognosis. Intra-articular fractures are more difficult to manage: limitation of flexion and extension and pain often occur, even after optimal treatment. In addition to AP and lateral x-rays, it may be advisable to obtain CT scans to help clarify the fracture pattern. For minimally displaced AO-ASIF type A fractures, conservative treat-
ment is appropriate, but for all other fractures, open reduction and plate osteosynthesis are required, frequently in conjunction with an olecranon osteotomy to provide adequate exposure. In comminuted fractures, the articular surface can be difficult to reduce. In osteoporotic bone, finding good bone stock can be a serious problem.4,5,63,64

ELBOW

Olecranon fractures are the most common fractures in the area of the elbow and usually are caused by falling directly on the elbow. They frequently lead to impaired extension as a consequence of the discontinuity between the triceps and the proximal ulna. All dislocated olecranon fractures are treated operatively, with Kirschner wires and a tension band employed for simple fractures and plate osteosynthesis for comminuted fractures. Both methods allow early functional therapy postoperatively.

Fractures of the radial head are caused by falling on the outstretched arm and may occur either in isolation or in combination with an elbow dislocation, an ulnar shaft fracture (Monteggia fracture), a coronoid process fracture, or a medial collateral ligament rupture. In addition, the interosseous membrane between the ulna and the radius may be disrupted over its entire length, thereby disturbing the distal radioulnar joint at the wrist (Essex-Lopresti injury). Fractures with dislocations smaller than 2 mm can be treated conservatively with early range-of-motion exercises; external support is usually unnecessary. Dislocated fractures and fractures causing mechanical blockage (e.g., of pronation or supination) are mostly treated operatively, with plate or screw fixation. When the fracture is comminuted, adequate reduction and fixation may be impossible. If the elbow is otherwise stable, radial head excision may be performed; if not, a radial head prosthesis may be inserted to stabilize the joint. Active and passive range-of-motion exercises should be started soon after the operation.

Elbow dislocations are typically caused by falling on the outstretched hand. Posterior dislocations, characterized by dorsal displacement of the radius and the ulna, are more common than anterior dislocations. Associated injuries may include coronoid process fractures and collateral ligament injuries, as well as neurovascular injuries. Most elbow dislocations can be treated with closed reduction by applying traction with the forearm flexed 30°. After reduction, the stability of the elbow should be carefully evaluated. Plaster immobilization should not be continued beyond 3 weeks. Operative reduction is necessary only when the dislocation is associated with an open fracture, when interposing fragments preclude adequate closed reduction, or when neurovascular injury is present.4,5

FOREARM

The bones in the forearm have a complex relation with each other and with the elbow and the wrist, and this complex relation allows numerous different combinations of flexion, extension, pronation, and supination. The mechanism of a forearm injury is a frequently a vehicular accident or a fall; isolated fractures of the radius or the ulna are rare and usually result from a direct blow. The goal of treatment is to achieve anatomic restoration of length, axial alignment, and rotation with stable fixation in a manner that permits free movement (especially pronation and supination) of the elbow and the wrist postoperatively [see Figure 6]. Only nondisplaced fractures may be treated nonoperatively; all other forearm fractures must be treated operatively. The standard technique is open reduction with plate fixation; intramedullary fixation is an alternative. The radial nerve is at risk during plate fixation of the proximal radius.55-67

Approximately 10% of ulnar fractures are accompanied by a radial head dislocation (Monteggia fracture). Appropriate x-rays must be obtained to ensure that this injury is not missed. The radial head is reduced by closed or open methods during plate fixation of the ulna. Radial shaft fractures are sometimes associated with a dislocation of the ulna in the distal radioulnar joint (Galeazzi fracture). If the distal radioulnar joint remains unstable after plate fixation of the radius, temporary transfixation is necessary.4,5

Wrist

Distal radial fractures are among the most commonly encountered fractures. Like elbow dislocations, they are usually caused by falling on the outstretched hand. The incidence rises sharply with increasing age, especially in osteoporotic women. Associated injuries include ulnar styloid process fractures and ligamentous carpal injuries. Dislocations are classified as dorsal (Colles type) or volar (Smith type); the former are more common. Partial articular fractures (AO-ASIF type B) are also referred to as dorsal or volar Barton fractures. Diagnostic imaging plays an important role in assessment; the critical radiographic parameters are radial angle, radial length, and dorsal angulation. Radiologic signs of instability include initial dorsal angulation greater than 20°, greater than 5 mm reduction in radial length, intra-articular involvement, and metaphyseal comminution. An articular stepoff greater than 2 mm is associated with a poor prognosis.
Minimally displaced AO-ASIF type A distal radial fractures and stable impacted fractures may be treated conservatively in plaster for 4 to 6 weeks. If necessary, this can be done after closed reduction, though loss of reduction may occur after an initial satisfactory position has been achieved. For all other fractures, operative treatment is advised, depending on fracture type and patient status [see Figure 7]. AO-ASIF type B fractures are best treated with open reduction and screw or plate fixation; however, optimal treatment of AO-ASIF type C fractures remains to be determined. External fixation combined with Kirschner wires and plate osteosynthesis is frequently employed. In some cases, it may be necessary to fill a subchondral or metaphyseal defect with a cancellous bone graft or a bone substitute. Reflex sympathetic dystrophy develops in some patients [see Special Considerations, Complications, Reflex Sympathetic Dystrophy, below]. Treatment of this syndrome can be difficult, and complete functional loss is occasionally the final result.

Fracture of the scaphoid typically is caused by falling on the outstretched or dorsally flexed hand. It tends to be difficult to diagnose and is easily missed. Signs such as pain, functional impairment, and tenderness at the anatomic snuff box are often absent initially, and standard AP and lateral x-rays of the wrist may be insufficient to identify the injury. If special scaphoid views do not confirm the presence of a fracture, the wrist is immobilized and x-rays are repeated after 7 to 10 days. Alternatively, CT, MRI, or bone scintigraphy may be performed to confirm the diagnosis. Undisplaced fractures may be treated conservatively in plaster. Immobilization should be continued for 6 to 12 weeks to minimize the risk that disturbance of the delicate blood supply of the scaphoid might result in avascular necrosis or pseudarthrosis. Dislocated fractures (with dislocation greater than 2 mm or angulation greater than 25°) are treated with screw osteosynthesis.

Perilunate dislocations result from high-energy trauma and include a spectrum of severe ligamentous wrist injuries, fractures, and dislocations characterized by dorsal dislocation of the distal carpal row, the scaphoid, and the triquetrum with respect to the lunate. Perilunate dislocations may be missed initially in multiply injured patients if the physical examination is incomplete or the x-rays of the wrist are inadequate or not carefully examined. Treatment consists of closed or open reduction; additional fixation may be performed as needed, depending on the degree of stability achieved after reduction. Associated fractures of the radius or the scaphoid are treated operatively.

HAND

Fractures of the hand can result from direct blows, twisting injuries, crush injuries, and gunshot wounds. Neurovascular status, wounds (e.g., bites), and tendon function should all be carefully evaluated. Most fractures can be detected on posteroanterior, lateral, and oblique views.

Metacarpal neck fractures, most frequently of the fourth or fifth metacarpal (so-called boxer’s fracture), can usually be treated conservatively with 3 to 4 weeks of immobilization and early range-of-motion exercises. Fracture healing may result in cosmetic deformity but good function. Severely dislocated fractures are typically treated with Kirschner wires or plate fixation. Most fractures of the metacarpal shafts can be treated nonoperatively with immobilization in a cast or splint for 4 weeks. If the wrist is immobilized in plaster, it should be positioned in 20° of extension, with the metacarpophalangeal joints in 70° to 90° of flexion and the interphalangeal joints in complete extension to prevent shortening of ligaments. Rotation (as indicated by nail position) should be checked frequently. Indications for operative treatment include angulation greater than 10° to 30°, shortening, malrotation (more

Figure 7  Illustrated is treatment of distal radial fracture with (a) volar plate osteosynthesis and (b) external fixation.
frequent in the second and fifth metacarpals), and multiple fractures. Bennett’s fracture (an intra-articular fracture of the base of the first metacarpal with a small ulnar fragment that remains attached to the second metacarpal) should be treated with reduction or, if unstable, fixation with percutaneously placed Kirschner wires or screws. Other metacarpal base fractures are less frequent but may also be associated with carpometacarpal dislocations. Treatment focuses on reduction of the joint and restoration of alignment and the articular surface, if necessary by means of open reduction.5,71,72

Phalangeal fractures are common. In the distal phalanx, fractures often result from crush injury and may be associated with subungual hematoma (which should be drained) and soft tissue injury. The vitality of the fingertip may be compromised. Nondisplaced fractures may be treated with immobilization in plaster or a splint for 3 weeks, followed by active range-of-motion exercises. Dislocated fractures may be treated with closed or open reduction and fixation with Kirschner wires or small screws or plates.71,72

Dislocations of the interphalangeal joints usually are easily recognized by the obvious deformity they cause, but x-rays must still be obtained to exclude fractures. Dorsal dislocations are associated with injuries to the volar plate or collateral ligaments, which tend to increase instability. Treatment consists of closed or open reduction, followed by testing through the range of motion to check stability and x-rays to ensure adequate reduction. If reduction is unstable, transarticular Kirschner wire fixation may be necessary.5

So-called gamekeeper’s thumb is an injury to the ulnar collateral ligament of thumb metacarpophalangeal joint that causes instability at that joint; the ulnar collateral ligament frequently becomes dislodged between the adductor pollicis aponeurosis and its normal position (Stener lesion). Partially unstable lesions (< 20° to 30° opening at stress examination in comparison with the uninjured side) may be treated in a plaster splint for 3 to 4 weeks. Completely unstable lesions are treated with surgical repair to prevent chronic instability.5

TENDONS

Injuries to the rotator cuff reduce the shoulder’s strength and impair its function. Most ruptures occur in cuff muscles or tendons that are already affected by degenerative changes. Operative treatment is advised for young patients and for patients who have experienced substantial ruptures as a result of recent trauma.

Rupture of the distal biceps tendon occurs mainly in middle-aged men. The tendon is torn off the radial tuberosity during flexion against resistance. The muscle belly is visibly retracted proximally, and flexion and supination are reduced by 30% to 40%. In cases where the diagnosis is not clear, MRI or ultrasonography may be helpful. Treatment consists of reattaching the tendon to the radius with suture anchors or drill holes.

In the case of tendon injuries around the wrist and the hand, appropriate clinical testing and diagnosis depend on a solid knowledge of the exact anatomy and function of the various tendons. The extensor tendons are located just under the skin, directly on the bone, on the back of the hands and the fingers; their superficial location makes them easily injured even by a minor cut. The flexor tendons pass through fibrous rings called pulleys, which guide the tendons and keep them close to the bones; because of the more complex anatomy, flexor tendon injuries are usually more challenging than extensor tendon injuries. Partial injuries with intact function may be treated conservatively, but most injuries, especially sharp lacerations, are treated with surgical repair followed by protected motion. Postoperative treatment and rehabilitation of tendon injuries are very important and require the services of a special hand therapist.

A commonly encountered extensor tendon injury is so-called mallet finger, which results from forcible flexion of the extended distal interphalangeal joint. The extensor tendon is torn off the distal phalanx, with or without an intra-articular fragment of its base. Clinically, the distal interphalangeal joint is in flexion, and active extension of the distal phalanx is impossible. Most lesions can be treated with a special splint that keeps the distal interphalangeal joint in extension for 4 to 6 weeks.5

Management of Pelvic and Acetabular Injuries

PELVIC RING

Pelvic fractures occur in about 3% of trauma patients. These injuries can have a devastating influence on the outcome of trauma care and therefore must be identified as early as possible. Internal retroperitoneal bleeding is the main concern in the early management of these patients because over 40% of the mortality from pelvic trauma is attributable to persistent bleeding. Accordingly, the initial physical examination and the AP pelvic x-ray (which is diagnostic in 90% of cases) during the primary survey are essential for placing the focus on the potential risk of internal bleeding. Additional inlet and outlet views (taken at a 45° angle from cephalad and caudal) may be useful for accurate classification and determination of dislocation.5,7 CT scanning is performed in nearly all cases but not necessarily as an emergency evaluation. The CT scan facilitates fracture classification and provides additional information on active bleeding and associated injuries. Administration of I.V. contrast material during CT scanning helps in detecting active arterial bleeding, which suggests the need for early angiographic embolization. Angiographic embolization may be lifesaving in patients with pelvic arterial bleeding.

Pelvic injuries are frequently associated with other serious injuries. Fractures of the anterior pelvic ring, especially when seen in combination with blood from the urethral meatus, are an indication for retrograde urethrography before placement of a transurethral catheter to detect or exclude urethral and bladder injuries. Vaginal and rectal examinations are components of the standard workup for detecting or excluding fracture perforations and abnormalities of prostate position (indicative of urethral injury).

Posterior pelvic ring injuries may be accompanied by sacral plexus nerve injuries. Perineal and groin wounds often are in continuity with fracture components and pose a serious threat of further complications. With open pelvic injuries, early surgical debridement and fecal deviation must be considered.

The AO-Tile classification of pelvic ring and acetabular fractures is based on the degree of pelvic stability or instability. The pelvis is divided into an anterior section (comprising the symphysis pubis and the pubic rami) and a posterior section (comprising the ilium, the sacroiliac joint complex, and the sacrum).4 Determination of whether and to what extent the posterior section is displaced is crucial for estimating the stability of the injury. Depending on the degree of posterior bony or ligamentous instability, pelvic ring injuries may be classified into three types as follows:

1. Type A: injuries where the mechanical stability of the pelvic ring is intact—the most common type, seen in 50% to 70% of pelvic fracture patients.
2. Type B: injuries characterized by partial posterior stability (i.e., injuries that are rotationally unstable but vertically stable)—seen in 20% to 30% of pelvic fracture patients.
3. Type C: injuries in which the posterior pelvic ring is completely disrupted—seen in 10% to 20% of pelvic fracture patients.
3. Type C: injuries characterized by combined anterior and posterior instability (i.e., injuries that are both rotationally and vertically unstable)—seen in 10% to 20% of pelvic fracture patients.

Another system used to categorize pelvic fractures is the Young-Burgess classification, which is based on the force vectors causing the fracture. In this system, pelvic ring fractures are divided into the following four major groups: (1) lateral compression, (2) anteroposterior compression, (3) vertical shear, and (4) combined mechanical injury. The stability or instability of the fracture can be determined on the basis of knowledge of the ligamentous anatomy of the pelvis coupled with assessment of the fracture pattern and the direction of the injuring force.4,5

Provisional stabilization is advised after manual reduction of pelvic ring disruption, especially in open-book fractures with significant dislocation. External fixation is one means of achieving provisional stabilization; however, it is more time consuming than applying a sheet wrap or a similar device for temporary stabilization. For this reason, many institutions prefer the latter approach during initial management in the ED. The Pelvic C-Clamp (Synthes, West Chester, Pennsylvania) is also employed for external stabilization, primarily in hemodynamically unstable patients with unstable (i.e., type B or C) pelvic ring injuries. This device acts by exerting direct compression on the posterior part of the pelvic ring, thereby reducing the intrapelvic volume, compressing fracture parts, and providing stability. Application of this device should also be considered if operative retroperitoneal pelvic packing is necessary.

Definitive treatment of pelvic injuries depends on the type of injury, the classification (stability), the local soft tissue situation, and the general condition of the patient [see Figure 8]. Type A fractures are stable and usually need not be treated operatively. Functional treatment, with early ambulation and weight bearing as tolerated, usually suffices.

Type B1 (open-book) injuries with minimal dislocation of the symphysis may be treated conservatively. If symphyseal dislocation is less than 2.5 cm, anterior plate fixation of the symphysis is usually sufficient. If the patient cannot undergo formal internal fixation, an external fixator (which may have been applied initially for bleeding control) is a reasonable alternative for definitive treatment. However, the discomfort and the complications (e.g., infection) caused by external fixator pins motivate many surgeons to convert to internal plate fixation after the initial stabilization phase. In the setting of an emergency laparotomy, early anterior plate fixation may be considered during the same laparotomy, provided that patient is or has been rendered physiologically stable. Type B2 (lateral compression) injuries with minimal anterior dislocation often have good intrinsic stability and can frequently be treated conservatively.

For type C injuries, both anterior and posterior stabilization is required. Of the many techniques currently in use, plate fixation of the anterior pelvic ring combined with either percutaneous sacroiliac screws or plate fixation of the posterior pelvis provides the best mechanical stability. The main goals are to restore the anatomy and prevent any leg-length discrepancy while encouraging allowing early mobilization of the patient to prevent the complications of prolonged bed rest.4,5,73-75

Percutaneous placement of iliosacral screws under fluoroscopic guidance is already the preferred technique for stabilization of the majority of unstable sacroiliac injuries. The continuing development and growing availability of modern surgical tools (e.g., computer-assisted intraoperative navigation) are providing ever more opportunities for minimally invasive approaches to pelvic fracture fixation. Nevertheless, stabilization of the pelvis through open surgical reduction and internal fixation using standard plate and screw techniques are still proper alternatives and are the treatment of choice for many pelvic ring fractures.

ACETABULUM

Traumatic acetabular fractures may occur either in isolation or as part of a pelvic ring injury [see Figure 8a]. On occasion, they occur in combination with hip dislocation; in such cases, urgent

Figure 8  Shown are (a) plate osteosynthesis for combined pelvic ring injury and left-side acetabular fracture in a multiply injured patient and (b) treatment of type C unstable pelvic ring injury with initial angioembolization (coils visible) and external fixation, followed by secondary percutaneous placement of sacroiliac and pubic screws.
reduction of the dislocated hip is essential for restoring blood flow to the femoral head. For adequate fracture classification, x-rays must be obtained in Judet views (oblique views taken with the beam stationary and with the patient rolled 45° to both sides along the vertical axis). CT scanning with axial and three-dimensional reconstructions can greatly clarify the extent of the injury and help identify the number and size of fracture fragments. An accurate neurologic examination that includes assessment of the integrity of the sciatic nerve should also be part of the initial workup.

Until the 1960s, the vast majority of patients with acetabular fractures were treated conservatively. Thanks to the impressive efforts of Letournel and Judet (who also introduced the most frequently used classification system), operative treatment has become standard for dislocated acetabular fractures. The most important goal of operative treatment is to restore the articular surface so that a congruent hip joint can be obtained. Achievement of this goal nearly always requires open reduction and internal fixation with plates or screws through anterior or posterior approaches. Extensive experience on the part of the operating team is necessary to ensure optimal long-term results. After the operation, the patient should be able to take part in non-weight-bearing exercises.

The majority of acetabular fractures can be treated in a delayed fashion between 3 and 14 days after the injury. Acute operative fracture treatment may be indicated if a dislocated hip cannot be reduced, if redislocation of the hip cannot be prevented, or if interference of the joint occurs. In many instances, however, initial skeletal traction (if indicated after hip reduction) will be applied.

Adequate prophylaxis of deep vein thrombosis (DVT) is essential for both patients with pelvic fractures and those with acetabular fractures. Functional outcome after acetabular fracture surgery is determined by many factors, the most important of which are anatomic fracture reduction, the development of osteoarthritis, avascular necrosis, and heterotopic ossification.

Management of Lower-Extremity Injuries

FEMUR

Proximal (Hip Fracture)

Fracture of the proximal femur (hip fracture) is one of the most common conditions seen by orthopedic and trauma surgeons. It is particularly common in the elderly. Substantial force is required to fracture a hip in a young person, whereas a minor trauma or fall may be sufficient to do so in an elderly osteoporotic woman. Almost 90% of patients with proximal femoral fractures are older than 70 years. Between 5% and 10% of these elderly patients die during hospital admission; 25% die within the first year after the accident.

Hip fractures are typically classified into four broad categories according to their anatomic site: (1) femoral head fractures, (2) intracapsular (femoral neck) fractures, (3) intertrochanteric fractures, and (4) subtrochanteric fractures. Within these broad categories, they may be further divided into subcategories according to various classification systems (see below). Such classifications can be helpful in guiding decision making with respect to treatment, which necessarily differs from one type of hip fracture to another.

In general, the choice of treatment is influenced by a range of patient-related factors that includes age, the presence and severity of comorbid medical conditions, previous mobility, cognitive status, fracture classification, and the status (i.e., preserved or disrupted) of the all-important blood supply to the femoral head. Failure of treatment frequently results from inappropriate choice of a fixation method or misinterpretation of the fracture configuration.

Fractures of the femoral head are the most devastating of hip injuries and must be handled as surgical emergencies. They are generally classified according to Pipkin’s system. Because substantial force is required to produce femoral head fractures, they are often seen in association with hip joint dislocations and acetabular fractures, most commonly in multiply injured patients who were involved in motor vehicle accidents. The diagnosis is made on the basis of pelvic and acetabular x-rays, supplemented by CT scans. Concomitant hip dislocations (most often posterior) should ideally be reduced with the patient under general anesthesia and with muscle relaxation achieved by upward traction with the hip in 90° of flexion. If possible, this should be done in the ED to minimize delay in restoring blood flow to the femoral head. After reduction, the stability of the joint is tested clinically, and CT scanning is performed to assess impaction fractures, loose fragments in the hip joint, and the integrity of the acetabulum.

Most femoral head fractures are treated operatively if the patient’s condition permits. For optimal results, this should be done within 24 to 48 hours after the injury, if possible. Closed treatment of dislocated fractures yields uniformly poor results. Internal fixation of these injuries is technically demanding and should allow early passive and active motion exercises postoperatively. Indomethacin is administered to prevent heterotopic ossification around the hip. Weight bearing is allowed after 10 to 12 weeks. In some patients, particularly physiologically older patients with major fractures, it may be best to insert a hip prosthesis primarily. Although operative treatment is usually necessary to provide the best chance of recovery, the magnitude of the initial trauma is generally such that good results can be obtained in only 50% to 70% of cases.4,5,81

A typical patient with an intracapsular (femoral neck) fracture presents with a shortened, externally rotated, and abducted lower extremity. These fractures are often classified according to Garden’s system. Treatment is determined by the fracture type and associated patient factors. Especially in young patients, because of the risk of nonunion and avascular necrosis, dislocated femoral neck fractures should preferably be treated on an emergency basis within 12 hours after the injury.82 In otherwise healthy and ambulatory patients, incomplete and impacted fractures (intact trabeculae of the inferior neck; Garden 1) may be managed with conservative treatment, consisting of early mobilization with crutches or a walker (to the extent permitted by the pain experienced) and supervised by a physical therapist. Secondary dislocation occurs in 10% to 50% of cases, leading to secondary operative treatment. Complete but undislocated fractures (Garden 2) are mostly treated operatively with cannulated screws or a sliding hip screw (e.g., Dynamic Hip Screw [DHS]; Synthes, West Chester, Pennsylvania). Sliding hip screws allow controlled compression of the fracture to be obtained during weight bearing as the lag screw slides into the plate. Complete fractures with partial (Garden 3) or complete displacement (Garden 4) are treated by means of early anatomic reduction with fixation to eliminate the risk of displacement and permit rapid mobilization. When the patient is physiologically older than 70 years, placement of a primary hip prosthesis is often indicated instead of internal fixation; however, this procedure is associated with higher perioperative morbidity and mortality.5,81,83

Trochanteric fractures are the most common fractures of the proximal femur. They do not threaten the blood supply to the femoral head, because they occur below the extracapsular ring of vessels. Trochanteric fractures are classified according to the AO-ASIF system. Almost all patients with such fractures are candidates for internal fixation. The main exceptions are elderly patients who...
had significant arthritis of the hip before sustaining the fracture; for these patients, placement of a hip prosthesis is an alternative.

The lesser trochanter provides crucial support for the medial femoral cortex; thus, assessment of its integrity is important for determining the stability of the fracture, which, in turn, helps determine treatment. The main treatment options are extramedullary and intramedullary implants. Extramedullary implants include sliding hip screws (see above), which are relatively easy to insert and also allow open reduction of the fracture if necessary. These implants are most suitable for stable (AO-ASIF type A1) fractures [see Figure 9a]. For unstable (AO-ASIF type A2 and A3) intertrochanteric fractures, intramedullary fixation is the treatment of choice because of the favorable position of the implants in the biomechanical loading axis of the femur. Examples include the Proximal Femoral Nail (PFN; Synthes, West Chester, Pennsylvania) [see Figure 9b], the Intramedullary Hip Screw (IMHS; Smith & Nephew, London, England), and the Gamma Nail (Stryker, Kalamazoo, Michigan). The operative technique for intramedullary fixation is more complex and unforgiving than that for extramedullary fixation, and various complications may arise, including malpositioning and femoral shaft fractures during insertion. Intramedullary implants are usually inserted percutaneously on a traction table with one or more screws in the femoral head and one or more distal locking screws. Internal fixation of trochanteric fractures should allow mobilization from postoperative day 1, preferably with full weight bearing or the use of a walker.1,5,84

Subtrochanteric (AO-ASIF type A3) fractures are inherently unstable. Operative treatment may be difficult because high bending forces in the region (resulting from the angular shape of the proximal femur) often lead to implant failure before union. The preferred management approach is intramedullary nailing; the use of angled blade plates is an alternative, especially in young patients who require anatomic reduction.4,5

**Shaft**

In most adults, considerable force is necessary to fracture the femoral shaft; a simple fall seldom results in this type of fracture unless the bone has been weakened by osteoporosis or other disease. A patient with a femoral shaft fracture should therefore be considered a victim of high-energy trauma and evaluated accordingly.

Most fractures of the femoral shaft are easily recognized clinically on the basis of pain and abnormal position or movement. Because of the shape of the thigh, more than 1 L of blood may be lost into this space with little or no external indication. Neurovascular injuries are relatively uncommon in this setting; however, when the fracture is in the distal third of the femoral shaft, injury to either the superficial femoral artery or the popliteal artery may ensue as a consequence of the tethering of these vessels against the shaft at the level of the adductor canal. Femoral shaft fractures are often associated with injuries to knee ligaments, which are difficult to assess in the presence of the femoral fracture. Thus, when the patient is under anesthesia for treatment of the fracture, the stability of the knee should be assessed as well. Imaging consists of AP and lateral x-rays, with the hip and knee joints included.

In the ED, a fractured femur is immobilized with a vacuum splint or a Thomas splint. This measure reduces blood loss and lessens patient discomfort, and the splints need not be removed for x-rays to be taken. Ideally, femoral shaft fractures should be treated within 12 to 24 hours after the injury; preoperative skeletal traction is therefore superfluous. The main goal is stable fixation that yields correct length, rotation, and alignment, with full weight bearing possible within a few days of the operation. Femoral shaft fractures of AO-ASIF types A to C are best treated with locked intramedullary nailing [see Figure 10]. In isolated instances, a plate or an external fixator may be indicated. Nailing lowers the incidence of respiratory distress syndrome, blood loss, and tissue trauma and reduces the patient's need for narcotics. In the setting of DCS, femoral fractures are initially stabilized by means of external fixation. The external fixator can then be exchanged for an intramedullary nail 2 to 10 days later without a significant increase in complications.12,13,85 Nailing can be performed with the patient supine on a fracture table or in a lateral position. The operative technique for intramedullary fixation is more complex and unforgiving than that for extramedullary fixation, and various complications may arise, including malpositioning and femoral shaft fractures during insertion. The femoral shaft is the most common site of femoral fracture; a simple fall seldom results in this type of fracture unless the bone has been weakened by osteoporosis or other disease. A patient with a femoral shaft fracture should therefore be considered a victim of high-energy trauma and evaluated accordingly.

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Figure 10  Illustrated (a through e) is treatment of comminuted AO-ASIF type C femoral fracture with intramedullary nailing. No attempt was made to reduce fracture fragments in order to preserve their vascularization. Healing was uneventful, with complete restoration of function.

decubitus position with closed reduction (or, if necessary, open reduction) of the fracture. Most nails are inserted in an antegrade manner through the greater trochanter or piriform fossa, though retrograde nailing through the intercondylar notch is becoming increasingly popular for distal shaft fractures. Reaming is generally advised because it reduces the rate of nonunion.51

Most complications with femoral shaft fractures are secondary to technical problems at the time of nailing and can therefore be prevented by paying close attention to technical details (in particular, the entry point of the nail and correct rotation). In rare instances, embolization of debris from reaming may lead to fat embolism syndrome (FES) [see Special Considerations, Complications, Fat Embolism Syndrome, below]. Infections occur mostly in open fractures and fractures where there is substantial soft tissue involvement. Compartment syndrome of the thigh may occur after femoral shaft fracture, albeit infrequently; it should be suspected if severe swelling is present.4,5

Distal

Supracondylar (AO-ASIF type A) and intercondylar (AO-ASIF type B and C) fractures of the distal femur typically occur in young patients who have sustained high-energy trauma or in elderly patients with osteoporotic bone. Careful assessment of neurovascular status is important. X-rays focused on the knee should be supplemented with x-rays of the femoral and tibial shafts. CT can provide additional information on the fracture pattern and help in preoperative planning. Standard treatment consists of operative reduction and internal fixation, followed by partial-weight-bearing or non-weight-bearing active or passive exercises.

Supracondylar fractures can be treated with retrograde intramedullary nailing or plating, depending on the surgeon’s preference. Open reduction with extensive techniques for applying angled blade plates, condylar plates, sliding hip screws, and similar devices is currently being replaced by less invasive plating techniques using screws that are locked into the plate. An example of the latter is the Less Invasive Stabilization System (LISS; Synthes, West Chester, Pennsylvania), which allows submuscular fixation and percutaneous placement of self-drilling unicortical fixed-angle screws. The focus with this system is more on correction of length and alignment and less on anatomic reduction.

Intercondylar fractures are treated with anatomic reduction and screw fixation of the articular surface to allow early motion and thereby facilitate cartilage healing. Either open methods or image intensifier-assisted closed methods may be employed. The reconstructed articular surface is then connected en bloc to the femoral shaft with one of the previously described techniques (usually plating).4,5,86

KNEE

Patellar Fracture

Knee injuries are common in multiply injured patients, in large part because of the vulnerability of this joint to dashboard injuries in automobile accidents and to direct trauma in motorcycle accidents. Patellar fractures usually result from a fall on the knee, a sudden forceful contraction of the quadriceps muscle with knee flexion, or a combination of the two. Other injuries (e.g., cruciate ligament failure and femoral fracture) may be present as well. The most important task in the examination is to confirm that the extensor mechanism is intact by asking the patient to raise the leg with the knee fully extended. X-rays should include AP, lateral, and
(optionally) tangential views. Transverse and stellate fractures with minimal (< 1 to 2 mm) displacement and an intact extensor mechanism may be treated conservatively by keeping the joint in a cast for 6 weeks, with weight bearing allowed. All other fractures are treated by open reduction with internal fixation, typically with Kirschner wires and tension bands or cerclage wires. Postoperatively, early active motion and partial weight bearing are allowed. Severely comminuted patellar fractures may be irreparable; in such instances, a partial or total patellectomy with reconstruction of the extensor apparatus may be required. Ligamentous patellar injuries (e.g., to the quadriceps tendon or the patellar tendon) are treated by means of operative repair and reinsertion to the patella.4,5

Dislocation

Knee dislocations, though potentially severe injuries, are generally rare, with only a few small series having been reported. They result primarily from motor vehicle and pedestrian accidents, falls, and sports activities, though they also occur spontaneously in morbidly obese persons. Their severity is determined by the complexity of the ligamentous injury and any associated trauma, including popliteal artery and vein injury (20% to 30% of cases) and peroneal nerve injury (25% to 35%). Failure to recognize vascular injury can lead to muscle necrosis and amputation. It is therefore essential that reduction of knee dislocations be carried out immediately, either before arrival at the hospital or in the ED, followed by vascular examination and x-rays. Anterior dislocation (30% to 40% of cases) is often caused by severe knee hyperextension, whereas posterior dislocation (25% to 30%) occurs with the application of force to the proximal tibia in an anterior-to-posterior direction, as in a dashboard-type injury or a high-energy fall on a flexed knee.

Physical examination reveals gross deformity around the knee with swelling and immobility. Occasionally, the knee will have relocated spontaneously before the patient arrives at the ED. Attention should be focused on the presence or absence of hard signs of vascular injury [see 7:13 Injuries to the Peripheral Blood Vessels]; if preferred, the ankle-brachial index (ABI), duplex scanning, or both may be employed in addition.3,37 Although many authors recommend mandatory arteriography or operative exploration for all knee dislocations, this recommendation is increasingly being questioned.47,48 The current literature indicates that the absence of hard signs reliably excludes a significant arterial injury that necessitates operative repair. The presence of hard signs of vascular injury, however, is an indication for arteriography; because about 25% of patients with hard signs actually have no vascular injury, arteriography serves to prevent many unnecessary vascular explorations. Another potentially valid (and timesaving) approach may be to take those with hard signs directly to the OR and obtain an on-table angiogram. In some instances, noninvasive tests may be able to distinguish patients who have vascular injuries requiring repair from those who do not.

Asymptomatic intimal injuries visualized by arteriography do not call for surgical exploration, and the clinical value of interventional radiology techniques (e.g., stent placement) in this context is questionable. If there is a vascular injury that requires surgical repair, an external fixator that spans the knee joint should be quickly placed. Restoration of circulation has absolute priority in this situation; the amputation rate exceeds 80% when vascular repairs are done more than 8 hours after injury. Operative repair of nerve injuries is controversial. Optimal treatment of multiple ligament ruptures is also subject to debate. Many authors recommend early operative ligamentous repair followed by functional bracing and mobilization for optimal results, whereas others recommend primary immobilization followed, if necessary, by late reconstructions.45,90

Ligamentous Injury and Meniscal Tearing

Distortions of the knee are common injuries; most involve varus, valgus, or rotational deformities. The history should focus on the mechanism of injury, the type and location of pain, any associated symptoms, the amount of immediate dysfunction, the presence and onset of joint edema, and any history of past knee problems. The physical examination should include inspection, active motion, and stress testing to detect instability. Hemarthrosis is a sign of possible cruciate ligament injury. If pain and swelling preclude reliable examination, the examination should be repeated in 5 to 7 days. Collateral ligament injuries are graded on a scale of I to III. A grade I injury is a sprain (with stretching but no tearing of the ligament, local tenderness, minimal edema, and no gross instability on stress testing), a grade II injury is a partial ligament tear (with moderate local tenderness and mild instability on stress testing), and a grade III injury is a complete tear (with discomfort on manipulation, a variable amount of edema, and clear instability on stress testing).

X-rays of the knee are obtained to detect any fractures of the tibial plateau or the intercondylar eminence. The number of unnecessary x-rays may be substantially and safely reduced by applying the so-called Ottawa knee rule. This rule specifies the following indications for x-rays; age 55 years or older, tenderness at the head of the fibula, isolated tenderness of the patella, inability to flex the knee 90°, and inability to walk four weight-bearing steps immediately after the injury and in the ED. MRI is useful for detecting ligamentous, meniscal, and cartilage injuries but is rarely indicated on an emergency basis.

Treatment depends on the patient’s age and activity level and should always include appropriate reeducation and strengthening of the relevant muscles (hamstrings and quadriceps). Grade I and II collateral ligament injuries (which are usually medial) may be treated conservatively with early active motion, with or without a knee brace. Grade III medial collateral ligament injuries may be treated in a knee brace for 6 weeks, but grade III lateral collateral ligament injuries must be treated surgically because conservative treatment frequently leads to chronic instability. Anterior cruciate ligament ruptures are increasingly being treated by operative means in serious athletes and other physically active persons. The ligament is arthroscopically reconstructed with a section of the patellar tendon or the semitendinous tendon. Isolated posterior cruciate ligament ruptures, which are considerably less common, are primarily treated nonoperatively.4,5,91

Meniscal tears occur mainly in physically active persons, though they may also result from simple distortions experienced during activities of daily living, especially if the meniscus has previously undergone some degeneration. Complaints include mild pain, swelling, grinding, locking, and “giving way.” Clinical diagnosis is aided by provocative tests (e.g., the McMurray and Appley tests), but when symptoms persist, MRI is often performed. Mild meniscal tears may be treated conservatively, whereas symptomatic lesions usually call for surgical treatment. In general, meniscal repair is indicated when the tear is in the vascular outer one third of the meniscus, and partial excision is indicated when the injury is in the avascular inner two thirds.5

Tibia

Proximal

Tibial plateau fractures are intra-articular fractures that mostly
result from indirect varus or valgus trauma. The amount of displacement and comminution is determined by the magnitude and direction of the forces applied. High-energy fractures may be associated with severe soft tissue injuries, as well as ligamentous and meniscal tears. It is important to recognize that severe proximal tibial fractures can represent a reduced fracture dislocation of the knee, and thus, the neurologic and vascular concerns that accompany knee dislocations can apply to these fractures as well [see Knee, Dislocation, above].

Tibial plateau fractures are characterized by local pain, swelling from hemorrhatosis, and, in some cases, instability of the knee joint. Aspiration of a tense hemorrhatosis is sometimes required to decompress the joint and relieve pain. Only 6% of patients with knee trauma have a fracture. The need for x-rays is generally deter-
duced from hemarthrosis, and, in some cases, instability of the knee joint. The extremity should be splinted, and appropriate x-rays should then be obtained to allow full assess-
ment of the fracture. This measure also helps the physician decide whether operative or nonoperative treatment is indicated and, if the former, which operative approach should be taken. If the condition of the soft tissues precludes early definitive operative treatment, a plaster splint or temporary external fixation may be employed to allow the soft tissues time to heal or to give the surgeon time to plan an operative procedure for soft tissue coverage.

Proximal tibial fractures are classified according to the AO- ASIF system or the Schatzker system. Extra-articular AO-ASIF type A1 and A2 fractures and minimally (< 2 mm) displaced intra-articular fractures (AO-ASIF type B and C) may be treated conservatively; all others should be treated operatively. Operative treatment consists of anatomic reduction of the articular surface, either under direct vision (arthrotomy) or via a less invasive approach (with arthroscopic or fluoroscopic assistance). Reduction is held with screws, plates, or both, and often, the use of iliac bone grafts or bone substitutes (e.g., calcium phosphates) is required to maintain the elevation of the articular surface. The articular “block” is connected to the tibial shaft by means of plates and screws; if soft tissue injuries preclude plating, special external fixation devices (i.e., ring fixators with tensioned wires) may be employed instead. Fixed-angle plating systems that allow less invasive insertion methods are also gaining popularity for use in the proximal tibia. Early motion is appropriate after operation, with weight bearing allowed after 8 to 12 weeks. Disabling complications include infection, posttraumatic arthritis, and instabil-
ity of the knee.4,5

**Shaft**

Fractures of the tibial shaft are among the most common serious fractures. The subcutaneous location of the tibia affords little protection from direct violence, and high-energy fractures are associ-
ated with longer healing times. Tibial fractures can be fraught with complications (e.g., compartment syndrome, nonunion, delayed union, malunion, and infection), and in their most severe manifes-
tations, they can end in amputation. Tibial shaft fractures are easi-
ly diagnosed clinically in the ED. Examination includes palpation for signs of possible compartment syndrome and assessment of the neurovascular status. If the fracture is grossly angulated or malaligned, gentle restoration of axial alignment helps relieve vascular kinking and compromise. The extremity should be splinted, and appropriate x-rays should then be obtained to allow full assess-
ment of the fracture.

Selected closed fractures without dislocation and minimally dis-
placed AO-ASIF type A fractures may be treated conservatively with an above-the-knee cast for 2 to 4 weeks, followed by functional bracing for 10 to 16 weeks. Bracing relies on the intact soft tissues, primarily the interosseous membrane, to prevent shortening and dislocation.93 Displaced and unstable AO-ASIF type A, B, and C fractures, as well as all open fractures, are treated operatively. The severity of any associated soft tissue injury is a crucial factor in deciding how to manage of tibial shaft fractures. The standard treatment for such fractures—closed reduction with reamed, inter-
locking intramedullary nailing—has a high success rate and a low complication rate [see Figure 11]. In those unusual circumstances in which the fracture pattern does not permit insertion of an intramedullary rod (e.g., certain fractures in the proximal or distal third of the shaft), plate fixation may be employed instead; unfortunately, this procedure is associated with a high rate of nonunion.4,5,51

For open fractures associated with complex wounds, the stand-
ard treatment has been external fixation, which permits stabilization of the fracture, affords ready access to large open wounds, and facilitates nursing care. Currently, however, nailing appears to be superior to external fixation for grade 1 and 2 open fractures: the infection rate is no higher, the complication rate is lower, and the functional end results are better. Grade 3 open fractures are highly complex injuries, and an expert team that includes a plastic surgeon is required for optimal management. Aggressive irrigation and debridement are followed by either external fixation or intramedullary nailing, depending on the state of the surrounding soft tissue factors, the fracture pattern, time-related factors, and the surgeon’s preference. If secondary soft tissue procedures involving a pedicle or a free flap are warranted, they should be planned at an early stage in treatment. In multiply injured patients who require DCS, tibial shaft fractures are initially stabilized with external fixation, with care taken to place the fixator pins strategically, in anticip-
ation of subsequent soft tissue coverage procedures. Once the patient is physiologically stable, the fixator may be removed and intramedullary nailing performed. In these patients, a combination of retrograde femoral nailing and antegrade tibial nailing done through a single knee incision offers an elegant and less invasive means of stabilizing a floating knee.

One of the most severe complications that may develop after a tibial fracture is compartment syndrome [see 7:13 Injuries to the Peripheral Blood Vessels]. When the fracture is in the distal third of the shaft, delayed union or nonunion is a particular risk as a conse-
quence of the limited vascularization provided by the predomin-
antly posterior soft tissue envelope.4,5

**Distal**

Fractures of the distal tibia mostly result either from vertical loading that drives the talus into the tibia (as in a fall from a height or a motor vehicle accident) or from low-energy trauma with tor-
sion (as in skiing). Intra-articular fractures in this region are called tibial plafond (ceiling) or pilon fractures. Pilon fractures are fre-
quently accompanied by severe soft tissue swelling and comminu-
ation of the articular surface and the metaphysis; the fibula may or may not be fractured. Standard AP and lateral x-rays are obtained in conjunction with CT scans to define the fracture pattern and aid in preoperative planning. The goals of treatment are to restore ankle joint integrity, congruency, and stability; to achieve bony union; and to allow functional painless motion. In cases where there is substantial soft tissue involvement, staged surgery may be advisable. A safe option is to apply a bridging external fixator from the midtibia to the foot, leaving enough distance between the fixator pins to allow future incisions in the distal tibia; this may be done with or without primary percutaneous screw fixation of the joint.
surface and with or without primary fixation of the fibula to restore the length of the ankle.

Fractures that are not accompanied by dislocation (mostly AO-ASIF type A1) may be treated conservatively in a cast for 8 weeks. All other distal tibial fractures generally require operative treatment, the basic principles of which resemble those appropriate for proximal tibial fractures. Because of the typical swelling and the frequent presence of fracture blisters, optimal timing of the procedure is critical. For extra-articular (AO-ASIF type A) fractures, a minimally invasive approach involving percutaneous insertion of a plate with locking screws (e.g., the LCP) may be feasible. For intra-articular (AO-ASIF type B and C) fractures, anatomic reduction of the articular surface and internal fixation are required, preferably performed by an experienced surgeon. Dissection should be minimized to prevent further soft tissue injury. Any debris present in the joint is removed. After reconstruction of the articular surface, a connection with the tibial shaft is made, most frequently with a plate and screws or with a hybrid ring fixator. With most AO-ASIF type C distal tibial fractures, the use of a bone graft or bone substitute is required to support the articular surface. Such fractures frequently give rise to severe posttraumatic arthritic pain, and delayed ankle fusion may be required.4,5

ACHILLES TENDON

Achilles tendon ruptures are mainly caused either by sudden forceful dorsiflexion of the foot with the knee extended (placing the soleus and gastrocnemius muscles on maximal stretch) or by sudden takeoff during athletics. They are frequently seen in weekend athletes, as well as in more regular participants in active sports (e.g., football, volleyball, tennis, and squash). A common scenario is one in which the patient wrongly believes that someone has hit him or her on the heel; sometimes, the patient hears a snap as well. On physical examination, a visible or palpable dent is apparent in the tendon 2 to 6 cm above the calcaneus. The Thompson test is useful for confirming or ruling out an Achilles tendon rupture. For this test, the patient is placed in the prone position with both feet extending past the end of the examining table. If squeezing of the calf muscles on the affected side does not result in plantar flexion of the foot, the tendon is ruptured; if this maneuver does result in plantar flexion, the tendon is intact. If the patient does not present until several days after the injury, diagnosis may be more difficult. In such cases, ultrasonography or MRI may be helpful.

Treatment may be nonoperative (i.e., immobilization in plantar flexion) in certain patients, but it is operative in most. Operative treatment consists of surgical repair of the tendon either via full exposure of the tendon or via a minimally invasive approach (e.g., suture anchors); the latter may be preferable for minimizing wound healing problems. After the procedure, the injured area is kept in a soft cast for 6 weeks, during which period the patient is allowed active movement with weight bearing. Surgical treatment substantially reduces the incidence of recurrent ruptures; however, it is also associated with an increased risk of wound healing problems and surgical site infection.594
ANKLE

Fracture and Dislocation

Ankle fractures are usually caused by indirect trauma. They are generally categorized according to the AO-ASIF classification system, which also guides treatment decisions. The factors that determine the type of fracture present include age, bone density, the position of the foot at the time of injury (pronation or supination), and the direction of the forces that acted on the joint to produce the injury (adduction, abduction, exorotation, or axial loading). The history and physical examination reveal pain, swelling, functional impairment, and inability to bear weight. Conventional x-rays usually suffice for diagnosis. A true AP (mortise) view requires 20° of internal rotation for adequate assessment of the joint. If the fracture is particularly complex, CT scanning should be performed to obtain additional information. The two main factors to consider in the management of ankle fractures are the congruency of the ankle joint medially, laterally, and superiorly (i.e., with respect to the tibia, the fibula, and the talus) and the presence of soft tissue injury (because there is little muscle coverage in this area). Even small disturbances of ankle congruity (e.g., widening of the mortise) can lead to overloading of the cartilage and predispose to posttraumatic arthritis.

Type A fractures are transverse lateral malleolar fractures that occur distal to the syndesmosis, at or just below the level of the ankle joint. They may be treated either conservatively in a plaster cast or functionally in a soft cast for 4 to 6 weeks with full weight bearing allowed.

Type B fractures are oblique or spiral fractures of the lateral malleolus that occur at the level of the syndesmosis, with or without a fracture of the medial malleolus. Whereas nondislocated type B fractures may be treated conservatively, all other type B fractures are treated by means of open reduction and internal fixation with a plate or screws, followed by protected weight bearing. The best time for operative treatment is within the 8 hours following admission. After 24 hours, edema increases, and surgery is best postponed until 5 to 7 days later, when the condition of the soft tissue has improved. In the meantime, the fracture or dislocation is reduced, and a splint is applied.

Type C fractures occur above the syndesmosis. Sometimes, a fracture is located near the fibular head proximally. In such cases, the interosseous membrane and the syndesmosis are ruptured between the fibular fracture and the ankle joint (Maisonneuve fracture). This type of injury is easily missed if a careful examination is not performed and the appropriate proximal x-ray obtained. Type C fractures are generally treated surgically with plating or with one or two fibulotibial syndesmotic positioning screws, which allow the syndesmosis to heal with a correct length and position relative to the talus of the fibula.

Malleolar fractures are frequently associated with fractures of the posterior lip of the tibial plafond (trimalleolar fractures). Large fragments (> 20% of articular surface) should be reduced and fixed to prevent posterior diastasis of the talus. Early complications include inadequate reduction and fixation, wound problems, and infection. Long-term results are primarily determined by the presence and extent of cartilage damage and by the congruency of the ankle joint. Approximately 30% of patients experience persistent symptoms around the ankle.4,5,95

Isolated ankle dislocations without fractures are rare; 30% of these injuries are associated with an open wound extending into the joint. A dislocated ankle should immediately be reduced—before x-rays are taken if possible—to minimize further neurovascular compromise. After closed or open reduction, wound care is provided and immobilization instituted.5

Ligamentous Injury

Ankle ligament injuries are among the most common injuries seen in the ED. They often occur during sports activities as a result of inversion during plantar flexion of the ankle. Approximately 85% of ligamentous ankle injuries involve one or another of the three lateral ligaments: the anterior talofibular ligament, the calcaneofibular ligament, and the posterior talofibular ligament. Approximately 65% of ankle sprains resulting from inversion occur in the anterior talofibular ligament alone. Ankle sprains are commonly classified into three grades: grade I is a sprain with stretching of the ligament, grade II is a partial ligament tear, and grade III is a complete tear. This classification does not, however, guide treatment. Diagnosis is based on the history and the physical examination (including the anterior drawer test). X-rays are obtained if a fracture is suspected. The number of unnecessary x-rays can be markedly and safely reduced by applying the so-called Ottawa ankle rule [see Figure 12], which is analogous to the Ottawa knee rule described earlier [see Knee, Ligamentous Injury and Meniscal Tears, above].96

The main treatment options for ankle ligament injuries are immobilization in plaster, functional treatment (early mobilization with the joint in tape or a soft cast), and surgical repair. Current evidence indicates that functional treatment is the recommended strategy for most patients.97,98 Approximately 20% of patients experience varying levels of recurrent or chronic symptoms.

FOOT

The foot is a complex system consisting of numerous bones, ligaments, and tendons. Accordingly, many different types of foot injury are seen. The history plays an important role in identifying the mechanism of injury. Foot injuries do occur as isolated events, but they also frequently occur in conjunction with distant injuries and thus may easily be missed initially in cases of polytrauma.

Physical examination includes assessment of the soft tissues of the foot and ankle, the degree of pain felt on compression, the stability of the injured area, and the neurovascular status of the foot. Conventional x-rays are often supplemented with CT scans; MRI and bone scintigraphy are also sometimes employed, though less frequently.4,5 The pain, swelling, functional impairment, and deformity associated with foot injuries can markedly limit the patient’s mobility. In recent years, it has become clear that function can be improved by restoring the normal anatomy and avoiding prolonged immobilization in plaster.

Talus

The talus plays an important role in the transmission of force to the rest of the foot, with 60% of its surface covered by cartilage. This cartilaginous covering, in combination with a delicate blood supply, makes talus fractures complex injuries. Fractures and dislocations of the talus typically result from high-energy trauma (as in motor vehicle accidents or falls). Most talus fractures are intra-articular; sometimes, the only damage consists of an osteochondral flake (e.g., from an ankle sprain).

Most talus fractures are treated operatively. Ideally, surgical treatment should be carried out as early as possible, especially if the fracture involves the talar neck. Screw fixation may be accomplished either via open reduction or percutaneously (if displacement is minimal). After the operation, active motion is allowed, and weight bearing is started after 8 to 12 weeks. The outcome of treatment is determined primarily by the presence or absence of open wounds, the fracture type, and the status of the remaining
Fractures and ligamentous injuries in these joints are easily missed. The cuneiforms articulate with the metatarsals (Lisfranc's joint) and the calcaneus (Chopart's joint); distally, the cuboid and the metatarsals articulate with the talus (three cuneiform bones: medial, intermediate, and lateral).

Proximally, the navicular and the cuboid articulate with the talus. Both these joints are candidates for arthrodesis of the subtalar joint. However, there is currently a trend toward operative treatment in situations where anatomic reconstruction of the subtalar and calcaneocuboidal joints can be achieved. Smoking, advanced age, diabetes, and noncompliance are relative contraindications to surgical management. A substantial percentage of patients heal with malunion or experience posttraumatic arthritis. These patients are managed with operative treatment in cases where anatomic reconstruction is not possible. The majority of nondislocated fractures, extra-articular fractures, and ligament avulsion fractures of the midfoot can be treated nonoperatively in plaster or with functional therapy and early motion. Dislocated fractures are generally treated operatively with screw or plate fixation unless such treatment is precluded by severe comminution. Fractures in Lisfranc’s joint mainly result from high-energy trauma and are often associated with dislocation of one or more metatarsal bones. Such fractures are treated by means of operative reduction and fixation with Kirschner wires or screws.

**Calcaneus**

The calcaneus is the most frequently fractured bone in the foot. Fractures of the calcaneus are primarily caused by falling or jumping from a height and thus are commonly seen in combination with other injuries (e.g., spine fractures). Examination typically reveals marked swelling of the foot, with or without deformity. Lateral x-rays of the foot show a reduction in Böhler’s angle (the posterior angle formed by the intersection of a line from the posterior to the middle facet with a line from the anterior to the middle facet) from the normal range of 20° to 40°. Conventional x-rays are always supplemented with CT scans to delineate the extent of the fracture.

Most extra-articular and nondislocated intra-articular fractures can be treated conservatively with non-weight-bearing mobilization of the ankle and the foot over a period of 6 to 12 weeks; there is no need for a splint or a cast. Optimal treatment of intra-articular fractures—in particular, the role of surgery—remains subject to debate, however. Depending on the fracture configuration, reduction and internal fixation of the joint surfaces may be accomplished either via an open approach or percutaneously. The same measures recommended as conservative treatment are then carried out as postoperative treatment. Whether this strategy yields better functional results than conservative treatment is not clear. However, there is currently a trend toward operative treatment in situations where anatomic reconstruction of the subtalar and calcaneocuboidal joints can be achieved. Smoking, advanced age, diabetes, and noncompliance are relative contraindications to surgical management. A substantial percentage of patients heal with malunion or experience posttraumatic arthritis. These patients are candidates for arthrodesis of the subtalar joint.

**Midfoot**

The midfoot contains the navicular bone, the cuboid bone, and the three cuneiform bones (medial, intermediate, and lateral). Proximally, the navicular and the cuboid articulate with the talus and the calcaneus (Chopart’s joint); distally, the cuboid and the cuneiforms articulate with the metatarsals (Lisfranc’s joint). Fractures and ligamentous injuries in these joints are easily missed and can lead to prolonged deformity, pain, and functional impairment. Restoration of the anatomy both medially and laterally is important for a good outcome.

The majority of nondislocated fractures, extra-articular fractures, and ligament avulsion fractures of the midfoot can be treated nonoperatively in plaster or with functional therapy and early motion. Dislocated fractures are generally treated operatively with screw or plate fixation unless such treatment is precluded by severe comminution. Fractures in Lisfranc’s joint mainly result from high-energy trauma and are often associated with dislocation of one or more metatarsal bones. Such fractures are treated by means of operative reduction and fixation with Kirschner wires or screws.

**Metatarsals and Toes**

Most metatarsal fractures result from direct trauma (e.g., from a heavy object falling on the foot); however, they can also occur with chronic repetitive loading in the absence of obvious trauma (so-called stress or march fracture).

For the most part, fractures of the second through fourth metatarsals and nondislocated fractures of the first and fifth metatarsals can be treated nonoperatively by using a plaster cast or a heavy supportive shoe for 4 to 6 weeks. With the majority of displaced fractures, closed reduction can be achieved, but maintenance of the reduction requires internal fixation; malunion can disturb ambulation. Many fractures of the lesser metatarsals and subcapital fractures can be treated with percutaneous pinning. Fractures with joint involvement and multiple fragments frequently necessitate treatment with open reduction and plate fixation. Fractures of the base of the fifth metatarsal form a special group. The mechanism of injury is identical to that seen in ankle sprains. These fractures are generally divided into two types: avulsion fractures (involving the insertion of the peroneus brevis tendon) and transverse fractures of the base of the fifth metatarsal (Jones fracture). Both types may be treated nonoperatively if displacement is minimal, but delayed healing is common with Jones fractures. Operative treatment consists of tension-band wiring or screw or plate fixation.

Fractures and dislocations of the toes result from direct trauma. Virtually all toe fractures can be treated conservatively by taping the injured toe to an adjacent, uninjured toe (so-called buddy tape).
rare occasions, reduction and Kirschner wire fixation of a dislocated toe fracture are indicated. Toe dislocations are reduced with traction and are treated in much the same way as toe fractures.5

### Special Considerations

#### GERIATRIC TRAUMA

Musculoskeletal injuries in the elderly are a rapidly growing health problem and cause considerable morbidity and mortality. Advanced age, increased risk of falling, and reduced bone mineral density are the most important risk factors for the occurrence of osteoporotic fractures. Although many standard principles of extremity trauma management apply to the elderly, there are also certain concerns that are specific to this population. Hence, in evaluating an elderly person who has sustained an extremity injury, it is essential to assess the entire patient, not just the affected bone or joint.

One issue is that injured elderly persons often have one or more comorbid conditions, the presence of which increases perioperative risk. Advances in medical and anesthetic techniques have made it safe for many patients to undergo surgical procedures that previously would have been contraindicated; however, the timing of surgery can still pose problems. Ideally, sufficient time should be taken to ensure that patients receive optimal preoperative preparation, but such preparation should be provided with the understanding that delaying surgery unnecessarily will increase mortality. Inadequate nutrition is common in the elderly and should receive appropriate attention. The presence of osteoporosis can be confirmed by measuring bone mineral density (e.g., with dual-energy x-ray absorptiometry). Treatment of osteoporosis consists of a combination of physical exercise, dietary supplementation (with calcium and vitamin D), and administration of bisphosphonates (e.g., alendronate). Elderly patients have special needs with regard to rehabilitation, in that dependence or immobility may necessitate institutional care.105-107

#### REHABILITATION

The care of a patient with musculoskeletal injuries does not stop when the last operation is performed. Adequate rehabilitation is critical for ensuring the best possible functional outcome. Physical therapists, occupational therapists, speech trainers, dietitians, social workers, and psychologists may all play roles in this process. To ensure optimal continuity of treatment from the hospital to the rehabilitation center, rehabilitation experts should be involved early after the admission of a patient who has sustained severe pelvic or extremity trauma.4,5

#### COMPLICATIONS

Systemic complications of pelvic and extremity trauma include FES, ARDS, hemorrhagic complications, crush syndrome, and thromboembolism. Severe local complications include compartment syndrome, acute and chronic infection, infected nonunion, malunion, and posttraumatic reflex sympathetic dystrophy.

### Fat Embolism Syndrome

FES is most commonly associated with fractures of long bones of the lower extremity. The classic clinical triad consists of respiratory distress, cerebral dysfunction, and petechial rash. The pathophysiology is not clear, but there is some evidence to suggest that extravasation of fat particles from long bone fractures may play an important part. Furthermore, early stabilization of long bone fractures has been shown to decrease the incidence of FES. Signs and symptoms of clinical FES usually begin within 24 to 48 hours after trauma. Treatment is primarily prophylactic and supportive, consisting of early fracture fixation, careful volume replacement, analgesia, and respiratory support. The role of corticosteroids in this setting is controversial.4,5,108,109

#### Thromboembolism

Both symptomatic and asymptomatic DVT can pose serious problems in trauma patients. DVT is an important cause of pulmonary embolism (PE) and often results in major morbidity or death. The incidence of DVT ranges from 4% in patients with conservatively treated lower-extremity injuries to between 20% and 35% in patients with pelvic and acetabular injuries and patients with hip fractures. All trauma patients should therefore receive DVT prophylaxis. Once a thromboembolic event has occurred, the patient should be immediately be treated with I.V. anticoagulants according to local protocols. Prevention and treatment of DVT and PE are discussed in greater detail elsewhere [see 6:6 Venous Thromboembolism].4,5,10,110-113

#### Infection

Infections that develop after osteosynthesis are nearly always caused by exogenous bacteria. Contamination may occur in the course of the injury (as with an open fracture), during surgical treatment, or postoperatively (as a result of disturbed wound healing). Most infections manifest themselves within the first 7 days after the operation. Some become apparent only after a longer period has elapsed; these are often preceded by an unnoticed low-grade infection. The infection types most frequently associated with osteosynthesis are implant-related infections (involving colonization of fixation materials), osteomyelitis (a bone infection), and infectious arthritis. Diagnosis is based primarily on clinical signs (e.g., redness, fever, and pain), laboratory studies (e.g., C-reactive protein level and leukocyte count), and bacteriologic tests. In patients with late-developing infections, x-rays, CT, and MRI can provide additional useful information. Treatment consists of surgical debridement, open or closed wound management, and supplemental local or systemic antibiotic coverage. For cases of chronic osteomyelitis, advanced soft-tissue coverage procedures are frequently required. Implant removal is generally unnecessary as long as the implant provides stable fixation.

Gas gangrene is the most serious infection seen in traumatic wounds; Clostridium perfringens is the classic causative pathogen. Other gas-forming organisms common seen include coliforms, anaerobic streptococci, and Bacteroides. Pain is the initial symptom of gas gangrene, followed by edema and exudation of a thin, dark fluid. The wound acquires a bronze discoloration and a musty smell, and crepitations develop in the muscles. Symptoms progress rapidly, and profound shock and MODS usually ensue. The diagnosis is made on clinical grounds, supported by Gram's staining. Successful treatment depends on early diagnosis, radical surgical debridement, fasciectomy, and I.V. antibiotic therapy.4,5,114

#### Delayed Union, Nonunion, and Malunion

At present, there is no consensus among surgeons on how best to assess fracture healing—and, therefore, no consensus on precisely what constitutes delayed union, nonunion, or malunion. In general, delayed union refers to a fracture that heals more slowly than the average. “Average” depends on the fracture’s location and type, but 3 months is a frequently accepted time limit for delayed union. Nonunion refers to a failure of bone healing that results from an arrested growth process; 6 months is the usual time limit. Nonunion has numerous potential causes, but the most important...
factors leading to nonunion are disturbance of the blood supply and insufficient fracture stability. The blood supply is disturbed both by the injury itself and by the surgical procedure performed to treat the injury. Instability results from inadequate fixation technique, a suboptimal implant choice, or implant failure. In some nonunions, a false joint with a fibrocartilaginous cavity lined with synovium is formed (a condition also referred to as pseudarthrosis). Treatment of hypertrophic nonunions focuses primarily on achieving adequate stability, whereas treatment of atrophic nonunions requires not only achieving stability but also reversing the atrophy to the extent possible. The gold standard for treatment of atrophic nonunions is placement of a cancellous autologous bone graft, which has the advantage of being osteogenic, osteoinductive, and osteoconductive. Unfortunately, the morbidity from cancellous bone harvesting can be considerable.

Malunion is a deformity characterized by abnormal length, rotation, or angulation. The degree of malunion that is acceptable with respect to function and cosmesis varies with the age of the patient and the location of the fracture.43

Reflex Sympathetic Dystrophy

Posttraumatic reflex sympathetic dystrophy (also referred to as complex regional pain syndrome) is a poorly understood complication that may develop in any of the extremities after an operation or even minor trauma. It is capable of causing severe disability.5,115,116 Symptoms include unexplained diffuse pain, skin changes, edema, temperature changes, and functional impairment. The optimal treatment regimen has not been established; common therapeutic measures include free radical scavenger treatment (e.g., with systemic acetylcysteine and local dimethyl sulfoxide cream), administration of vitamin C, analgesia, vasodilatation, and careful physical therapy.

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