Critical Orthopedic Skills and Procedures

Stuart E. Boss, MD*, Amit Mehta, MD, Charles Maddow, MD, Samuel D. Luber, MD, MPH

KEYWORDS

- Dislocation  •  Reduction  •  Arthrocentesis  •  Splint  •  Fracture
- Compartment pressure  •  Immobilize

KEY POINTS

- Arthrocentesis is both a diagnostic and therapeutic tool, and knowledge of technique and various approaches will aid the emergency physician in rapidly evaluating a joint effusion.
- Synovial fluid analysis provides important information about the etiology of a monoarticular arthritis, and being able to interpret the analysis to distinguish between inflammatory, noninflammatory, and septic processes is a critical skill.
- Fractures are commonly seen in patients who sustain an acute traumatic injury, and Emergency Department treatment usually consists of fracture reduction, pain control, and immobilization.
- Joint dislocations are extremely painful injuries that require prompt evaluation with a thorough neurovascular examination, and timely reduction not only decreases time to patient comfort but also yields better long-term clinical outcomes.
- Joint dislocations are typically the result of high-energy trauma, and reduction techniques are multiple and varied. One should understand different techniques, yet be cognizant of potential complications, which include neurovascular injury, fracture, and inability to reduce.
- Acute limb compartment syndrome is a limb-threatening entity, and the emergency physician should maintain a high index of suspicion for the development of this condition in any patient with extremity trauma.

ARTHROCENTESIS

Arthrocentesis is the aspiration of synovial fluid from a joint capsule (Figs. 1–4). It is a safe and simple procedure that may be indicated in the presence of a joint effusion for either diagnostic or therapeutic purposes. As a diagnostic procedure, the fluid obtained by arthrocentesis may provide clues as to the specific conditions or injuries...
Fig. 1. Shoulder joint arthrocentesis. A, Lateral approach; B, Anterior approach. The site of needle insertion is represented by an X. (Used with permission from Reichman EF, Simon RR: Emergency Medicine Procedures, McGraw-Hill, 2004, copyright Eric F. Reichman.)

Fig. 2. Posterior approach for shoulder joint arthrocentesis. (Used with permission from Reichman EF, Simon RR: Emergency Medicine Procedures, McGraw-Hill, 2004, copyright Eric F. Reichman.)
leading to a joint effusion. Diagnostic arthrocentesis should be performed when the cause of a joint effusion is not clear based on history and physical examination, and must be performed when the differential diagnosis includes septic arthritis. As a therapeutic procedure, arthrocentesis can provide pain relief and improve acute mobility by decompressing a tense joint effusion. It also provides a means for injecting analgesic and therapeutic drugs into a joint. Injection of local anesthetic solutions can relieve pain, as well as improve the quality and reliability of the physical examination. Because of their anti-inflammatory and analgesic properties, corticosteroid solutions injected into the joint offer more durable comfort and range of motion for patients with chronic or recurrent arthritis (Box 1). In most cases of traumatic arthritis, the patient can easily recall the traumatic event, and the resultant injury is acute and obvious to the examiner. However, in cases where the trauma might be remote or minimal, an arthrocentesis can be used to determine if an effusion is a result of trauma. If the synovial fluid is grossly bloody or contains a large number of red blood cells, this likely represents an intra-articular injury to either the

Fig. 3. Elbow joint arthrocentesis. The site of needle insertion is represented by an X. A, Lateral approach; B, Posterior approach; C, Posterolateral approach. (Used with permission from Reichman EF, Simon RR: Emergency Medicine Procedures, McGraw-Hill, 2004, copyright Eric F. Reichman.)
bone or other structures. In addition, evaluation of the synovial fluid for fat globules can be performed, which if positive confirms the presence of an intra-articular fracture versus a disruption of an intra-articular ligament.  

The therapeutic benefits of arthrocentesis include decreasing pain and increasing joint range of motion by the removal of synovial fluid or blood as well as the injection of therapeutic agents. For patients who have hemophilia and are predisposed to developing acute hemarthroses, an arthrocentesis can be performed to aspirate a significant amount of blood from the joint space, once the appropriate clotting factor is replaced.

**Box 1**

**Indications for arthrocentesis**

- Evaluate monoarticular arthritis
- Evaluate traumatic arthritis
- Identify the cause of an effusion
- Rule out joint infection
- Diagnose inflammatory versus noninflammatory disorders
- Identify intra-articular fracture or disruption of intra-articular structures
- Identify crystal-induced arthritis
- Relieve pain caused by a tense effusion or acute hemarthrosis by aspiration of fluid
- Inject therapeutic agents

*Data from Refs. 3,7,8*
**Contraindications**

Arthrocentesis should not be performed through sites of overlying skin or soft-tissue infection because of the risk of introducing infectious organisms into the joint capsule. In the presence of such infection, an uninvolved entry site should be selected. If all potential entry sites over a patient’s joint are affected, arthrocentesis is generally thought to be contraindicated. Likewise, bacteremia and sepsis are considered relative contraindications out of concern for hematogenous introduction of infectious organisms. However, given the substantial morbidity of septic arthritis, some advise diagnostic arthrocentesis if this condition is suspected.8,9 If performed under such conditions, these investigators suggest that arthrocentesis should be followed by admission for 24 hours of intravenous antibiotic administration.

Although proposed as a relative contraindication to arthrocentesis, few data exist regarding the safety of arthrocentesis in patients receiving anticoagulant therapy.3 One study, involving 32 arthrocentesis procedures, demonstrated that patients with international normalized ratios as high as 4.5 experienced no joint or soft-tissue hemorrhage.10 When performing this procedure on anticoagulated patients, it has been suggested to use a smaller-gauge needle and that special care be taken not to strike articular surfaces when directing the needle (Box 2).1

**Patient Preparation**

The joint should first be examined for any overlying superficial lesions, wounds, or signs of infection such as erythema, warmth, and tenderness, and any such areas should be avoided.

Patient positioning will depend on which joint is to be aspirated. Once the patient is positioned, the necessary bony landmarks should be identified. If a large effusion is present, it may be difficult to palpate and identify these landmarks, in which case it may be useful to compare the patient’s affected joint with their contralateral, “normal” joint. Ultrasound-guided arthrocentesis has been evaluated, with mixed results. Some evidence demonstrates improved success, greater synovial fluid yield, and less procedural pain11; however, other investigators have not found this to be the case.12

Once the proper landmarks are identified, the skin over the entry site should be cleansed thoroughly with either povidone-iodine or a chlorhexidine-based solution.

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**Box 2**

**Equipment for arthrocentesis**

- Sterile gloves
- Sterile drapes
- 10 x 10-cm gauze
- Povidone-iodine solution or chlorhexidine topical solution
- 1% lidocaine solution for local anesthesia
- One 3- to 10-mL syringe for local anesthetic
- One small-bore needle (25- or 27-gauge) to inject local anesthetic
- One 10- to 60-mL syringe to collect aspirated synovial fluid
- One 18- to 22-gauge needle to aspirate synovial fluid
- Specimen tubes for laboratory analysis of synovial fluid
- Culture tubes or media
Next, the joint should be covered with a sterile drape to create a sterile field for the procedure.

Adequate anesthesia may be obtained by injecting lidocaine (with or without epinephrine), first as a superficial wheal at the puncture site, then by infiltrating deeper into the subcutaneous tissues. One should avoid injecting local anesthetic into the joint space at this stage, as doing so may interfere with laboratory analysis of the synovial fluid.

**General Technique**

The needle should be attached to the syringe before penetrating the skin to avoid sudden and painful movements of the needle in the joint cavity. Stretch the skin over the needle insertion site, and insert the needle through the skin and into the joint space. Aspirating with the syringe, the needle should be advanced until synovial fluid is returned. If the articular surface is encountered, an occurrence that generally produces significant pain, the needle should be slightly withdrawn and advanced at a different angle away from the joint surface. Once synovial fluid is encountered, aspiration should continue until no more fluid can be withdrawn. Once the synovial fluid has been collected, the needle should be withdrawn and the puncture site dressed.

**Joint-Specific Techniques**

### Shoulder arthrocentesis

#### Anterior Approach

<table>
<thead>
<tr>
<th>Positioning</th>
<th>The patient may be sitting upright or supine. The arm should be flexed 90° at the elbow, adducted, and internally rotated so that the forearm is resting against the abdomen.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks</td>
<td>Palpate the coracoid process of the scapula below the lateral third of the clavicle. Then palpate the groove between the coracoid process and the humeral head. This landmark will serve as the needle entry site.</td>
</tr>
<tr>
<td>Needle insertion</td>
<td>Insert the needle perpendicular to the skin, into the aforementioned groove. The needle should be aimed directly posterior and should be advanced until a loss of resistance is encountered signaling that the needle is in the joint cavity.</td>
</tr>
<tr>
<td>Comments</td>
<td>In regard of all the approaches for a shoulder arthrocentesis, this is the simplest but most painful. A rare but serious complication is damage to the brachial plexus or axillary vessels with the needle.</td>
</tr>
</tbody>
</table>

#### Posterior Approach

<table>
<thead>
<tr>
<th>Positioning</th>
<th>With the patient sitting upright, place the palm of the hand of the patient’s affected shoulder on the anterior surface of the opposite shoulder, with the arm and forearm held against the chest.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks</td>
<td>Identify the spine of the scapula and follow it laterally to the acromion process. The posterior border of the acromion process will be the landmark for needle insertion.</td>
</tr>
<tr>
<td>Needle insertion</td>
<td>As the clinician, place the nondominant thumb on the posterior border of the acromion process and the nondominant index finger on the coracoid process. Insert the needle 1–2 cm below the thumb, parallel to the floor, and directed to the tip of the index finger. The needle should be aimed approximately 30° medially.</td>
</tr>
</tbody>
</table>

(continued on next page)
### Shoulder arthrocentesis (continued)

<table>
<thead>
<tr>
<th>Comments</th>
<th>With this approach, the needle avoids the tendons of the rotator cuff, the joint capsule is more easily penetrated because it is thinner than compared with the anterior aspect, and there are no neurovascular structures that can be injured.</th>
</tr>
</thead>
</table>

#### Lateral Approach

<table>
<thead>
<tr>
<th>Positioning</th>
<th>The patient should be seated upright with the affected arm hanging by the side.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks</td>
<td>Identify the acromion process of the scapula and locate the groove just inferior to the lateral aspect of the acromion process. This groove lies between the acromion process and the greater tubercle of the humerus.</td>
</tr>
<tr>
<td>Needle insertion</td>
<td>Insert the needle into the midpoint of the groove, directing it medially and slightly posteriorly.</td>
</tr>
<tr>
<td>Comments</td>
<td>The subacromial bursa is just below the deltoid muscle and does not communicate with the shoulder joint. The needle must be inserted at least 2.5–3 cm to ensure insertion into the joint capsule and to avoid aspirating fluid from the subacromial bursa.</td>
</tr>
</tbody>
</table>

### Elbow arthrocentesis

#### Lateral Approach

<table>
<thead>
<tr>
<th>Positioning</th>
<th>Have the patient sit upright with the affected elbow flexed 45° and with the hand pronated; this will widen the joint space and help the clinician avoid any neurovascular structures during the procedure.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks</td>
<td>Identify the depression between the lateral epicondyle of the humerus, the radial head, and the tip of the olecranon process of the ulna. It will be located proximal to the radial head in the area where no bony structures can be palpated. Having the patient flex the elbow 45° and pronate the hand will widen the cavity and should help with identifying the needle insertion site.</td>
</tr>
<tr>
<td>Needle insertion</td>
<td>Insert the needle perpendicular to the skin into the depression.</td>
</tr>
<tr>
<td>Comments</td>
<td>This is the preferred approach because it avoids tendons and neurovascular structures.</td>
</tr>
</tbody>
</table>

#### Posterior Approach

<table>
<thead>
<tr>
<th>Positioning</th>
<th>With the patient seated upright, flex the elbow 90° with the hand supinated.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks</td>
<td>Find the top of the olecranon process and the triceps muscle insertion into the olecranon. The needle will be inserted at the point just proximal to the top of the olecranon and just lateral to the triceps insertion point.</td>
</tr>
<tr>
<td>Needle insertion</td>
<td>Insert the needle perpendicular to the skin and parallel to the radial shaft at the palpated indentation.</td>
</tr>
<tr>
<td>Comments</td>
<td>Because the radial nerve can be damaged, this approach should be used in patients in whom the lateral approach cannot be used.</td>
</tr>
</tbody>
</table>

#### Posterolateral Approach

<table>
<thead>
<tr>
<th>Positioning</th>
<th>With the patient sitting upright, flex the elbow 90° with the hand supinated.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landmarks</td>
<td>Palpate the indentation just lateral to the olecranon process and just distal to the lateral epicondyle.</td>
</tr>
<tr>
<td>Needle insertion</td>
<td>Insert the needle perpendicular to the skin and parallel to the radial shaft at the palpated indentation.</td>
</tr>
<tr>
<td>Comments</td>
<td>Can be used as an alternative approach to the lateral approach.</td>
</tr>
</tbody>
</table>
Complications

Arthrocentesis is a relatively safe procedure. Infection of a sterile joint can occur when the needle used for the procedure pierces through infected skin or subcutaneous tissue. Performing this procedure under rigorous sterile technique can minimize the risk of infection, with the incidence of infection approximately 1 in 10,000 arthrocenteses.7 Significant bleeding with subsequent hemarthrosis is extremely rare, and any external bleeding can usually be controlled with direct pressure over the needle insertion site. In patients with a bleeding diathesis or who are on anticoagulants, arthrocentesis can be safely performed.

Synovial Fluid Analysis

The synovial fluid should be grossly inspected for color, clarity, viscosity, and the presence of blood or inclusions (eg, fat globules) that indicate fracture. Normal synovial fluid is straw colored, clear enough to read newsprint through, and will not clot. The clarity of the synovial fluid roughly predicts the leukocyte count in the specimen, as an elevated synovial fluid leukocyte count results in a more opaque specimen.
Regardless of general appearance, samples of the fluid obtained should always have laboratory analysis of cell count with differential, Gram stain, culture, and crystal analysis to help determine the etiology of the patient’s condition. The total leukocyte count is used to help differentiate between an inflammatory, noninflammatory, or septic process. In general, a leukocyte count greater than 100,000 indicates an infectious process, a leukocyte count between 2000 and 100,000 indicates an inflammatory process, and a leukocyte count less than 2000 is considered within normal limits. However, significant overlap exists within these cutoffs. A moderate white blood cell count does not exclude an infectious process, as lower white blood cell counts may be seen early in the course of an infectious process or in a partially treated septic arthritis, whereas higher counts can be seen in rheumatoid arthritis or crystal-induced arthropathies. As a result, the clinician must not rely solely on the total leukocyte count to establish a diagnosis.

Crystal analysis is best performed using polarized microscopy. Analysis involves microscopic examination of the shape, size, and birefringence of any crystals identified. Monosodium urate crystals are commonly seen in gout and are needle-shaped, 2 to 10 μm in length, and negatively birefringent. Calcium pyrophosphate crystals are seen in pseudogout and appear as rods, rhomboids, plates, or needle-like forms. These crystals are weakly positively birefringent under polarized microscopy.

**FRACTURE MANAGEMENT**

Fractures typically result from acute trauma, although overuse syndromes and underlying pathology may be the cause in certain cases. In most cases, acute pain and deformity prompts the visit to the Emergency Department (ED). Plain radiography is sufficient in the majority of cases, but special imaging techniques such as computed tomography (CT), magnetic resonance imaging (MRI), and radionucleotide bone scanning may be useful in some instances. The keys to management of acute fractures in the ED are pain control, fracture reduction, and immobilization.

Essential components of the musculoskeletal physical examination include a detailed neurovascular examination and inspection of the overlying skin to determine whether the fracture is open or closed. Deformity or bony tenderness suggestive of fracture should prompt plain radiography of the injured area. All radiographic series should include a minimum of 2 views taken at right angles to each other.

Fractures should be reduced and splinted as quickly as possible to minimize pain, blood loss, and injury to surrounding structures. The goal of reduction is to reestablish anatomic alignment, providing the best chance of healing effectively, as the local hematoma creates a medium for eventual callus formation, which then bridges together the two ends of the fractured bone. Every effort should be made to attain this goal, as it helps to limit the downstream complications of delayed union, malunion, and nonunion. It is not always possible to achieve satisfactory alignment via closed reduction in the ED, and some fractures may require operative reduction.

**Indications**

The emergency physician (EP) should be well-versed in splint application techniques and in splint selection for various injuries (Tables 1). All fractured extremities and dislocated joints that have been reduced should be splinted. Other musculoskeletal injuries such as sprains and strains may also benefit from splint immobilization, as may tendon repairs and certain lacerations over or near joints, to prevent wound dehiscence.
Contraindications
There are no absolute contraindications to splint application, and splinting may offer distinct advantages over circumferential casting. Among these is the risk of lower compartment syndrome by splinting, rather than casting of an acute injury. In addition, extremity injuries that require frequent wound care may benefit from standard or modified splinting as a means of stabilization. For example, a splint could be fashioned so that easy removal is possible and/or access to the wound is available through a “window” in the splint.18

Patient Preparation
After the injury is identified a thorough physical examination should be performed, including a meticulous neurovascular assessment and inspection for associated wounds that may require attention or that may complicate the injury. The patient should always be optimally positioned to allow the most efficient and effective application of the splint, as well as to obtain appropriate pain control during the procedure.

General Splinting Techniques
The general components of a properly constructed splint include cotton padding, plaster or fiberglass splinting material, and an elastic bandage to hold the splint in place (Box 3; Figs. 5–9). First, apply the cotton padding. The goal is to provide sufficient protection from the overlying splinting material. The padding may be wrapped in 1 to 2 layers around the affected limb. Use 3 to 4 layers at bony prominences and at the proximal and distal ends of the splint so as to adequately distribute stresses.19 Alternatively, padding may be layered to fit the length of the casting material, to form a “sandwich splint.” Using enough padding is crucial. Pressure sores are a common splint complication and may develop rapidly if the proper amount of padding is not applied underneath the splint. However, too much padding may result in inadequate immobilization. Splinting material should be measured and cut with

Table 1
Common orthopedic injuries and splints

<table>
<thead>
<tr>
<th>Injury</th>
<th>Preferred Splint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal phalanx fracture of the hand</td>
<td>Finger protector splint</td>
</tr>
<tr>
<td>Boxer’s fracture</td>
<td>Ulnar gutter splint</td>
</tr>
<tr>
<td>Metacarpal fracture</td>
<td>Radial or ulnar gutter splint</td>
</tr>
<tr>
<td>Scaphoid fracture</td>
<td>Thumb spica splint</td>
</tr>
<tr>
<td>Carpal fracture</td>
<td>Dorsal splint of the forearm</td>
</tr>
<tr>
<td>Radius and ulna fracture</td>
<td>Sugar-tong splint</td>
</tr>
<tr>
<td>Elbow dislocation</td>
<td>Posterior long arm (elbow) splint</td>
</tr>
<tr>
<td>Supracondylar fracture of the humerus</td>
<td>Posterior long arm (elbow) splint</td>
</tr>
<tr>
<td>Proximal humerus fracture</td>
<td>Coaptation splint, sling, and swathe</td>
</tr>
<tr>
<td>Shoulder dislocation</td>
<td>Shoulder immobilizer or sling and swathe</td>
</tr>
<tr>
<td>Metatarsal fracture</td>
<td>Posterior short leg (posterior ankle) splint</td>
</tr>
<tr>
<td>Ankle sprain</td>
<td>Posterior short leg (posterior ankle) splint</td>
</tr>
<tr>
<td>Ankle dislocation</td>
<td>Trilaminar ankle splint</td>
</tr>
<tr>
<td>Distal tibia/fibula fracture</td>
<td>Trilaminar ankle splint</td>
</tr>
<tr>
<td>Knee dislocation</td>
<td>Knee immobilizer or knee splint</td>
</tr>
<tr>
<td>Patellar dislocation</td>
<td>Knee immobilizer or knee splint</td>
</tr>
</tbody>
</table>
Wetting the material is required before application; this induces an exothermic reaction, forming crystals that cross-link through the gauze matrix, and take form, approximating the mineralized matrix of bone. Excess water should be wrung out before splint application, and the splint applied in the desired position and shape. Exposed fiberglass strands may cause painful abrasions or lacerations once they harden, so care must be taken to ensure that no fiberglass comes into direct contact with the skin. Once the splint is in the desired shape and position, it should be secured in place with an elastic bandage wrapped around the splinted extremity. Each wrap of the elastic bandage should overlap the next layer by 50% until the splint is secured. Some further molding of the splint into the desired form may be necessary. The splint should be smoothed and molded with the palm of the hand rather than the fingers to avoid creating indented areas that could result in pressure against the surface of the limb, which may lead to ulceration. The hardening process should be complete in several minutes, depending on the temperature of the water: because crystal

<table>
<thead>
<tr>
<th>Box 3</th>
<th>Equipment for splinting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water source and sink</td>
<td></td>
</tr>
<tr>
<td>Padding material (cotton roll)</td>
<td></td>
</tr>
<tr>
<td>Splinting material (fiberglass, plaster)</td>
<td></td>
</tr>
<tr>
<td>Elastic bandages</td>
<td></td>
</tr>
<tr>
<td>Adhesive tape</td>
<td></td>
</tr>
<tr>
<td>Metal clips</td>
<td></td>
</tr>
</tbody>
</table>

sufficient length to cross and immobilize the joints proximal and distal to the injury. Wetting the material is required before application; this induces an exothermic reaction, forming crystals that cross-link through the gauze matrix, and take form, approximating the mineralized matrix of bone. Excess water should be wrung out before splint application, and the splint applied in the desired position and shape. Exposed fiberglass strands may cause painful abrasions or lacerations once they harden, so care must be taken to ensure that no fiberglass comes into direct contact with the skin. Once the splint is in the desired shape and position, it should be secured in place with an elastic bandage wrapped around the splinted extremity. Each wrap of the elastic bandage should overlap the next layer by 50% until the splint is secured. Some further molding of the splint into the desired form may be necessary. The splint should be smoothed and molded with the palm of the hand rather than the fingers to avoid creating indented areas that could result in pressure against the surface of the limb, which may lead to ulceration. The hardening process should be complete in several minutes, depending on the temperature of the water: because crystal

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Fig. 5. Ulnar Gutter Splint. (Courtesy of EzySplint, DeFuniak Springs, FL; with permission.)
formation is an exothermic reaction, the warmer the water used to wet the material, the faster it will set (Box 4).

**JOINT DISLOCATIONS**

**Indications**

Dislocated joints should be reduced as rapidly as feasible, not only to relieve pain and anxiety but also because earlier reduction is believed to lead to better long-term outcomes.

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Fig. 6. Thumb Spica Splint. (Courtesy of EzySplint, DeFuniak Springs, FL; with permission.)

Fig. 7. Volar Splint. (Courtesy of EzySplint, DeFuniak Springs, FL; with permission.)
functional outcomes.\cite{20} If vascular or neurologic deficits are present, immediate reduction is indicated so as to limit the time-dependent and potentially devastating consequences of nerve damage and avascular necrosis.\cite{21}

**Contraindications**

There are no absolute contraindications to reducing a dislocated joint, although attention to more critical conditions and resuscitation should always come first. Relative
contraindications are few and include interposition of osteochondral fragments in the joint, or the presence of an open fracture-dislocation with immediate orthopedic surgical intervention available, in which case surgery is the definitive therapy.\textsuperscript{22} Even in such circumstances, however, if neurovascular deficits are present, the EP should nonetheless proceed with reduction without delay.

**Patient Preparation**

After a joint dislocation has been identified, a thorough physical examination of the affected extremity should be performed and the urgency of reduction determined. Next, the clinician should prepare by selecting the particular reduction technique, providing adequate analgesia, determining whether procedural sedation will be required, recruiting appropriate assistants and personnel, and gathering necessary materials, including those for postprocedural immobilization. Preprocedural and/or postprocedural radiography may also be necessary to characterize the injury or confirm success. After the joint has been reduced and appropriately immobilized, a repeat neurovascular examination should be performed.

**SHOULDER DISLOCATION**

The glenohumeral joint is one of the most mobile joints in the human body.\textsuperscript{23} While capable of substantial range of motion and flexibility, the shoulder’s mobility also makes it prone to injury, particularly dislocation. The shoulder is the most commonly dislocated large joint; the annual incidence of shoulder dislocations is 17 per 100,000,\textsuperscript{24} accounting for approximately 50\% of all large joint dislocations.\textsuperscript{25} The shoulder may be dislocated in 3 different directions: anterior, posterior, or inferior; however, in 95\% to 97\% of all shoulder dislocations, anterior dislocation is the most common type.\textsuperscript{24} Most anterior shoulder dislocations are reducible in the ED, but posterior and inferior dislocations can be highly unstable injuries. After ED reduction of these rare kinds of dislocation, urgent orthopedic consultation should be obtained to discuss the possibility of early follow-up versus hospital admission for prompt operative intervention.\textsuperscript{24} In glenohumeral dislocations, the brachial plexus and axillary nerve and artery are at risk for injury. Fortunately, these injuries are rare and patients usually have good functional recovery.\textsuperscript{26} Muscle relaxation is crucial for a successful reduction, as this not only decreases the time requirement for reduction but also minimizes the patient’s pain during the procedure. Relaxation may be achieved with adjunctive sedative medications, with intravenous, intramuscular, and/or intra-articular analgesic agents, as well as by procedural sedation. Intra-articular local anesthetic injection has received recent support,
demonstrating similar procedural success rates and shorter recovery times when compared with procedural sedation with benzodiazepines and narcotics.  

**Common Shoulder Dislocations and Reduction Techniques**

**Anterior dislocation**

**Hennepin technique** Depicted in Figs. 10 and 11, this technique is a popular method of reduction and is accomplished with the patient supine or at a 45° angle on a stretcher. This technique often requires procedural sedation. The provider should gently externally rotate the arm with the elbow flexed at 90° until the arm approaches the coronal plane. If the humeral head has not already been relocated, the arm may then be abducted until reduction of the humeral head occurs. Full abduction, signaled by the ability of the patient’s hand to cross over the head and touch the contralateral ear, may be required for successful reduction. A palpable “clunk” is typically noted as the humeral head relocates.

**Stimson technique (shoulder)** The Stimson technique shares the advantages of requiring neither procedural sedation nor constant vigilance by the EP. With the patient prone on a stretcher and a pillow supporting the affected shoulder, allow the arm to dangle off the side of the stretcher toward the ground. Apply a strap to the distal forearm and attach 10 to 15 lb (4.5–7 kg) of weight to the strap. The constant arm traction tires the spastic shoulder musculature, after which the humeral head will relocate, usually within 20 to 30 minutes. If reduction is not achieved spontaneously after 30 minutes, the provider may grasp the forearm and externally rotate and then internally rotate the arm while gently applying traction to complete the reduction.

**Traction/countertraction technique (shoulder)** This technique generally requires procedural sedation and an assistant. With the patient supine, wrap a sheet around the axilla and torso of the affected extremity. As the assistant holds tightly to the ends of the sheet to provide countertraction, grasp the distal forearm of the patient with both hands and steadily apply traction with the patient’s arm abducted at a 45° angle (Fig. 12). Slight external rotation may be used to promote reduction, and relocation should occur within several minutes.

**Traction with lateral traction technique** More commonly used as an alternative technique in difficult reductions, this technique is slightly different to the traction/
countertraction method. An additional force is used and requires another assistant. When using this technique for shoulder reduction, one should apply traction and direct the first assistant to exert countertraction as previously described. The second assistant should then wrap a sheet around the affected humerus and gradually exert lateral traction in a direction perpendicular to the examiner’s in-line traction until relocation occurs.

Scapular manipulation technique Rather than using humeral head manipulation to effect reduction, this technique uses glenoid fossa repositioning. Like the Stimson technique, this method generally does not require procedural sedation. As with the Stimson technique, the patient is placed prone on a stretcher with a pillow situated under the affected shoulder and the arm hanging over the side. Next, palpate the borders of the scapula and stabilize the superior portion with one hand. The thumb should be positioned along the superolateral aspect of the scapula. With the other hand or thumb, palpate the inferior tip of the scapula and direct pressure medially.

Fig. 11. The Hennepin technique. After external rotation the arm is abducted until the humeral head relocates.

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Fig. 12. Traction/countertraction technique. An assistant exerts countertraction while the provider applies steady traction until reduction occurs. This technique should not be used for shoulder dislocations associated with significant fractures, as it may lead to displacement of fracture fragments.
and superiorly. This maneuver is also very useful as an adjunct to the standard Stimson technique. Reduction should occur within 1 to 3 minutes.\textsuperscript{29}

\textit{Posterior dislocation}

Similar to the traction/countertraction technique described for anterior dislocations, a sheet should be placed around the axilla and torso of the affected arm with the patient in the supine position before reduction. As an assistant provides countertraction by pulling the sheet looped around the patient, grasp the forearm of the affected extremity and apply steady traction in-line with the humerus and simultaneously adduct and internally rotate the arm.\textsuperscript{29} For this difficult reduction a second assistant may be required, who should be instructed to apply posterior pressure on the humeral head in an attempt to slide it over the glenoid rim and reduce the shoulder.

\textit{Inferior dislocation (luxatio erecta)}

With the patient supine, wrap a sheet around the clavicle of the affected extremity with the loose ends directed toward the opposite hip. As an assistant exerts countertraction by pulling on the loose ends of the sheet one must grasp the forearm, apply steady traction in line with the humerus, and slowly adduct the arm until it reaches the patient’s side. A noteworthy barrier to reduction is the classically described “buttonhole” deformity that has been observed in cases of inferior shoulder dislocation. Although not common, buttonholing describes the situation whereby the humeral head protrudes through a defect in the inferior glenohumeral capsule\textsuperscript{32}; this may render the joint locked and irreducible, mandating open reduction in the operating room.

\textbf{ELBOW DISLOCATION}

The elbow is the second most commonly dislocated joint.\textsuperscript{25} The articulations between the humerus, ulna, and radius as well as 4 ligamentous structures (medial collateral ligament, lateral collateral ligament, annular ligament, and the anterior capsule) provide the stability of the elbow joint. In particular, the medial collateral ligament appears to be the foundation of elbow joint stability.\textsuperscript{33} The relationship of these components allow for movements of flexion, extension, pronation, and supination. Five types of elbow dislocation can occur: anterior, posterior, medial, lateral, and divergent. The classification terminology is based on the relationship of the ulna and radius relative to the humerus (ie, in a posterior elbow dislocation the ulna and radius are displaced posteriorly to the distal humerus). Posterior dislocations comprise the great majority of elbow dislocations (>90%) with all other types being uncommon; of importance, 10% to 20% have associated fractures.\textsuperscript{34} The divergent type is extremely rare and is separate from other types of dislocations, as not only are the radiohumeral and ulnohumeral articulations disrupted, but there is dissociation of the proximal radius and ulna via tearing of the annular ligament and interosseous membrane. Several important neurovascular structures course through the elbow region and are at particular risk for injury. These structures include the median, ulnar, and radial nerves, and the brachial artery. Neurovascular deficits are an indication for emergent reduction, but certainly any elbow dislocation should be reduced expeditiously because prolonged dislocation can increase joint effusions and hemarthroses, potentially creating an environment that leads to an inability to reduce. Simple elbow dislocations, which are successfully reduced, have a good prognosis and can be effectively managed with immobilization, orthopedic follow-up, and early range of motion. However, complex dislocations, those dislocations that have an associated fracture, have a poorer prognosis and often require surgical treatment owing to the instability of the joint.\textsuperscript{35}
Common Elbow Dislocations and Reduction Techniques

Posterior dislocation
Stimson technique (elbow) Position the patient prone on the stretcher with the affected extremity hanging off the side. The antecubital fossa of the affected elbow should meet the edge of the stretcher. Place towels or sheets under the shoulder and humerus for padding. Suspend 10 to 15 lb (4.5–7 kg) of weight from the wrist. This weight will provide constant traction on the forearm, and the dislocation should reduce within 20 minutes.

Traction/countertraction technique (elbow) With the patient sitting upright or at a 45° angle and the affected elbow held in slight flexion, the provider should firmly grasp the mid-humerus with the nondominant hand. This action will stabilize the upper arm and provide countertraction. Next, with the dominant hand the provider should firmly grasp the distal forearm and provide steady in-line traction to effect reduction, which is noted by a sudden release in resistance and a palpable clunk (Fig. 13).

Anterior dislocation
With the patient sitting upright or at a 45° angle and the affected elbow held in slight flexion, an assistant should firmly grasp the mid-humerus to provide stabilization and countertraction. Then the provider should grasp the distal forearm with the dominant hand and provide steady in-line traction. Simultaneously the provider should use his or her other hand to apply downward and backward pressure to the proximal forearm until reduction occurs.

Medial and lateral dislocations
Medial and lateral elbow dislocations are extraordinarily uncommon and can usually be reduced using a traction/countertraction technique similar to that used for posterior dislocations. However, it is advised that reduction of these types of dislocations be completed in conjunction with orthopedic consultation, because of the severity of concomitant injuries to the elbow that are likely present.

HIP DISLOCATION
The hip is the major weight-bearing joint of the human body. Because it is a true ball-and-socket joint, and because it is reinforced by strong ligaments, a fibrous ring, and

Fig. 13. Traction/countertraction technique for the elbow.
the tendons of large muscles, it is an incredibly strong and secure joint. Therefore large forces are required to dislocate this joint, and a hip dislocation constitutes a true orthopedic emergency. High-speed motor vehicle crashes and falls are common mechanisms of injury. Dislocations may be posterior, anterior, or central based on the relationship of the femoral head to the acetabulum. Posterior dislocations are the most common type and account for 90% or more of all hip dislocations. Central-type dislocations are rare and occur when the femoral head is dislocated superiorly to the acetabulum, although remaining in the same coronal plane. Because of the large amount of energy required to dislocate a hip, patients frequently have other injuries. Up to 88% of patients with hip dislocations have associated fractures (eg, fractures of the acetabulum and femoral head), and 95% have injuries to other areas of the body. Fracture-dislocations may be highly unstable or irreducible, and may require open reduction in the operating room.

Late complications of hip dislocation include avascular necrosis, arthritis, and sciatic nerve palsy. Avascular necrosis of the femoral head is a particularly devastating complication. The majority of the blood supply to the femoral head is via the lateral ascending cervical arteries, and flow through these vessels may easily be compromised in the event of hip dislocation. Although there is no evidence for a definitive time frame for which reduction should occur to avoid avascular necrosis, it is commonly agreed that a delay of 6 hours may result in this debilitating problem.

**Common Hip Dislocations and Reduction Techniques**

**Posterior dislocation**

Allis maneuver This reduction method is the most commonly used reduction technique. With the patient supine an assistant should stabilize the pelvis by directing force posteriorly to the ipsilateral anterior superior iliac spine. The provider should then flex the affected hip and knee to 90°, grasp the knee with both hands, and apply progressively increasing traction anteriorly to the femur (Fig. 14). Simultaneous gentle lateral to medial rotation of the femur should be used to effect reduction.

Bigelow maneuver With the patient in the supine position, an assistant should apply force posteriorly to the ipsilateral anterior superior iliac spine. With the patient’s affected knee and hip flexed to 90°, the provider should grasp the ankle of the affected

![Fig. 14. Allis maneuver. An assistant stabilizes the pelvis while the physician provides steady anterior traction to the femur.](image-url)
limb with one hand and lever his or her opposite elbow behind the knee. Progressive distal traction should be applied to the femur, then hip extension and external rotation is used to effect reduction (Fig. 15).

**Whistler/Rochester/Tulsa technique** With the advantage being able to perform this reduction technique without the requirement of an assistant, the provider performs this with the patient supine and the unaffected leg flexed to 130° at the knee. The provider places one arm under the knee of the affected leg and then grasps the unaffected knee with the palm. With the other hand the provider grasps the ankle of the affected leg. The affected knee is then elevated by raising the shoulder, using the arm for leverage to apply distal traction to the femur. Lastly, with the hand that is holding the affected ankle, the leg is externally rotated to complete the reduction.

**Anterior dislocation**
Reduction techniques described for posterior dislocations should be attempted. If irreducible, emergent orthopedic consultation is warranted.

**KNEE DISLOCATION**
Dislocations of the knee are rare, and gross deformity of the knee is readily noted. Dislocations are commonly the result of high-energy impacts from auto-pedestrian accidents and motor vehicle crashes, although obese patients may sustain this injury with seemingly minor trauma. The stability of the knee can be attributed to strong support provided by the anterior and posterior cruciate ligaments, medial and lateral collateral ligaments, and the joint capsule. Inevitably, injuries to multiple ligamentous structures accompany a dislocation.

The 5 types of knee dislocations are anterior, posterior, medial, lateral, and rotatory, and are described based on the relationship of the tibia to the femur. Anterior-type dislocations are the most common and result from an acute hyperextension of the knee. Medial, lateral, and rotatory types are uncommonly seen. As a knee dislocation is a true orthopedic emergency, it requires the EP to respond in a timely fashion. Reduction should be performed as quickly as possible. Careful attention must be paid to ensure the vascular integrity of the popliteal artery in the event of dislocation. As the popliteal artery courses posterior to the knee it is anchored to surrounding soft tissue.
tissues both proximally and distally, which make it particularly vulnerable to injury. Approximately 20% of patients with a knee dislocation also have a popliteal artery injury. This rate is even higher, 30 to 40%, in patients with anterior knee dislocations. CT angiography has become a widely used modality for assessment of vascular damage, and has started to supplant traditional angiography as the preferred method. In addition, nerve injury is a familiar complication of knee dislocations. The peroneal nerve is the most frequently injured nerve and is found in 10% to 35% of patients with knee dislocations. The EP should evaluate both its sensory components (sensation to lateral calf, dorsum of foot, and first dorsal web space) and its motor components (ankle eversion, dorsiflexion, and great toe extension) before and after reduction. In most cases, inpatient admission for frequent neurovascular checks and monitoring for delayed hard signs of arterial injury are advised.

**Common Knee Dislocations and Reduction Techniques**

**Anterior dislocation**

One assistant should grasp the tibia distally and apply steady in-line, longitudinal traction. A second assistant should simultaneously grasp the distal femur and provide countertraction. The provider should then grasp the proximal tibia and apply a posteriorly directed force until the knee reduces (Fig. 16). Take caution to avoid hyperextension of the knee. Reduction usually occurs without much difficulty.

**Posterior dislocation**

One assistant should grasp the tibia distally and apply steady in-line, longitudinal traction. A second assistant should simultaneously grasp the distal femur and provide countertraction. The provider should then grasp the proximal tibia and apply an anteriorly directed force until the knee reduces.

**Lateral dislocation**

This reduction technique is similar to that for anterior and posterior knee dislocations. With assistants providing traction and countertraction, the provider exerts a medially directed force to the proximal tibia until it reduces and slides back into normal alignment.

![Fig. 16. Anterior knee dislocation reduction. Depicted here using 2 operators instead of 3, the assistant stabilizes the distal femur while the physician grasps the proximal tibia with both hands and exerts force posteriorly.](image-url)
Medial dislocation
This reduction technique is similar to that for anterior and posterior knee dislocations. With assistants providing traction and countertraction, the physician exerts a laterally directed force to the proximal tibia until it reduces and slides back into normal alignment.

ANKLE DISLOCATION
The ankle comprises the tibia, fibula, and talus. It is a strong modified saddle joint, supported by multiple ligamentous connections between the proximal bones of the foot and malleoli. The strength of this joint is necessary, as it must provide stability while large amounts of forces are translated through it during everyday activities. Walking, running, or jumping may require the ankle to bear more than several times the body’s weight. These great stresses certainly make the ankle more susceptible to injury, as sprains, fractures, and dislocations are common ED injuries. Dislocations occur when the talus is extruded outside of the mortise created by the distal tibia and fibula. Because of the significant force that it takes to dislocate an ankle, the patient will frequently have associated fractures as surrounding ligaments stretch and avulse portions of the malleoli. Ankle dislocations can be posterior, anterior, lateral, or superior, and are described based on the relationship of the talus to the tibia. Lateral dislocations are the most common type and are always associated with a fracture of either the distal fibula or the malleoli. Superior dislocations are rare and are caused by substantial axial loading, which results in diastasis of the tibiofibular joint. As the EP assesses these severe injuries it is of paramount importance to note the neurovascular examination of the distal extremity. Extensive soft-tissue edema can make palpation of the dorsalis pedis and posterior tibial pulses difficult. It is advantageous in these cases to use a Doppler ultrasound to rapidly evaluate vascular integrity. Reduction of an ankle dislocation is an exceedingly painful procedure for the awake patient and almost always necessitates the use of procedural sedation for a satisfactory result.

Common Ankle Dislocations and Reduction Techniques

Posterior dislocation
With the patient supine and the knee flexed, the provider should grasp the hindfoot with one hand and the forefoot with the other hand, then apply steady distal traction and plantarflex the foot while one assistant grasps the calf and provides countertraction. Next, the provider should dorsiflex the foot while maintaining distal traction. Simultaneously a second assistant grasps the distal tibia and exerts force posteriorly until the talus reduces.

Anterior dislocation
With the patient supine and the knee flexed, the provider should grasp the hindfoot with one hand and the forefoot with the other hand, then apply steady distal traction and dorsiflex the foot while one assistant grasps the calf and provides countertraction. A second assistant then grasps the distal tibia and exerts an anteriorly directed force. While maintaining dorsiflexion and distal traction, the provider then simultaneously exerts a posteriorly directed force on the foot until reduction occurs.

Lateral dislocation
With the patient supine and the knee flexed, the provider should grasp the hindfoot with one hand and the forefoot with the other hand, then apply distal traction while an assistant grasps the calf and provides countertraction. Then the provider
simultaneously dorsiflexes and medially rotates the foot while maintaining steady traction to effect reduction (Box 5).

**ACUTE LIMB COMPARTMENT SYNDROME**

Acute limb compartment syndrome (ALCS) is a condition whereby the pressure within 1 or more limb compartments prevents perfusion of the intracompartmental tissues, leading to ischemia and, in a matter of hours, necrosis and permanent damage. Without early diagnosis and treatment, ALCS may result in disabling contractures, lost sensation, amputation, renal failure, or even death.

A limb compartment consists of compressible tissues, bound by an inelastic sheath of fascia and bone. Limb perfusion occurs across the tissue arteriovenous gradient \((P_{\text{arterial}} - P_{\text{venous}})\), where \(P_{\text{arterial}}\) is a function of diastolic blood pressure and \(P_{\text{venous}}\) is a function of intracompartmental pressure (ICP). Perfusion depends on the lower arteriolar, rather than the systemic, arterial pressures. The normal ICP in adults is 0 to 10 mm Hg; in children, it is 13 to 16 mm Hg.

The sine qua non of ALCS is increased ICP, sufficient to decrease limb perfusion to less than the metabolic needs of tissues within a compartment. The numerous causes of ALCS increase ICP by either decreasing the volume of a compartment by compression and/or increasing the contents of a compartment. Constrictive bandages and casts are the most common causes of decreased compartment volume, but other causes include intravenous fluid extravasation, compression by prolonged lying on a limb, extracompartmental hemorrhage or hematoma, prolonged tourniquet time, excessive traction, and burns. Common causes of increased intracompartmental contents include fractures, spontaneous or traumatic muscular hemorrhage or hematoma, excessive exercise, seizures, tetany, and reperfusion. Fractures are by far the most common cause, responsible for 70% of all ALCS cases; isolated soft-tissue injury represents 23%. Tibial fractures are the most common, involved in 40% of ALCS cases, followed by forearm fractures, which cause 18% of adult ALCS cases. In terms of ICP and ALCS, there is no difference between open and closed fractures, and reduced fractures have a higher risk of ALCS than do fractures that have not been reduced.

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**Box 5**

**Complications and pitfalls of joint reductions**

*Inability to reduce.* Although the great majority of patients present to the ED soon after an injury occurs, some patients with joint dislocations may present many hours or even days after the injury. Such may especially be the case in elderly patients who have been unable to call for help because of an incapacitating injury. Such delays in care allow severe muscle spasm and edema to develop, making reduction of the dislocated joint considerably more difficult. If this occurs, open reduction in the operating room may be required. Other special situations that may also lend toward an inability to reduce include injuries associated with significant fractures or extreme ligamentous instability; interposed fracture fragments or soft tissue may also render a joint irreducible.

*Neurovascular injury.* This injury may occur as a result of the injury or as a complication of the reduction. Orthopedic consultation should be sought immediately if this occurs.

*Fractures.* Great forces may be required to reduce a dislocation. Uncommonly a fracture may result. The EP should carefully inspect the postreduction radiographs, not only for successful reduction but also for any fractures that may have resulted as a complication of the procedure or were not detected on the initial radiographs because of the distorted anatomy of the dislocated joint.
In terms of clinical assessment, much emphasis has been given to the “5 Ps” of a compartment syndrome: pain, pallor, paresthesias, pulselessness, and paralysis. Of these, however, only pain, resulting from muscular ischemia, is reliable. The pain is often of a burning character out of expected proportion to the original injury, worsens over time, and is exacerbated by passive stretch of the structures running through the involved compartment. Paresthesias, resulting from nerve ischemia, may only occur if the involved compartment contains a major nerve. In the appropriate clinical circumstances pain, with or without paresthesias, should prompt consideration of ALCS at an early enough stage to prevent significant morbidity.

### Box 6
**Needle-manometer technique**

**Equipment (Fig. 17)**
- Sterile skin preparation (povidone-iodine solution or chlorhexidine)
- Local anesthetic with syringe and small-gauge needle for superficial infiltration
- Two sets of intravenous extension tubing
- One 18-gauge needle
- One 3-way stopcock
- One 10-mL syringe
- One vial of sterile water or saline
- One radial or mercury column manometer from a manual blood pressure cuff

**Procedure**
1. Anesthetize and sterilize puncture site
2. Connect 18-gauge needle to one end of intravenous tubing A and connect 3-way stopcock to the other end
3. Connect syringe to the 3-way stopcock
4. Turn stopcock lever to close the remaining, open stopcock port
5. Pierce vial with needle, and using syringe withdraw fluid until it reaches halfway along tubing A. Note, or mark with a marker, the position of the meniscus in tubing A
6. Turn stopcock lever to close tubing A port
7. Pull back on plunger to fill syringe with air
8. Connect one end of intravenous tubing B to the stopcock’s remaining port, and fit the other to the rubber tubing of the manometer. If using a radial manometer with a connected balloon, turn the dial to close balloon
9. Insert needle at a 90° angle to the compartment and sufficiently deep to enter the selected compartment
10. Turn stopcock lever to bottom so that all ports are open
11. Slowly press the syringe plunger while observing the meniscus in tubing A
12. When the meniscus in tubing A begins to move toward the needle, stop depressing the plunger and turn the stopcock lever to close the tubing B port, which will “lock in” the measurement reading (the value on the manometer is equal to the ICP)
13. Remove needle and dress the puncture site

Fig. 17. Needle insertion sites to measure intracompartmental pressures. A, The leg compartments: anterior (1), lateral (2), superficial posterior (3), and deep posterior (4); B, The forearm compartments: anterior (1), mobile wad (2), and posterior (3).

### Box 7
**Handheld compartment pressure monitor**

**Equipment** *(Fig. 18)*  
- Sterile skin preparation (povidone-iodine solution or chlorhexidine)  
- Local anesthetic with syringe and small-gauge needle for superficial infiltration  
- Stryker handheld ICP monitor  
- One 3-mL syringe  
- Sterile saline  
- One device side-port needle  
- One device diaphragm chamber  

**Procedure**  
1. Anesthetize and sterilize puncture site  
2. Attach needle to end of diaphragm chamber  
3. Draw up 3-mL sterile saline in syringe and connect syringe to diaphragm chamber  
4. Connect syringe to diaphragm chamber  
5. Raise device cover, seat diaphragm chamber into device, and close cover  
6. Aim device at a 45° upward angle and depress syringe plunger to clear air and prime needle with fluid  
7. Turn on device, hold device at 90° to compartment, press button to “ZERO”  
8. When monitor reads “00,” puncture needle into intended compartment; pressure reading will be shown on device  
9. Remove needle and dress puncture site  

Fig. 18. Measuring intracompartmental pressure with the Stryker system. A, The contents of the quick pressure monitor pack are assembled; B, The assembled needle-diaphragm-syringe is placed onto the monitor.

Box 8
Arterial/central venous pressure transducer

*Equipment (Fig. 19)*
- Sterile skin preparation (povidone-iodine solution or chlorhexidine)
- Local anesthetic with syringe and small-gauge needle for superficial infiltration
- One 18-gauge needle
- High-pressure tubing
- Pressure transducer with cable
- Pressure monitor
- Sterile saline
- Transducer stand
- One 3-way stopcock
- One 20-mL syringe

*Procedure*
1. Anesthetize and sterilize puncture site
2. Connect transducer to monitor
3. Assemble system as shown in Fig. 19
4. Fill syringe with 15 mL saline, place one stopcock on syringe. Open stopcocks to allow filling of transducer, high-pressure tubing, and needle. Once filled, close stopcock to high-pressure tubing
5. Open top stopcock to air and place transducer at same level of compartment being measured; calibrate system to "0"
6. Open lower stopcock attached to high-pressure tubing
7. Insert needle into compartment

If clinical signs and symptoms are clearly diagnostic of a compartment syndrome, no further testing is necessary. In less certain cases, direct measurement of compartment pressure is indicated. Stated simply, “if one starts to think about tissue pressure measurements, then one should probably be making them.” There are no absolute contraindications to invasive measurement of compartment pressure.

The specific setup and steps for obtaining compartment pressures depends on the technique and equipment chosen for the procedure. Use of 3 of the most common and simplest methods, the needle manometer, handheld device (in this case the Stryker intracompartmental pressure monitor device), and arterial/central venous transducer, are described here. Each of these techniques (when performed properly) yields sufficiently accurate readings.

For each of these techniques the patient should be supine, with the affected limb position that the level of the heart. The skin at the puncture site should be sterilized, and the puncture site anesthetized with local anesthesia. The patient must also receive adequate analgesia or, if necessary, procedural sedation, to tolerate the procedure (Boxes 6–8).

**Compartment Pressure Interpretation**

Although various values have been proposed, there is no specific ICP that defines ALCS and mandates a fasciotomy, because tissue perfusion depends on the arteriolar...
pressure exceeding the ICP. When ICP equals $P_{\text{arteriolar}}$, tissue perfusion ceases. Although $P_{\text{arteriolar}}$ is lower than systemic circulatory pressures, it is supported by those pressures and thus depends on the body’s hemodynamic state. As a result, a substantially lower ICP may result in ALCS in a hypotensive patient as opposed to a normotensive patient. Therefore, a more physiologic variable is appropriate for the decision to perform fasciotomy. This variable is the $\Delta P$, the difference between diastolic pressure (some use mean arterial pressure) and the ICP.$^{52,53}$ A $\Delta P$ less than 20 mm Hg (or less than 30 mm Hg if based on mean arterial pressure) has been validated as an appropriate value for fasciotomy.

REFERENCES