CHAPTER 41 Upper Extremity Injuries

Injuries to the Clavicle

The clavicle is one of the most frequently broken bones in children.[135,211,279,287] This is not surprising, given that it is the only connection between the arm and trunk and consequently is subjected to all of the forces exerted on the upper limb.[10,13,87,171] Fortunately, nearly all clavicle fractures in children heal uneventfully with minimal or no treatment.*

ANATOMY

The clavicle is the first bone in the body to ossify and has the last physis in the body to close. Initially the clavicle ossifies via intramembranous bone formation. Later, secondary ossification centers develop at both its medial and lateral ends. The medial epiphysis is the last physis in the body to close, often not until the third decade of life.† The abundant and mobile soft tissue overlying the clavicle make open fractures unusual.[11,58,290]

In the horizontal plane the clavicle has a double curve, convex forward in its medial two-thirds and concave forward in its lateral third. Biomechanically, the point of juncture of the two curves is the weakest point. The superior surface of the clavicle is subcutaneous throughout its length. Along its inferior surface, the costoclavicular ligaments insert medially, the coracoclavicular ligaments (the conoid and trapezoid ligaments) insert laterally, and the subclavius muscle arises along the middle two-thirds.[25,92,171] The subclavian vessels and brachial plexus travel beneath the clavicle. In the middle third of the clavicle, the thin subclavius muscle and clavipectoral fascia are the only structures interposed between the clavicle and the medial and lateral cords of the brachial plexus. Fortunately, when fractures of the midportion of the clavicle occur, the brachial plexus and subclavian vessels are protected by the thick periosteum, the clavipectoral fascia, and the subclavius muscle.[114,168,203,289]

The physes present at both the medial and lateral end of the clavicle make true dislocation of the sternoclavicular or acromioclavicular joint a rare occurrence in children. Rather, injuries to either end of the clavicle are usually physeal separations.* The physis at the medial end of the clavicle does not begin to ossify until the 18th year and does not close until between the 22nd and 25th years.† Thus, most injuries to the medial clavicle in children and young adults are physeal separations, with the lateral metaphyseal fragment displaced either anteriorly or posteriorly, leaving the physeal sleeve intact. The strong costoclavicular and sternoclavicular ligaments generally remain in continuity with the periosteal sleeve (Fig. 41–1).[25,38,142,178,180] It is important to remember the vital structures immediately posterior to the sternoclavicular joint. The innominate artery and vein, the internal jugular vein, the phrenic and vagus nerves, the trachea, and the esophagus all lie immediately posterior to the sternoclavicular joint and can be injured with posterior displacement of the clavicle (Fig. 41–1)‡.

Injuries to the lateral clavicle are also more likely to be physeal fractures than true acromioclavicular separations. Laterally, the coracoclavicular ligaments (the conoid and trapezoid ligaments) usually remain in continuity with the periosteal sleeve and the small lateral epiphyseal fragment.§ The medial metaphyseal fragment may be dramatically displaced, resembling a severe acromioclavicular separation (Fig. 41–2). As these fractures heal, the intact periosteal sleeve may form a "new" metaphysis, resulting in a "duplicated" lateral clavicle (Fig. 41–3). Rockwood has modified the adult classification of acromioclavicular joint injuries to reflect the more common physeal fractures that occur in children (Fig. 41–4).[224] Although uncommon, true dislocations of both the sternoclavicular joint and the acromioclavicular joint can and do occur in children.‖

*See references 10, 31, 56, 64, 71, 75, 94, 105, 112, 119, 122, 176, 180, 216, 225, 253, 270, 271.

†See references 13, 77, 191, 194, 204, 260, 276.

*See references 10, 13, 38, 92, 105, 112, 142, 178, 180, 191, 216, 262, 270, 271, 277.

†See references 13, 77, 142, 193, 195, 205, 262, 277.

‡See references 21, 40, 53, 64, 73, 78, 90, 96, 131, 140, 152, 178, 201, 202, 242, 249, 252, 255, 268, 277, 284, 288.

§See references 10, 87, 105, 176, 180, 191, 216, 219.

‖See references 13, 119, 155, 180, 270, 271, 277.

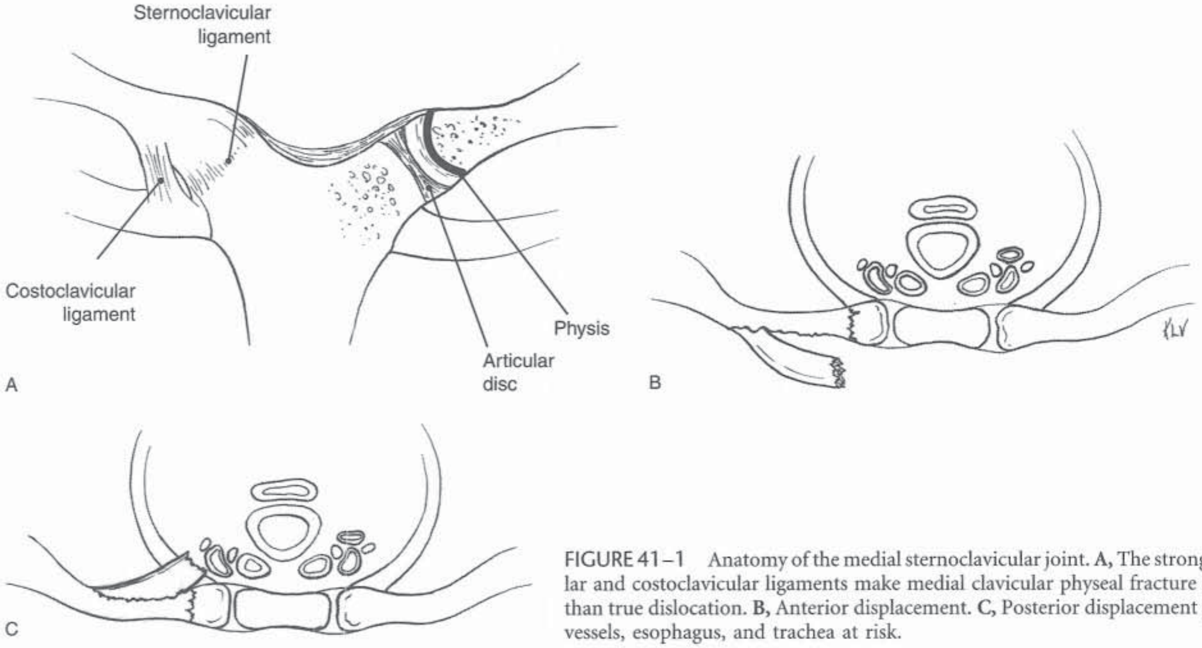


FIGURE 41–1 Anatomy of the medial sternoclavicular joint. **A,** The strong sternoclavicular and costoclavicular ligaments make medial clavicular physeal fracture more common than true dislocation. **B,** Anterior displacement. **C,** Posterior displacement places the great vessels, esophagus, and trachea at risk.

MECHANISM OF INJURY

In the newborn, clavicle fractures generally occur from compression of the shoulders during delivery. In children and adolescents, clavicle fractures are usually the result of a fall onto either the outstretched extremity or the side of the shoulder. Fractures may also result from a direct blow. This mechanism accounts for most of the injuries to the lateral end of the clavicle (Fig. 41–5).

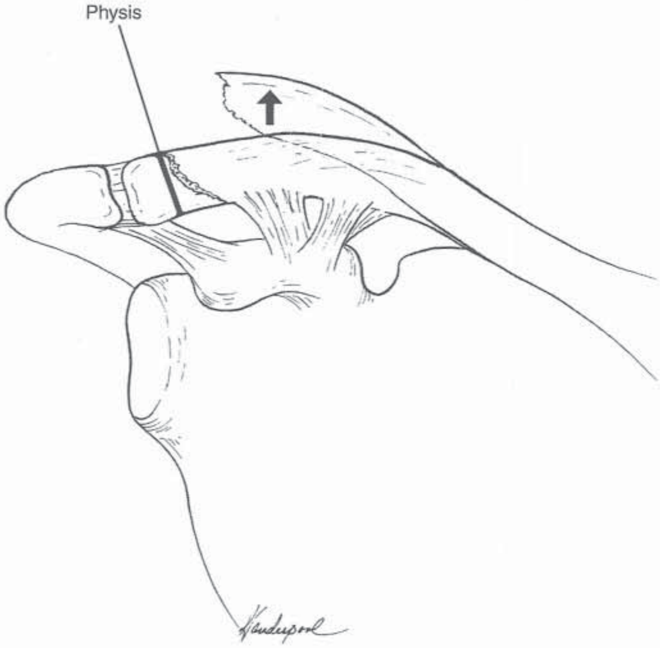


FIGURE 41–2 In a skeletally immature patient, injury around the acromioclavicular joint is more likely to be a physeal fracture than a true separation.

DIAGNOSIS

Birth Fractures. A fractured clavicle in a newborn may be difficult to diagnose, as the infant is often asymptomatic.[50,76,238] In a radiographic survey of 300 newborns, five unsuspected clavicle fractures were discovered.[76] Fractures during delivery usually involve the clavicle, which is most anterior in the birth canal.[50,76] The diagnosis is often made when the child has "pseudoparalysis," or lack of active, spontaneous movement of the limb.

The differential diagnosis includes brachial plexus palsy, congenital pseudarthrosis, and acute osteoarticular infection. It is important to remember that brachial plexus palsy and clavicle fractures may coexist. Although the clinical diagnosis of a fractured clavicle may be straightforward, assessing the status of the brachial plexus is often difficult. Neonatal reflexes such as the Moro and "fencing" reflexes may be helpful in demonstrating active upper extremity muscle function.[238] The diagnosis of osteoarticular infection in the newborn may also be difficult to make. Often there are few systemic signs, and bone scans are notoriously unreliable. Infection should be suspected in "at-risk patients" (i.e., those with indwelling catheters) or in the setting of radiographic lucencies in the metaphysis, diffuse swelling, or increasing pain. Often needle aspiration is required to make the diagnosis.* Occasionally a birth fracture of the clavicle is accompanied by fracture of the upper humeral physis. Often this injury is not appreciated on the initial x-rays; however, on follow-up films, massive subperiosteal new bone formation will be seen and the condition may be mistaken for osteomyelitis. Fracture of the clavicle in the newborn may also be misdiagnosed as congenital muscular torticollis.[126]

Midshaft Clavicle Fractures. In the infant or young child, clavicle fractures are often incomplete or "greenstick" frac-

*See references 70, 80, 120, 194, 204, 283.

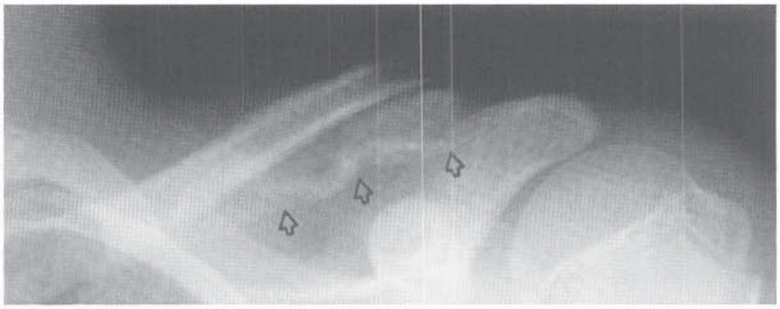


FIGURE 41–3 AP radiograph of the left clavicle following lateral physeal separation. The intact periosteal sleeve has formed a "new" lateral clavicle inferior to the superiorly displaced medial fragment (*arrows*).

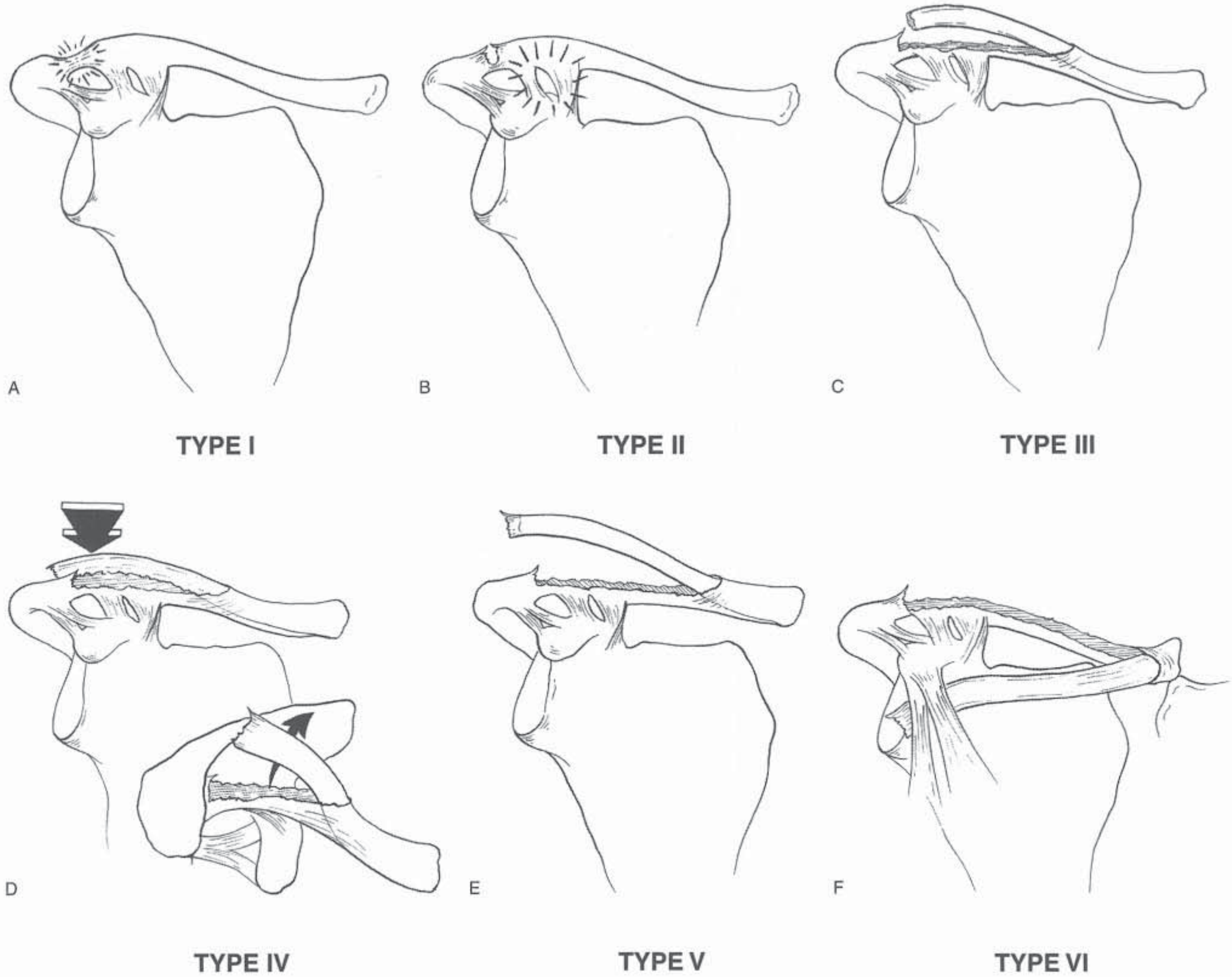


FIGURE 41–4 Rockwood classification of acromioclavicular joint injuries in children. **A,** Type I—sprain of the acromioclavicular ligaments without disruption of the periosteal tube. **B,** Type II—partial disruption of the periosteal tube. This may produce some acromioclavicular instability. **C,** Type III—large split in the periosteal tube, allowing superior displacement of the lateral clavicle. **D,** Type IV—large split in the periosteal tube with posterior displacement of the lateral clavicle through the trapezius muscle. **E,** Type V—complete disruption of the periosteal tube with displacement of the clavicle through the deltoid and trapezius muscles into the subcutaneous tissues. **F,** Type VI—inferior dislocation of the distal clavicle below the coracoid process. (Modified from Sanders JO, Rockwood CA, Curtis RJ: Fractures and dislocations of the humeral shaft and shoulder. In Rockwood CA, Wilkins KE, Beaty JH (eds): Fractures in Children, 3rd ed, vol 3, p 974. Philadelphia, Lippincott-Raven Publishers, 1996.)

FIGURE 41–5 The most common mechanism of injury to the lateral end of the clavicle is a direct blow sustained during a fall onto the shoulder.

tures. These greenstick fractures of the clavicle may escape notice until the appearance of the developing callus. In such instances the fracture should not be mistaken for congenital pseudarthrosis of the clavicle, which is also painless. Radiographically, the distinction between congenital pseudarthrosis and acute fracture is straightforward. In congenital pseudarthrosis, there is a wide zone of radiolucency with smooth margins at the site of the defect and no evidence of callus formation.[108,234,244,274]

Older children and adolescents usually have completely displaced fractures of the clavicle, which have a classic clinical appearance. The affected shoulder is lower than the opposite normal one and droops forward and inward. The child rests the involved arm against the body and supports it at the elbow with the opposite hand. The tension on the sternocleidomastoid muscle tilts the head toward the affected side and rotates the chin toward the opposite side (Fig. 41–6). Any change in position of the upper limb or

FIGURE 41–6 Clinical appearance of a child with a clavicular fracture. The affected shoulder is displaced anteriorly and inferiorly.

the cervical spine is painful. There is local swelling, tenderness, and crepitation over the fracture site.

Medial Physeal Separation (Pseudodislocation of the Sternoclavicular Joint). Medial physeal separation or pseudosubluxation of the sternoclavicular joint may present with either anterior or posterior displacement.

With anterior displacement of the metaphyseal fragment, the sternal end of the clavicle may be sharp and palpable immediately beneath the skin. The clavicular head of the sternocleidomastoid muscle is pulled anteriorly with the bone and is in spasm, causing the patient's head to tilt toward the affected side.*

Posteromedial displacement is accompanied by local swelling, tenderness, and depression of the medial end of the clavicle. Severe posterior displacement can cause compression of the trachea, resulting in dyspnea or hoarseness. Posterior displaced fractures may also compress subclavian vessels or brachial plexus, producing vascular insufficiency with diminution or absence of distal pulses and/or as paresthesias and paresis.†

Lateral Physeal Separation/Acromioclavicular Joint Dislocation. When there is separation of the lateral physis of the clavicle, the clinical findings will depend on the type of injury. Rockwood has classified injuries to the distal clavicle in children based on the direction and degree of displacement (see Fig. 41–4).[216] Type I and type II injuries represent the classic mild acromioclavicular joint sprain. Patients complain of pain on all motions of the shoulder, and point tenderness and swelling are present over the acromioclavicular joint. Patients with type III and V injuries have complete disruption of the acromioclavicular joint. The clinical findings are similar to those in patients with type I and II injuries, but with more obvious deformity over the lateral clavicle. With type V injuries the skin may be "tented." The posterior displacement of type IV injuries may be difficult to appreciate unless the patient is examined from above. Patients who sustain the rare inferiorly displaced type VI injury have a prominent acromion and severe limitation of motion.‡

RADIOGRAPHIC EVALUATION

Fractures of the middle third of the clavicle will be easily identified on routine anteroposterior (AP) x-rays. Injuries to the medial end of the clavicle may be difficult to discern with simple AP radiographs. Rockwood has described the serendipity view to assess the medial end of the clavicle. This view is a 40-degree cephalic tilt with both clavicles projected on a chest x-ray cassette.[215] Computed tomography (CT) can also be helpful in assessing the anatomy of the sternoclavicular region.[65,102,147] Laterally, the anatomy of the acromioclavicular joint is often overpenetrated on a routine AP radiograph. A radiograph obtained using soft tissue technique and centered on the acromioclavicular joint will demonstrate pathology of the lateral clavicle. An AP radiograph obtained with a 20-degree cephalic tilt is also helpful in assessing the lateral clavicle. A "stress view," an AP radio-

*See references 13, 21, 38, 64, 142, 178, 180.

†See references 40, 53, 73, 78, 90, 96, 131, 140, 152, 180, 201, 202, 242, 249, 252, 255, 268, 288.

‡See references 10, 71, 75, 105, 112, 130, 170, 176, 180, 191, 235, 250.

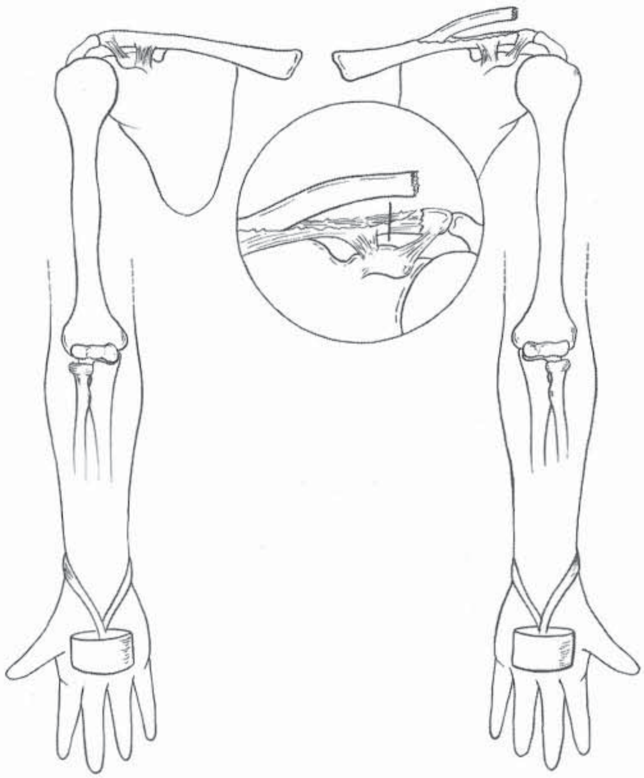


FIGURE 41–7 An AP radiograph of both clavicles taken with the patient holding weights will distinguish a type I acromioclavicular joint injury from a type II or III injury.

graph of both clavicles obtained with the patient holding weights in each hand, can help distinguish between type I and II acromioclavicular joint injuries (Fig. 41–7).[38,105,215] An axillary lateral view may be required to demonstrate a type IV lateral physeal injury.[175,215]

TREATMENT

Birth Fractures. An asymptomatic clavicle fracture in the neonate or young infant may be treated with "benign neglect." It will unite without external immobilization, and any malalignment will gradually correct with growth. The nurses and parents should be instructed to handle the infant gently, avoiding direct pressure over the broken clavicle.[50,76,238]

When the fracture is painful and accompanied by "pseudoparalysis," it may be necessary to splint the arm for 1 or 2 weeks. A soft cotton pad is placed in the axilla, and the upper limb is loosely swathed across the chest with two or three turns of an elastic bandage. The parents are instructed in skin care and bathing. Within 7 to 14 days, the pain will subside, the fracture will be united clinically, and the splint is removed. Parents should be warned about the palpable subcutaneous callus that will develop and later resolve.[50,76,238]

Midshaft Clavicle Fractures. In children and adolescents, displaced fractures of the clavicle rarely if ever require reduction. Malalignment and the "bump" of the callus will remodel and disappear within 6 to 9 months. Treatment consists of keeping the child comfortable with a figure-of-eight bandage or sling.[253] Well padded, premade figure-of-eight clavicular supports are available commercially. The clavicular splints do not immobilize the fracture; their purpose is to provide patient comfort by holding the shoulders back. The fracture sling or harness is worn for 1 to 4 weeks until the pain subsides and the patient can resume normal use of the extremity.

In general, we attempt reduction of a clavicle fracture only when the fragments are displaced so significantly that the integrity of the skin is in jeopardy (Fig. 41–8). The reduction may be done with the patient seated or supine. We prefer the supine position with the patient under conscious sedation. The lower limbs and pelvis are anchored on the table with sheets. A padded sandbag is placed posteriorly between the shoulders, and the affected arm is allowed to hang in extended position at the side of the table. The weight of the arm alone is generally sufficient to reduce the fracture; however, if necessary, the shoulders may be pushed posteriorly to reduce the fracture. In the sitting position, anesthesia is best achieved with a hematoma block. The shoulders are then pulled posteriorly and superiorly with the surgeon's knee placed between the scapulae to serve as a fulcrum (Fig. 41–9). Once reduced, the stability of the fragments is assessed. If stable, the patient may be treated symptomatically with a sling or figure-of-eight harness. If the reduction is unstable, an attempt can be made to immobilize the patient with a figure-of-eight harness or cast. We usually find external immobilization to be of little benefit. However, the combination of a reduction maneuver and external immobilization, albeit imperfect, is often adequate to remove the pressure on the overlying skin. If the fracture remains displaced to the point that the skin remains compromised, open reduction may be indicated.

Open reduction of clavicle fractures in children is rarely if ever indicated.[9,58,181,280,294] Even in adolescents, it is far better to accept angulation and deformity than to attempt open reduction. The operative scar is often more displeasing than the bony prominence of the malunited fracture. Generally, we consider open reduction of clavicle only if there is a neurovascular injury, or an open injury that is unstable following irrigation and debridement. Usually a one-third

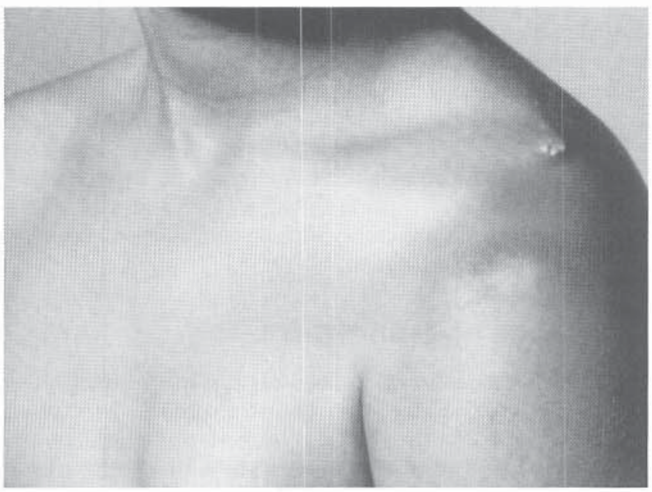


FIGURE 41–8 Clinical photograph of a type V acromioclavicular joint injury that was not reduced. The superiorly displaced fragment eventually eroded through the skin.

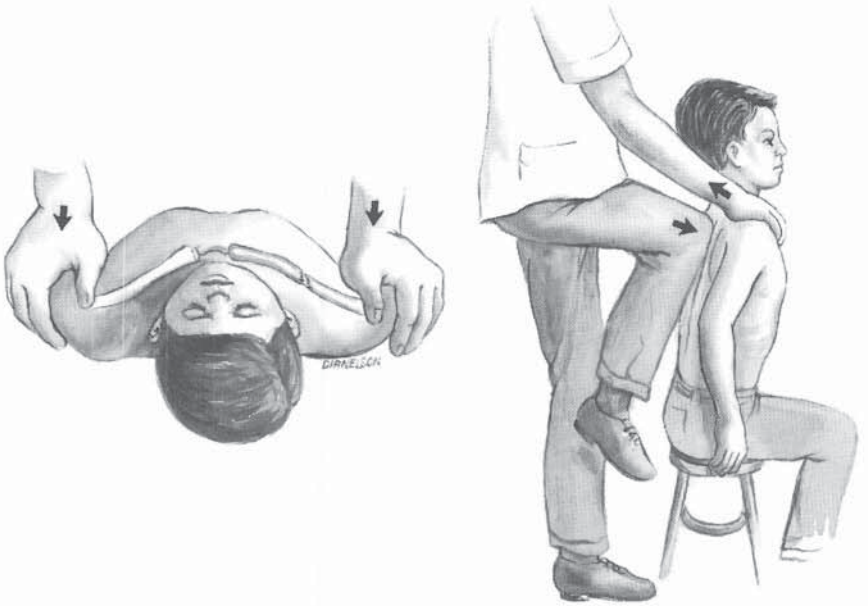


FIGURE 41–9 Technique for closed reduction of displaced clavicle fractures. A fulcrum is placed between the shoulders and a posteriorly directed force is applied to the lateral clavicle.

tubular plate provides adequate fixation. We have also been successful in stabilizing some clavicle fractures with a No. 1 or 2 absorbable polydioxanone suture utilized as a "cerclage wire." This technique has the advantage of avoiding permanent hardware without the disadvantages of pin fixation in the shoulder region. We do not use percutaneous pin fixation about the clavicle because of the visceral problems associated with pin migration.*

Medial Physeal Separation (Pseudodislocation of the Sternoclavicular Joint). Because the physeal sleeve remains intact, a significant amount of remodeling can be expected with medial physeal injuries, and consequently conservative treatment is the rule. Patients with anterior displacement and those with posterior displacement without evidence of visceral injury to the mediastinal structures can be managed symptomatically with a sling or figure-of-eight harness. If there is a significant cosmetic deformity, we may attempt a closed reduction. Often these injuries are quite stable following a closed reduction. However, if the reduction is lost, we will generally accept the deformity and anticipate significant remodeling. If there is posterior displacement with evidence of airway, esophageal, or neurovascular impingement we will attempt a closed reduction emergently in the operating room. If closed reduction fails, we proceed immediately to an open reduction, preferably with the assistance of a general trauma or thoracic surgeon.[21,38,64,142,178]

TECHNIQUE OF REDUCTION

Anterior Displacement. Anesthesia is achieved using conscious sedation techniques or a hematoma block. The patient is placed supine with a bolster between the scapulae. An assistant applies longitudinal traction to both upper extremities, and gentle posterior pressure is applied to the displaced medial metaphyseal fragment to affect a reduction. The displaced medial fragment may be grasped with a towel clip to help facilitate reduction. As previously mentioned, if a reduction is not obtainable, or if the reduction is unstable, we generally accept the deformity, with the knowledge that significant remodeling nearly always occurs.[21,38,64,142,178]

Posterior Displacement. If the metaphyseal fragment is displaced posteriorly with evidence of compression of the mediastinal structures, we first attempt a closed reduction under general anesthesia. The patient is placed supine with a bolster between the shoulder blades. Longitudinal traction is applied to the arm with the shoulder adducted. A posteriorly directed force is applied to the shoulder while the medial end of the clavicle is grasped with a towel clip in an effort to bring the metaphyseal fragment anteriorly. If closed reduction fails, we proceed to an open reduction. This is best accomplished through an incision superior to the clavicle. Patients with minimal posterior displacement can be managed symptomatically with a sling or harness.*

Lateral Physeal Separation/Acromioclavicular Joint Dislocation. Treatment depends upon the degree of injury to the joint. All type I and II injuries, and type III injuries in patients less than 15 or 16 years old, can be managed symptomatically with a sling or harness until the patient can comfortably use the extremity.† Type IV, V, and VI injuries usually require open reduction.[216, 235, 250] Often fixation can be achieved by repairing the periosteal sleeve. Again, we avoid the use of percutaneous pins in the clavicle because of the well-documented problems with migration.‡

*See references 49, 88, 114, 123, 144, 149, 168, 186, 203, 207.

*See references 21, 40, 53, 73, 78, 90, 96, 131, 140, 152, 201, 202, 242, 249, 252, 255, 268, 288.

†See references 10, 13, 31, 71, 75, 82, 105, 112, 119, 122, 127, 130, 138, 170, 176, 191, 208, 216.

‡See references 49, 88, 114, 123, 144, 149, 168, 186, 203.

COMPLICATIONS

Neurovascular complications are extremely rare. They are usually the result of direct force or a comminuted fracture. Laceration of the subclavian artery or vein can occur, although the thick periosteum usually protects the vessels from damage. The presence of a subclavian vessel laceration is suggested by the development of a large, rapidly increasing hematoma. Surgical intervention for repair of the torn vessel should be immediate, as the patient may exsauguinate.[66,114,168,203] Subclavian vein compression following a greenstick fracture of the clavicle with inferior bowing has been reported in a child.[168] Venous congestion and swelling of the involved extremity suggest such a complication.

Nonunion of clavicular fractures is also rare; it is seen most commonly after attempts at open reduction. If nonunion develops, open reduction and internal fixation with iliac crest bone grafting has been shown to yield excellent results.*

The use of pins around the clavicle and shoulder joint should be avoided because of complication of pin migration, often into the vital structures within the mediastinum.[49,88,114,123,144,149,168,186,203]

Failure to recognize acute atlanto-axial rotary displacement has been reported as a complication of clavicular fractures. The diagnosis may be missed if the orthopaedist inappropriately relates the torticollis to a clavicular fracture.[145]

Fractures of the Scapula

The scapula is a thin triangular bone that is attached to the clavicle by the acromioclavicular joint, coracoclavicular ligaments, and multiple muscular attachments. The flexibility of the attachment of the scapula to the torso and the thick muscular envelope on both its anterior and posterior surface make it resistant to fracture. When they occur, scapular injuries are generally the result of high-energy trauma.†

ANATOMY

Scapular fractures may occur in the body, spine, neck, glenoid, acromion, or coracoid (Fig. 41–10). The scapula contains at least eight secondary ossification centers: one at the inferior margin of the body, one along the vertebral border, one at the inferior glenoid, two for the acromion, two for the coracoid process, and a bipolar physis between the coracoid and body.[105,195] As in all physes, the zone of provisional calcification is a "weak link," and avulsion fractures are likely to occur at these growth centers, particularly in adolescents. It is also important to be aware of these ossification centers so that they are not mistaken for injuries.

Fractures of the scapular body are often comminuted, with fracture lines running in multiple directions. The spine of the scapula may also be fractured with the body. (The infraspinous portion is more frequently fractured than the supraspinous portion.) The abundant muscular envelope usually prevents significant displacement of scapular body fractures.‡

*See references 93, 98, 158, 175, 185, 210, 258, 263, 281.

†See references 1, 12, 23, 101, 117, 118, 141, 165, 166, 179, 224, 261, 278.

‡See references 1, 23, 101, 117, 118, 278.

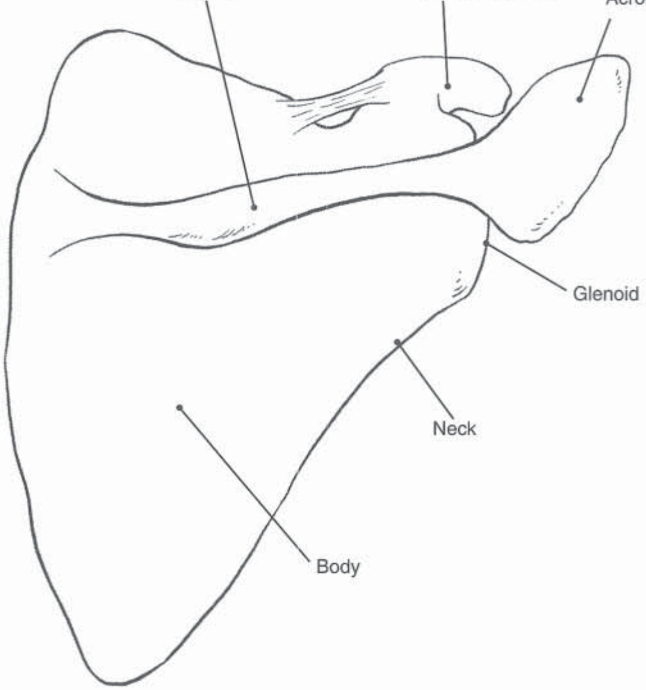


FIGURE 41–10 Scapular anatomy, posterior view.

Fractures of the neck of the scapula usually begin in the suprascapular notch and run inferior laterally to the axillary border of the scapula. The capsular attachments of the glenohumeral joint and the articular surface of the glenoid remain intact. Depending on the force of injury, the fracture may be undisplaced, minimally displaced, markedly displaced, or comminuted. If the coracoclavicular ligaments are intact and the clavicle not fractured, there is little if any displacement of the articular fragment; however, if these ligaments are torn, or if the scapular fracture is lateral to the coracoid process, the articular fragment is displaced downward and inward by the weight of the limb (Fig. 41–11).*

MECHANISM OF INJURY

Scapular fractures are most commonly the result of direct trauma, such as a crush injury in an automobile accident or a fall from a height. Fractures of the glenoid or acromion may result from either direct trauma or forces transmitted through the humeral head. Fractures of the inferior rim of the glenoid may also result from eccentric contraction of the long head of the biceps. Similarly, fractures of the coracoid may result from either direct injury or an eccentric contraction of the short head of the biceps and the coracobrachialis muscles.†

The high energy required to produce scapular injuries may also result in significant injury to adjacent structures. Thus, scapular fractures are often associated with rib or clavicle fractures, pneumothoraces, thoracic vertebral fractures, or fractures involving the humerus.‡

*See references 1, 23, 101, 118, 146, 278.

†See references 1, 23, 91, 101, 106, 114, 117, 118, 121, 179, 191, 278.

‡See references 1, 23, 101, 114, 117, 118, 179, 191, 261, 278.

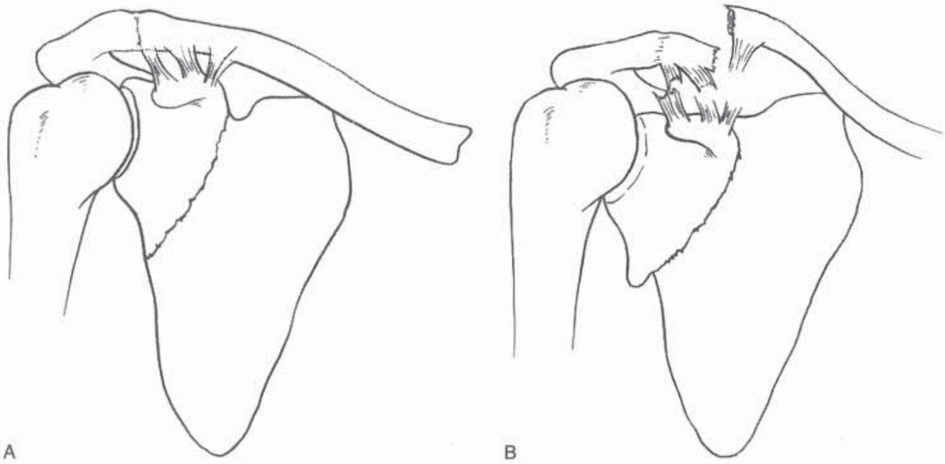


FIGURE 41–11 Fracture of the scapular neck. **A,** If the coracoclavicular ligaments and clavicle are intact, there is little displacement of the glenoid. **B,** Fracture of the scapular neck with disruption of the coracoclavicular ligaments or clavicle fracture creates a "floating shoulder."

DIAGNOSIS

The diagnosis of scapular fractures is often delayed or missed because of the significance of associated injuries. This difficulty is compounded by the fact that the scapula is projected obliquely on an AP chest radiograph, often the only radiograph of the scapula obtained in polytraumatized patients. Thus, in order to make a timely and accurate diagnosis, scapular fractures must be considered in any patient who sustains significant direct trauma to the upper thorax or proximal upper extremity.* In order to see the fracture, it is often necessary to obtain a true AP radiograph of the scapula (Fig. 41–12). CT scans will also clearly demonstrate the injury.[141,176,182,196]

TREATMENT

Fortunately, the vast majority of scapular fractures can be managed conservatively. In general, management is directed toward patient comfort. Most patients do well with minimal immobilization in a sling or sling and swath or "shoulder immobilizer." Gentle range of motion exercises can usually be started in the second week after the patient's injury, with progression to full use of the upper extremity as tolerated.†

Recent reports have attempted to address indications for operative stabilization of scapular fractures. It is important to note that few of these reports deal with injuries in children,‡ and little can be definitively stated regarding operative indications. Nevertheless, we believe that significantly displaced intra-articular fractures as well as glenoid rim fractures associated with subluxation of the humeral head require open reduction and internal fixation.[9,15,23,101,134,141] Additionally, consideration should be given to operative stabilization of unstable fractures through the scapular neck, including ipsilateral fractures of the neck and clavicle, and displaced fractures involving both the scapular spine and neck.[1,101,146,278]

*See references 1, 8, 23, 101, 114, 117, 118, 191, 232, 261, 278.

†See references 1, 8, 106, 114, 117, 118, 191, 278.

‡See references 1, 9, 23, 101, 117, 141, 146.

COMPLICATIONS

Complications from scapular fractures are rare. The most frequent problems encountered with scapular fractures are often related to associated injuries or a delay in diagnosis.* Problems related to malunion or nonunion are quite uncommon.[167,203,292] Untreated fractures of the glenoid can result in glenohumeral instability.[9,15,134] Malunion of acromion fractures can result in symptomatic impingement.[167,278] Coracoid fractures, however, have been reported to do well even if they result in a fibrous nonunion.†

Ada and Miller reported no complications in patients with fractures of the body.[1] However they noted a high incidence of pain, both at rest (50 to 100 percent) and with exertion (20 to 66 percent) and weakness (40 to 66 percent) in patients with displaced fractures of the scapular neck, comminuted fractures of the spine, or intra-articular fractures of the glenoid. They attributed most of these symptoms to rotator cuff impingement and dysfunction and recommended consideration of operative treatment for these fractures.[1]

ASSOCIATED CONDITIONS

Scapulothoracic Dissociation. Scapulothoracic dissociation is a rare injury that is usually the result of a massive traction injury to the upper extremity. It represents a traumatic forequarter amputation and is nearly universally associated with major neurovascular injury. Radiographically, lateral displacement of the scapula is noted on an AP chest radiograph. Patients frequently have other life- or limb-threatening injuries, and recognition of the extent of damage to the upper extremity may be delayed, with devastating consequences.‡ Death has been reported in 10 to 20 percent of patients.[61,68] Patients nearly universally have a poor result, with a functionless extremity.§ Sampson and colleagues have noted that if the extremity is viable, attempts at vascular

*See references 1, 23, 101, 106, 117, 118, 278.

†See references 56, 91, 106, 139, 162, 209, 221, 238, 257, 295, 296.

‡See references 11, 61, 68, 94, 197, 232.

§See references 1, 11, 61, 68, 197, 232, 236.

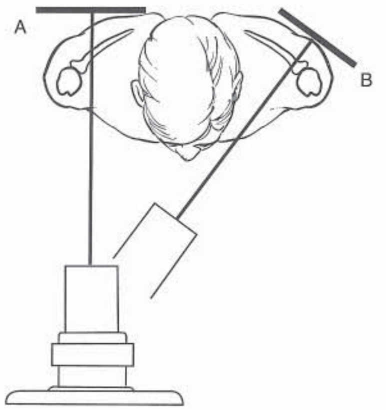
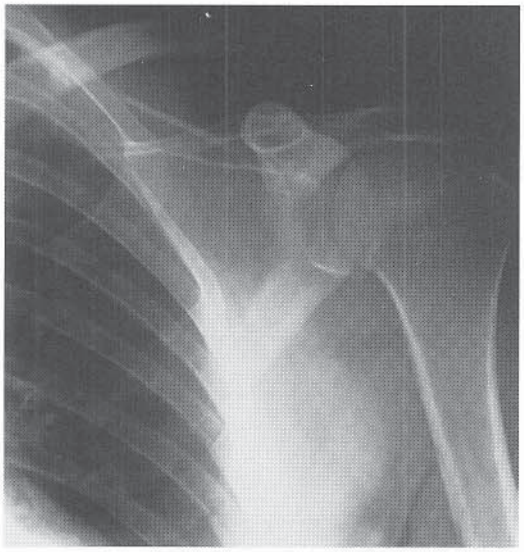


FIGURE 41–12 **A,** The standard chest x-ray technique produces an oblique view of the scapula. **B,** Orientation of beam to obtain a true AP radiograph of the scapula. **C,** Scapula as seen on a chest film. **D,** AP radiograph of the scapula. Compare with oblique view in C. Fractures are more likely to be missed on the oblique projection.



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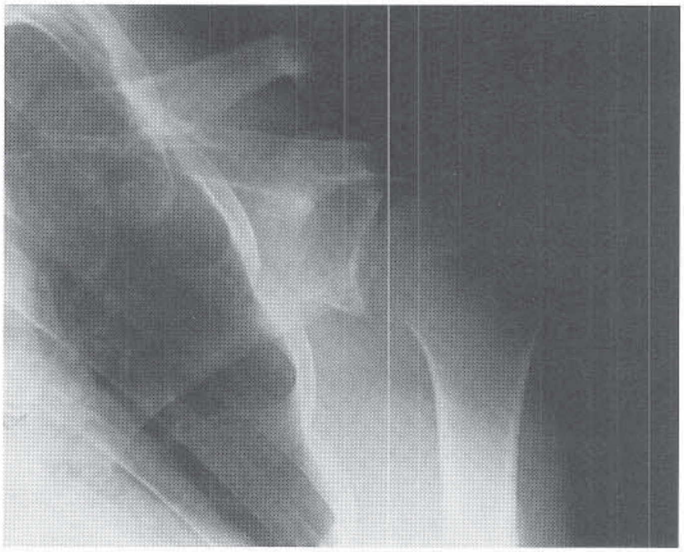


D

repair are not warranted and do not result in a functional extremity.[236]

Os Acromionale. An os acromionale represents failure of the apophysis of the acromion to close. While this is considered a normal variant, present in nearly 10 percent of shoulders,[69] it may occasionally be symptomatic.[69,95,269,276] Os acromionale has been shown to be associated with pathology of the rotator cuff in some instances.[269,276] Warner and colleagues have reported good results in treating symptomatic os acromionale with internal fixation and bone grafting.[276]

Fractures Involving the Proximal Humeral Physis

Fractures of the proximal humeral physis make up about 3 percent of all physeal injuries.[169] They may occur in children of any age but are most common in adolescents. They are almost exclusively Salter-Harris type I or II injuries and are most notable for their tremendous potential to remodel. This remodeling potential is a result of the universal motion of the glenohumeral joint (Wolfe's law) and the fact that approximately 80 percent of the growth of the humerus comes from its proximal physis* (Fig. 41–13). (See Chapter 39, General Principles of Managing Orthopaedic Injuries.)

ANATOMY

The proximal humeral epiphysis develops from three secondary ossification centers: one each for the humeral head, greater tuberosity, and lesser tuberosity. The secondary ossification center for the humeral head usually appears between the ages of 4 and 6 months, although it may be present before birth. The ossification center of the greater tuberosity is usually present by age 3 years. The lesser tuberosity ossification center is visible radiographically by the age of 5. These three ossification centers coalesce into a single large center at around 7 years of age (Fig. 41–14).[2a]

The physis of the proximal humerus is concave inferiorly. Medially, it follows the line of the anatomic neck. Laterally, it extends distal to the inferior border of the greater tuberosity. The timing of closure of the proximal humeral physis is quite variable, occurring as early as 14 years in some girls and as late as 22 years in males.[192]

*See references 6, 7, 24, 27, 36, 41, 44, 45, 55, 60, 109, 133, 137, 164, 177, 184, 247

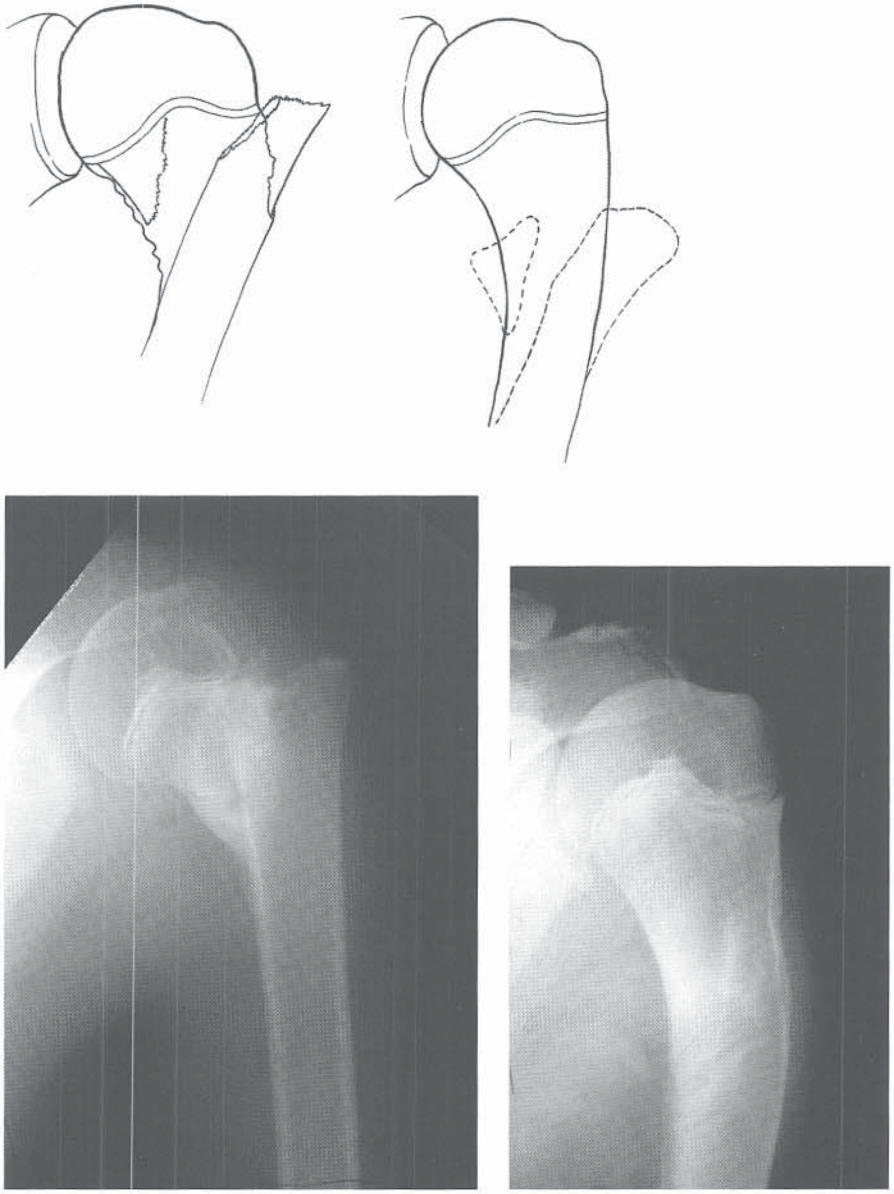


FIGURE 41–13 The remodeling potential of the proximal humerus is great, owing to the amount of growth (80 percent of the entire humerus) coming from the proximal physis, as well as the universal motion of the shoulder joint.

The supraspinatus, infraspinatus, and teres minor muscles insert onto the greater tuberosity, and the subscapularis inserts on the lesser tuberosity. At the metadiaphyseal junction, the pectoralis major tendon inserts onto the crest of the greater tuberosity and the teres major attaches to the inferior crest of the lesser tuberosity. The latissimus dorsi arises from the floor of the intertubercular groove.

Dameron and Reibel performed a cadaveric study of the proximal humeri of 12 stillborn infants, seeking to explain the anatomic basis for the displacement of proximal humeral fractures.[60] They found it was difficult to displace the proximal metaphysis posteriorly, but, with the arm extended and adducted, relatively easy to displace it anteriorly. They noted that the periosteum consistently tore just lateral to the biceps tendon and that the stability of the fracture decreased as the periosteal stripping progressed. They attributed the preference for anterior displacement to the asymmetric dome of the proximal humeral physis, with its apex posteromedial; and to the stronger attachment of the periosteum to the posterior surface of the metaphysis. They noted that all 12 humeri fractured through the physis without an attached fragment of metaphyseal bone.[60]

MECHANISM OF INJURY

Fractures involving the proximal humeral physis can result from an indirect force extended through the humeral shaft, such as a fall on an outstretched hand, or from a direct blow to the lateral aspect of the shoulder. Neer and Horwitz attributed 59 of their 89 fractures of the proximal humerus to a direct force, usually applied to the posterolateral shoulder.[177] Neonates may sustain proximal humeral fractures as

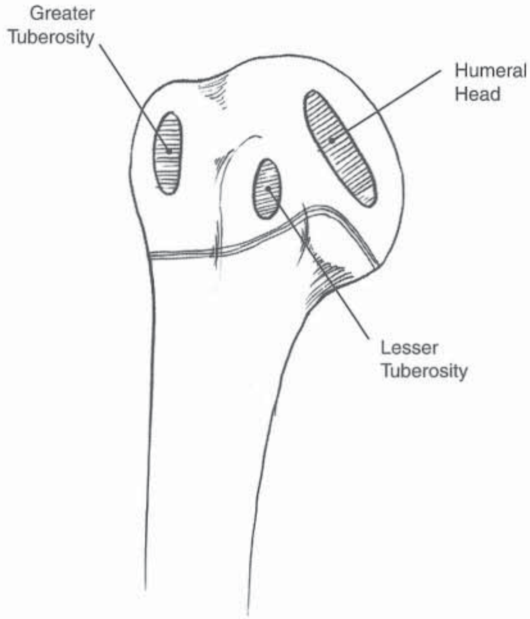


FIGURE 41–14 The three secondary ossification centers of the proximal humerus: the humeral head, greater tuberosity, and lesser tuberosity.

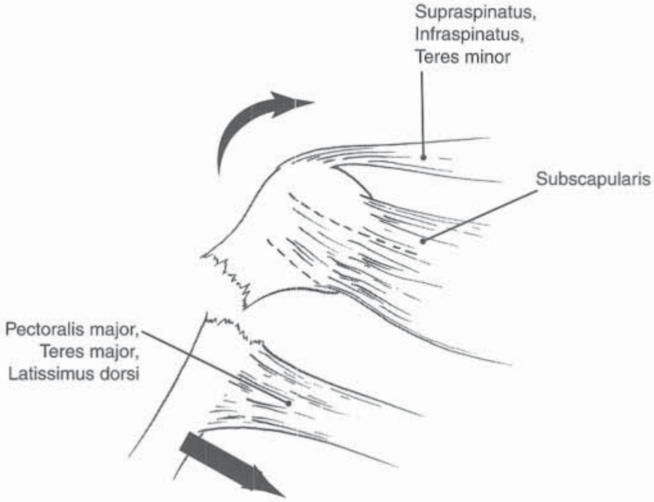


FIGURE 41–15 Displacement of proximal humeral fractures. The muscles of the rotator cuff produce abduction and external rotation of the proximal fragment, while the pectoralis major, teres major, and latissimus dorsi pull the distal fragment medially.

a result of birth trauma. Proximal humeral fractures in infants may be associated with child abuse.[37,81,183]

DIAGNOSIS

Fracture of the proximal humeral physis should be the first diagnosis considered in injuries to the shoulder region in children between ages 9 and 15 years. If the fracture is displaced, the initial findings can be dramatic. The arm is often shortened and held in abduction and extension. The displaced distal fragment causes a prominence in the front of the axilla near the coracoid process. Often, the anterior axillary fold is distorted, with a characteristic puckering of the skin caused by the distal fragment. The humeral head maybe palpable in its normal position. With minimally displaced fractures, the physical findings may be limited to localized swelling and tenderness.[60,133,177]

In displaced fractures the epiphysis usually remains in the glenoid fossa but is abducted and externally rotated by the pull of the attached rotator cuff. The distal fragment is displaced anteromedially by the combined action of the pectoralis major, latissimus dorsi, and teres major muscles (Fig. 41–15). The intact periosteum on the posteromedial aspect of the metaphysis prevents complete displacement and often makes closed reduction difficult. This intact periosteum also serves as a "mold" for the callus and later for the new bone produced by the physis (see Fig. 41–13).[60] Occasionally the fracture is impacted, with the upper end of the metaphysis driven into the epiphysis.

When assessing trauma about the shoulder it is imperative to obtain two orthogonal radiographs in order to adequately assess the glenohumeral joint. Often this is quite difficult, as the limb is painful and there is resistance on the part of both the patient and the radiology technician to move the extremity. It is incumbent on the treating surgeon to educate the radiology technician on the importance of obtaining a true AP view of the glenohumeral joint (rather than the torso; see Fig. 41–12) *and* positioning the arm in limited abduction in order to obtain an axillary lateral view view of the proximal humerus. Alternatively, a "Y-scapular" view can be used to assess the status of the glenohumeral joint, although obtaining and interpreting this radiograph is generally more difficult than obtaining and interpreting an axillary lateral view (Fig. 41–16).

The differential diagnosis of proximal humeral fracture in the neonate or infant includes septic arthritis, osteomyelitis, and brachial plexus palsy. Radiographs of the proximal humerus may be of little help in distinguishing among these entities because much of the anatomy is nonossified cartilage. Ultrasound has proved useful in these instances as it can readily demonstrate proximal humeral fractures and can confirm reduction of the glenohumeral joint and the presence or absence of an intra-articular effusion.[31,81,143,154,241]

CLASSIFICATION

Proximal humeral physeal fractures are most commonly classified according to the type of physeal injury and/or the amount of displacement. Generally, infants and small children with proximal humeral physeal injuries have Salter-Harris type I fractures, while older children and adolescents have Salter-Harris type II injuries. The universal motion of the glenohumeral joint makes the proximal fragment resistant to injury. Thus, fractures extending through the proximal segment (i.e., Salter-Harris type III or IV injuries) or physeal fractures combined with dislocation of the glenohumeral joint are rare. However, these injuries have been described, and it is important to carefully assess adequate radiographs to ensure there are no unusual occult injuries.[183,187,275,286]

Neer and Horwitz classified proximal humeral physeal fractures based on the amount of displacement. In grade I injuries there is less than 5 mm of displacement. Grade II injuries are displaced between 5 mm and one-third the diameter of the humeral shaft. Grade III injuries are displaced between one- and two-thirds the diameter of the

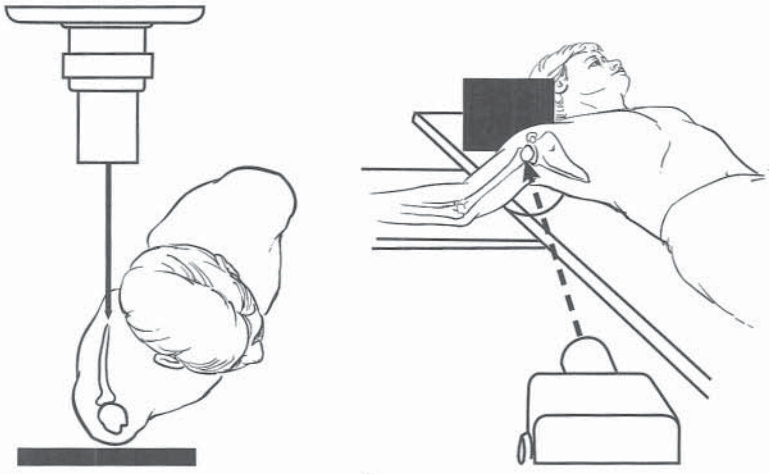


FIGURE 41–16 Sagittal assessment of the glenohumeral joint requires either a Y-scapular (**A**) or an axillary lateral (**B**) view. The Y-scapular view does not require abduction of the arm but is more difficult to obtain and interpret. An axillary lateral view can be obtained with as little as 45 degrees of abduction.

shaft. Grade IV fractures are displaced more than two-thirds the diameter of the humeral shaft. In grades III and IV displacement there is always a varying degree of angulation.[177]

TREATMENT

Nearly all proximal humeral physeal fractures can be treated nonoperatively, regardless of the age of the patient or degree of displacement.* Injuries with grade I and II displacement can be treated symptomatically without an attempt at reduction, regardless of the age of the patient. A simple arm sling or sling and swath or Velcro shoulder immobilizer should be worn until the pain subsides. Gentle pendulum exercises can be instituted in the second week, and most patients will resume some overhead activities within 4 to 6 weeks.

Indications for treatment of more displaced proximal humeral physeal fractures (i.e., grade II and IV injuries) are somewhat controversial. Nearly all authors agree that displaced injuries in younger children (less than 6 years old) can be treated symptomatically.† Controversy exists over the management of displaced fractures in older patients. Some authors have advocated open reduction of severely displaced fractures in older children. These reports have noted that open reduction is justified based on intraoperative findings, which often include infolded periosteum and/or interposed biceps tendon.[41,58,133,151,198] However, in a review of 48 patients with displaced (all grade III and IV) proximal humeral fractures, Beringer and colleagues reported an increased complication rate in patients treated operatively. Three of the nine operative patients developed complications, while none of the 39 patients treated by closed reduction developed a complication. Complications of operative treatment included a fracture through a percutaneous pin site, symptomatic impingement requiring hardware removal, and osteomyelitis requiring four operative debridements. They further explored the functional results by comparing patients who maintained an "acceptable" reduction with those in whom an "acceptable" closed reduction either could not be obtained or could not be maintained. No patient in either group had a functional deficit. To assess the results of closed treatment in patients near skeletal maturity, they examined the results of closed treatment in patients more than 15 years old. Again, they found no functional limitations and no significant differences between patients with an "acceptable" reduction and those with persistent malposition. They did note an increased prevalence of "minor abnormalities" in patients with persistent malposition, although these differences were not functionally or cosmetically significant. They concluded that an attempt at maintaining an anatomic closed reduction was beneficial, particularly in the older adolescent, but that persistent malposition did not warrant an open reduction.[27]

Our treatment approach for displaced proximal humeral physeal fractures parallels the recommendations of Beringer and colleagues. We attempt a closed reduction under conscious sedation in the emergency room in all patients with grade III and IV displacement. We find that once reduced, these fractures are occasionally quite stable (Fig. 41–17).[109] In younger patients, who have tremendous remodeling potential, we believe the benefits of a stable closed reduction, primarily less pain and less immediate cosmetic deformity, must be weighed against the risks of the conscious sedation. The technique of closed reduction usually includes traction, abduction, forward flexion, and external rotation of the arm and forearm. Fluoroscopic guidance can be helpful during reduction, particularly if there is atypical displacement of the fracture. Once a stable reduction has been achieved the extremity is placed in a sling and swath or a shoulder immobilizer that is maintained for 2 to 3 weeks until the fracture fragments are "sticky." At that point the immobilization can be discontinued and range-of-motion exercises instituted.

Occasionally a reduction can be achieved but is lost once traction or abduction is removed. In these instances, and in patients in whom we cannot obtain an adequate closed reduction, the existing deformity is accepted and patients are managed symptomatically. The parents of these patients usually need a fair amount of reassurance

*See references 6, 7, 24, 27, 36, 41, 44, 45, 55, 58, 60, 86, 109, 133, 137, 164, 177, 184, 247, 282.

†See references 6, 7, 24, 27, 36, 41, 44, 45, 55, 60, 86, 109, 133, 137, 164, 177, 184, 247, 282.

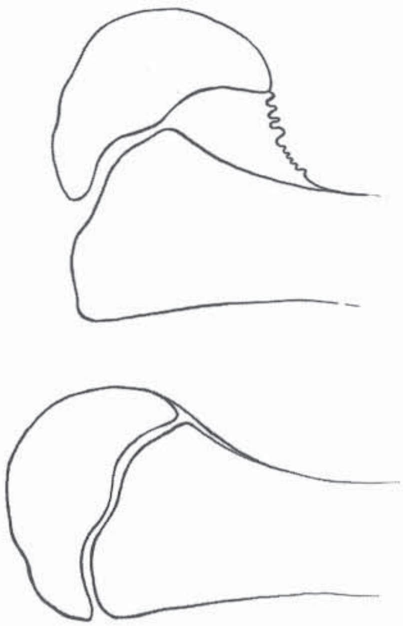


FIGURE 41–17 The intact periosteum on the displaced side of a proximal humerus fracture may enhance the stability of the fracture once the fracture has been reduced.

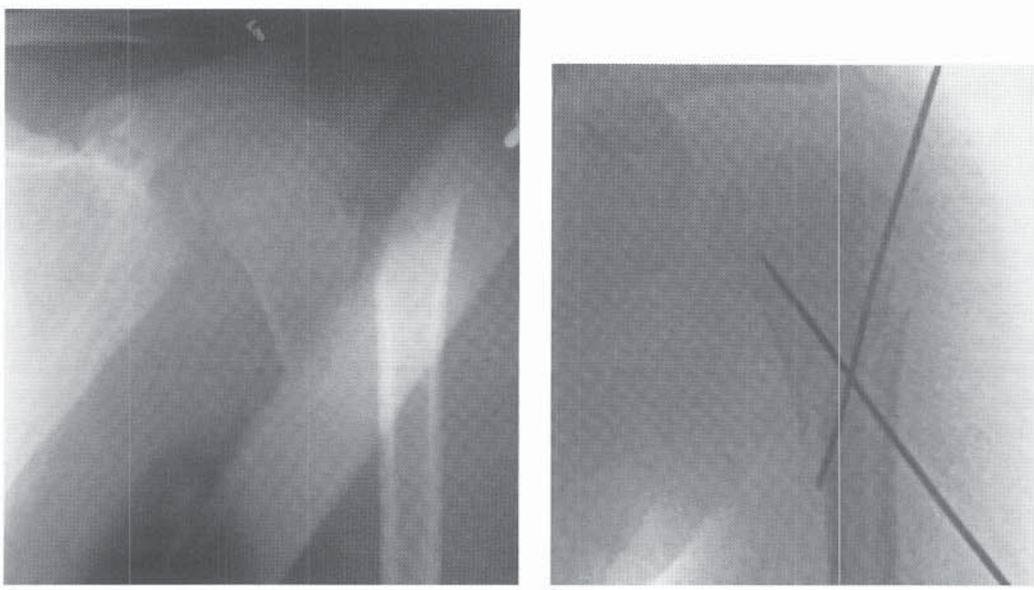
that remodeling will provide an acceptable cosmetic and functional result.

We reserve operative treatment of displaced proximal humeral fractures for patients with intra-articular or open fractures or neurovascular injury. Additionally, we will occasionally percutaneously stabilize a proximal humeral fracture in a polytraumatized patient who is undergoing operative treatment of other injuries because we believe a stabilized extremity is easier to care for in an ICU setting.[183,187,275,286]

Intra-articular fractures require an anatomic reduction, which can usually be performed through an anterior arthrotomy via a standard deltopectoral approach. Fixation can be achieved with a combination of screws and percutaneous pins. Every effort should be made to avoid crossing the physis with threaded fixation devices. Our goal in operative treatment of nonarticular fractures is to stabilize the fracture to allow adequate management of concurrent injuries, whether they are neurovascular, soft tissue, or multiorgan injuries. We do not insist on an anatomic reduction, and we usually stabilize the fracture with two percutaneous 0.062-inch K-wires (Fig. 41–18).[172,177] We remove the K-wires after 2 to 3 weeks and limit the motion of the extremity while they are in place in an attempt to minimize soft tissue complications. As with nonoperative treatment, range-of-motion exercises are begun as soon as all percutaneous pins are removed and the patient is comfortable, usually in 2 to 3 weeks.

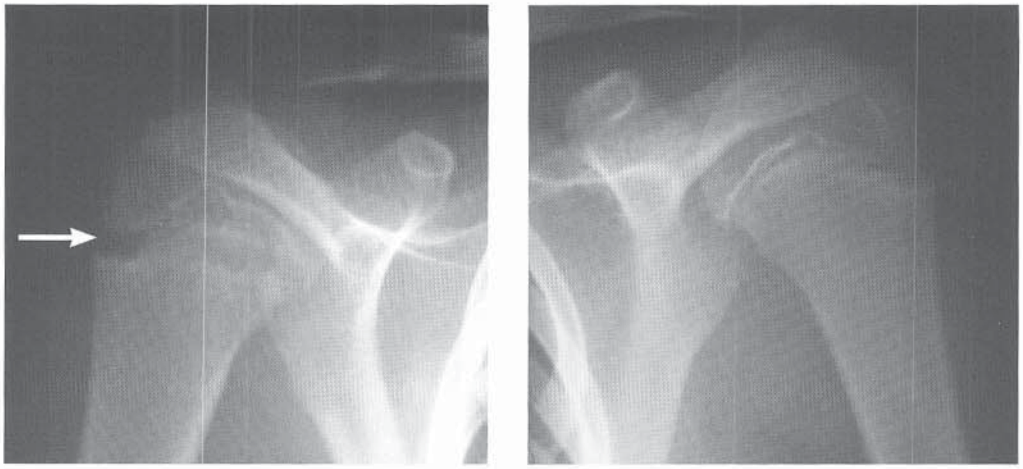
COMPLICATIONS

Complications of proximal humeral physeal fractures are rare. The most commonly reported complication is shortening of the humerus. This complication is rarely a functional or cosmetic concern and is noted more frequently in older patients with more severely displaced fractures.[6,133] Neer and Horwitz noted inequality of humeral length in 11 percent of patients with grade I or II displacement and approximately 33 percent of patients with grade III or IV displacement. No patient had shortening greater than 3 cm, and inequality was seen only in patients older than 11 years at the time of injury.[177] Baxter and Wiley noted shortening greater than 1 cm in nine of 30 patients.[24] No patient had more than 2 cm of shortening, and none of their patients were clinically aware of the inequality. Unlike Neer and Horwitz, they noted shortening in patients less than 11 years



A B

FIGURE 41–18 **A,** AP radiograph of a displaced proximal humeral metaphyseal fracture. **B,** AP radiograph obtained following closed reduction and percutaneous pin fixation. Fracture stabilization eases nursing care in the polytraumatized patient.



A B

FIGURE 41–19 **A** and **B,** AP radiographs of both shoulders in an adolescent baseball player. Note the widened right proximal humeral epiphysis (*arrow* in A).

old.[24] Beringer and colleagues noted shortening greater than 2 cm in five of 18 patients treated conservatively and available for review an average of 4 years after the injury. Again, none of these patients had a functional complaint.[27]

Varus malalignment of the proximal humerus has also been reported as a complication of proximal humeral epiphyseal fractures. Like shortening, this complication is rarely a functional concern and most commonly is noted as an incidental finding at follow-up. There have been cases reported of severe varus combined with shortening that caused significant functional deficits. This complication is quite rare, and probably represents an infantile fracture complicated by a growth arrest.[36,72,133,136,154]

Injuries to the brachial plexus and axillary nerve, as well as brachial artery disruption, valgus malalignment, and osteonecrosis of the humeral head, have been reported as rare or unusual complications of proximal humeral fractures.[24,67,161]

ASSOCIATED CONDITIONS

Little League Shoulder. "Little League" shoulder, also called proximal humeral epiphysiolysis, osteochondrosis of the proximal humerus, or traction apophysitis of the proximal humerus, is an overuse injury seen most commonly in pitchers, but occasionally in other overhead athletes.* This entity usually presents as nonspecific shoulder pain, often at the beginning of the season or after a significant change in training protocol. There may be point tenderness along the proximal humeral physis and painful or limited range of motion. It is believed to be the result of rotary torque generated during the cocking and acceleration phases of throwing or from deceleration distraction forces during follow-through.[3,4,100,150,266] Radiographs may be normal or may show widening of the proximal humeral physis (Fig. 41–19). Occasionally a stress fracture may be present, with metaphyseal lucency and periosteal new bone formation.[265] This condition almost always responds to rest, although displacement through the physis has been reported.*

*See references 3, 4, 20, 42, 59, 100, 150, 265, 266.

Traumatic Dislocation of the Glenohumeral Joint

Traumatic glenohumeral dislocation is an unusual injury in children, occurring most commonly in older adolescents involved in contact sports.† It is important to distinguish traumatic dislocation from atraumatic or voluntary dislocation or subluxation as the treatment of these conditions is vastly different.[227,248]

ANATOMY

The glenohumeral joint is one of the most mobile joints of the musculoskeletal system. While its unique anatomic features give it nearly "universal motion," they do so at the expense of stability. Conceptually, the shoulder is similar to a ball suspended from a plate. Thus, there is little inherent bony stability to the glenohumeral joint. Rather, shoulder stability is provided entirely by the muscles and ligaments that suspend the humerus from the glenoid.[28,30,57,163]

The muscles of the rotator cuff—the supraspinatus, infraspinatus, teres minor, and subscapularis—provide dynamic stability to the shoulder, while the capsule and ligamentous complex provide static support. The shoulder capsule has about twice the surface area of the humeral head. The capsule extends from the glenoid neck and labrum to the anatomic neck of the humerus. Medially, the capsule extends distally past the physis to insert on the proximal humeral metaphysis.[57] The inner surface of the capsule is thickened into the anterior glenohumeral ligaments. The most important of these is the anteroinferior glenohumeral ligament, which is the most common site of pathology in anterior shoulder instability.‡

*See references 3, 4, 20, 42, 59, 150, 265, 266.

†See references 74, 84, 103, 128, 159, 187, 222.

‡See references 29, 79, 188, 189, 223, 229, 251, 254, 260, 267.

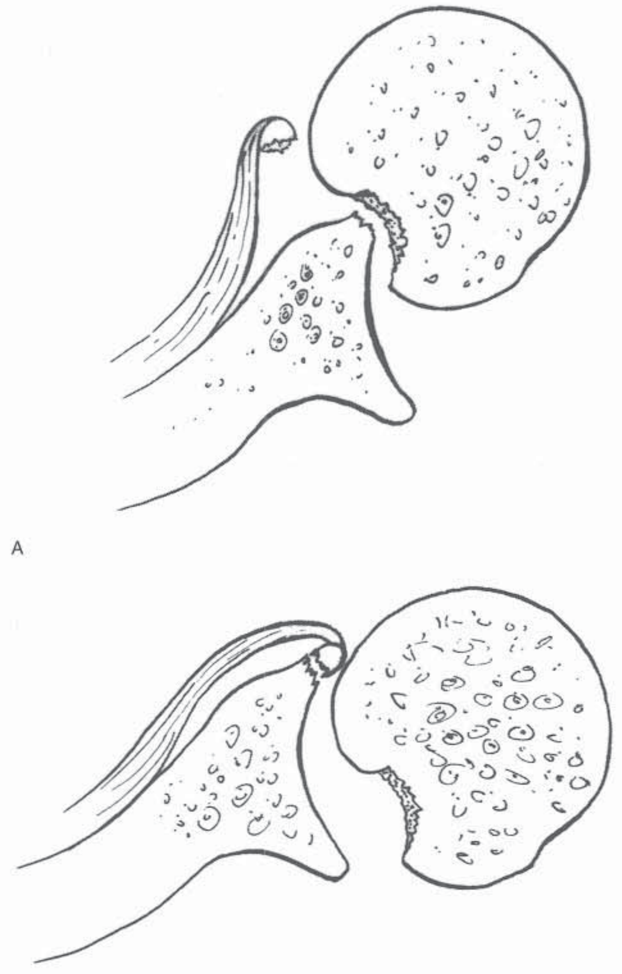


FIGURE 41–20 **A,** Anterior dislocation of the glenohumeral joint produces the characteristic Bankart lesion of the glenoid and a Hill-Sachs lesion of the humeral head. **B,** Anatomy following reduction.

With traumatic anterior dislocation of the humeral head the inferior glenohumeral ligament and anterior labrum are usually traumatically disrupted. Although repair of this "essential lesion" was first described by Broca and Hartman as well as Perthes, it was popularized by Bankart and is commonly referred to as a "Bankart lesion" (or repair).[17–19] When displaced anteriorly, the posterior aspect of the humeral head lies against the anterior glenoid, potentially producing a defect in the humeral head, the so-called Hill-Sachs lesion.[107] With posterior dislocation, defects can be found on the anterior aspect of the humeral head (Fig. 41–20).*

MECHANISM OF INJURY

Traumatic shoulder dislocation most commonly occurs as a result of an indirect force. Anterior dislocations represent over 90 percent of glenohumeral dislocations.[222] Anterior dislocation usually occurs when a force is applied to the arm in an abducted, extended, and externally rotated position.

*See references 16, 32, 43, 163, 213, 259, 272.

Traumatic shoulder dislocations may also occur posteriorly or inferiorly. Posterior dislocations may be the result of a direct blow to the anterior aspect of the shoulder, an indirect force with the arm in flexion, adduction, and internal rotation, or a massive muscle contraction, as occurs with an electrical shock or seizure.* Inferior glenohumeral dislocation is also known as *luxatio erecta.* When seen in children or adolescents, luxatio erecta is almost always the result of a high-energy hyperabduction force.[62,63,85,153,157]

DIAGNOSIS

Traumatic dislocation of the glenohumeral joint generally results in a fixed dislocation that is usually acutely painful. With anterior dislocation the arm is usually held in slight abduction and external rotation. Attempts to move the arm are often extremely painful, owing to the muscle spasm that occurs in an attempt to stabilize the joint. The humeral head is palpable anteriorly and there is a "defect" inferior to the acromion. Occasionally, patients with recurrent anterior dislocations may spontaneously reduce the dislocation, although care must be taken to distinguish these patients from those who "voluntarily" dislocate their shoulders, as the latter have a high incidence of psychological problems.[228,248] A careful history will help to distinguish the "psychological voluntary dislocator" from the patient who can voluntarily demonstrate the instability but whose primary problem is painful involuntary dislocation.

Historically, posterior dislocation of the glenohumeral joint has been a frequently missed diagnosis. Rowe and Zarins reported that 11 of 14 posterior shoulder dislocations were not recognized by the initial treating physician.[230] However, careful physical examination of a patient with a posterior dislocation will reveal several characteristic findings. The arm is usually held in adduction and internal rotation and has limited and painful external rotation and abduction. Additionally, the shoulder will be flattened anteriorly and have a prominent coracoid process and posterior appearance.† Patients with luxatio erecta present with the arm maximally abducted adjacent to the head. The force of the injury may drive the humeral head through the soft tissues of the axilla, producing an open injury.[62,63,85,153,157,239]

The diagnosis of glenohumeral dislocation is often obvious on the basis of the physical examination alone and is simply confirmed radiographically. The high rate of missed diagnosis of posterior dislocations may be due to the near-normal appearance of a posterior dislocation of the shoulder on an AP radiograph of the torso. This emphasizes the importance of high-quality orthogonal radiographs, as discussed early for fractures of the proximal humeral physis (see Figs. 41–12 and 41–16).

Every patient with a traumatic glenohumeral dislocation should have a complete neurovascular examination, including assessment of the radial, median, ulnar, musculoskeletal, and axillary nerves. The axillary nerve is the most commonly injured nerve with anterior dislocation. Often the pain associated with an acute shoulder dislocation will make assessment of deltoid muscle function difficult. Thus, it is impor-

*See references 28, 48, 84, 129, 173, 174, 190, 230.

†See references 28, 48, 84, 129, 173, 174, 190, 230.

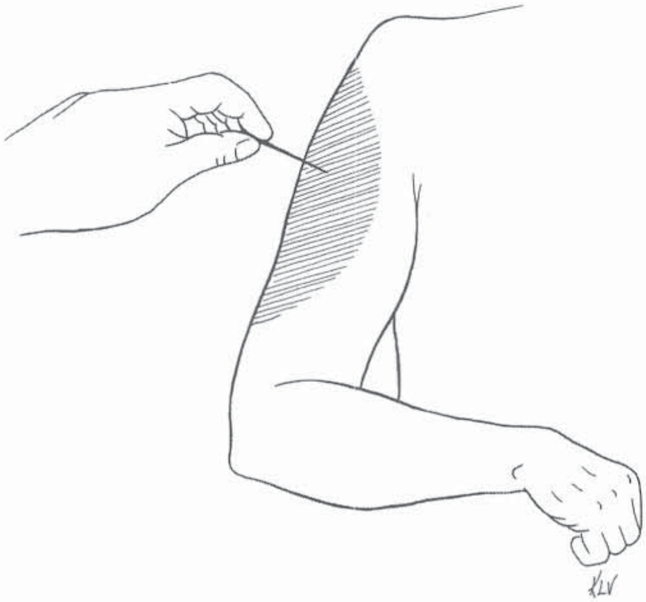


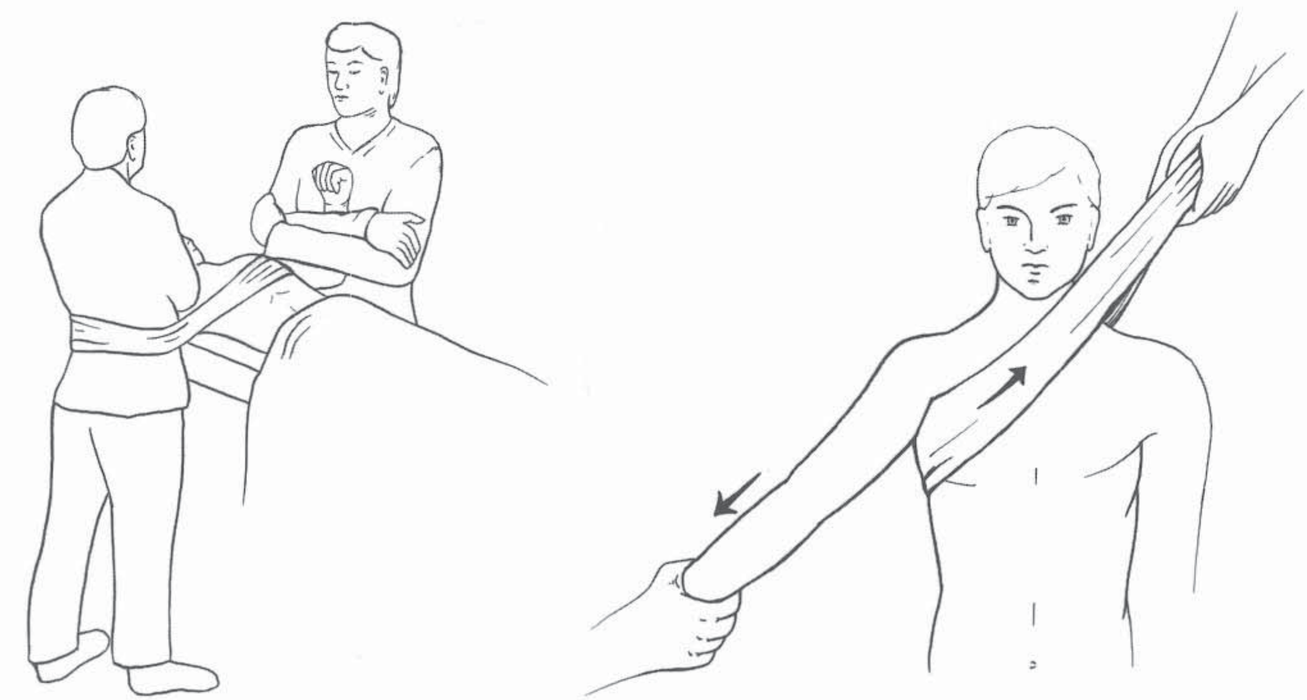
FIGURE 41–21 Sensory distribution of the axillary nerve.

tant to assess the sensory distribution of the axillary nerve in all patients with anterior shoulder dislocations (Fig. 41–21).

TREATMENT

Acute traumatic dislocation of the glenohumeral joint should be reduced as quickly and atraumatically as possible. There are numerous techniques for reduction, with descriptions dating to ancient times.[2,256,291] We prefer closed reduction under conscious sedation using the traction/countertraction technique. A sheet is placed around the affected axilla to allow an assistant to apply countertraction. Once adequate sedation has been achieved, longitudinal traction is applied through the arm and forearm with the arm abducted and the elbow flexed. Gentle internal and external rotation will help to disengage the humeral head. Eventually the spastic muscles will be fatigued and reduction can be achieved. This technique is effective for both anterior and posterior dislocations (Fig. 41–22). If an assistant is not available, countertraction can be achieved by the surgeon's placing his or her foot across the anterior and posterior axillary folds and against the chest wall (Fig. 41–23) (This is the technique described by Hippocrates.[2]) Another useful technique that requires no assistant is a modification of the technique described by Stimson. The patient is placed prone with the affected extremity dangling over the edge of the table. With adequate sedation and time, the shoulder will reduce. Reduction can be facilitated by adding weights to the wrist. The amount of weight depends on the size of the patient. We generally start with approximately 5 pounds in an athletic adolescent (Fig. 41–24).[256]

Postreduction management consists of a careful repeat neurovascular examination, orthogonal radiographs, and sling immobilization. We generally manage patients symptomatically following reduction, utilizing a sling for immobilization until upper extremity function can resume, usually in 2 to 3 weeks. Although children and adolescents with traumatic dislocations of the glenohumeral joint are at high risk for recurrence, there is little evidence that prolonged postreduction immobilization alters the natural history of



A B

FIGURE 41–22 **A** and **B,** Traction/countertraction technique for reduction of glenohumeral dislocation. Longitudinal traction is applied through the arm and forearm with the arm abducted and the elbow flexed. Gentle internal and external rotation will help reduce the humeral head.

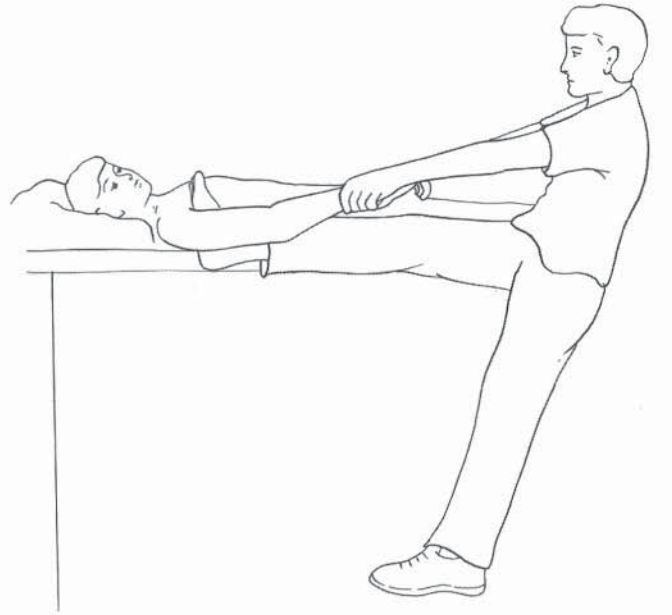


FIGURE 41–23 Hippocrates' technique for reducing a glenohumeral dislocation. This technique is useful when no assistant is available. The surgeon's foot should be placed against the chest wall, not in the axilla.

posttraumatic instability.[74,103,128,159] Operative treatment is reserved for patients with open dislocations, "unreducible" dislocations and intra-articular fractures.

COMPLICATIONS

The most common complication of traumatic dislocation of the shoulder is recurrent shoulder instability. Other rare

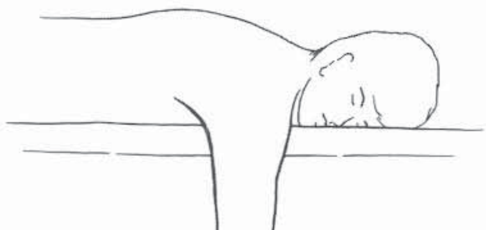


FIGURE 41–24 Modified Stimson technique for reducing a glenohumeral dislocation. The patient is placed prone with the shoulder over the edge of a table and weights suspended from the wrist.

but reported complications include fractures, neurovascular injuries, and, rarely, osteonecrosis of the humeral head.* Fractures of the glenoid or humeral head were discussed earlier. In general, intra-articular fractures require open reduction and internal fixation.† This is usually best performed through an anterior deltopectoral approach. Efforts should be made to avoid threaded fixation across the physis and percutaneous pins around the shoulder because of the potentially devastating complication of pin migration.[88,123] Open injuries and neurovascular injuries are extremely rare and should be managed individually, with care to adhere to the general principles discussed in Chapter 39, General Principles of Managing Orthopaedic Injuries.[63,153]

Recurrent instability can manifest as either repetitive episodes of fixed dislocation or symptomatic instability presenting as a vague sense of shoulder dysfunction or pain.‡ Although the diagnosis of recurrent fixed dislocation is relatively straightforward, the diagnosis of symptomatic recurrent instability is often difficult to make. Patients suspected of having symptomatic anterior instability should be assessed for evidence of generalized ligamentous laxity. The contralateral shoulder should be carefully examined for comparison and the involved shoulder should be examined for evidence of anterior, posterior, and inferior instability. Examination should include the apprehension test, the "load-shift" or "drawer" test, the "sulcus" test, the "jerk" test, and the "push-pull" test. As previously mentioned, it is extremely important to identify patients who voluntarily dislocate their shoulders, as no amount of surgery or rehabilitation can change the desire to dislocate the shoulder. These patients frequently have significant psychological problems.[228,248]

Rockwood and colleagues have described the acronyms TUBS and AMBRI to discuss symptomatic shoulder instability. TUBS describes **T**raumatic shoulder instability, which is usually **U**nilateral. There is usually a **B**ankart lesion present, and most patients will require **S**urgical stabilization. The acronym AMBRI represents **A**traumatic shoulder instability which is usually **M**ultidirectional and **B**ilateral and is usually successfully treated with a **R**ehabilitation program. If surgery is required, an **I**nferior capsule shift is usually indicated.[52,217]

The incidence of recurrent dislocation in children and adolescents who sustain a traumatic glenohumeral dislocation has been reported to be as high as 70 to 100 percent.§ Although most patients who develop symptomatic posttraumatic recurrent instability, whether recurrent dislocators or patients with pain without dislocation, will eventually require surgical stabilization, the first line of treatment is an appropriate rehabilitation program that emphasizes strengthening of the rotator cuff muscles. Although this may not alleviate all symptoms, it often improves both function and stability and provides an elevated preoperative "baseline" with regard to strength, range of motion, pain, and an understanding of the postoperative rehabilitative efforts required. Surgical treatment of symptomatic anterior instability is most commonly accomplished with a modification of the Bankart repair. This may be accomplished either open

*See references 15, 85, 134, 153, 157, 174, 187, 220.

†See references 15, 48, 51, 134, 183, 187, 190.

‡See references 16, 159, 220, 223, 226, 229, 259, 272.

§See references 16, 74, 103, 159, 220, 223, 226, 227, 229.

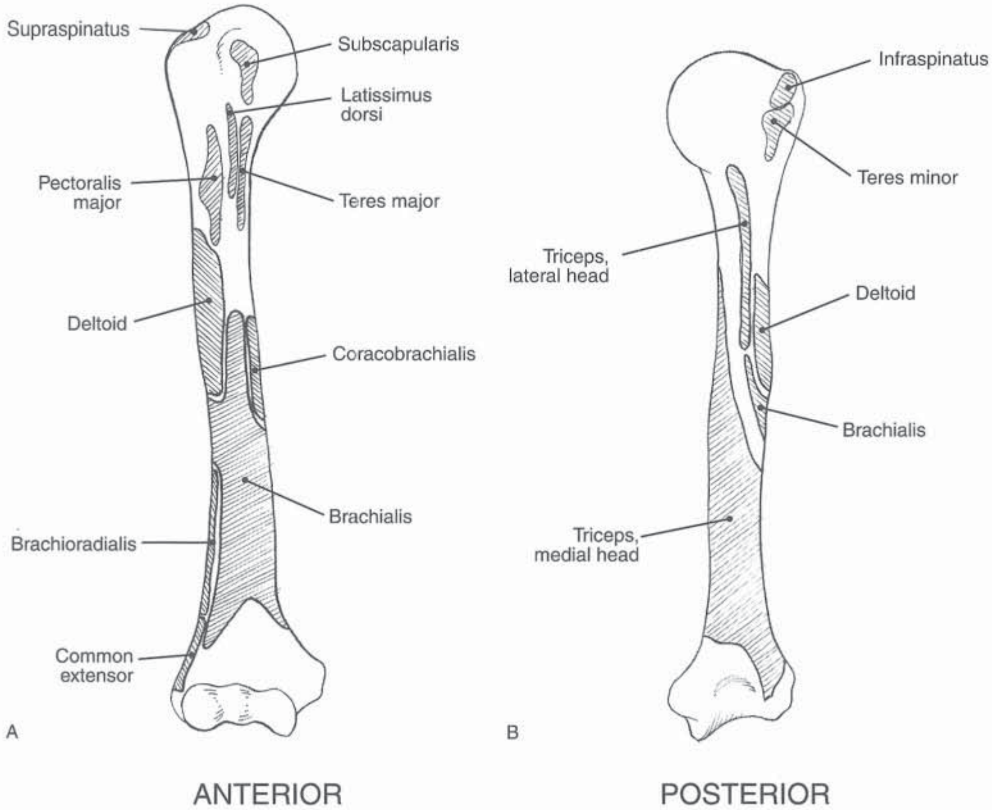


FIGURE 41–25 Muscular insertions of the humerus. **A,** Anterior. **B,** Posterior.

or arthroscopically. It is important to realize that some patients may have traumatic instability that is compounded by preexisting multidirectional instability.[32,231] The operative repair of these patients should include efforts to "tighten" the redundant inferior capsule. There are numerous references in the adult literature that describe both the open and arthroscopic surgical techniques.*

Fractures of the Proximal Metaphysis and Shaft of the Humerus

Fractures of the proximal metaphysis and shaft of the humerus are usually quite straightforward.† Fractures of the proximal humeral metaphysis are more common in children than adolescents, as adolescents are more likely to sustain physeal injuries. Humeral shaft fractures are the second most common birth fracture.[81,246] Fractures of the humeral shaft are less common in children than in adults but, as in adults, are frequently associated with radial nerve injury.

ANATOMY

The humerus is cylindrical proximally and becomes broad and flat in its distal metaphysis. The deltoid, biceps brachii, and brachialis muscles cover it anteriorly. The coracobrachialis muscle inserts beneath the upper half of the biceps brachii muscle. The pectoralis major inserts into the lateral lip of the bicipital groove. The posterior surface is covered by the deltoid and triceps muscles (Fig. 41–25). On the lateral and medial aspects of the humerus, intermuscular septa divide the arm into anterior and posterior compartments. Anteriorly the neurovascular bundle, consisting of the brachial vessels and the median, musculocutaneous, and ulnar nerves, courses along the medial aspect of the humerus. The radial nerve lies in the posterior compartment in a shallow groove between the origins of the medial and lateral heads of the triceps. The radial nerve runs obliquely downward and laterally as it passes from the axilla to the anterolateral epicondylar region.*

Fracture angulation is dependent on whether the fracture is proximal or distal to the insertion of the deltoid. When the fracture is distal to the deltoid insertion, the action of the supraspinatus, deltoid, and coracobrachialis muscles displaces the proximal fragment laterally and anteriorly, whereas the distal fragment is drawn upward by the biceps and brachialis muscles. If the fracture occurs proximal to the insertion of the deltoid but distal to that of the pectoralis major, the pull of the deltoid will displace the distal fragment laterally and upward, while the pectoralis major, latissimus dorsi, and teres major muscles will adduct and medially rotate the proximal fragment. The displacement of the fracture fragments is also influenced by gravity, the position in which the upper limb is held, and the forces causing the fracture. The distal fragment is usually internally rotated, as

*See references 16, 32, 79, 159, 220, 226, 259, 260, 272.
†See references 33, 46, 97, 110, 116, 132.

*See references 33–35, 46, 97, 110, 111, 116, 132, 199, 206, 243.

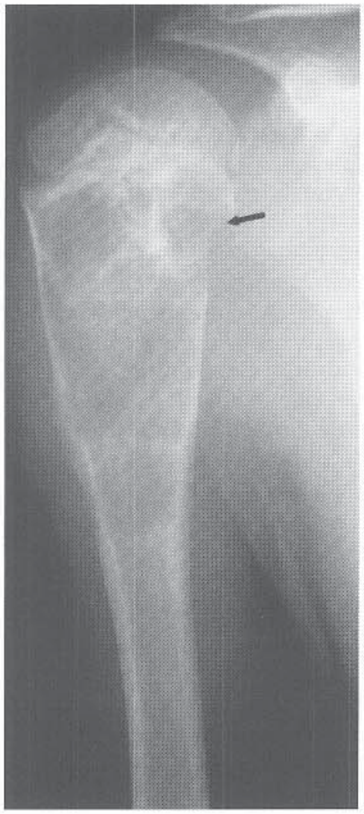


FIGURE 41–26 AP radiograph of the proximal humerus showing a fracture of the medial metaphysis (*arrow*) after minimal trauma. Note the large, expansile unicameral bone cyst.

FIGURE 41–27 AP radiograph showing healing pathologic fracture of the humeral shaft. The diaphyseal lesion has the characteristic "ground-glass" appearance of fibrous dysplasia.

the arm is held across the chest while the proximal fragment remains in midposition.*

MECHANISM OF INJURY

Fractures of the proximal humeral metaphysis are usually a result of a high-energy direct force.† As such they are frequently associated with multiple trauma. Fractures in this area that occur after minimal trauma should raise the suspicion of a pathologic fracture, as this is a common location for unicameral bone cysts and other benign lesions (Fig. 41–26). Most fractures of the shaft of the humerus are also caused by a direct force, such as a fall on the side of the arm. Consequently they are usually transverse or comminuted fractures and frequently are open injuries. An indirect force, such as a fall on an outstretched hand, can produce an oblique or spiral fracture of the humeral shaft. Forceful muscular contraction, such as throwing a baseball, has also been reported to cause humeral shaft fractures, although such a history should raise the possibility of a pathologic fracture through a lesion such as a unicameral bone cyst or fibrous dysplasia (Fig. 41–27).‡

DIAGNOSIS

The obvious deformity, localized swelling, and pain caused by fractures of the proximal humeral metaphysis or humeral shaft make the clinical diagnosis straightforward. However, due diligence is required in order to detect associated neurovascular injury. The intimate relation of the radial nerve to the humerus makes it especially vulnerable to injury. Radial nerve injury results in anesthesia over the dorsum of the hand between the first and second metacarpals and loss of motor strength of the wrist, finger, and thumb extensors as well as forearm supinators. The median and ulnar nerves are rarely injured. Vascular injury is also extremely rare.*

TREATMENT

In infants with obstetric fractures, the fracture is immobilized for a period of 1 to 3 weeks by bandaging the arm to the side of the thorax in a modified Velpeau bandage or a sling and swath. The parents should be instructed in skin care for the immobilized extremity and forewarned of the large palpable callus that will develop in 6 to 8 weeks. Efforts to control alignment are not necessary, as the remodeling potential is great. Follow-up examination is required only to assess brachial plexus function to ensure that a concomitant nerve palsy does not exist. Primitive reflexes such as the Moro reflex can be valuable in assessing upper extremity function in the infant.[14,37,81,246]

As with fractures involving the proximal humeral physis, the remodeling potential of proximal humeral metaphyseal

*See references 33, 46, 97, 110, 116, 132.

†See references 33, 46, 97, 110, 116, 132.

‡See references 5, 33, 46, 83, 97, 110, 116, 124, 132, 160, 214.

*See references 33–35, 46, 89, 97, 110, 111, 116, 132, 156, 199, 206, 243, 285.

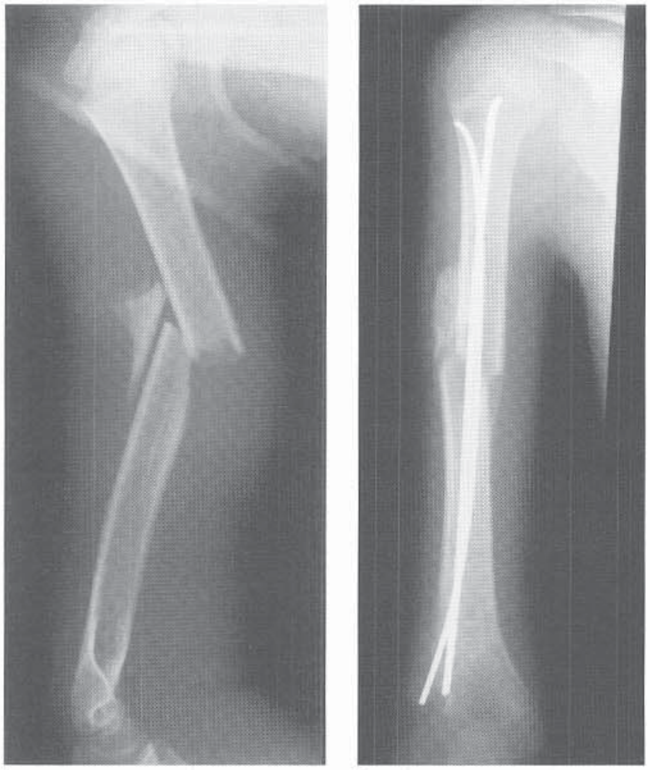


FIGURE 41–28 **A** and **B**, Comminuted humeral shaft fracture treated with flexible intramedullary fixation.

fractures is great. Consequently, these fractures rarely require more than symptomatic treatment with sling immobilization. Occasionally we will manage polytraumatized patients or open fractures with percutaneous fixation (see Fig. 41–18).[125,233]

Fractures of the humeral shaft are generally best managed with closed techniques. Most commonly, we initially place these patients in a coaptation splint. After 2 to 3 weeks patients can be managed in a sling or hanging arm cast. It is not essential to obtain end-to-end anatomic alignment, as overgrowth is common in humeral shaft fractures. Overriding of 1 to 1.5 cm can be easily accepted; however, angulation of more than 15 to 20 degrees in either plane is not desirable, and, as with any fracture, rotational remodeling potential is minimal. Subsequently, rotational alignment should be maintained. Circumduction and pendulum exercises for the shoulder are demonstrated and begun as soon as pain allows, usually after 2 to 3 weeks. Again, we occasionally treat open injuries or polytraumatized patients with operative techniques.[39,218] External fixation may be indicated for extensive soft tissue injuries, although internal fixation allows for easier nursing care.[125] We have found flexible nails to be an easy and effective means of managing humeral shaft fractures in polytraumatized patients (Fig. 41–28).[22,115,233,293]

COMPLICATIONS

Complications following fractures of the proximal metaphysis or shaft of the humerus are unusual. As with any fracture, open or vascular injuries can occur. These injuries should be managed individually with attention to the general guidelines discussed in Chapter 39, General Principles of Managing Orthopaedic Injuries.[89,99]

Radial nerve injury, which is not uncommon in adults, is rare in children. Complete severance of the nerve in closed fractures is very unlikely, and nerve function usually recovers if the fracture is managed conservatively. Primary open reduction of a closed fracture of the humeral shaft is not indicated on the basis of a radial nerve palsy. Rather, the wrist and hand should be splinted in a functional position and passive exercises performed to maintain full range of motion. If after 3 to 4 months there is no evidence of functional recovery, electromyographic studies or exploration of the nerve may be indicated.*

Nonunion of humeral shaft fractures is much less common in children and adolescents than in adults but does occasionally occur. In general, we prefer to treat nonunions with open reduction and plate fixation.[58,99,148,264]

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Fractures About the Elbow

Mercer Rang uses the old saying, "Pity the young surgeon whose first case is a fracture around the elbow," as an introduction to his chapter on elbow fractures, for good reason.[414] Although common—fractures about the elbow account for 5 to 10 percent of all fractures in children[240,282,418,546,562]—the unique anatomy of the elbow and the high potential for complications associated with elbow fractures makes their treatment anxiety producing for many orthopaedic surgeons. Fortunately, with an understanding of the anatomy and adherence to a few basic principles, their treatment can be straightforward.

It is best to address elbow fractures from an anatomic perspective, as each specific fracture has its own unique challenges in diagnosis and treatment. One frequent source of problems in the management of pediatric elbow injuries is distinguishing fractures from the six normal secondary ossification centers. The six ossification centers develop in a systematic, predictable fashion. The mnemonic CRITOE is helpful in remembering the progression of the radiographic appearance of the ossification centers about the elbow in children: *c*apitellum, *r*adius, *i*nternal (or medial) epicondyle, *t*rochlea, *o*lecranon, and *e*xternal (or lateral) epicondyle. In general, the capitellum appears radiographically at around 2 years of age and the remaining ossification centers appear sequentially every 2 years.[487] It is important to remember that girls mature early and boys late, so the age at which these landmarks appear may vary—earlier for girls, later for boys; however, the sequence remains constant (Fig. 41–29).

The most common fractures about the elbow include supracondylar humerus fractures, transphyseal distal humeral fractures, fractures of the lateral humeral condyle, fractures of the radial head and neck, fractures of the olecranon, and fractures of the medial humeral epicondyle (often associated with elbow dislocation). Fractures involving the capitellum, coronoid, medial condyle, and the lateral epicondyle and intracondylar or "T-condylar" fractures do occur but are quite rare. Each of these injuries will be discussed in the context of their unique characteristics, which can assist in diagnosis and treatment.

SUPRACONDYLAR FRACTURES OF THE HUMERUS

Supracondylar fractures of the humerus are the most common type of elbow fracture in children and adolescents.

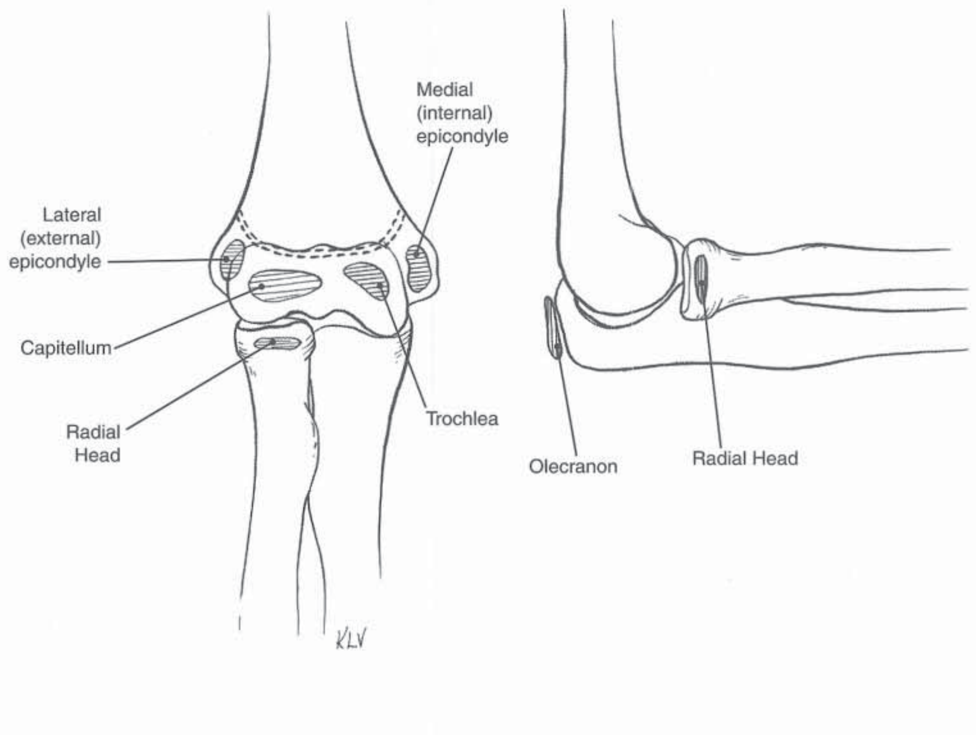


FIGURE 41–29 The secondary ossification centers about the elbow.

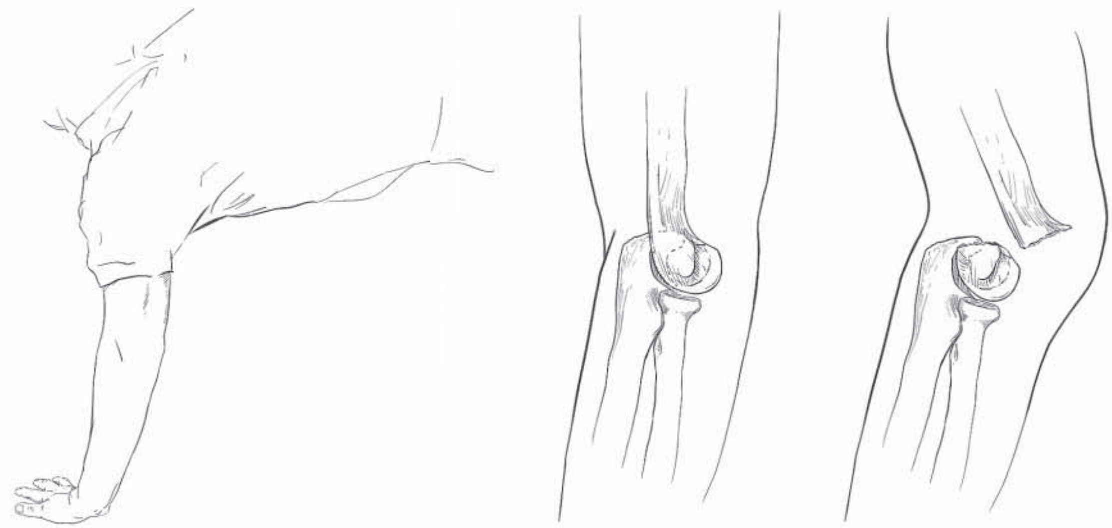


FIGURE 41–30 **A,** Supracondylar humerus fractures are most commonly the result of a fall on an outstretched extremity producing hyperextension of the elbow. **B** and **C,** As the elbow hyperextends, the olecranon serves as a "fulcrum" to produce the fracture. Thus, supracondylar fractures are most commonly at the level of the olecranon fossa.

They account for 50 to 70 percent of all elbow fractures and are seen most frequently in children between the ages of 3 and 10 years.[144,201] The high incidence of residual deformity and the potential for neurovascular complications make supracondylar humeral fractures a serious injury.*

Anatomy. The elbow joint is a complex articulation of three bones that allows motion in all three planes. The distal humerus has unique articulations with the radius and the ulna that make this mobility possible. The radial-humeral articulation allows pronation and supination of the forearm, while the ulnar-humeral articulation allows flexion and extension of the elbow. The separate articulating surfaces of the distal humerus are attached to the humeral shaft via medial and lateral columns. These two columns are separated by a thin area of bone that is the result of the coronoid fossa anteriorly and the olecranon fossa posteriorly. This thin area is the "weak link" in the distal humerus and is where supracondylar humerus fractures originate. When forced into hyperextension, the olecranon can act as a fulcrum through which an extension force can propagate a fracture across the medial and lateral columns (Fig. 41–30). Similarly, a force applied posteriorly with the elbow in flexion can create a fracture originating at the level of the olecranon fossa (Fig. 41–31). Thus, whether the result of an extension or a flexion force, fractures of the supracondylar humerus are usually transverse and at the level of the olecranon fossa. For reasons that are unclear, older patients often have fractures that are oblique rather than transverse. Oblique fractures are less stable than transverse fractures because rotation produces additional angulation (Fig. 41–32).

Although the bony architecture of the distal humerus is responsible for the frequency of supracondylar humeral fractures, it is the soft tissue anatomy that has the potential to produce devastating long-term complications. Anteriorly, the brachial artery and median nerve traverse the antecubital fossa. Laterally, the radial nerve crosses from posterior to anterior just above the olecranon fossa. The ulnar nerve passes behind the medial epicondyle (Fig. 41–33). In extension supracondylar fractures, the brachialis muscle usually shields the anterior neurovascular structures from injury. However, in severely displaced fractures, the proximal fragment may perforate the brachialis muscle and contuse, occlude, or lacerate the vessel or nerve. The vessels or median nerve may also become trapped and compressed between the fracture fragments.[21,498] Even without direct injury, a severely displaced fracture can cause neurovascular injury simply from the stretch or traction that is associated with displacement. Similarly, the radial nerve may be injured by severe anterolateral displacement of the proximal fragment. With flexion-type injuries (anterior displacement of the distal fragment) the ulnar nerve is at risk, as it may become "tented" over the posterior margin of the proximal fragment. Neurovascular problems can also develop in minimally displaced fractures as a result of hematoma formation or swelling. Hematomas usually spread anteriorly across the antecubital fossa deep to the fascia, potentially compressing the neurovascular structures.

Mechanism of Injury. Supracondylar humeral fractures may be the result of either an extension or a flexion force on the distal humerus. Most commonly, they are the result of a fall on an outstretched hand that causes hyperextension of the elbow.[3,21,310] These "extension-type" supracondylar humerus fractures account for 95 to 98 percent of all supracondylar fractures. With hyperextension injuries the distal fragment will be displaced posteriorly. "Flexion-type" supracondylar fractures are rare, occurring in only 2 to 5 percent of cases. The mechanism of flexion supracondylar fractures is usually a direct blow on the posterior aspect of a flexed elbow that results in anterior displacement of the distal fragment.[144,346,549]

*See references 21, 310, 346, 350, 443, 508, 548, 551.

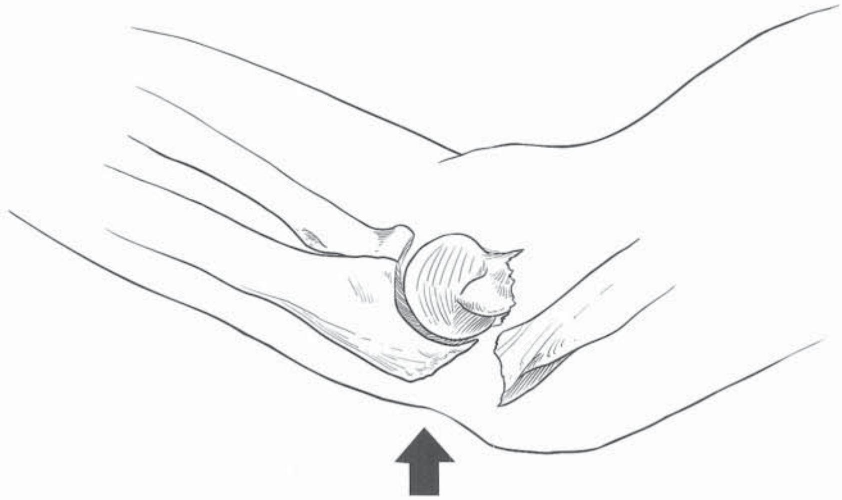


FIGURE 41–31 A posteriorly applied force with the elbow in flexion creates a "flexion-type" supracondylar humeral fracture. This mechanism accounts for only 2 to 5 percent of all supracondylar humeral fractures.

Diagnosis. Supracondylar fractures may be inherently obvious or nearly impossible to diagnose. The clinical findings in severely displaced fractures are usually so obvious that the most difficult part of the diagnosis is remembering to perform a thorough examination to assess for other injuries as well as possible neurologic injury. This is particularly important, given the fact that neurologic injury is present in 10 to 15 percent of cases and ipsilateral fractures in 5 percent (usually the distal radius).* A complete and thorough assessment of the neurologic function of the hand is often difficult in the very young child with an acute elbow fracture. However, if a gentle and deliberate effort is made, most children by the age of 3 or 4 years will cooperate with a two-point sensory and directed motor examination. For uncooperative children, it is important to forewarn the parents that when a thorough examination is possible, there is a 10 to 15 percent chance that a neurologic injury will be discovered. Fortunately, these injuries nearly always do well.†

Although a complete neurologic examination is not always possible, it is always possible to assess the vascular status of patients with displaced supracondylar humeral fractures. It is also of paramount importance to be vigilant for clinical signs of a developing compartment syndrome. The earliest sign of compartment syndrome is pain out of proportion to physical findings. Obviously, in the emergency department all patients with severely displaced supracondylar fractures will have significant pain. However, the pain associated with compartment syndrome is usually of greater intensity and more persistent than that associated with "routine injury." Additionally, patients developing compartment syndrome may experience pain on passive extension of the fingers. Other than pain, the most reliable early sign of compartment syndrome is a full or tense compartment. Unfortunately, by the time the classic symptoms of pallor, paresthesia, and paralysis develop, there has usually been irreversible damage to the neuromuscular tissue.

The differential diagnosis of severely displaced supracondylar humeral fractures includes elbow dislocations and all conditions that mimic them. These include transphyseal distal humeral fractures and unstable lateral condylar fractures (Milch type II). True elbow dislocations are relatively uncommon. When elbow dislocations do occur, they are generally in older children and may be associated with medial epicondylar fractures.[38,120,161,220,474] Transphyseal distal humeral fractures are more common than supracondylar fractures in children less than 2 years old but are uncommon in children over 2. Transphyseal fractures have been reported to be associated with child abuse in as many as 50 percent of cases.[31,114,326,549,551] Unstable lateral condylar fractures can be differentiated from supracondylar fractures most readily on the lateral radiograph. Supracondylar fractures usually originate at the olecranon fossa and are transverse or, less commonly, short oblique. Lateral condylar fractures originate more distally, often with only a small metaphyseal fragment visible on the lateral radiograph (Thurston Holland sign) (Fig. 41–34). On the AP view, an unstable lateral condyle fracture (Milch type II) may have a normal-appearing radial capitellar joint but will have subluxation of the ulnar trochlear joint. Conversely, a Milch type I lateral condyle fracture will have a disrupted radial-capitellar joint

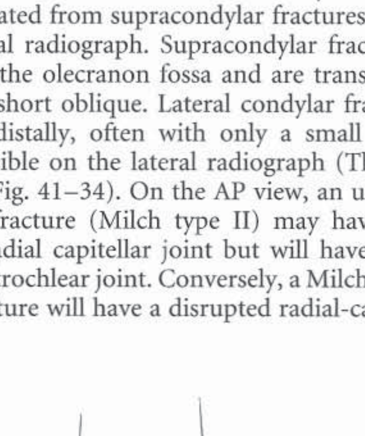


FIGURE 41–32 Oblique fractures, which are more common in older patients, are less stable than transverse fractures.

*See references 27, 46, 48, 70, 81, 99, 124, 239, 251, 262, 301, 346, 361, 441, 495, 549.

†See references 27, 70, 81, 98, 99, 124, 238, 239, 251, 262, 301, 441, 549.

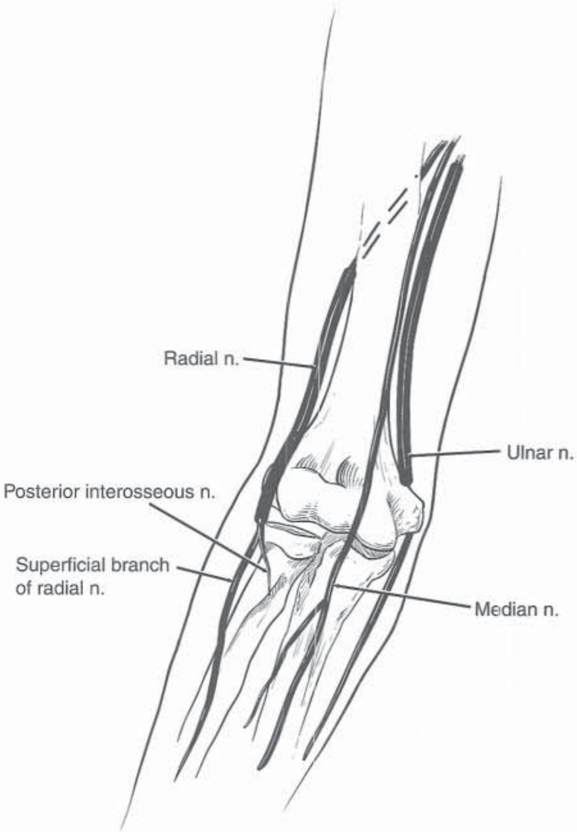
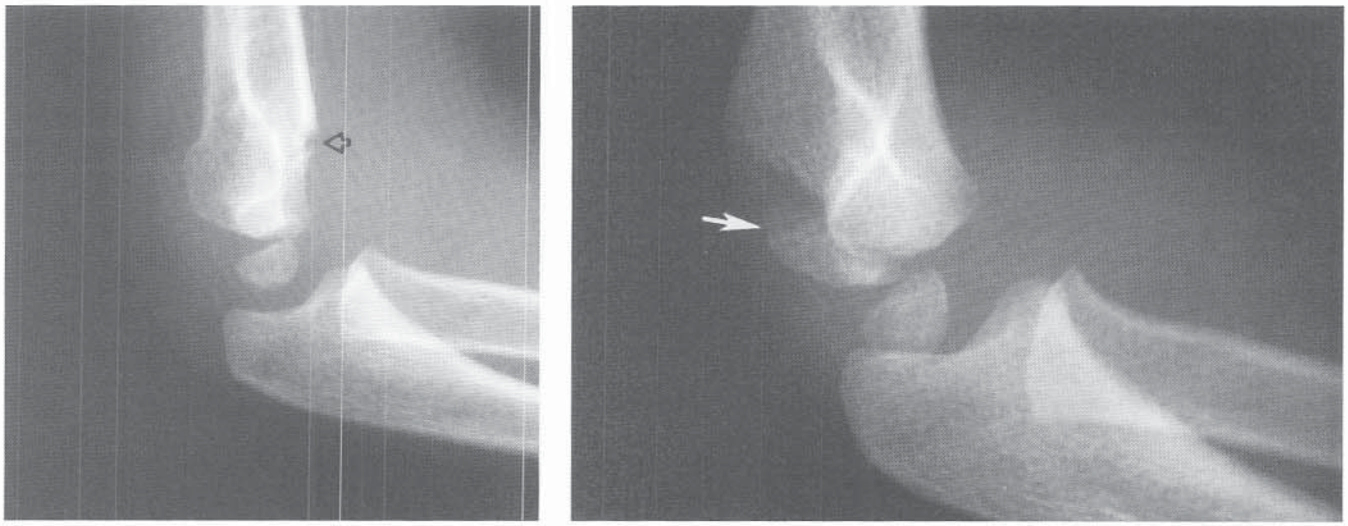


FIGURE 41–33 Neurovascular anatomy around the elbow. The brachial artery and median nerve lie anteromedially. The radial nerve crosses from posterior to anterior, laterally proximal to the lateral condyle. The ulnar nerve lies posteromedially.

(Fig. 41–35). The diagnosis of a minimally displaced supracondylar humeral fracture may be difficult to make.[53,56,60,429] If seen soon after the injury, nondisplaced supracondylar fractures may have minimal swelling and can be difficult to differentiate from minimally displaced lateral condylar, medial epicondylar, or radial neck fractures. The most notable findings may be mild swelling and tenderness over the supracondylar region of the humerus. Careful clinical examination will reveal tenderness both medially and laterally over the supracondylar ridges, whereas in lateral condylar fractures the tenderness is lateral, and in medial epicondylar fractures it is medial. In radial neck fractures the tenderness is over the radial neck posterolaterally. However, a small child with a painful elbow will not always cooperate with such a "careful" examination. In such cases the definitive diagnosis may not be evident until the cast is removed several weeks later (Fig. 41–36). When the fracture cannot be seen clearly on x-rays, it is important to obtain a thorough history to ensure there was indeed a witnessed fall and that the symptoms began immediately after the injury, because patients with osteoarticular sepsis often present with a swollen, painful elbow and a history of trauma. If the elbow pain did not begin immediately after a witnessed traumatic event, consideration should be given to assessment of laboratory indices (complete blood cell count differential, erythrocyte sedimentation rate, and C-reactive protein level) to ensure that the symptoms are not a result of occult infection.

Radiographic Findings. The diagnosis of a supracondylar humeral fracture is confirmed radiographically. Obtaining good-quality radiographs is complicated by the fact that the elbow is painful and difficult to move. Because of rotational displacement, it may be impossible to obtain true orthogonal views of severely displaced fractures. However, with proper instruction to the radiographer, true AP and lateral radiographs can be obtained in fractures with moderate or mini-



A B

FIGURE 41–34 **A,** Lateral radiograph of a type II extension, supracondylar humeral fracture. The fracture originates just proximal to the "hourglass" of the olecranon fossa (*open arrow*). **B,** Lateral radiograph of a displaced lateral condylar fracture. The Thurston-Holland, or metaphyseal, fragment is at the posterior aspect of the metaphysis (*arrow*). The fracture originates distal to the "hourglass" of the olecranon fossa.

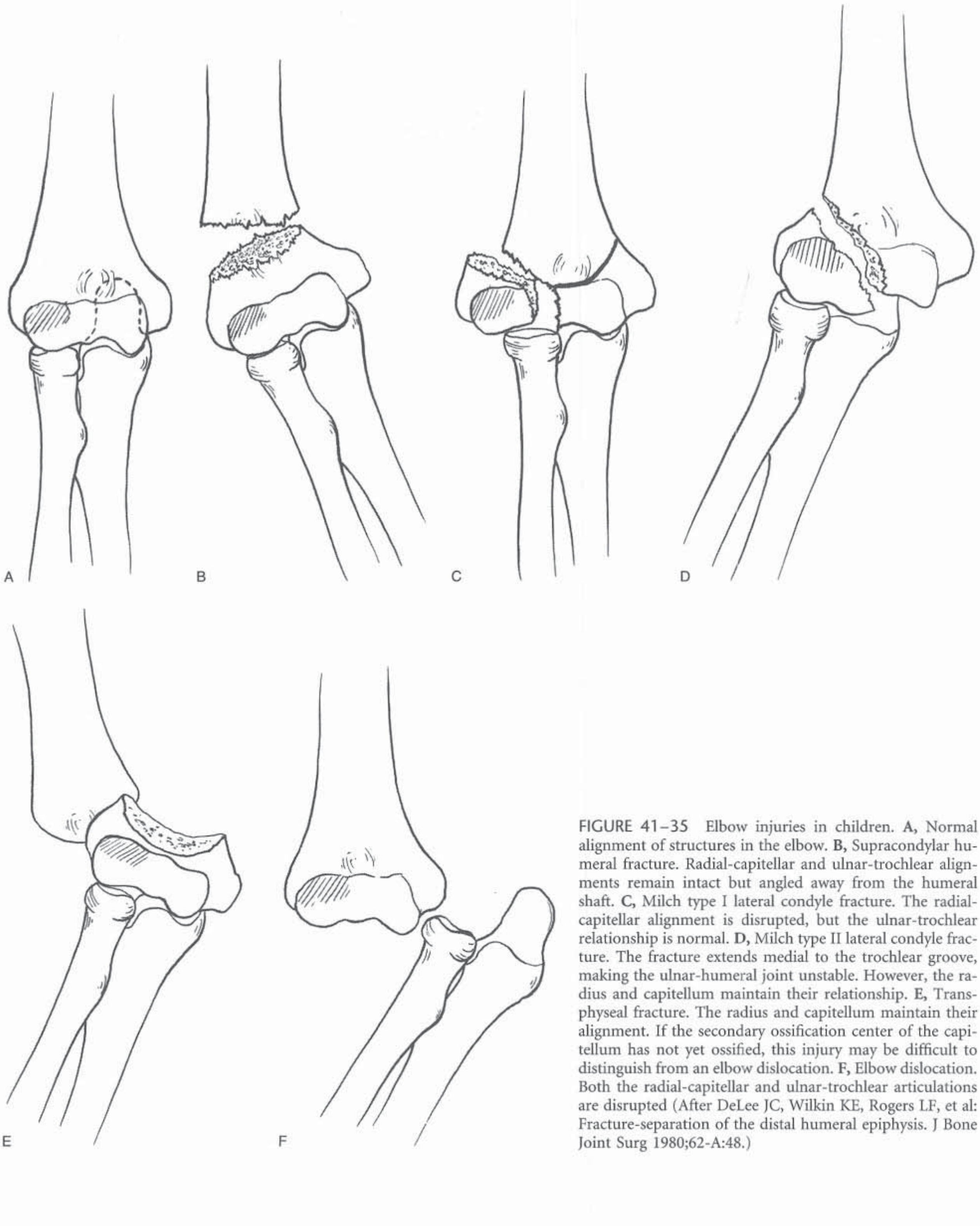
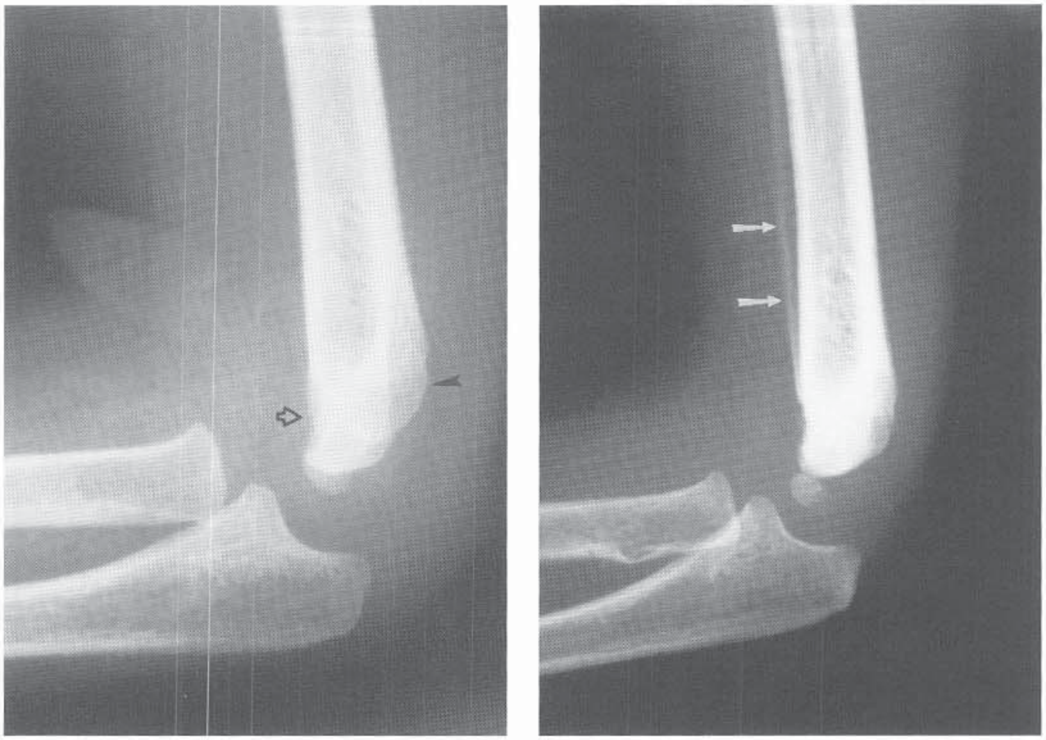


FIGURE 41–35 Elbow injuries in children. **A,** Normal alignment of structures in the elbow. **B,** Supracondylar humeral fracture. Radial-capitellar and ulnar-trochlear alignments remain intact but angled away from the humeral shaft. **C,** Milch type I lateral condyle fracture. The radial-capitellar alignment is disrupted, but the ulnar-trochlear relationship is normal. **D,** Milch type II lateral condyle fracture. The fracture extends medial to the trochlear groove, making the ulnar-humeral joint unstable. However, the radius and capitellum maintain their relationship. **E,** Transphyseal fracture. The radius and capitellum maintain their alignment. If the secondary ossification center of the capitellum has not yet ossified, this injury may be difficult to distinguish from an elbow dislocation. **F,** Elbow dislocation. Both the radial-capitellar and ulnar-trochlear articulations are disrupted (After DeLee JC, Wilkin KE, Rogers LF, et al: Fracture-separation of the distal humeral epiphysis. J Bone Joint Surg 1980;62-A:48.)



A B

FIGURE 41–36 **A,** Lateral radiograph obtained after a hyperextension elbow injury in a child. Although there is no obvious fracture, there is a suggestion of a break in the anterior cortex (*open arrow*) as well as some buckling posteriorly (*black arrowhead*). **B,** Two weeks later, abundant periosteal reaction is evident (*arrows*).

mal displacement. Obtaining a true AP view of the elbow requires full elbow extension and is therefore seldom possible. Consequently, we obtain an AP view of the distal humerus, which can be achieved with any degree of elbow extension (Fig. 41–37). The importance of obtaining a true lateral radiograph of the distal humerus cannot be overstated, as the majority of treatment decisions are made from assessment of the lateral radiograph. Although repeating radiographs is slow, tedious, and frustrating, it is worth the effort, as too often "bad x-rays lead to bad decisions."

Several radiographic parameters are helpful in managing patients with supracondylar humeral fractures. One is Baumann's angle, determined from an AP radiograph of the distal humerus. It is the angle between the physeal line of the lateral condyle of the humerus and a line drawn perpendicular to the long axis of the humeral shaft (Fig. 41–38). A number of studies have assessed the use of Baumann's angle in the management of supracondylar humeral fractures.* These studies have shown that although the "normal angle" varies from 8 to 28 degrees, depending on the patient, there is little side-to-side variance in any one individual. It has also been shown that relatively small changes in elbow position, either rotation or flexion, may alter Baumann's angle significantly.[69,265,552,561] Because of the wide range of "normal" values and the potential for "positional" differences, we find Baumann's angle to be of limited role in the management of supracondylar humeral fractures. Clearly, the presence of a small angle should alert the physician to the possibility of significant varus. Additionally, obtaining a comparison view to calculate Baumann's angle on the uninjured extremity may be a useful adjuvant in the decision-making process for minimally displaced fractures.[19] The AP radiograph should also be assessed for comminution of the medial or lateral columns as well as for translation. Occasionally a completely displaced fracture will look relatively well-aligned on the lateral radiograph but will show translation on the AP film. This translation cannot occur without complete disruption of both the anterior and posterior cortices. Therefore, if present, it always represents an unstable fracture (Fig. 41–39).

There are also several important radiographic parameters on the lateral radiograph. A "fat pad sign" may alert the physician to the presence of an effusion within the elbow. The anterior "fat pad" is a triangular radiolucency anterior to the distal humeral diaphysis; it is clearly seen, and, in the presence of elbow effusion, it is displaced anteriorly. The posterior "fat pad" is not normally visible when the elbow is flexed at right angles; however, if an effusion is present, it also will be visible posteriorly (Fig. 41–40). There are several additional radiographic parameters to assess on the lateral radiograph (Fig. 41–41). First, the distal humerus should project as a teardrop or hourglass. The distal part of the teardrop or hourglass is formed by the ossific center of the capitellum (Fig. 41–41, *A*). This should appear as a nearly perfect circle. An imperfect circle or obscured teardrop or hourglass implies an oblique orientation to the distal portion of the humerus, either from inadequate x-ray technique or from fracture displacement. Second, the angle formed by the long axis of the humerus and the long axis

*See references 19, 34, 42, 69, 81, 148, 265, 277, 335, 353, 514, 521, 541, 552, 561.

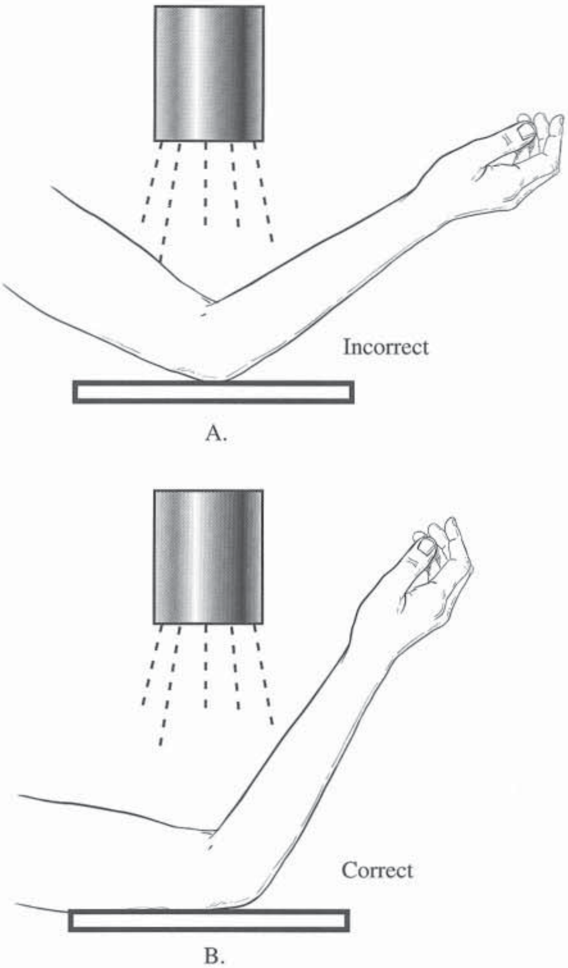


FIGURE 41–37 Radiographic technique to obtain a true AP view of the distal humerus. **A,** If the elbow does not fully extend, an attempt to obtain an AP view of the entire elbow will produce an oblique view of both the distal humerus and the proximal radius and ulna. **B,** The distal humerus is placed on the cassette without extending the elbow. A true AP view of the distal humerus is obtained. An AP view of the proximal radius and forearm can be obtained by placing the forearm on the cassette.

of the capitellum should be approximately 40 degrees (Fig. 41–41, *B*). In supracondylar fractures with posterior tilting of the distal fragment (seen with extension fractures), the humerocapitellar angle will diminish, whereas with anterior tilting of the distal fragment (seen with less common flexion injuries) it will increase. Third, the anterior humeral line—the line drawn through the anterior cortex of the distal humerus—should pass through the middle third of the ossific nucleus of the capitellum (Fig. 41–41, *C*). With extension supracondylar fractures the anterior humeral line will pass anterior to the middle of the capitellum. Finally, the coronoid line—a line drawn projected superiorly along the anterior border of the coronoid process—should just touch the anterior border of the lateral condyle of the humerus (Fig. 41–41, *D*). However, with extension supracondylar fractures the coronoid line will pass anterior to the anterior border of the lateral condyle.[370] If a nondisplaced or minimally displaced fracture is suspected but the AP and lateral views do not show a fracture, oblique views may be helpful.

Classification. Supracondylar humeral fractures are usually initially classified as either extension or flexion injuries. They are then most commonly classified according to the amount of radiographic displacement. This three-part classification system was first described by Gartland in 1959.[171] Type I fractures are nondisplaced or minimally displaced. Type II fractures have angulation of the distal fragment (posteriorly in extension injuries and anteriorly in flexion injuries), with one cortex remaining intact (the posterior in extension and the anterior in flexion). Type III injuries are completely displaced, with both cortices fractured (Fig. 41–42).

There have been several modifications of this scheme. Wilkins subdivided type III injuries based on the coronal plane displacement of the distal fragment (Fig. 41–43).[549] This modification is clinically helpful in identifying complications from the injury and problems with treatment. Posterolaterally displaced type III fractures, although less common, accounting for only 25 percent of extension supracondylar fractures, are more commonly associated with neurovascular injuries. Undoubtedly, this is because the proximal fragment is displaced anteromedially in the direction of the neurovascular bundle (Fig. 41–44). In extension supracondylar fractures the coronal plane displacement of the distal fragment also helps predict the stability of the fracture at the time of reduction. In a classic study in monkeys, Abraham and colleagues demonstrated that the periosteal sleeve remains intact on the side to which the distal fragment is displaced.[3] This periosteal sleeve helps stabilize the fracture when it is reduced. Pronation of the forearm "tightens" the medial sleeve to a greater extent than supination "tightens" the lateral sleeve; thus, posterior medial fractures are usually more stable once reduced (Fig. 41–45).

Mubarak and Davids subdivided type I fractures into IA and IB injuries.[391] Type IA injuries are truly nondisplaced fractures, with no comminution, collapse, or angulation. Type IB fractures have comminution or collapse of the medial column in the coronal plane and may have mild hyperextension in the sagittal plane (Fig. 41–46). They expressed concern that unreduced, these minimally displaced type IB fractures could lead to a cosmetically unacceptable result, particularly in children with a neutral or varus preinjury carrying angle.[361]

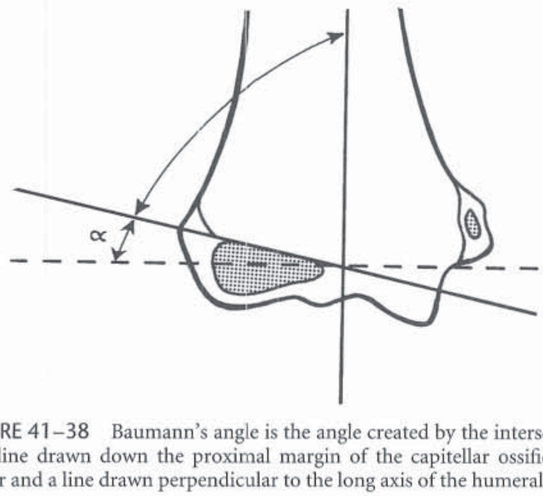


FIGURE 41–38 Baumann's angle is the angle created by the intersection of a line drawn down the proximal margin of the capitellar ossification center and a line drawn perpendicular to the long axis of the humeral shaft.

A

B

FIGURE 41–39 **A,** AP and lateral radiographs of a "minimally displaced" supracondylar humeral fracture. The importance of the medial translation of the distal fragment on the AP view was not appreciated (*arrow*), and the patient was managed in a long-arm cast. **B,** At the time of cast removal, the fracture had angulated further into varus and hyperextension.

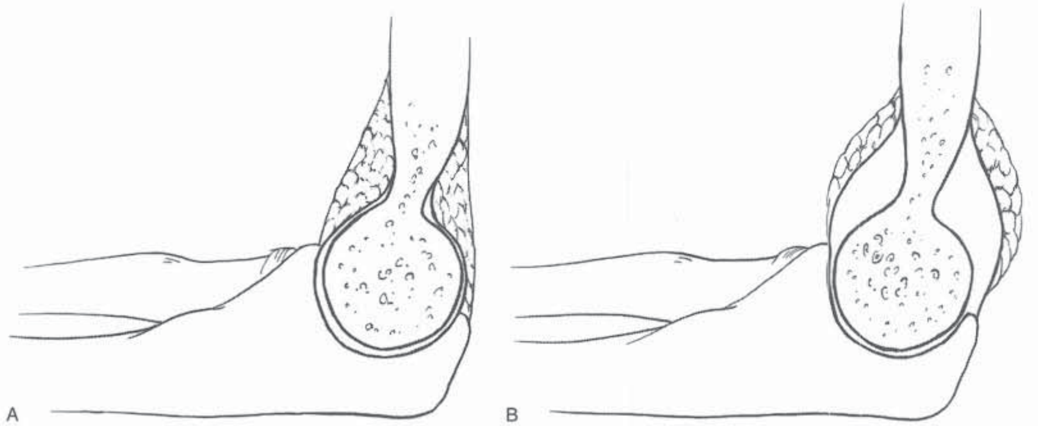


FIGURE 41–40 "Fat pad sign." **A,** There is normally both an anterior and a posterior fat pad. These may be seen as radiolucencies adjacent to their respective cortex. **B,** In the presence of an effusion, the fat pad will be elevated, creating a radiolucent "sail."

Treatment. To again quote Mercer Rang, the goal of treatment of supracondylar humeral fractures is to "avoid catastrophes" (vascular compromise, compartment syndrome) and "minimize embarrassments" (cubitus varus, iatrogenic nerve palsies).[414] With this goal in mind, the treatment of supracondylar humeral fractures can be divided into a discussion of their management in the emergency department, the care of nondisplaced fractures, and the treatment of displaced fractures.

EMERGENCY TREATMENT. It is important that the child and limb receive proper care while awaiting definitive treatment. Unless the patient presents with an ischemic hand or "tented" skin, the limb should be immobilized "as it lies" with a simple splint. If possible, radiographs should be obtained prior to splinting, or radiolucent splint material should be used. If the distal extremity is initially ischemic, an attempt to better align the fracture fragments should be made immediately in the emergency room. In extension supracondylar fractures, this can be accomplished by extending the elbow, correcting any coronal plane deformity, and reducing the fracture by bringing the proximal fragment posteriorly and the distal fragment

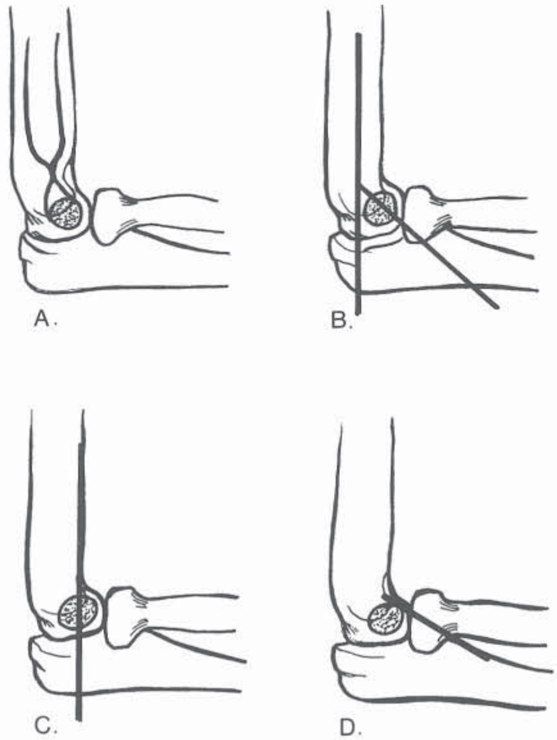


FIGURE 41–41 **A** to **D,** Normal radiographic parameters of a lateral view of the elbow. See text for description.

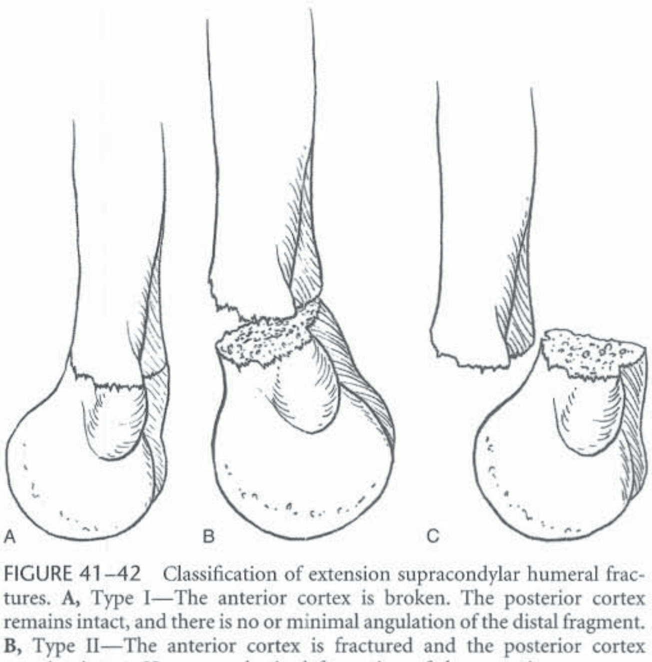
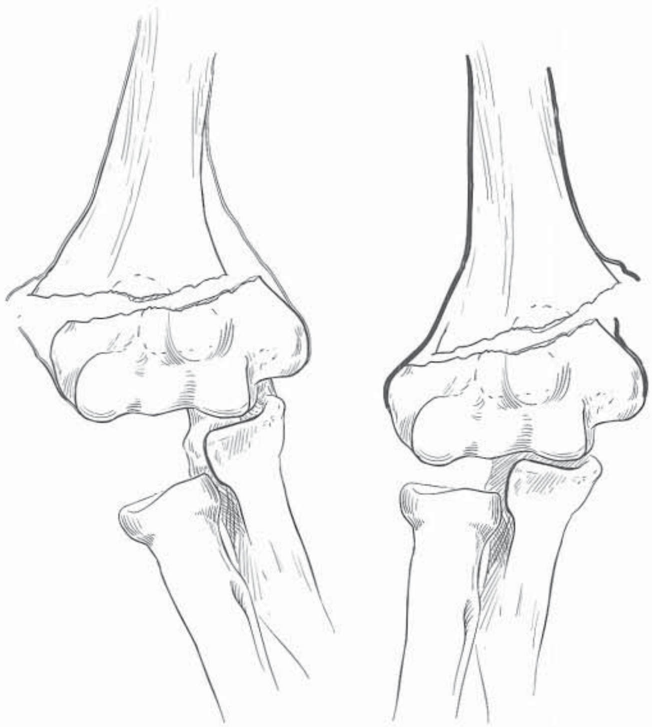


FIGURE 41–42 Classification of extension supracondylar humeral fractures. **A,** Type I—The anterior cortex is broken. The posterior cortex remains intact, and there is no or minimal angulation of the distal fragment. **B,** Type II—The anterior cortex is fractured and the posterior cortex remains intact. However, plastic deformation of the posterior cortex, or "greensticking," allows angulation of the distal fragment. **C,** Type III—The distal fragment is completely displaced posteriorly.



A B

FIGURE 41–43 **A,** Posteromedially displaced fracture. **B,** Posterolaterally displaced fracture.

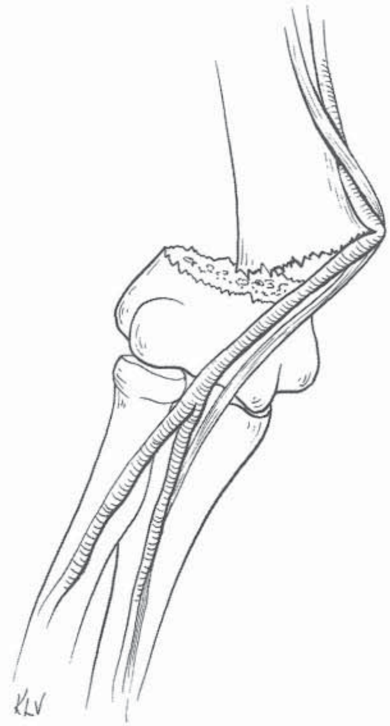
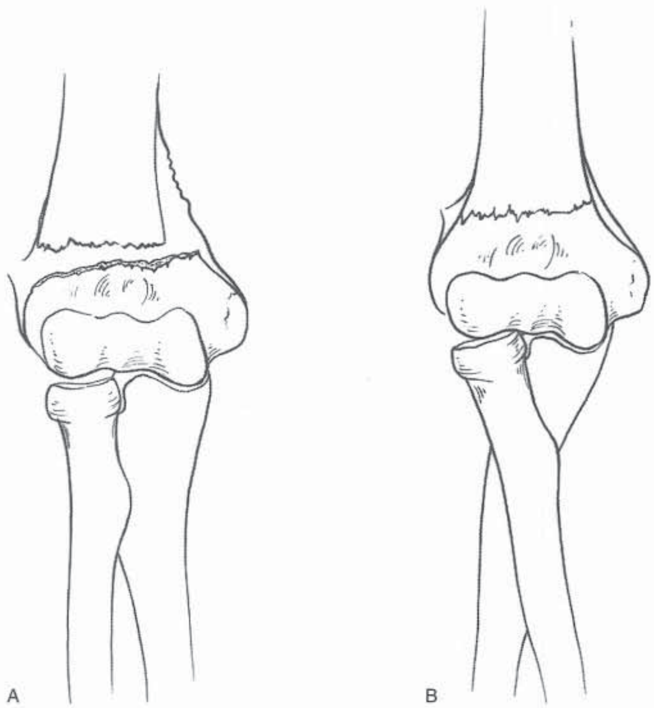


FIGURE 41–44 Posterolaterally displaced type III (extension-type) supracondylar humeral fracture. The proximal fragment displaces anteromedially, placing the brachial artery and median nerve at risk.



A B

FIGURE 41–45 **A,** Posteromedially displaced fractures have an intact medial periosteal sleeve. **B,** Pronation of the forearm tightens the medial soft tissues, stabilizing the reduction.

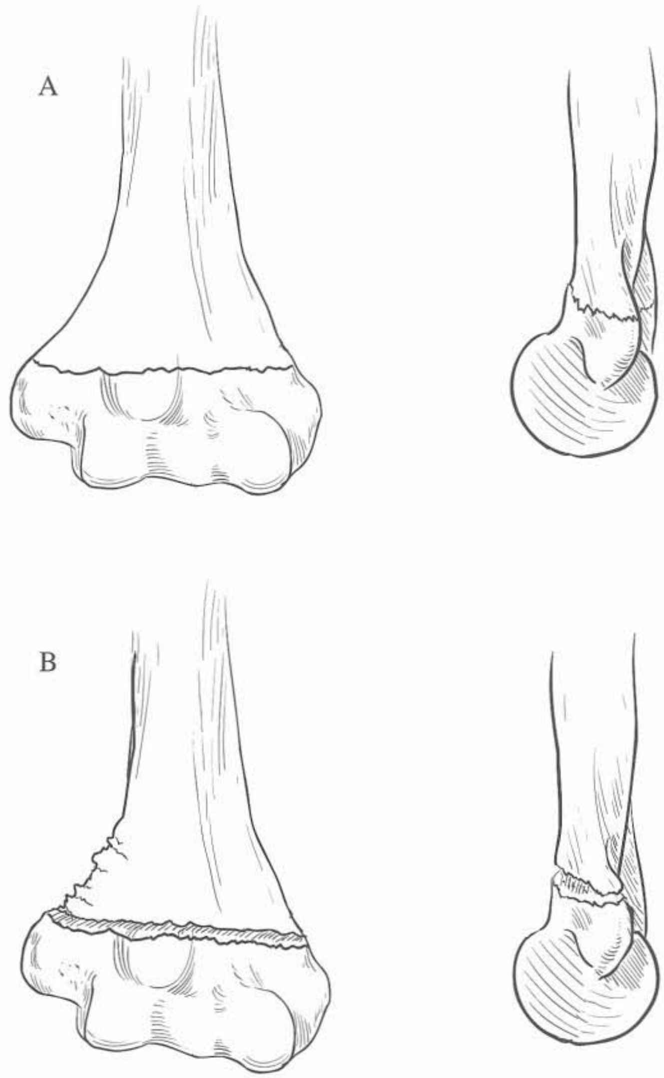


FIGURE 41–46 Type IA and IB supracondylar humeral fractures. **A,** Type IA. There is no angulation in either plane. **B,** Type IB. There is medial column collapse, and there may be slight hyperextension in the sagittal plane.

anteriorly (Fig. 41–47). Often this simple maneuver will immediately restore circulation to the hand. In extension-type fractures, flexion of the elbow should be avoided, as it may cause further damage to the neurovascular structures. The distal circulation should always be checked before and after the splint is applied. Sensation, motor function, and skin integrity should also be carefully checked and recorded.[22] Patients with open fractures should receive intravenous antibiotics and appropriate tetanus prophylaxis (see discussion of open fractures in Chapter 39, General Principles of Managing Orthopaedic Injuries). All patients should be kept from having any food or drink by mouth until a definitive treatment plan has been outlined.

NONDISPLACED FRACTURES. Treatment of nondisplaced fractures is straightforward and noncontroversial and consists of long-arm cast immobilization for 3 weeks. We often initially treat the patient in the emergency room with a posterior splint with figure-of-eight reinforcement. The position of the forearm in the long-arm cast has been the subject of a great deal of speculation. For truly nondisplaced fractures there is no theoretical advantage to either pronation or supination. We generally immobilize nondisplaced fractures with the forearm in neutral position. The patient returns 5 to 10 days after injury and the splint is removed. Radiographs are repeated to ensure there has been no displacement, and the patient is placed in a long-arm cast for an additional 2 to 3 weeks at which time immobilization is discontinued. Following cast removal the parents are forewarned that normal use of the arm may not resume for 1 to 2 weeks and that some pain and stiffness should be expected for the first 2 months. Children return 6 to 8 weeks following cast removal for a review of their range of motion. We have found that patients returning for a "range of motion check" at 3 to 4 weeks may have mild residual deficits in extension and/or flexion. This can be quite disconcerting to the parents who expect everything to be "normal" at this visit. This parental anxiety (and the long discourse of reassurance) can be avoided by allowing the child to be out of the cast for a longer period of time before returning for the "final checkup."

There are a few potential pitfalls in the management of nondisplaced supracondylar humeral fractures that merit further discussion. The first concerns the diagnosis. There are times when the only visible radiographic abnormality will be the presence of a fat pad sign. Often after 1 to 3 weeks the fracture, and the periosteal reaction associated with its healing, will be obvious (see Fig. 41–36). Failure to make this diagnosis at the outset is of little concern, since the fracture is stable. Of more concern is the possibility of misdiagnosing an occult infection or "nursemaid's elbow" as a nondisplaced supracondylar humeral fracture. A thorough history will suggest the correct diagnosis. At times, undisplaced fractures cause soft tissue swelling and may even result in a compartment syndrome. Thus, we are careful not to immobilize the arm in more than 90 degrees of flexion, and we often use a posterior splint rather than a cast. If a cast is applied, it is generously split. The parents must be educated on the importance of edema control and watching for the signs of increased swelling and pressure. Too often patients are discharged from the emergency room with instructions to elevate the arm and to use a sling. It should not be surprising that a number of these patients return for follow-up with swollen extremities. Parents, in an effort to follow directions, are dogmatic about the use of the sling. Unfortunately, this keeps the extremity in a dependent position and incites swelling. Time should be taken in the emergency department to explain to the parents (and the nurses giving discharge instructions!) that the extremity should be elevated with "the fingers above the elbow and the elbow above the heart" for the first 48 hours after the injury. The sling is for comfort after the swelling has subsided (Fig. 41–48). Parents should be instructed to return immediately to the emergency department if it appears that the splint or cast is becoming too tight or if the pain seems to be increasing inappropriately.

DISPLACED FRACTURES. There are several treatment options for the management of displaced, type II and III, fractures. By definition, all of these fractures require a reduction. Usually, even for severe type III injuries, the reduction can be

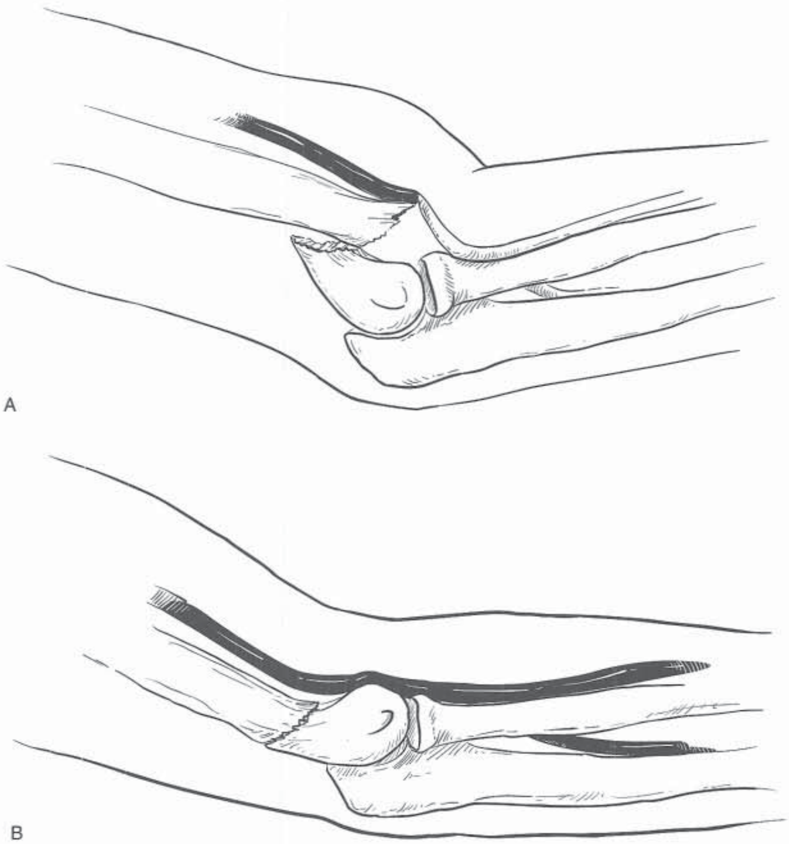


FIGURE 41–47 A and B, Simple realignment of an ischemic limb may reduce the tension on a vessel and restore the circulation.

FIGURE 41–48 A, A sling holds the hand and elbow in a dependent position, creating edema and pain. B, Parents (and patients) should be instructed in true elevation of the extremity, with the fingers above the elbow and the elbow above the heart.

accomplished closed. Options exist with reference to the method of maintaining the reduction until the fracture has healed. These methods include cast immobilization, traction and percutaneous pin fixation. If an adequate closed reduction cannot be achieved an open reduction should be performed; this is almost universally followed with pin fixation.

TECHNIQUE FOR CLOSED REDUCTION

Extension-Type Fracture. Under general anesthesia, the child is positioned at the edge of the operating table with the arm over a radiolucent table to allow an image intensifier to assess the reduction (Fig. 41–49). Some surgeons elect to use the image intensifier itself as the table. An assistant grasps the proximal humerus fixed to allow traction to be placed on the distal fragment. Traction should be applied in a steady continuous force with the elbow in full extension. Once adequate traction has been applied, the coronal plane (varus/valgus) deformity is corrected while traction is maintained (Fig. 41–49B). Continuing to maintain traction with the nondominant hand, the surgeon uses the fingers of the dominant hand to apply a posterior force to the proximal fragment. The thumb of the dominant hand is advanced along the posterior humeral shaft in an attempt to "milk" the distal fragment further distally. Once the thumb reaches the olecranon it applies an anterior force to the distal fragment while the fingers continue to "pull" the proximal

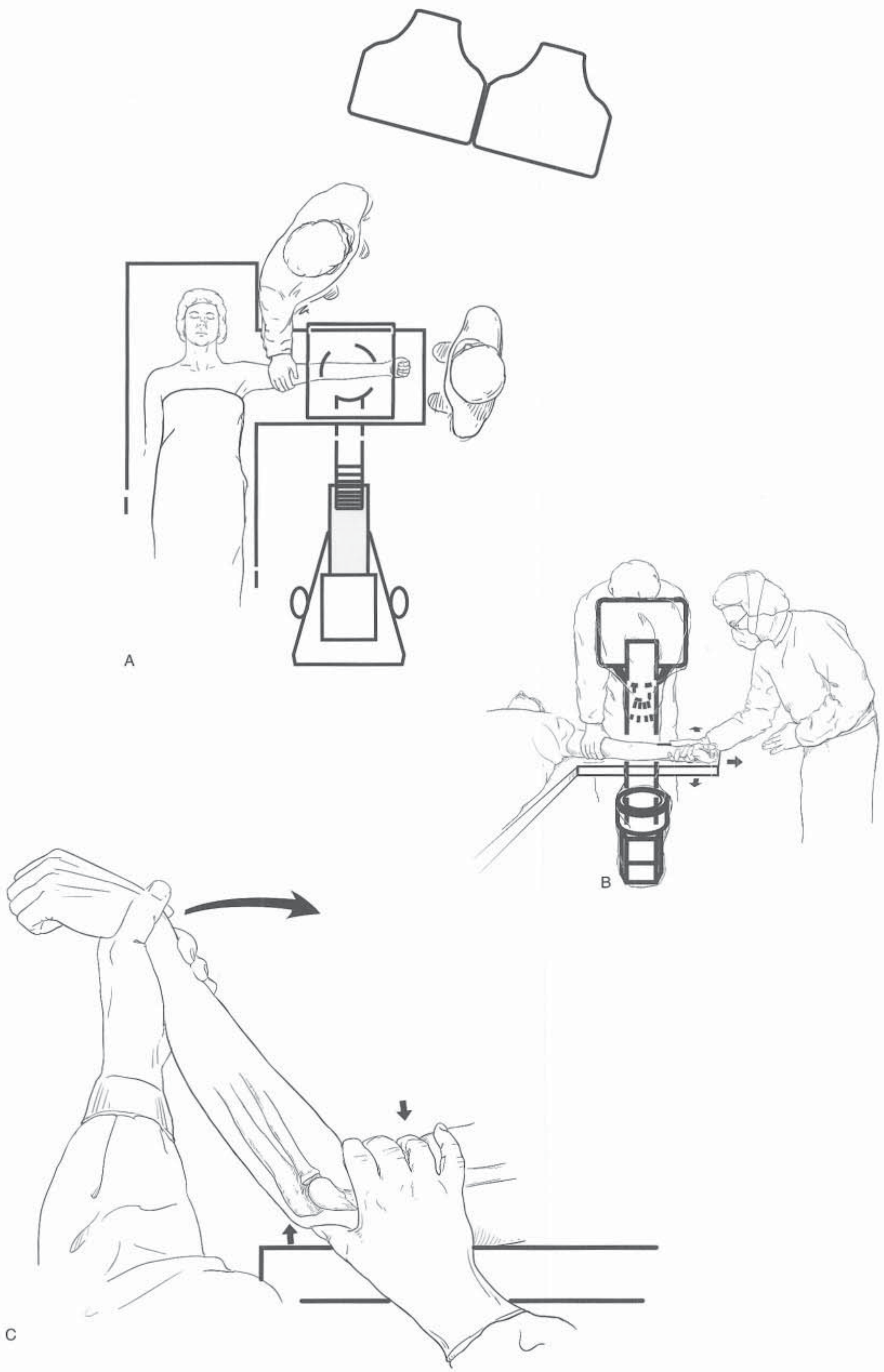


FIGURE 41–49 Technique for closed reduction and percutaneous pinning of supracondylar humeral fracture. **A,** Diagram of patient and C-arm positioning. **B,** Initially, traction is applied and the coronal plane (varus/valgus) deformity is corrected. **C,** The surgeon's dominant hand is used to reduce the fracture in the sagittal plane while the nondominant hand flexes the elbow and pronates (posteromedially displaced fractures) or supinates (posterolaterally displaced fractures) the forearm. The fingers of the dominant hand are used to apply a posteriorly directed force to the proximal fragment while the thumb is slid posteriorly from proximal to distal to "milk" the distal fragment anteriorly.

Illustration continued on following page

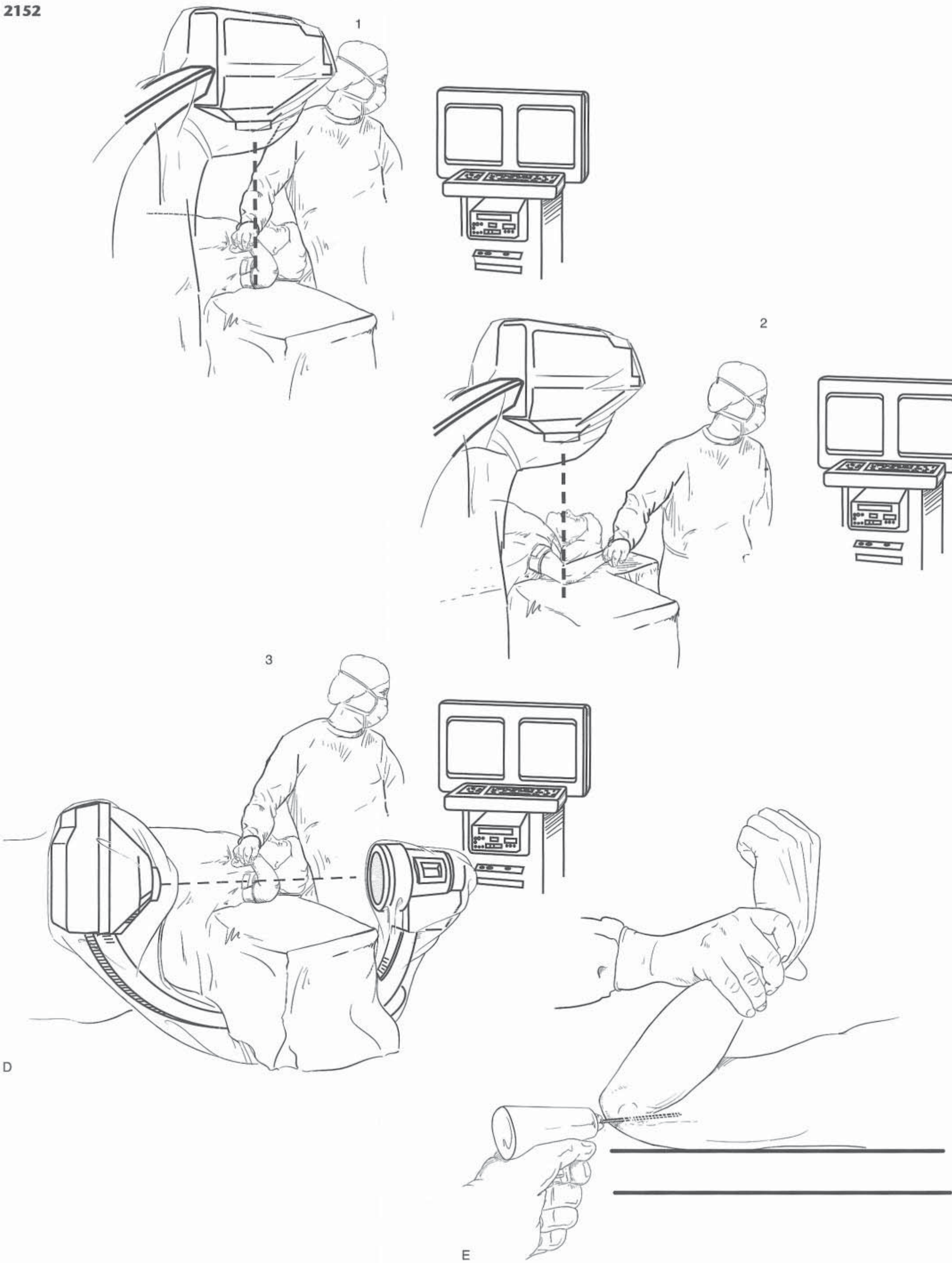


FIGURE 41–49 *Continued.* **D,** Reduction is confirmed with the arm in a hyperflexed position. The Jones view is used to obtain an AP view (1). The lateral view may be obtained by either externally rotating the shoulder (2) or rotating the image intensifier (3). **E,** The fracture is pinned with the arm in a hyperflexed position and the reduction and pin placement are confirmed in the AP and lateral planes.

FIGURE 41–50 Lateral radiograph of a type III flexion supracondylar humeral fracture. Note the anterior displacement of the distal fragment.

fragment posteriorly (Fig. 41–49C). Concurrently, the nondominant hand flexes the elbow and pronates the forearm for posterior medially displaced fractures, and supinates the forearm for posterior lateral fractures. (With the elbow in a flexed position, the patient's thumb should point in the direction of the distal fragment's initial displacement.) While the elbow is being flexed, the surgeon's nondominant hand can continue to exert a distracting force on the distal fragment. With the elbow hyperflexed, the reduction is then assessed on AP and lateral views. The lateral image can be obtained by either externally rotating the shoulder or rotating the image intensifier. With very unstable fractures the surgeon may need to rotate the image intensifier to avoid displacing the fracture. Once the reduction has been confirmed, the fracture can be immobilized with a cast, traction, or percutaneous pin fixation.

There are several caveats to a successful closed reduction that merit further discussion. The first is that every effort should be made to avoid vigorous manipulations and remanipulations, as they only damage soft tissue and elicit more swelling. The second is the management of extremely unstable fractures, which are often posterolaterally displaced. Maintenance of reduction is difficult because supination is not as effective at "tightening" the intact lateral soft tissue hinge as pronation is at stabilizing posteromedially displaced fractures (see Fig. 41–45). During reduction, as the elbow is placed into hyperflexion, these fractures will occasionally displace into valgus. When valgus displacement is noted, a different reduction maneuver is required. Traction and the posteriorly directed force to the proximal fragment remain unchanged. However, as the elbow is flexed, a varus force is applied, and flexion is stopped at 90 degrees. The reduction is confirmed and usually stabilized with percutaneous pinning (Fig. 41–49D and E).

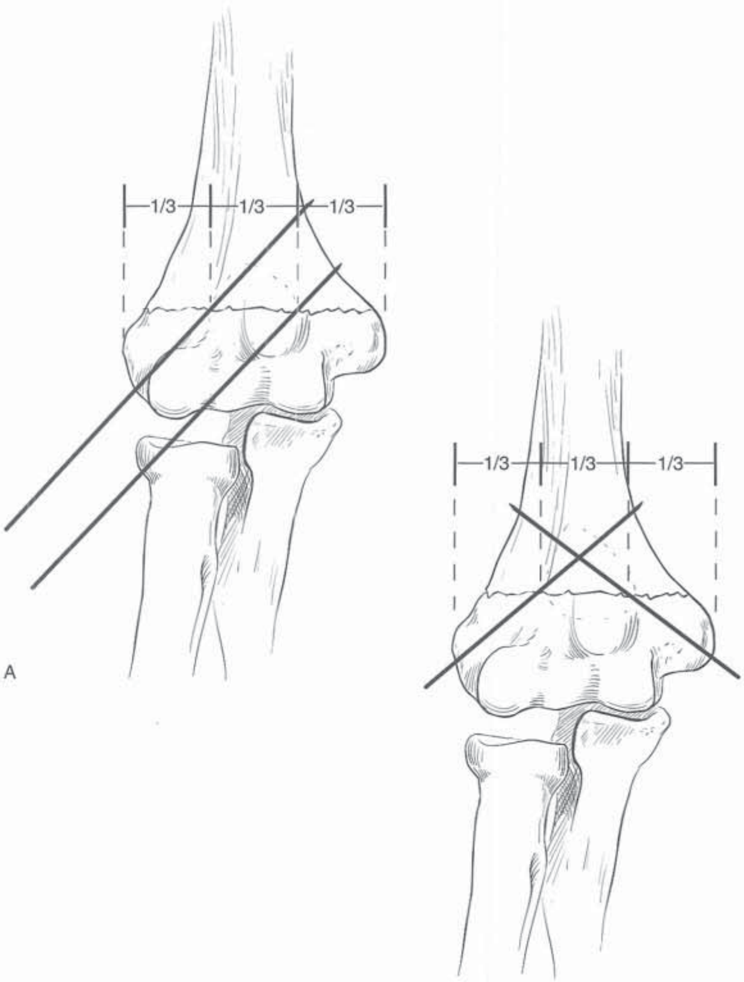
Flexion-Type Fractures. Closed reduction is obtained with longitudinal traction with the elbow in extension; the distal fragment is reduced with a posteriorly directed force (Fig. 41–50). Any coronal plane deformity is then corrected. Once an adequate reduction has been confirmed it is most commonly maintained with percutaneous pinning. Severely displaced flexion-type injuries are more likely to require an open reduction than the more common extension-type fracture.

PERCUTANEOUS PINNING. The development of image intensifiers and power pin drivers has made percutaneous pin fixation of supracondylar humeral fractures a relatively simple procedure. Because percutaneous pin fixation yields the most predictable results with the fewest complications, it is our preferred technique for immobilization for displaced supracondylar humeral fractures.* The technique for percutaneous pinning involves placement of two or three 0.62-inch smooth K-wires (smaller K-wires may be used in patients less than 2 years old) from distal to proximal in a crossed or parallel fashion. (Whether a crossed-pin or parallel pin technique should be used is the subject of considerable debate and is discussed later under Controversies in Treatment.) Once a closed reduction has been achieved the extremity is held in the reduced position by either the surgeon's nondominant hand or an assistant. We usually place the lateral pin first, although occasionally with an unstable posterolaterally displaced fracture, the initial pin may have to be placed medially. If two lateral pins are to be used, the first pin should be placed as close to the midline as possible (just lateral to the olecranon). If only one lateral pin is to be placed, the starting point is the center of the lateral condyle. After the first pin is placed, the second pin is placed either laterally (in the center of the lateral column) or medially. The relationship of the second pin to the first pin and the fracture is an important aspect of percutaneous pin fixation. The rotational stability of the fixation is enhanced if the second pin crosses the fracture line at a significant distance from the first pin. Careful attention must be given to ensure that the pins do *not* cross the fracture at the same point. This potential error can be made with either crossed or parallel pins. We avoid this problem by attempting to divide the fracture into thirds with the pins (Fig. 41–51).

If a medial pin is utilized, care must be taken to ensure that the ulnar nerve is not injured. The starting position for a medial pin is the inferiormost aspect of the medial epicondyle (Fig. 41–51). The pin should be started as far anterior as possible. It is often helpful for the surgeon holding the reduction to "milk" the soft tissue posteriorly, leaving his thumb immediately posterior to the medial epicondyle to protect the ulnar nerve (Fig. 41–52). If the elbow is extremely swollen, a small incision can be made to identify and protect the ulnar nerve. It is important to remember that flexion of the elbow displaces the ulnar nerve anteriorly. Thus, it is safer to place a medial pin with the elbow in extension. Similarly, if the arm is immobilized in flexion, the nerve may be "tented" around the pin, leading to ulnar nerve symptoms, without direct penetration of the nerve by the pin (Fig. 41–53).

Placement of K-wires percutaneously through the narrow distal humerus requires some finesse. As in all percutaneous procedures in orthopaedics, it is facilitated by knowing the anatomy and by reducing the task into two separate, two-dimensional problems. Appropriate pin placement is made easier by first "lining up" the pin driver in the AP plane,

*See references 19, 71, 81, 98, 150, 156, 180, 195, 196, 252, 257, 335, 345, 365, 399, 407, 415, 504, 543, 549.



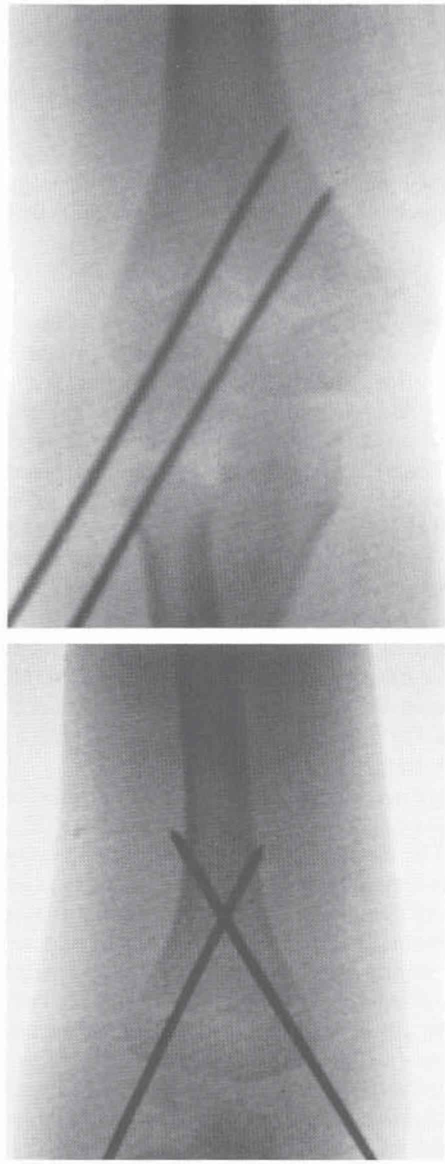


FIGURE 41–51 Pin placement for optimal rotational stability. **A,** Schematic diagram of parallel lateral pins and crossed medial and lateral pins. Ideally, the pins should be the greatest possible distance from one another at the fracture site. This can be accomplished with either technique. **B,** AP radiographs demonstrating fractures fixed with both parallel lateral and crossed medial and lateral pins.

FIGURE 41–52 The assistant holding the reduction protects the ulnar nerve by sweeping the soft tissues posteriorly away from the medial epicondyle.

"locking this angle in," and then "lining up" the pin driver in the lateral plane, without changing the angle in the AP plane. Positioning the pin driver, and subsequently the pin, *sequentially* in *only* these two orthogonal planes simplifies a conceptually difficult task. The use of a pin driver rather than a drill (which requires a "chuck key") also facilitates pin placement, as the pin can more readily be advanced in the power driver.

Once the fracture has been stabilized with at least two pins, the elbow is extended and the reduction and pin placement are confirmed on orthogonal x-ray views. If the reduction and pin placement are acceptable, the pins are bent, cut (it is best to leave a few centimeters of pin out of the skin to facilitate removal), and covered with sterile felt to decrease skin motion around the pin. The arm is immobilized in 30 to 60 degrees of flexion in either a posterior splint or a widely split or bivalved cast. Patients are observed overnight and discharged with instructions in elevation. Patients return 5 to 10 days after injury, at which time the splint is replaced with a cast or the cast is overwrapped. For most uncomplicated supracondylar humerus fractures, radiographs are not routinely required at this visit. However, if the pinning was less than ideal or there is any possibility of fracture displacement, x-rays should be assessed, as this usually represents the last opportunity to manipulate the fracture. Patients return in 3 to 4 weeks post injury, at which time the cast and pins are removed and radiographs are obtained. Cast immobilization is usually discontinued and, as with cast management, parents are instructed in the expected course following cast removal and return in 6 to 8 weeks for a range-of-motion examination.

As with all treatment methods, there are potential complications with percutaneous pinning. These include pin tract inflammation or infection, iatrogenic ulnar nerve injury, and loss of reduction. Pin tract inflammation or infection occurs in 2 to 3 percent in most large series of supracondylar humeral fractures treated with pin fixation.[81] Fortunately, these infections usually respond to removal of the pin and a short course of oral antibiotics, although osteomyelitis can develop. Ulnar nerve injury from a medially placed percutaneous pin is another potential complication. The true incidence of this problem is difficult to determine, because not all ulnar nerve injuries are iatrogenic. However, the ulnar nerve is the least commonly injured nerve in supracondylar fractures, occurring most frequently in rare flexion injuries. If an ulnar nerve deficit is noted postoperatively and a medial pin is present, we recommend removal of the medial pin and observation. Fortunately, in most

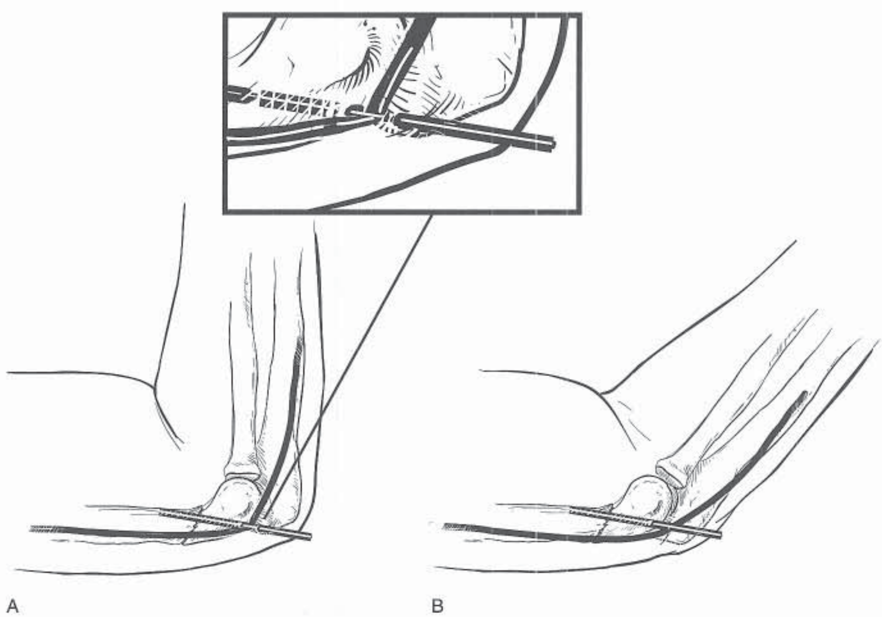


FIGURE 41–53 **A,** Elbow flexion brings the ulnar nerve anteriorly, closer to the medial epicondyle—placing it at greater risk during medial pin placement. Additionally, immobilization of the elbow in flexion may "tent" the nerve around the pin, producing ulnar nerve symptoms despite a properly placed pin. **B,** With the elbow in extension, the ulnar nerve lies in a safer position, posterior to the medial epicondyle.

cases the ulnar nerve makes a complete recovery.* Loss of reduction can occur following closed reduction and percutaneous pinning of supracondylar humeral fractures (Fig. 41–54). This complication is usually a result of inadequate surgical technique and can be minimized with close attention to detail to ensure that the pins are maximally separated at the fracture and have adequate purchase in the proximal fragment.

CAST IMMOBILIZATION. The advantages of cast immobilization are that a cast is easy to apply, readily available, and familiar to most orthopaedists. Casting does not require sophisticated equipment, there is little chance of iatrogenic infection or growth arrest, and casting can yield good results. For these reasons, some surgeons advocate closed reduction and cast immobilization as the initial treatment option for all displaced supracondylar humeral fractures, reserving percutaneous pinning for patients in whom cast management fails. After obtaining a closed reduction, treatment of displaced fractures with a cast is quite similar to treating a nondisplaced fracture.[58] There are, however, a few differences. First, the cast should be carefully applied to avoid compression in the antecubital fossa. Second, patients requiring a reduction are admitted to the hospital overnight for observation. Again, it is imperative to discuss with the parents the importance and technique of edema control and to educate them about the signs that warrant a return to the emergency room. The final, and perhaps most significant, difference in the management of displaced fractures with a cast is that the cast is not removed at the follow-up visit but rather radiographs are obtained with the arm in the cast. Again, the cast is maintained for 3 to 4 weeks and the parents are warned to expect a period of pain and stiffness following cast removal.

Cast immobilization is not without potential problems. Most displaced supracondylar fractures are stable only if immobilized in more than 90 degrees of flexion. Casting an injured elbow in hyperflexion may lead to further swelling, increased compartment pressure, and possibly the development of Volkmann's ischemic contracture (compartment syndrome). Although Volkmann's ischemic contracture can develop in any patient with a supracondylar humeral fracture, regardless of treatment method, cast immobilization requires flexion of the elbow and a rigid circumferential dressing, both of which may exacerbate the condition.

Loss of reduction is the other potential problem with cast immobilization. As the swelling subsides, a cast inevitably loosens over time, allowing the elbow to extend, which may result in loss of reduction. Often this will occur after the first follow-up radiograph shows maintenance of the reduction. In this scenario, it is not until the cast is removed a few weeks later that the varus, hyperextension malunion is discovered. Although good results can be obtained with cast immobilization, particularly with type II fractures, the necessity to immobilize the elbow in flexion and the unpredictable problem of loss of reduction have led us away from cast immobilization of supracondylar fractures that require a reduction.

*See references 81, 124, 180, 234, 238, 257, 304, 340, 415, 435, 514, 541.

TRACTION. Traction also yields good results in the management of displaced supracondylar humeral fractures.[12,122,401,563] Numerous traction techniques have been described. These techniques include overhead or lateral traction utilizing either skin traction or skeletal traction applied with an olecranon pin or screw (Fig. 41–55). Traction has been advocated to maintain a closed reduction as well as to achieve reduction in irreducible fractures. A period of traction preceding an attempt at closed reduction in the massively swollen arm has also been described. However, the most effective way to prevent local swelling (or to decrease it if the elbow is already swollen) is to achieve immediate reduction and stabilize the fracture and soft tissue. There are several drawbacks to skeletal traction, which have led to a steady decline in its use. These include the need for prolonged hospitalization, the relative discomfort for the child until the fracture becomes "sticky," pin inflammation and infection, the potential for loss of reduction, and the potential for neurovascular complications. Neurovascular complications associated with traction include ulnar nerve injury from olecranon pins, compartment syndrome from excessive traction or circumferential bandages, and circulatory embarrassment from acute hyperflexion of the elbow while in traction.* We do not use traction in the management of supracondylar humeral fractures. Its use is described for historical completeness. It may have a role in the rare fracture that cannot be managed routinely because of extenuating circumstances.

OPEN REDUCTION. Indications for open reduction of a supracondylar humeral fracture include a nonviable hand that does not revascularize with reduction of the fracture, an open fracture, an irreducible fracture, and inability to obtain a satisfactory closed reduction. If the hand remains ischemic after reduction of the fracture, the brachial artery should be immediately explored through an anterior approach. Once the arterial pathology (entrapment, laceration, or compression) has been identified, the fracture should be reduced and percutaneously pinned. If necessary, the arterial pathology can then be addressed.† Open fractures require emergency operative debridement. Following debridement, the fracture can be reduced with an open technique and percutaneously pinned. With appropriate debridement, fracture stabilization, and antibiotic coverage, the complication rate of open fractures is not significantly different from the complication rate of severely displaced closed fractures.[22,194,208,549]

Supracondylar fractures may be irreducible if the distal aspect of the proximal fragment "buttonholes" through the brachialis muscle. This buttonholing often produces a characteristic puckering of the skin over the displaced proximal fragment. The presence of this "pucker sign" is not in itself an indication for an open reduction, as a closed reduction may be successful. However, this sign should alert the surgeon to a potentially refractory fracture that may require an open reduction.[116,137,148,399]

*See references 25, 42, 102, 133, 190, 196, 199, 279, 345, 360, 383, 407, 476, 481, 482, 496, 497, 535.

†See references 17, 70, 92, 124, 148, 281, 291, 359, 459, 526, 529, 535, 543, 549.

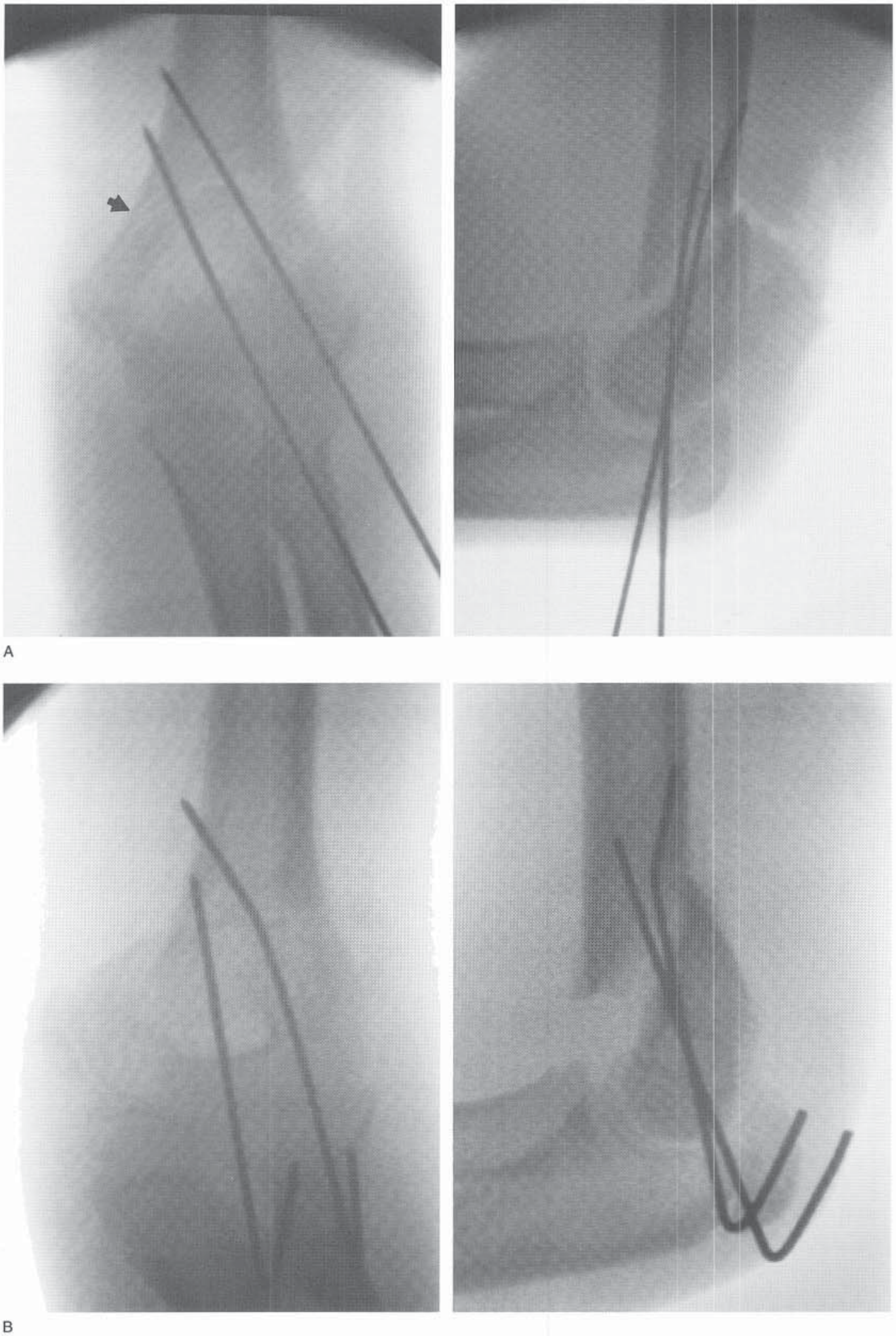


FIGURE 41–54 **A,** Immediate postoperative AP and lateral radiographs of a type III supracondylar humeral fracture. The fracture is atypically proximal and oblique. Note that the most medial pin has very little purchase in the proximal fragment (*arrow*). **B,** Eighteen days postoperatively the medial pin has lost its marginal purchase, the lateral pin has bent, and the fracture has migrated into hyperextension and varus.

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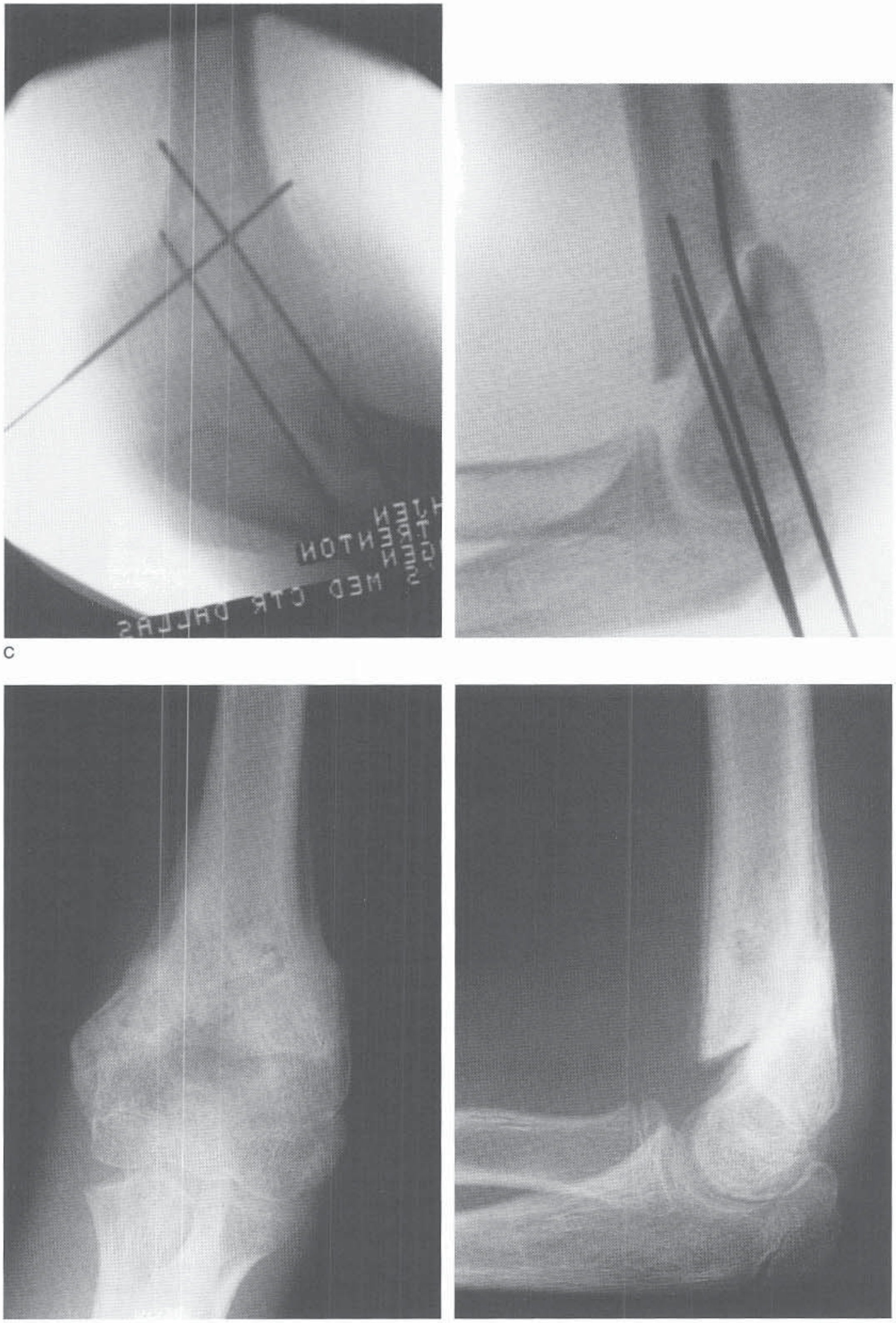


C

D

FIGURE 41–54 *Continued.* **C,** Despite early callus formation, an attempt at closed osteoclasis was made. Note the improved alignment and addition of a medial pin. **D,** The fracture healed uneventfully.

A B

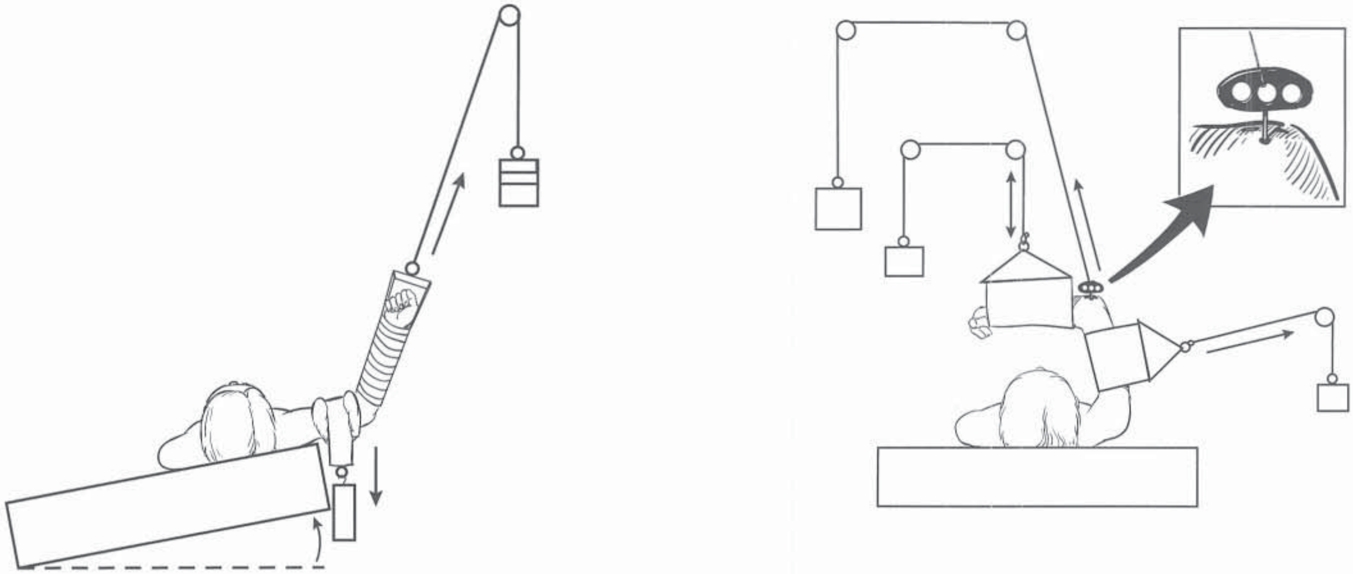
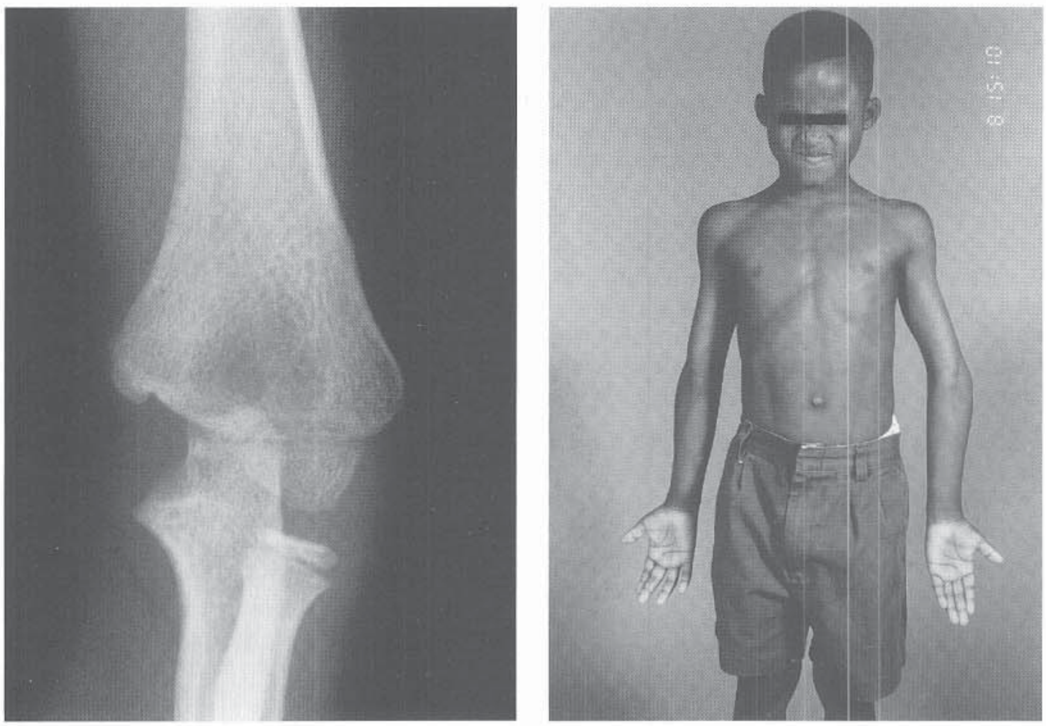


FIGURE 41–55 **A** and **B**, Historically, supracondylar fractures were treated with traction. Currently traction techniques are rarely used.

The decision that a closed reduction is "unacceptable" and an open reduction indicated must be made on an individual basis. We accept mild angulation in the sagittal plane and translation in the coronal plane. A mild amount of valgus angulation in the coronal plane is also acceptable. However, varus angulation in the coronal plane, particularly if associated with either a small amount of hyperextension in the sagittal plane or a contralateral carrying angle that is neutral or varus, is likely to yield a cosmetically poor result that will not remodel (Fig. 41–56). If significant varus deformity exists following the best attempt at a closed reduction, we proceed to an open reduction. We usually approach the



A B

FIGURE 41–56 **A,** AP radiograph of varus malunion. **B,** Clinical appearance.

elbow from the side opposite the displaced distal fragment. This allows any interposed soft tissue to be removed from the fracture site. Once reduced with an open technique, the fracture is stabilized with percutaneous pins.

Controversies in Treatment

MANAGEMENT OF MINIMALLY DISPLACED FRACTURES. There is debate regarding the necessity of closed reduction and pinning for all displaced supracondylar fractures, particularly minimally displaced type IB or II fractures. A number of studies report good results with closed reduction and casting of displaced fractures.[25,196,208,383] However, other studies note superior results with closed reduction and pinning.[1,16,81,335,345,399,535] Although we recognize that some minimally displaced fractures may be managed successfully without pin fixation, we believe there are several potential hazards to the cast management of minimally displaced supracondylar fracures. Type IB fractures with medial column collapse or comminution are difficult, for two reasons. First, they may be more unstable than appreciated on initial radiographs (Fig. 41–57). If treated with simple immobilization, these "occultly unstable" fractures are likely to displace into varus and hyperextension, producing a malunion and a cosmetically unacceptable result. Second, even if stable, the collapse of the medial column may produce enough varus and hyperextension to produce a poor result if not reduced.[111,361] There are also two potential problems with closed reduction and cast management of type II fractures. The first is loss of reduction, and the second is increased swelling and the potential development of compartment syndrome secondary to immobilization with the elbow in flexion. The difficulty of cast management of minimally displaced fractures is demonstrated in the study of Hadlow and colleagues.[196] They reported good results in 37 of 48 type II fractures managed with closed reduction and casting without pin fixation. They concluded that pin fixation of *all* type II fractures would result in "unnecessary" pinning 77 percent of the time. However, they failed to acknowledge that cast treatment produces an unacceptable result in the remaining 23 percent of cases. Obviously, the problem is identifying correctly which fractures are at risk for malunion. To our knowledge there are no reliable predictors of malunion, and many studies have reported superior results with percutaneous pinning of displaced supracondylar fractures.[111,361,407] Therefore, we prefer closed reduction and pinning for all type IB and type II supracondylar humeral fractures. Although this aggressive management may lead to a few "unnecessary" pinnings, we believe it also results in the fewest complications.

TIMING OF REDUCTION FOR TYPE III FRACTURES. Although there is growing agreement that pin fixation yields the best results for type III fractures, there is some controversy regarding the timing of treatment. Traditionally, type III fractures were regarded as an orthopaedic emergency that had to be treated immediately. Recently, however, good results have been reported when type III fractures were treated on an urgent rather than emergency basis.[241,333] Those who advocate delayed treatment cite the advantages of an adequate NPO status and a more efficient operative setting.

Provided that the skin is intact and not tented, the swelling is minimal, and the neurovascular examination is normal, we will allow an 8- to 10-hour delay to avoid operating on these fractures in the middle of the night. Patients with type III injuries that are treated in delayed fashion are splinted in extension, with care to ensure that the proximal fragment is not displacing the skin, and are admitted for elevation and observation until definitive treatment. Patients in whom the skin is compromised, the swelling is severe, or the neurovascular examination is abnormal are treated with closed reduction and pinning on an emergency basis.

PINNING TECHNIQUE AND IATROGENIC ULNAR NERVE INJURY. The technique of pin placement and management of iatrogenic ulnar nerve injury are also controversial topics. Although several biomechanical studies have shown that crossed pins are the most stable configuration, recent reports have shown good clinical results with parallel lateral pin fixation.* Although more stable, the crossed-pin technique requires placement of a medial pin, which may injure the ulnar nerve.† Skaggs and colleagues, in a review of 369 supracondylar fractures, reported that the incidence of ulnar nerve injury could be decreased from 15 percent to 2 percent by placing two lateral pins, followed by the selective use of medial pins only for those fractures that remain unstable after placement of the lateral pins.[473] In this technique, the lateral pins are placed in a parallel or divergent fashion to provide maximal rotational control. The arm is then extended and examined under fluoroscopy. If the fracture remains unstable, a third pin can be placed medially with the arm in extension (Fig. 41–58). This technique not only allows placement of the medial pin with the elbow in the safer extended position (see Fig. 41–53), it also provides a "safety net" of two lateral pins. If an iatrogenic ulnar nerve injury is noted postoperatively, the medial pin can be removed and two pins will still be present, usually providing adequate stability.

We use both the crossed-pin and the double lateral/selective medial pin techniques. We believe the most important factor in the pinning technique is not where the pins are inserted, but where they cross the fracture site. Stability is increased by maximizing the distance between the pins at the fracture sites. This can be accomplished by "dividing the fracture into thirds" with the pins, regardless of whether pin placement is lateral or medial (see Fig. 41–51).

Treatment of iatrogenic ulnar nerve injury is also controversial. Although iatrogenic ulnar nerve injury almost always recovers, there are case reports of permanent injury.[81,234,257,415,435] Thus, we believe that an ulnar nerve palsy associated with a medial pin requires immediate treatment. Initially, we ensure the elbow is immobilized in an extended position. Often the ulnar nerve is not directly injured by the K-wire but is stretched around the medial pin when the elbow is in a flexed position (see Fig. 41–53). If the elbow is adequately extended, or if extension does not alleviate the ulnar nerve symptoms, management is controversial. Immediate removal of the pin is the best treatment for the nerve palsy but may result in loss of reduction and subsequent malunion. Some surgeons, citing the nearly universal likelihood of ulnar nerve recovery, favor leaving the medial pin until the fracture is united. Others prefer immediate

*See references 19, 81, 180, 257, 304, 361, 415, 473, 514, 549, 569.

†See references 234, 257, 304, 340, 415, 435, 514.

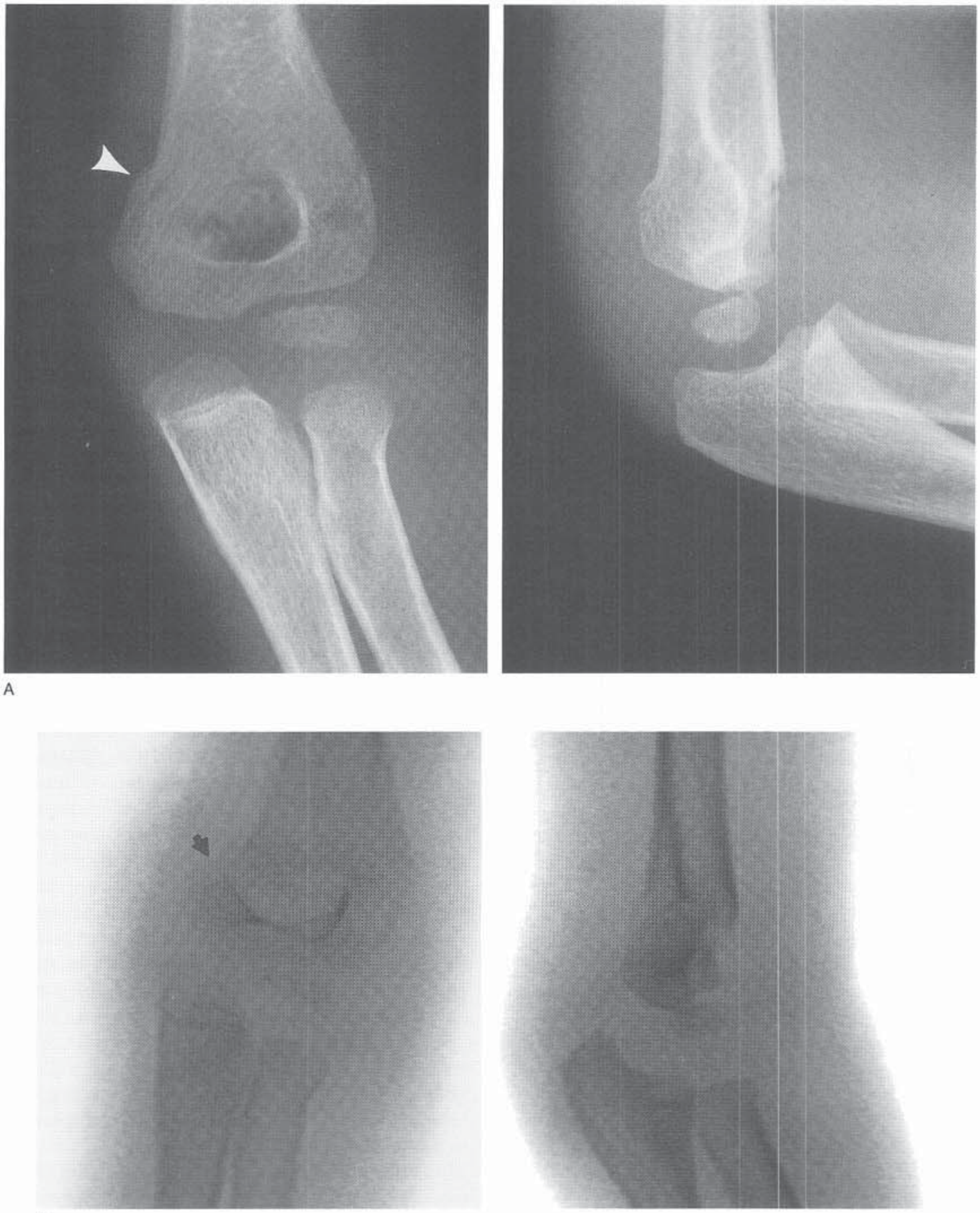


FIGURE 41–57 Unstable type IB supracondylar humeral fracture. **A,** Initial AP and lateral radiographs showing minimal medial comminution (*arrowhead*) and slight hyperextension. **B,** Intraoperative "stress" radiographs showing significant varus and hyperextension instability.

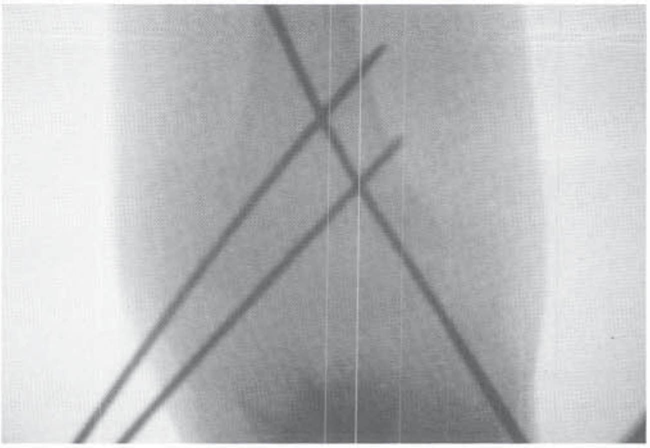


FIGURE 41–58 AP radiograph showing fracture pinned using the two lateral pin, selective medial pin technique.

removal of the pin to limit the possibility of a permanent nerve palsy (a functional problem), therefore risking malunion (a cosmetic problem). We most commonly remove the pin at the time of diagnosis. As previously discussed, use of two lateral pins and a selective medial pin provides additional stability should the need arise to remove the medial pin.

MANAGEMENT OF THE VIABLE, PULSELESS HAND. Controversy exists regarding the best management of the "pulseless pink hand." The elbow's abundant collateral circulation allows the distal extremity to remain viable despite complete disruption of the brachial artery (Fig. 41–59). Recommendations for management of a "viable" but pulseless hand range from observation to arteriography to immediate surgical exploration.* Several groups have shown that the hand can remain viable, and a radial pulse can even return, after ligation of the brachial artery.[84,529] Nevertheless, some authors recommend aggressive surgical attempts to restore a normal pulse because of concern that conservative management of a pulseless, viable extremity could lead to progressive ischemia due to thrombus formation or future problems with cold intolerance, exercise claudication, or growth discrepancy.† Interestingly, although a number of papers discuss cold intolerance and exercise claudication, only Marck and colleagues actually described a patient with either of these symptoms.[315] They described a patient who had normal function but cold intolerance 4 years after a supracondylar fracture associated with complete transection of the median nerve and brachial artery. The median nerve had been repaired but the artery was ligated because of good distal perfusion from collateral circulation. It is unclear whether the patient's symptoms (cold intolerance) were due to the vascular or the neurologic injury.

The study by Sabharwal and colleagues is unique in that the investigators attempted to determine the fate of vascular interventions using noninvasive vascular studies, including magnetic resonance angiography.[440] A normal pulse was restored in 13 patients with pulseless but viable extremities. Eleven of these patients underwent follow-up that included noninvasive vascular studies. Of these 11 patients, a normal pulse was restored with an open reduction in four, with urokinase therapy in three, with reverse vein patch angioplasty in three, and with end-to-end anastamosis in one. At follow-up, all patients were asymptomatic and had a normal radial pulse. Five had hypertrophic antecubital scars. Noninvasive vascular studies were normal in three of the four patients treated with open reduction and mobilization of an entrapped brachial artery, in two of the three patients treated with urokinase, and in two of the three patients treated with vein patch angioplasty. The remaining four patients all had noninvasive vascular studies that showed evidence of brachial artery stenosis.[440]

Our approach to a viable hand with abnormal pulses is close observation. We believe that the lack of clinical studies documenting late problems as well as the uncertain fate of aggressive surgical interventions supports a conservative approach to these injuries. It is important to realize that unidentified vascular pathology can lead to thrombus formation and subsequently to an ischemic limb.[62,92,457,463] Thus, continued close observation of these patients is of paramount importance. Although controversial, we have found pulse oximetry a valuable tool in monitoring these patients after closed reduction and pinning.[183,416,471] If a pulseless, viable limb becomes ischemic, arteriography and thrombolytic therapy may be useful adjuvants.[92,440]

MANAGEMENT OF THE LATE-PRESENTING OR MALREDUCED FRACTURE. Appropriate management of the patient who presents 1 to 2 weeks after injury with a nonreduced or unacceptably reduced fracture is often difficult to determine. Obviously, the condition of the skin and neurovascular structures are important factors to consider in determining treatment. Other factors include the age of the patient and the time since injury. Some surgeons advocate a "wait and see" approach to these fractures, arguing that attempts at manipulation once early callus begins to form may not improve the reduction and could risk increasing stiffness. This argument is strengthened by the knowledge that functional limitations following nonunion are rare. Others favor a more aggressive approach, attempting closed or even open reduction of these fractures. Unfortunately, there is little in the literature to guide the decision-making progress. Alburger and associates have shown that a 3- to 5-day delay before closed reduction and pinning is not deleterious.[11] Lal and Bhan reported good results in 20 children treated by open reduction 11 to 17 days after injury.[281] Vahvaven and Aalto recommended routine remanipulation at 2 weeks for all "redisplaced" fractures, without adverse sequelae.[521] We have had success with remanipulation of supracondylar fractures after delays of 2 to 3 weeks (Fig. 41–60). The management of these injuries must be determined on an individual basis and must take into account such factors as the patient's age, the condition of the soft tissues, the amount of residual deformity, and the amount of radiographic healing. It is important that treatment decisions regarding these "malreductions" be made with good information. Unfortunately, obtaining an adequate examination and radiographs in a young patient a few weeks after a displaced supracondylar fracture can be extremely difficult and may require an examination under anesthesia. We believe it is important to remember that

*See references 62, 70, 92, 100, 124, 163, 208, 239, 291, 315, 359, 403, 433, 440, 457, 459, 463, 526, 529, 544, 549.

†See references 62, 163, 315, 403, 457, 459, 463, 544.

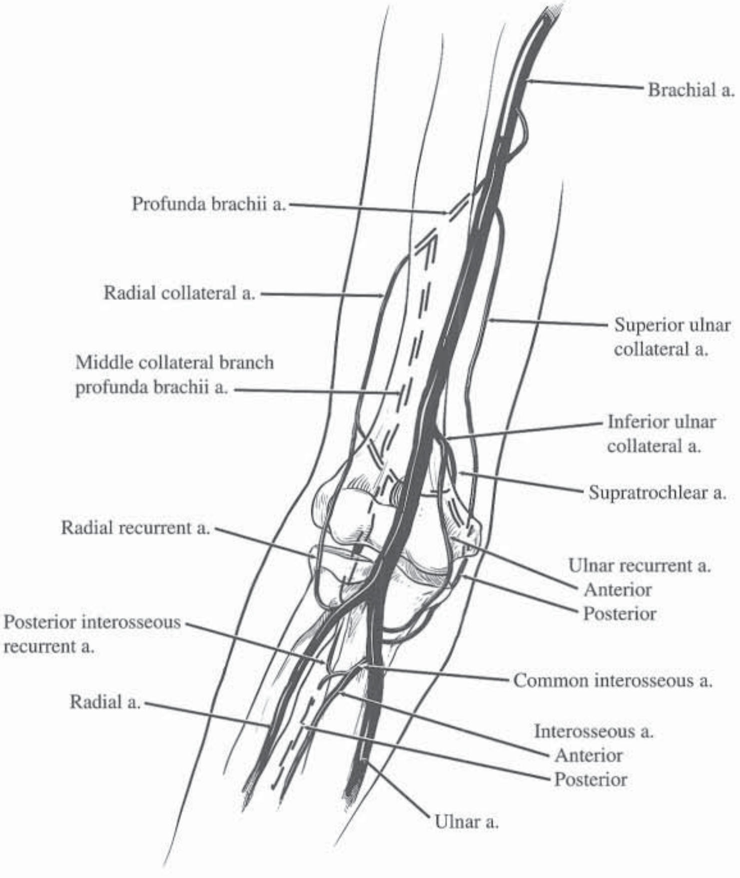


FIGURE 41–59 The collateral circulation around the elbow may provide adequate circulation to the forearm and hand despite complete brachial artery disruption.

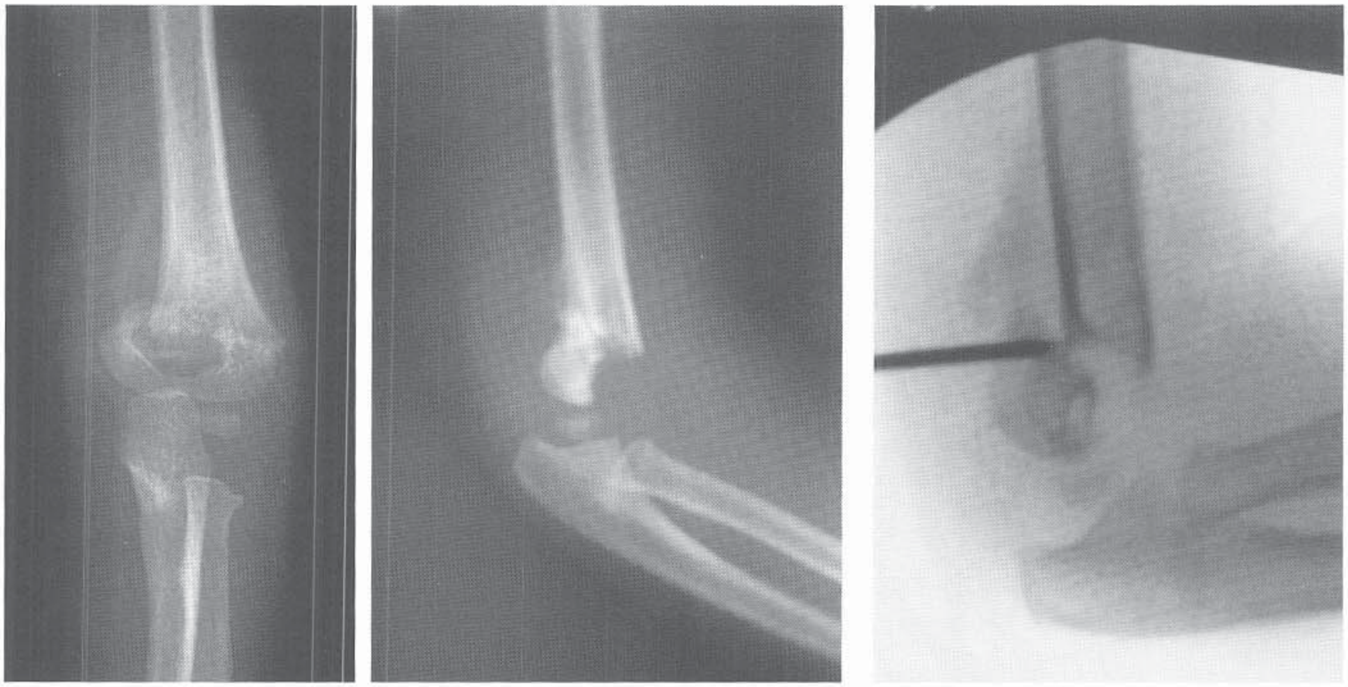
although functional limitations are uncommon with malunion of supracondylar humeral fractures, these injuries have little potential to remodel. Even a small improvement in alignment may represent the difference between a cosmetically acceptable result and one that is unacceptable. If an attempt is made to improve the alignment of a supracondylar fracture in delayed fashion, it is important to remember that an "anatomic" reduction may not be an achievable goal. In such a case, we will usually accept an "adequate nonanatomic" reduction rather than proceed to an open reduction.

Complications. The complications of supracondylar humeral fractures can be categorized as either early or late. Early complications include vascular injury, peripheral nerve palsies, and Volkmann's ischemia, or compartment syndrome. Late complications include malunion, stiffness, and myositis ossificans. Although attention to detail at the time of initial treatment may limit the long-term sequelae of early complications and minimize late complications, the severity of the injury and nature of the anatomy make problems from supracondylar fractures unavoidable.

VASCULAR INJURY. The incidence of vascular compromise in type III extension supracondylar fractures has been reported as between 2 and 38 percent.* The reported incidence varies with the definition of vascular compromise, as this term has been used to describe a wide variety of patients, including those with a diminished pulse, without a pulse, or with an ischemic limb. Vascular injury may be induced either directly or indirectly. Direct injury by the fracture may result in complete transection of the brachial artery, an intimal tear, or compression either between the fracture fragments or over the anteriorly displaced fragment.[485] Indirect injury is usually the result of compression. Compression can produce temporary ischemia that is reversible with reduction, reversible spasm, or permanent sequelae such as intimal tears, aneurysms, or thrombosis.[100] If the level of vascular injury, whether produced directly or indirectly, is distal to the inferior ulnar collateral artery, the rich collateral circulation about the elbow will usually provide adequate blood supply to the forearm and hand (see Fig. 41–59).

The management of acute vascular injury associated with supracondylar fractures of the humerus is controversial and must be individualized. The initial treatment consists of a thorough evaluation of the skin and neurologic status, as well as assessment for other injuries. If the hand is obviously ischemic, the arm should be immediately manipulated into an extended postion. Often this will immediately restore circulation to the hand (see Fig. 41–47). If improving the alignment fails to provide distal circulation, the child should be taken immediately to the operating room for closed reduction and pinning. We do not believe arteriography is warranted prior to an operative attempt at closed reduction, for two reasons. First, reduction of the fracture will frequently restore circulation. Second, even if the limb remains ischemic following reduction, the location of the arterial pathology is known. Thus, an arteriogram provides little information that will alter the clinical management but can

*See references 70, 92, 100, 124, 301, 359, 381, 433.



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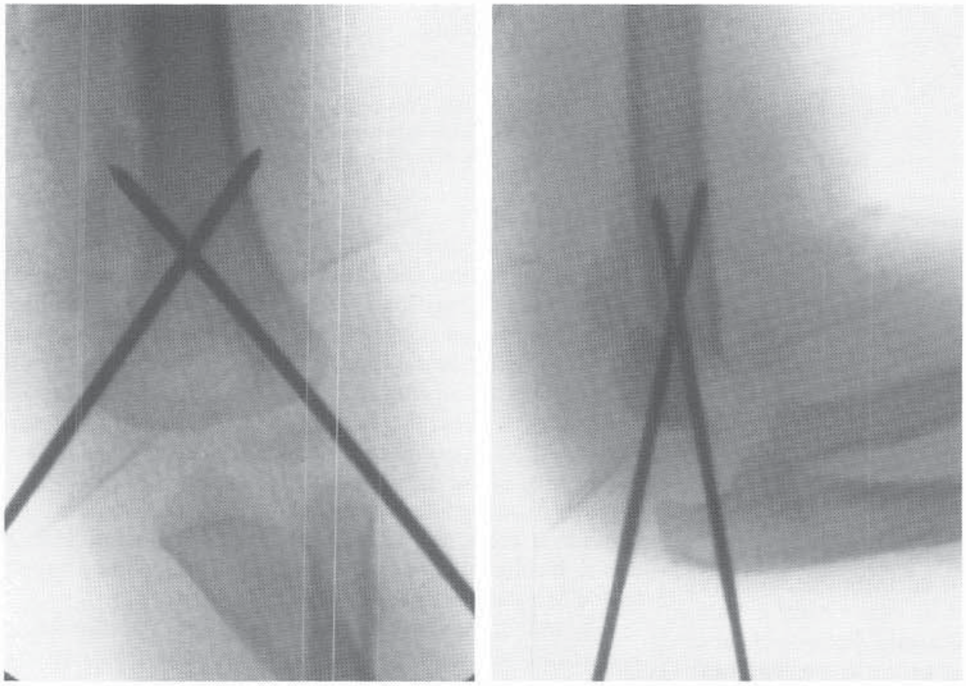


C

FIGURE 41–60 **A,** AP and lateral radiographs of a type III supracondylar humeral fracture first seen 10 days after the injury. Despite radiographic evidence of early callus formation, a closed reduction was attempted. **B,** Intraoperative radiograph showing "percutaneous osteoclasis" which was necessary to improve the sagittal alignment. **C,** AP and lateral radiographs obtained following reduction and pinning.

significantly prolong the ischemic time. Similarly, we do not generally obtain preoperative vascular or microsurgical consultation, as the ischemia often resolves with reduction. If the limb remains ischemic, the exposure of the brachial vessels can be performed while awaiting the arrival of a vascular surgeon or microsurgeon. If on exploration the artery is found to be trapped witin the fracture fragments, the pins can be removed, the artery liberated, the fracture repinned, and the circulation of the limb reassessed. Spasm and intimal lesions of the brachial artery may require arteriography for complete assessment. This can usually be obtained intraoperatively with little difficulty using standard fluoroscopy. Spasm may be relieved with a stellate ganglion block or local application of papaverine, or it may require resection and reverse interpositional vein grafting. These decisions are usually made in conjunction with a vascular or microsurgeon. It is important to remember to perform fasciotomies if there has been significant ischemic time, or there is any concern regarding elevated compartment pressures.

As previously discussed, the management of a limb that is initially ischemic but becomes viable with reduction or of a viable limb with a "deficient pulse" is controversial. Options include observation, noninvasive studies, arteriography, and exploration.* We favor a conservative approach with close observation. It is important to realize that although a pulse difference is relatively common and frequently inconsequential, it may be the earliest sign of a potentially devastating complication. Arterial spasm or compression initially producing only a diminished pulse can progress to complete thrombosis, ischemia, and potentially to a compartment syndrome. Although we do not routinely use arteriography in the initial management of supracondylar fractures with a vascular injury, the review by Sabharwal and associates points out the potential benefit of arteriography in a patient with a deteriorating examination, as interventional radiographic techniques may allow effective treatment of spasm or thrombosis without surgical exploration.[440]

PERIPHERAL NERVE INJURY. Peripheral nerve injury occurs in approximately 10 to 15 percent of supracondylar humeral fractures.† There is a growing consensus that the anterior interosseous nerve is the most commonly injured nerve with extension-type supracondylar fractures, although the median, radial, and ulnar nerves may all also be damaged.[99,124,178,491,549] Anterior interosseous nerve palsy is probably underreported because it is not associated with a sensory loss. Median nerve injury has been reported more commonly with posterolaterally displaced fractures and radial nerve injury with posteromedial displacement. Although ulnar nerve injury may occur as a consequence of the fracture, the ulnar nerve is more commonly injured iatrogenically from a medial pin.‡ Perhaps the single most important, and often the most difficult, aspect of managing peripheral nerve injuries associated with supracondylar humeral fractures is the challenge of reaching an accurate and timely diagnosis. Unfortunately, it is often impossible to obtain an adequate neurologic examination in a young child with a supracondylar humeral fracture in the emergency room. Thus, it is imperative to counsel the parents that as time progresses, there is a chance that a nerve injury will be discovered. Fortunately, the parents can be reassured that nearly all of these injuries will spontaneously improve. Because peripheral nerve palsies can be expected to recover spontaneously, little treatment is required other than close monitoring for recovery, and perhaps splinting and/or range-of-motion exercises to ensure that a fixed contracture does not develop. Although most peripheral nerve injuries will recover fully, there are numerous reports of those that do not.§ Thus, if within 8 to 12 weeks function is not returning, consideration should be given to performing nerve conduction and electromyographic studies to ensure that the nerve has not been transected. If a peripheral nerve is found to be transected, appropriate reanastomosis with grafting or tendon transfers should be undertaken.

VOLKMANN'S ISCHEMIC CONTRACTURE (COMPARTMENT SYNDROME). In 1881, Richard von Volkmann described ischemic paralysis and contracture of the muscles of the forearm and hand, and less frequently of the leg, following the application of taut bandages in the treatment of injuries in the region of the elbow and knee. He suggested that the pathologic changes primarily resulted from obstruction of arterial blood flow, which, if unrelieved, would result in death of the muscles.[531] Fortunately, with improved management of elbow fractures in children, the incidence of Volkmann's ischemic contracture following supracondylar humeral fractures is decreasing.[92,134,338] However, this potentially devastating complication may still develop despite appropriate care.[37]

The pathophysiology, diagnosis, and management of compartment syndrome are discussed in Chapter 39, General Principles of Managing Orthopaedic Injuries. A supracondylar fracture associated with a compartment syndrome is usually best managed with closed reduction and pinning. Following decompression of a compartment syndrome, proper splinting and active and passive range-of-motion exercises for the extremity are essential to maintain joint mobility until function returns.

MALUNION: CUBITUS VARUS AND CUBITUS VALGUS. Cubitus varus and cubitus valgus are the most common complications of supracondylar humeral fractures. The reported incidence ranges from zero to 50 percent.* In general, posteromedially displaced fractures tend to develop varus angulation and posterolaterally displaced fractures tend to develop valgus deviation. Cubitus varus deformity is more commonly noted to be a problem than cubitus valgus, probably because posteromedial fractures are more common. However, varus deformity may be more frequently reported simply because it is more cosmetically noticeable. Although some authors have suggested that angular deformity is a result of growth imbalance,[238] the consensus opinion is that cubitus varus and valgus are the result of malunion (Fig. 41–61).†

Cubitus varus or valgus is assessed by measuring the carrying angle of the arm. The carrying angle is the angle created by the medial border of the fully supinated forearm and the medial border of the humerus with the elbow extended (Fig. 41–62). It is important to remember that the carrying angle exhibits considerable individual variation.[36,480] Thus, comparisons should be made with the contralateral side rather than with any "normal standard." As the elbow extends, the carrying angle decreases ("more varus"); thus, hyperextension tends to accentuate cubitus varus deformity while a flexion contracture can create the appearance of cubitus valgus. Smith has demonstrated that changes in the carrying angle are a result of angular displacement or tilting of the distal fragment, not translation or rotation.[480] However, rotation of the distal fragment can contribute to the cosmetic deformity of a malunion.[420] In fact, a residual rotational deformity is nearly always present after corrective osteotomies for cubitus varus (Fig. 41–63).

Problems arising from cubitus varus or valgus include functional limitation, recurrent elbow fracture, and cosmetic deformity. Fortunately, functional problems are uncommon with either deformity. In cubitus valgus, functional problems may be related either to a coexisting flexion contracture or,

*See references 11, 70, 84, 92, 124, 291, 312, 440, 459, 485, 519, 526, 529, 535, 549.

†See references 27, 99, 124, 251, 262, 301, 485, 492, 505, 549.

‡See references 63, 81, 124, 234, 325, 340, 415, 435, 514.

§See references 63, 70, 81, 99, 124, 234, 238, 239, 325, 404, 415, 435, 441, 549.

*See references 7, 19, 25, 28, 41, 59, 81, 215, 224, 230, 238, 307, 365, 407, 420, 472, 480, 514, 521, 543, 547, 549, 564.

†See references 19, 25, 81, 365, 407, 472, 480, 521, 543, 547, 549.

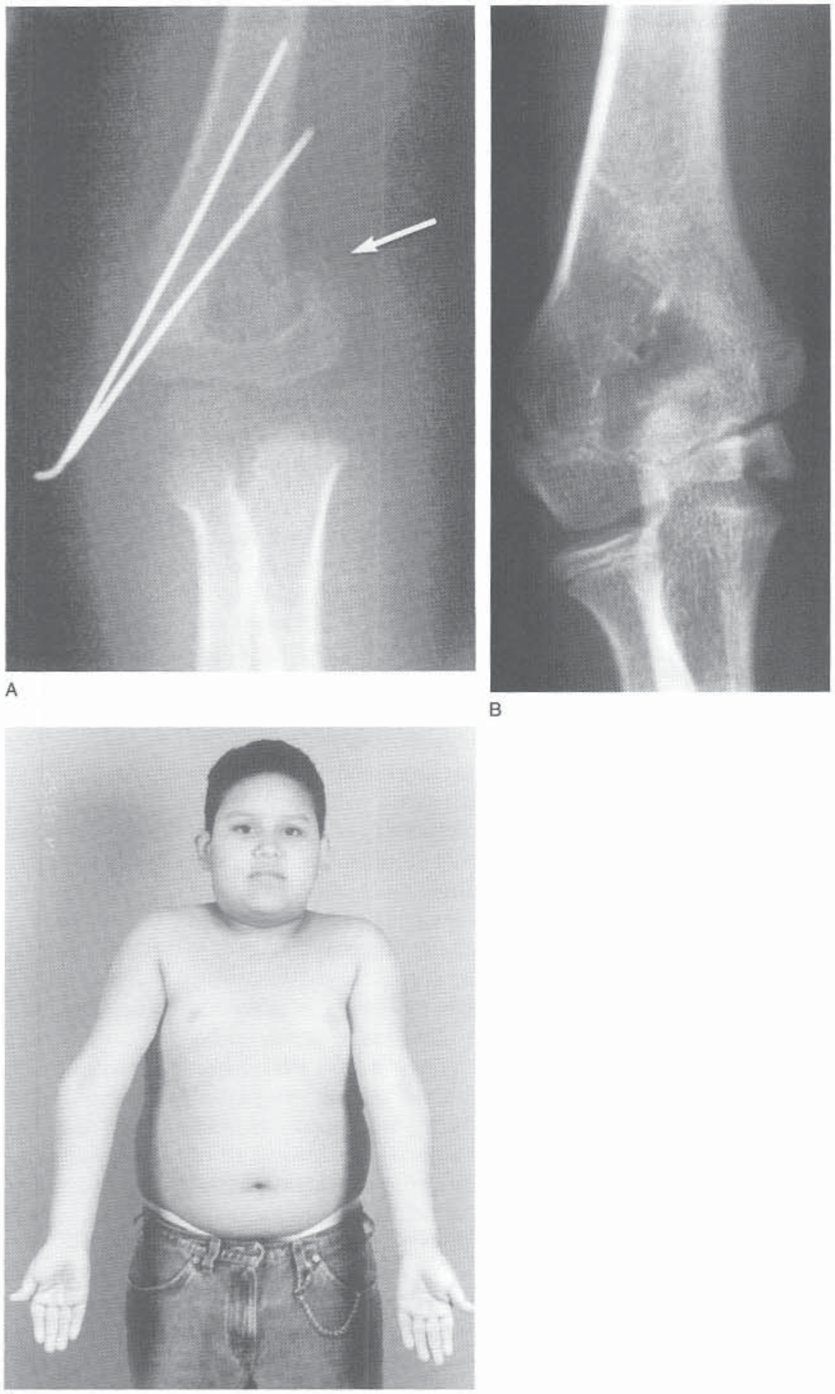


FIGURE 41–61 Malunion producing cubitus varus. **A,** The fracture has been reduced and pinned in varus. Note the shortening of the medial column (*arrow*). **B,** Varus malalignment persists 6 years after injury. **C,** Clinical appearance.

in extreme cases, to tardy ulnar nerve symptoms.[110,215,224,286,547] With cubitus varus, functional problems are almost always related to a limitation of flexion, although tardy ulnar nerve palsy and elbow instability have also been reported as functional complications of varus deformity.[166,293,354] The limitation of flexion is a result of the hyperextension associated with varus malunion. Usually the arc of elbow motion remains constant. Thus, varus/hyperextension malunion creates a flexion deficit. If significant, this flexion deficit can interfere with activities of daily living.[520,564] Lateral condyle fractures, or the less commonly distal humeral epiphyseal separation, have also been described as potential complications of varus malunion.[108,508] Davids and colleagues have shown that the torsional moment and shear force generated across the capitellar physis by a routine fall are increased by varus malalignment.[108] However, cosmetic deformity is by far the most common problem associated with malunion of supracondylar fractures.

Unfortunately, due to the limited growth and the fact that deformity is most commonly perpendicular to the plane of motion, there is little potential for angular malunion of the distal humerus to remodel; therefore, the best treatment of malunion of a supracondylar humeral fracture is avoidance.[278] Awareness of the pitfalls associated with obtaining

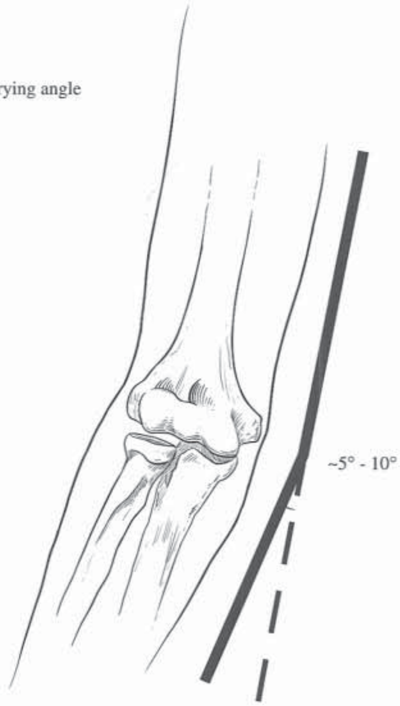
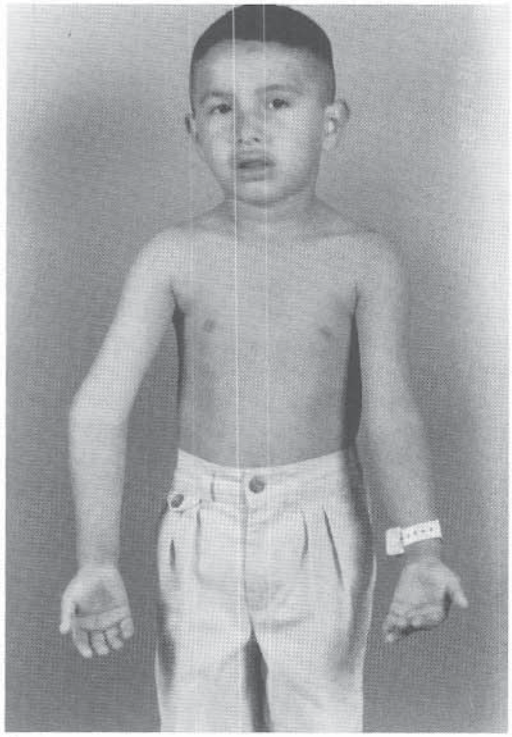


FIGURE 41–62 The carrying angle is that angle defined by the border of the fully supinated forearm and the long axis of the humerus when the elbow is fully extended.

and maintaining an adequate reduction will aid the orthopaedist in minimizing both the occurrence of malunion and the degree of deformity when it does occur. Because both cubitus valgus and varus are primarily cosmetic deformities, mild degrees of malunion can be treated with simple reassurance. However, if the deformity is severe, cosmetic concerns, or less commonly functional limitations, may warrant surgical reconstruction. The reported complication rate with corrective osteotomy is between 30 and 50 percent; thus it is important to explain to the parents that surgical reconstruction is a technically demanding procedure with no well-defined indications other than "unacceptable cosmesis."*

Loss of fixation and persistent deformity are the most common complications following corrective supracondylar osteotomy.† In an effort to limit these complications, a wide variety of osteotomy and fixation techniques have been described. Osteotomy techniques include medial or lateral closing wedge, step-cut, and dome osteotomies. Fixation has been described with crossed pins, staples, screws, screws and tension wires, plates and pins, and external fixation.‡ In considering which of these techniques to use, it is important to consider the patient and the individual deformity. Most patients have a complex three-dimensional deformity that includes a significant component of rotational malunion of



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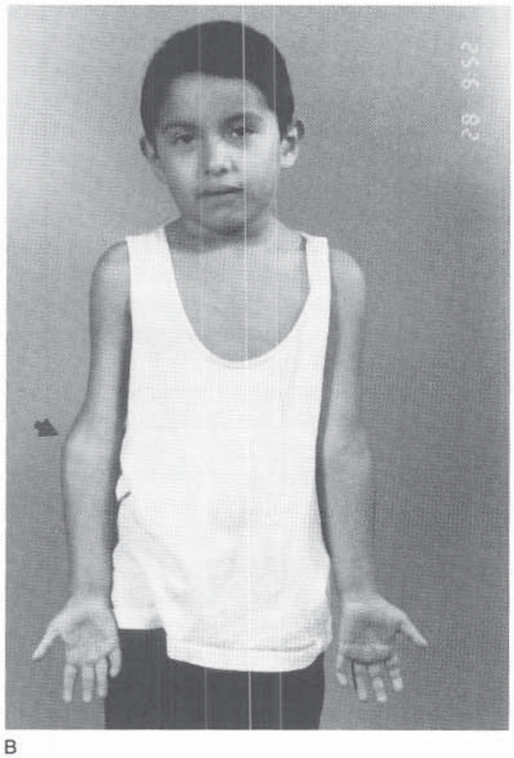

B

FIGURE 41–63 Persistent rotational deformity. **A,** Preoperative clinical appearance. Note significant cubitus varus. **B,** Postoperatively, the carrying angle is improved. However, there is still a significant rotational deformity on the lateral aspect of the distal humerus (*arrow*).

*See references 2, 25, 30, 40, 55, 115, 167, 217, 219, 294, 319, 351, 354, 379, 520, 532, 547.

†See references 30, 55, 115, 167, 217, 294, 319, 351, 379, 520, 532, 547.

‡See references 30, 40, 53, 55, 115, 118, 167, 217, 219, 259, 272, 273, 294, 319, 351, 354, 364, 379, 420, 520, 532, 536, 547.

the distal fragment. There is also frequently hyperextension in the sagittal plane. In our experience, the distal rotational deformity is not correctable with any of the described techniques. The sagittal plane deformity may be corrected; however, flexion of the distal fragment makes the osteotomy significantly less stable and increases the demands on the fixation. We most commonly use a lateral closing wedge osteotomy with single-plane correction and crossed-pin fixation (Fig. 41–64). This technique is usually performed through a lateral incision and has the advantage of being stable and technically simple. It is important to note, and to forewarn the parents, that this technique may actually increase the prominence of the lateral condyle, which may create the appearance of persistent cubitus varus (Fig. 41–65). We have also utilized a medial opening wedge osteotomy with external fixation and no bone graft (Fig. 41–66).[273,536] This technique affords a more cosmetic medial incision and fixation that is stable enough to allow sagittal plane correction. Another advantage of this technique is that the alignment can be manipulated after the wound is closed. We have found this technique particularly helpful when there is significant hyperextension deformity (Fig. 41–67).

ELBOW STIFFNESS AND MYOSITIS OSSIFICANS. These are rare complications of supracondylar humeral fractures.* We usually assess the range of motion of the elbow 6 to 8 weeks after the cast has been removed. It is extremely unusual to identify more than a 10- to 15-degree difference in flexion or extension at this point. However, if significant stiffness is present, we begin a supervised home program of gentle range-of-motion exercises and continue to monitor the patient's progress on a monthly basis. Mild stiffness generally resolves with a few months of gentle therapy, although some patients may need more intensive therapy, including a splinting program. Persistent stiffness requiring surgical release is extremely uncommon. Mih and associates reported an average increase in range of motion of 53 degrees in nine pediatric patients who underwent capsular release through a lateral and, if necessary, medial approach.[341,386]

Myositis ossificans is an extremely unusual complication that has been noted to resolve spontaneously over 1 to 2 years (Fig. 41–68).

TRANSPHYSEAL FRACTURES

Transphyseal fractures usually occur in children less than 2 years old. The diagnosis is usually missed because in these young children the distal humerus is either entirely cartilaginous or nearly so, making interpretation of radiographs difficult. It is important for the orthopaedic surgeon to know that transphyseal fractures are the result of abuse in up to 50 percent of children less than 2 years of age.[9,114,336,369]

Anatomy. The anatomic considerations for distal humeral transphyseal fractures are the same as those for supracondylar fractures of the distal humerus. The young age and consequently small anatomy of the children who typically sustain these injuries may make the diagnosis and treatment difficult. Interestingly, despite sharing the same important anatomic considerations as supracondylar fractures, neurovascular complications are rarely reported with this injury.[2,112,114,225,326]

*See references 7, 98, 102, 208, 238, 281, 543.

Mechanism of Injury. The mechanism of injury depends on age. In the newborn and infant, there is usually a rotary or shear force associated with birth trauma or child abuse.* In the older child the mechanism is most commonly a hyperextension force from a fall on an outstretched hand.

Diagnosis. The most difficult aspect of the diagnosis is distinguishing a transphyseal fracture from an elbow dislocation. Other injuries in the differential include lateral condylar and supracondylar fractures. The key to distinguishing a transphyseal separation from a true elbow dislocation is the radial head-capitellum relationship.[437] In an elbow dislocation, the radial head does not articulate with the capitellum; however, in a transphyseal fracture the radial head and capitellum remain congruous (Fig. 41–69A). In the very young patient the capitellum may not be ossified, making the distinction difficult if not impossible.[9,50,428,487] In such cases, the correct diagnosis can be made with a high degree of suspicion and the knowledge that physeal separations are more common in this age group than elbow dislocations.[114] It may also be difficult to distinguish transphyseal separations from lateral condyle fractures that extend medial to the trochlear notch and consequently produce subluxation of the ulnar-humeral joint (Milch type II fractures) (see Fig. 41–35). In both of these injuries the radial head-capitellum relationship remains normal. Although oblique radiographs may assist in delineating these details, the distinction may require arthrography or MRI evaluation in the small child with little ossification of the distal humeral epiphysis.[9,202,352,437] Supracondylar fractures usually occur at the level of the olecranon fossa, whereas transphyseal separations are more distal (see Fig. 41–35).

Radiographic Findings. As with supracondylar fractures, obtaining good-quality radiographs of transphyseal separations is imperative but often difficult. Even under the best of circumstances, further evaluation may be required. Ultrasound, MRI, and arthrography have all been used in the evaluation of transphyseal separations.† Of these modalities, we have the most experience with arthrography, as it can be performed at the time of definitive therapy.

Classification. Although classification schemes for transphyseal separations exist, they are not clinically necessary. De Lee and colleagues separated transphyseal fractures into three groups based on their radiographic appearance.[114] Their criteria included the presence or absence of the secondary ossification center of the radial head and the presence and size of the metaphyseal fragment (Thurston-Holland sign). These radiographic parameters correspond to the age of the patient but add little to the clinical management.[326] These fractures may also be classified according to the Salter-Harris classification of physeal injuries.[444] In infants these injuries are most commonly Salter-Harris type I fractures. In older children they are usually type II injuries.

Treatment. The goal of treatment of transphyseal fractures is to achieve an acceptable reduction and maintain it until

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*See references 9, 31, 50, 80, 114, 321, 382, 454, 464.

†See references 9, 50, 121, 352, 369, 382, 437, 566.

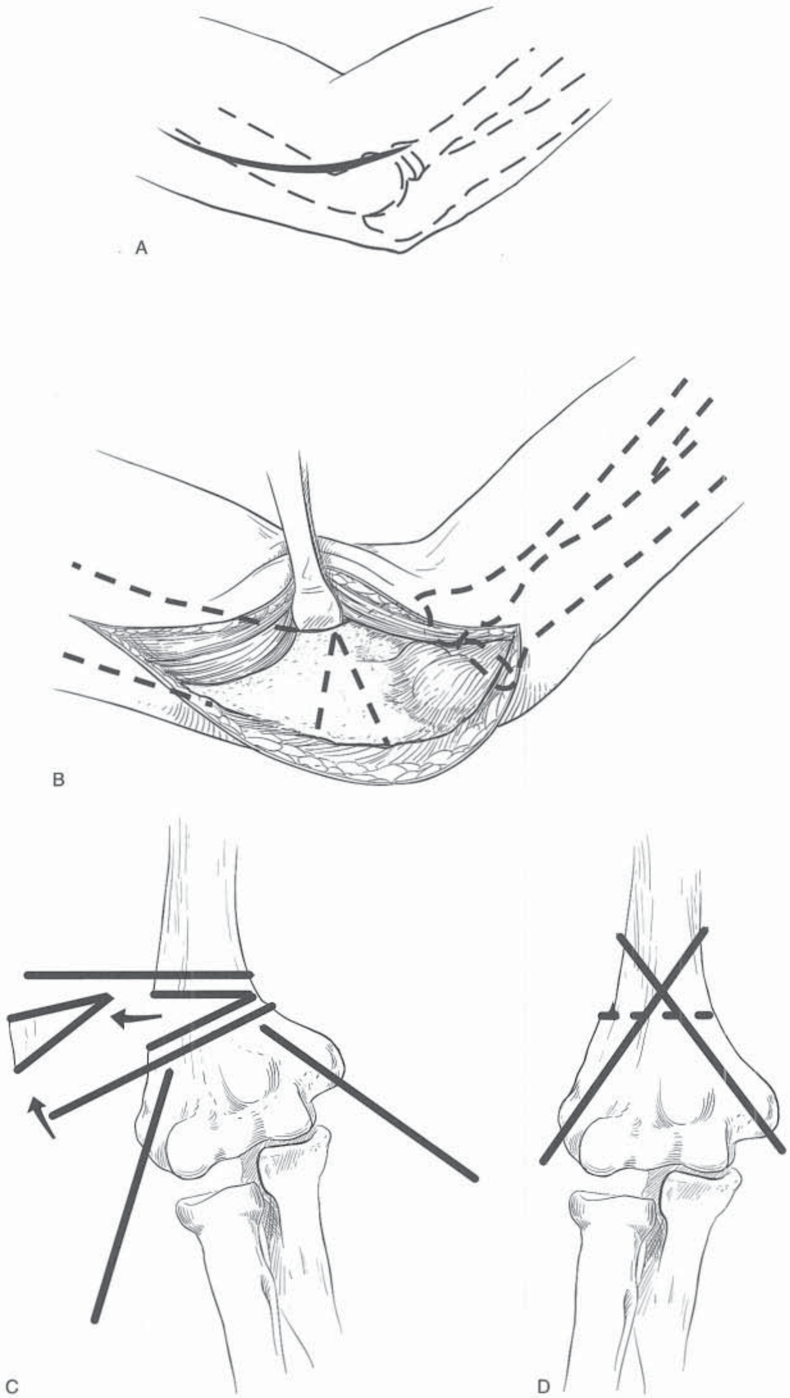
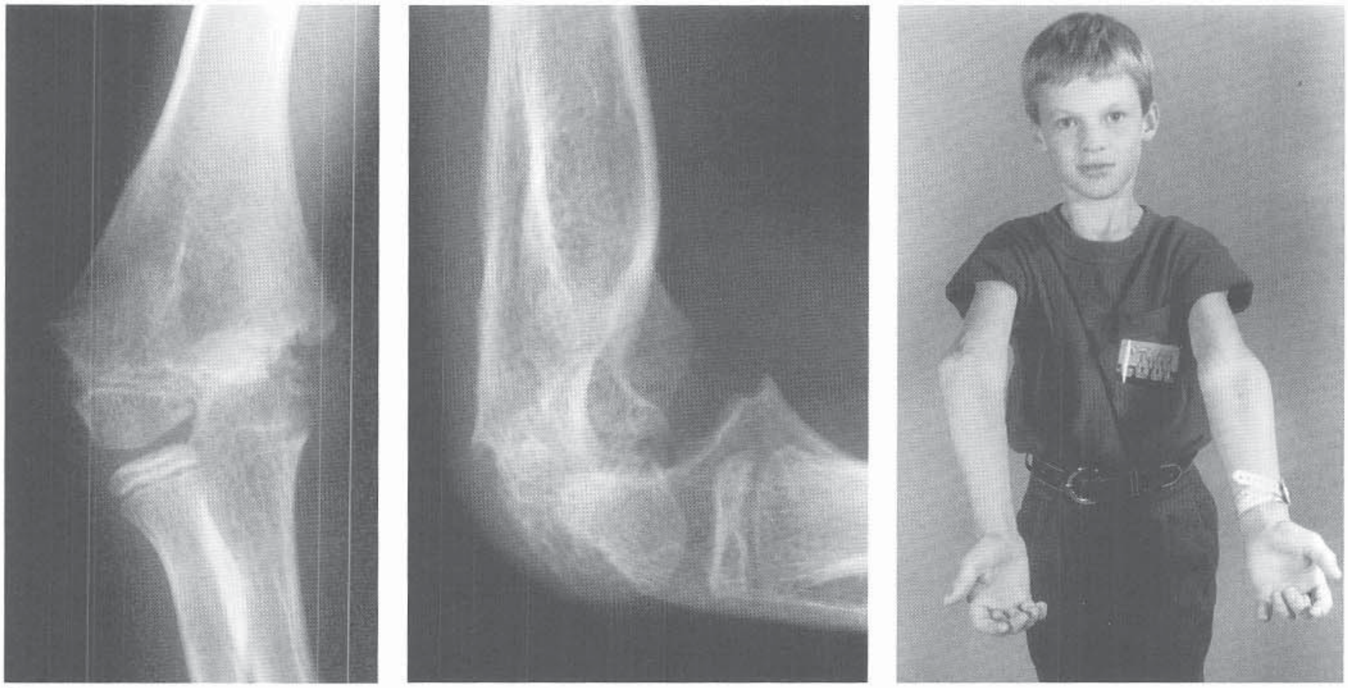


FIGURE 41–64 Technique for lateral closing wedge osteotomy for correction of posttraumatic cubitus varus. **A,** Skin incision. It is helpful to have the uninjured arm exposed in the anatomic position for intraoperative comparison. **B,** The lateral distal humerus is approached between the triceps and the common extensor origin. Care must be taken to avoid injury to the radial nerve with proximal exposure. Osteotomy sites are planned parallel to the joint and perpendicular to the humerus shaft. **C,** Medial and lateral pins are introduced prior to performing the osteotomies. A lateral wedge of bone is then removed. An attempt is made to preserve the medial cortex. **D,** The osteotomy site is closed and the pins are advanced into the proximal fragment.



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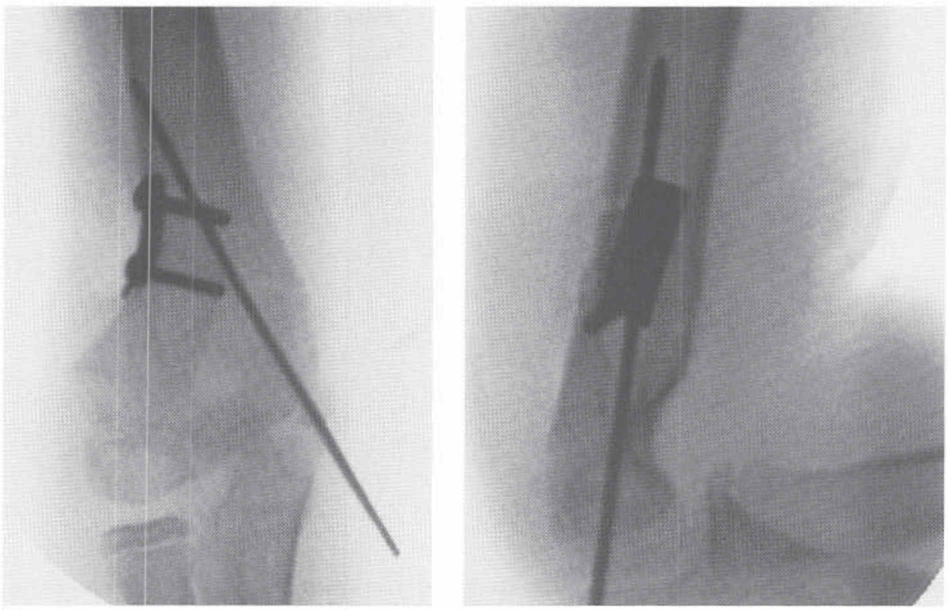
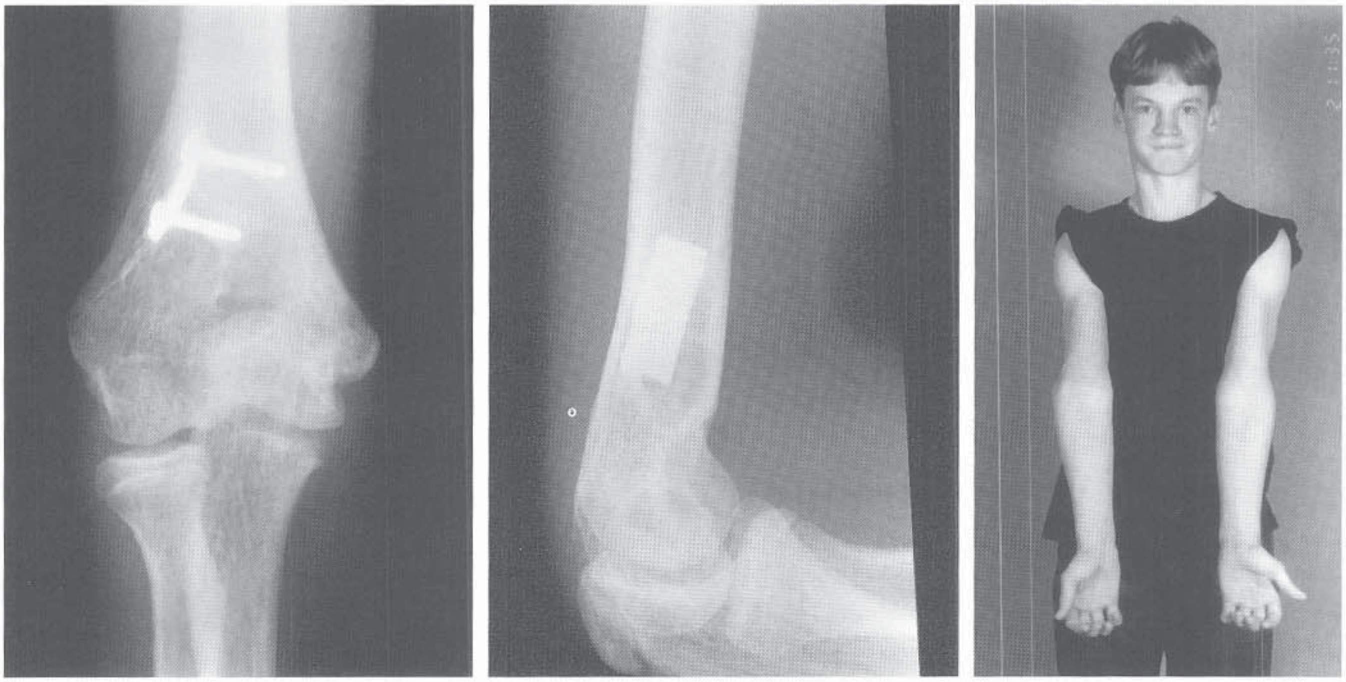


B

FIGURE 41–65 Example of lateral closing wedge osteotomy for cubitus varus. **A,** Varus malunion: AP and lateral radiographs and clinical appearance. **B,** Intraoperative radiographs obtained following a lateral closing wedge osteotomy. (A medial pin and lateral plate were used, rather than crossed pins.) Note the prominence of the lateral condyle.



C

FIGURE 41–65 *Continued.* **C,** Radiographic and clinical appearance 4 years postoperatively. Significant remodeling has occurred, and the clinical appearance has improved.

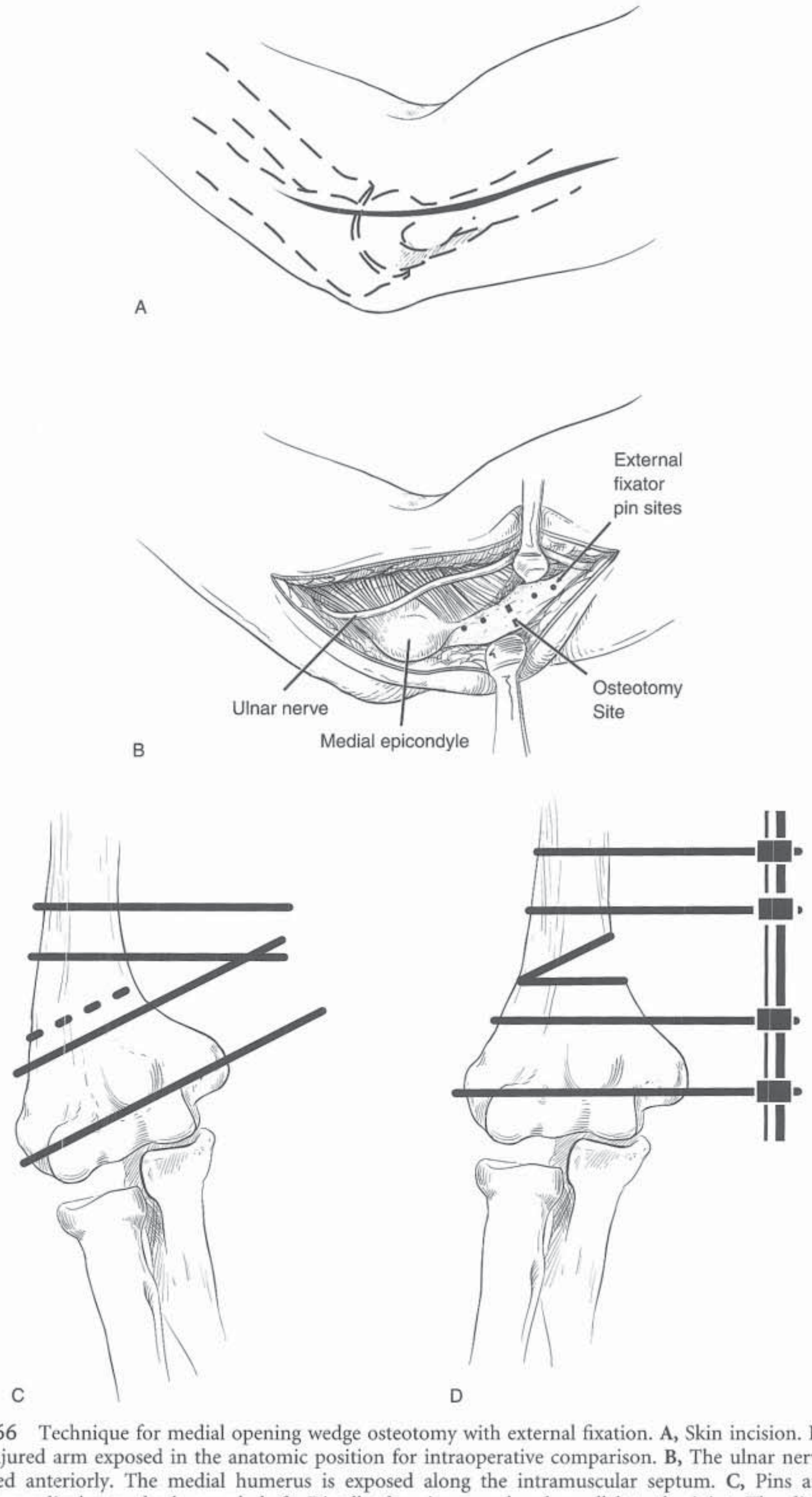


FIGURE 41–66 Technique for medial opening wedge osteotomy with external fixation. **A,** Skin incision. It is helpful to have the uninjured arm exposed in the anatomic position for intraoperative comparison. **B,** The ulnar nerve is dissected and transposed anteriorly. The medial humerus is exposed along the intramuscular septum. **C,** Pins are introduced proximally perpendicular to the humeral shaft. Distally the pins are placed parallel to the joint. The distal pin is just proximal to the medial epicondyle. The osteotomy can be made parallel to either group of pins. **D,** After completion of the osteotomy, the deformity is corrected in both planes and the correction is secured with the external fixator. The pins are brought out through the wound. The ulnar nerve is transposed into the flexor origin. Care should be taken to ensure the ulnar nerve does not contact the proximal pins.

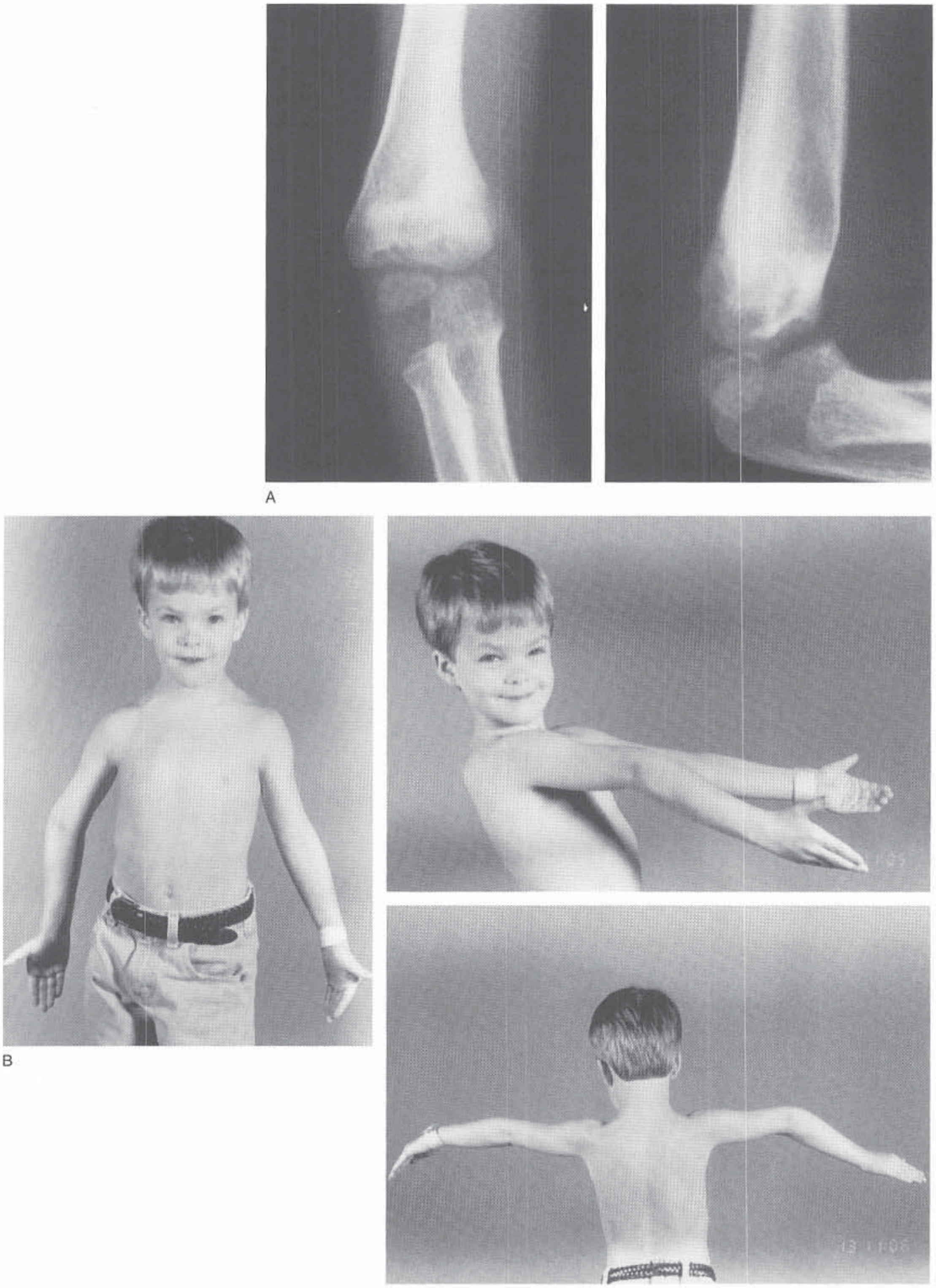


FIGURE 41–67 Medial opening wedge osteotomy to correct cubitus varus. **A,** Preoperative radiographs showing varus malunion with hyperextension. **B,** Preoperative clinical appearance. Note the significant hyperextension component of the deformity.

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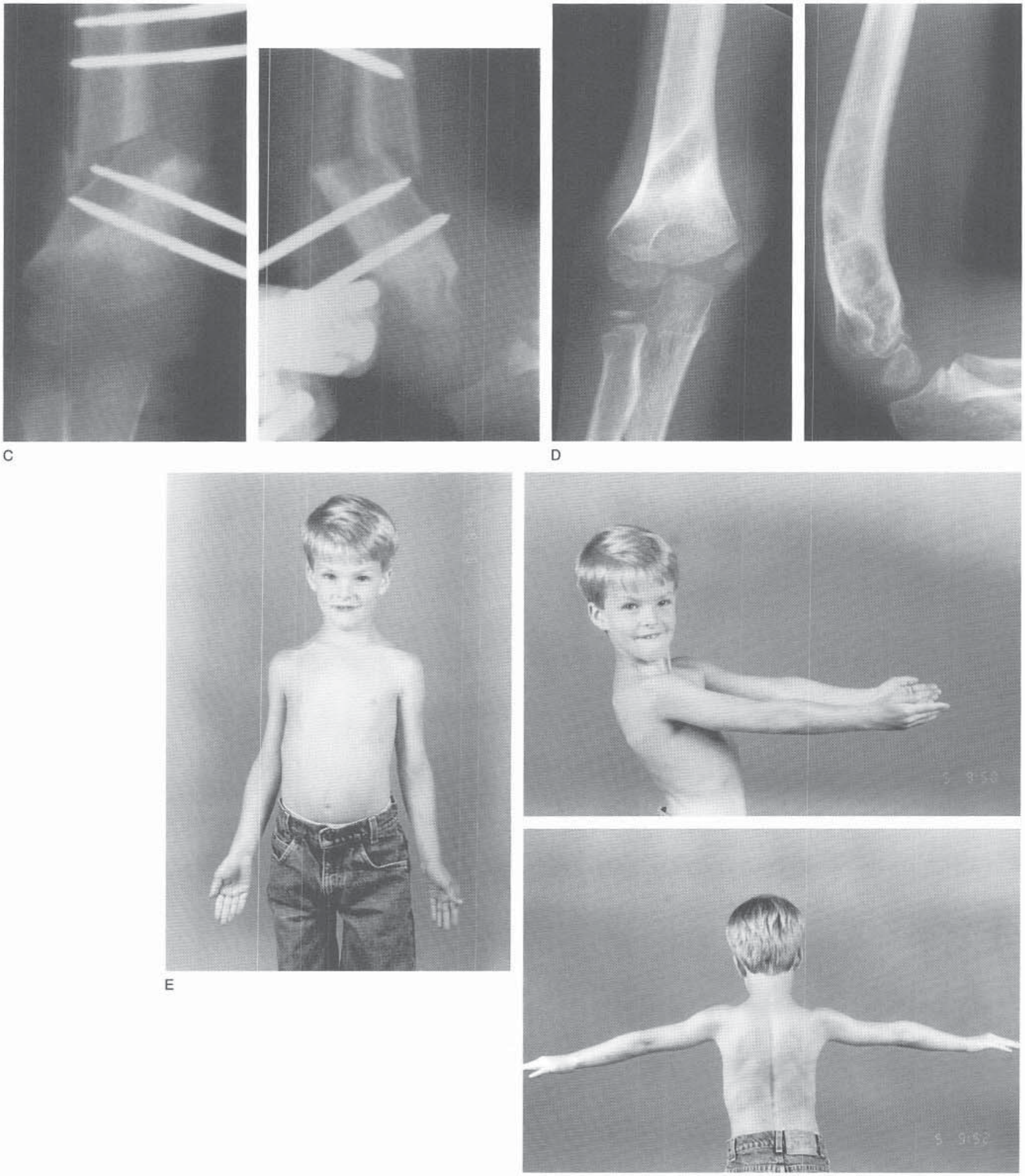
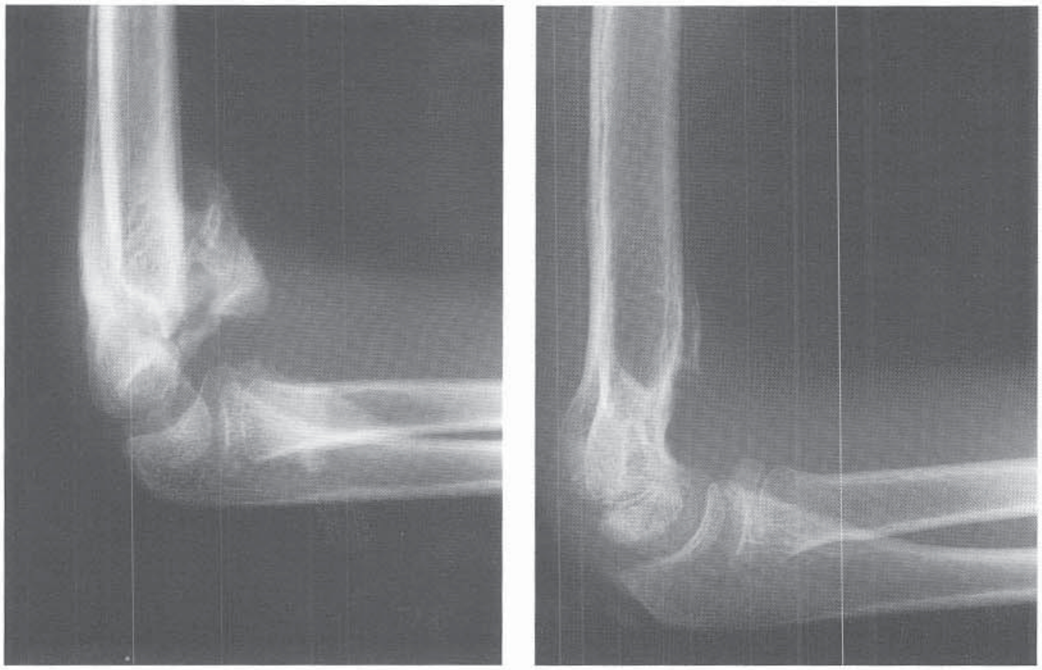


FIGURE 41–67 *Continued.* **C,** Immediate postoperative films showing the opening wedge osteotomy without a bone graft. The external fixator allows sagittal plane correction. **D,** AP and lateral radiographs obtained 1 year postoperatively. Significant remodeling has occurred. **E,** Clinical appearance 1 year postoperatively.



A B

FIGURE 41–68 Myositis ossificans following type III supracondylar humeral fracture. **A,** Lateral radiograph obtained 3 months after injury. Note the significant calcification in the anterior soft tissues. **B,** Three years after injury, the myositis has resolved without treatment.

the fracture unites, usually in 2 to 3 weeks. Some authors have advocated simple splint immobilization for transphyseal separations.[31,114,326,382] However, a number of investigators, including some of those who advocate cast treatment, have reported cubitus varus following simple immobilization of transphyseal fractures.[2,112,114,225] De Lee and associates noted that three of 12 patients, all less than 2, had significant varus following closed treatment. Abe and colleagues noted varus in 15 of 21 patients[2] and Holda and colleagues in five of seven.[225] Our experience has paralleled that of those authors who have reported significant cubitus varus following cast immobilization, particularly in patients less than 2 years old (Fig. 41–69). Consequently we favor closed reduction and pin fixation for most patients with transphyseal separations. The technique for reduction and pinning is identical to that for supracondylar fractures (Fig. 41–49). We have found arthrography helpful in delineating the pathology, and we do not hesitate to perform arthrography following pin fixation, or if necessary for diagnostic purposes, before reduction and pinning (Fig. 41–70). Following reduction and pinning the arm is immobilized in relative extension for 2 to 3 weeks, at which time the cast and pins are discontinued.

Complications. In infants, this injury is most frequently the result of a rotary or shear force applied by an adult. Thus, the most devastating potential complication of a transphyseal separation is failure to recognize the possibility of child abuse and to return a child to a dangerous environment. The re-injury rate of abused children is between 30 and 50 percent, and the risk of death is 5 to 10 percent.[8,47,170] In older children the mechanism of transphyseal separations is the same as for supracondylar fractures. Not surprisingly, the potential complications are similar, although neurovascular injuries are less common. The most significant and frequent orthopaedic complication of transphyseal separations is cubitus varus.[2,112,114,225,547] The management of varus deformity following transphyseal fracture is similar to that following supracondylar fractures (see earlier discussion under the heading Supracondylar Fractures of the Humerus). Deformity secondary to avascular necrosis has also been reported following transphyseal separation.[358,565,567]

LATERAL CONDYLE FRACTURES

Fractures of the lateral humeral condyle are transphyseal, intra-articular injuries. As such, they frequently require open reduction and fixation. In fact, they are the second most common "operative" elbow injury in children, second in frequency only to supracondylar fractures.[283] Lateral condyle fractures may be difficult to diagnose and have a propensity for late displacement, factors that make their treatment perilous.

Anatomy. The pertinent anatomic considerations in lateral condyle fractures include the capitellum, the lateral epicondyle, and the soft tissues attached to it, namely the extensors and supinator. The capitellum is the first secondary ossification center of the elbow to appear, usually around 2 years of age. The lateral epicondyle is the last, often not appearing until 12 or 13 years of age (see Fig. 41–29). The two ossification centers fuse at skeletal maturity.[487] Fractures of the lateral humeral condyle originate proximally at the posterior aspect of the distal humeral metaphysis and extend distally and anteriorly across the physis and epiphysis into the elbow joint. The fracture line may extend through the ossification center of the capitellum or may extend more medially, entering the joint medial to the trochlear groove. If the fracture

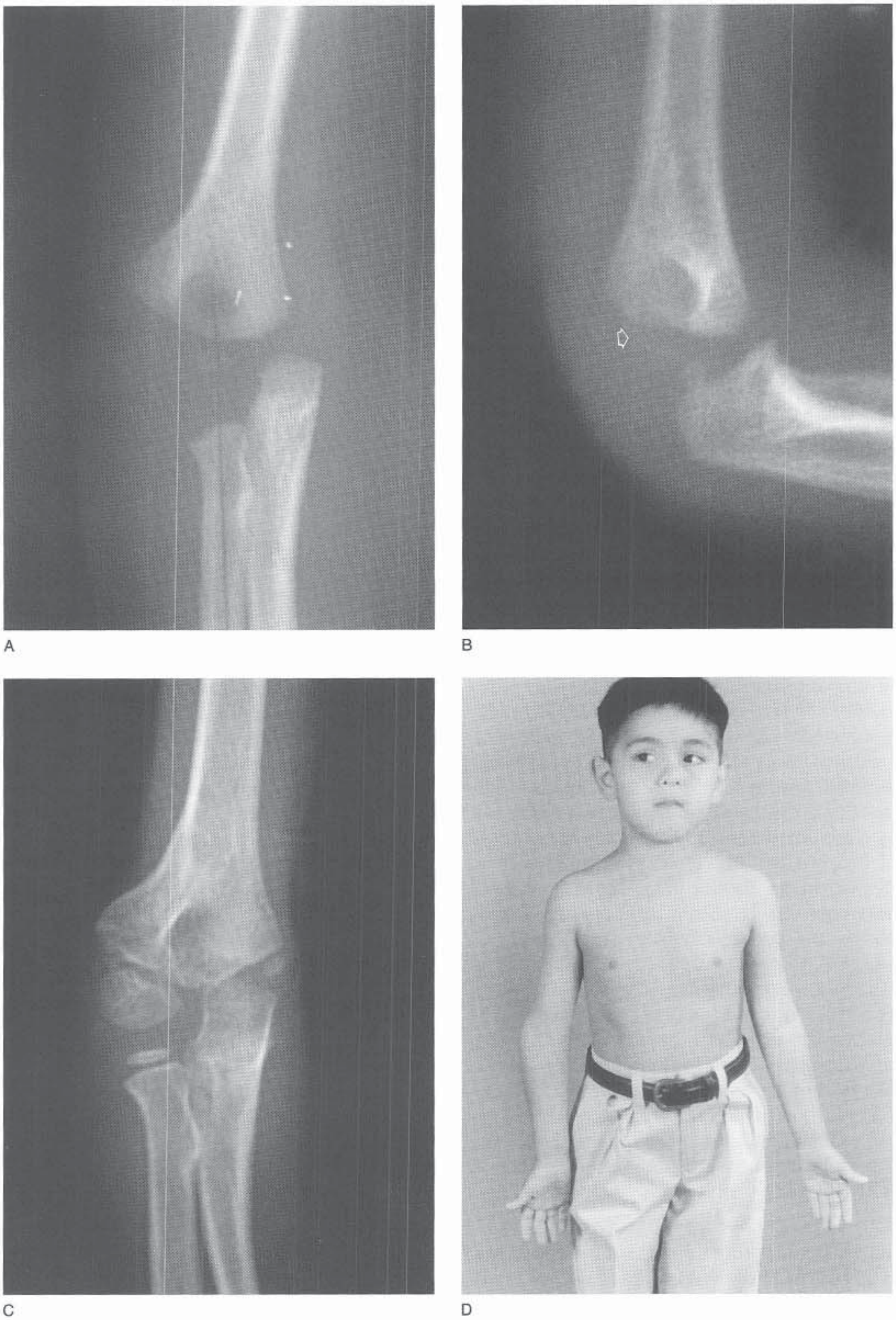
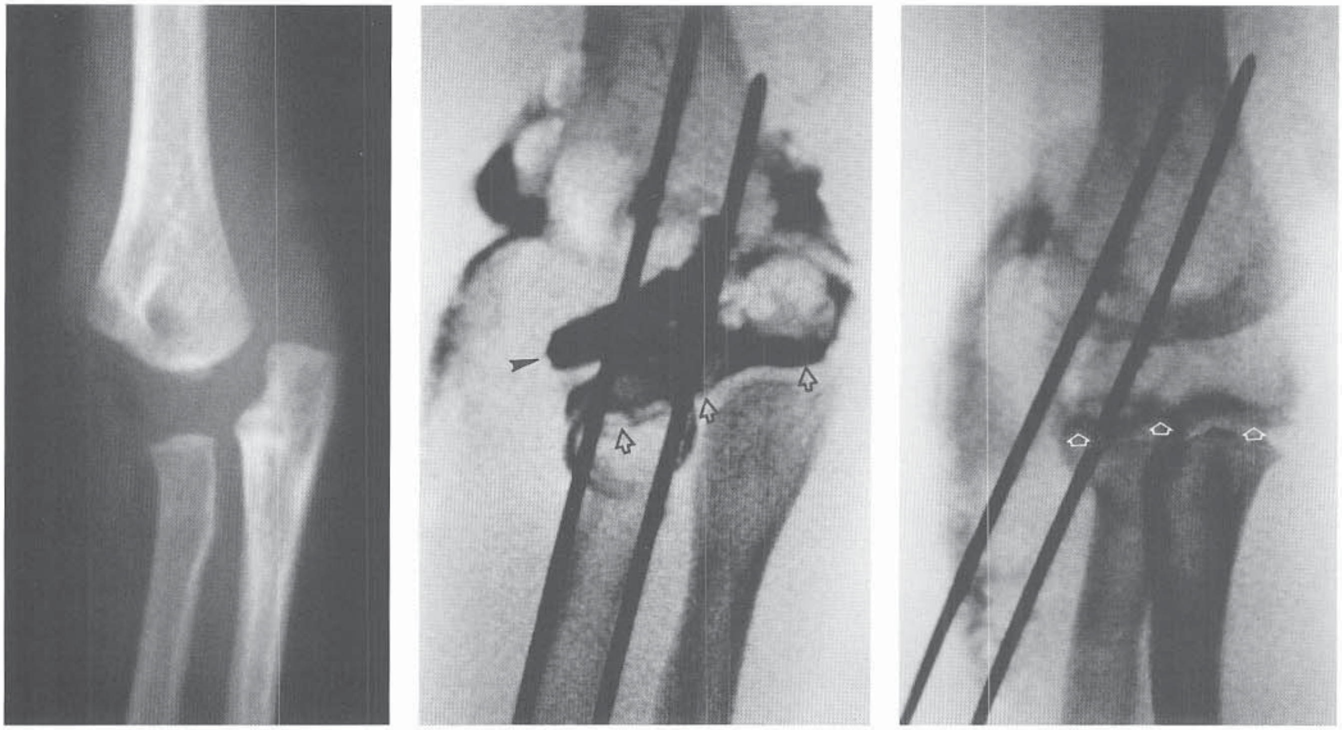


FIGURE 41–69 **A,** AP radiograph of transphyseal separation of the distal humerus. The medial translation of the forearm gives the appearance of an elbow dislocation; however, the radius and capitellum remain congruent. **B,** Lateral radiograph of transphyseal separation. Note the small posteriorly based metaphyseal (Thurston-Holland) fragment (*arrow*). The patient was treated with closed reduction and cast immobilization. **C,** AP radiograph 3 years after injury shows varus malunion. **D,** Clinical appearance 3 years after the injury.



A B C

FIGURE 41–70 **A,** AP radiograph of transphyseal separation of the distal humerus. The radius and capitellum remain congruent despite the medial translation of the forearm. **B,** Arthrogram obtained after an initial attempt at closed reduction and pinning. Note the varus alignment of the joint surface (*open arrows*) and the dye spreading laterally between the metaphysis and the distal fragment (*arrowhead*). **C,** Arthrogram obtained after remanipulation. The joint surface is now anatomically reduced (*open white arrows*).

extends medially to the trochlear groove, the elbow may be unstable and dislocate.

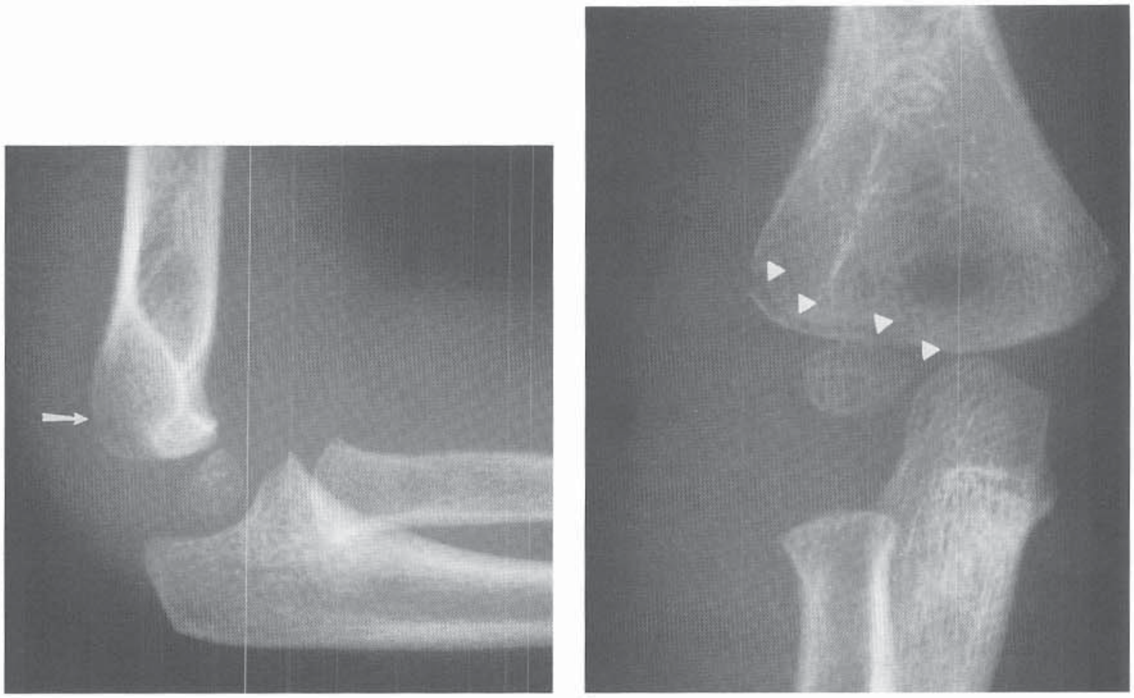
Mechanism of Injury. Lateral condylar fractures are usually the result of a fall on an outstretched arm. The fall may produce a varus stress that avulses the lateral condyle, or a valgus force in which the radial head directly "pushes off" the lateral condyle.[244]

Diagnosis. As with all elbow injuries, the diagnosis of lateral condyle fractures may be obvious or frustratingly subtle. The child with a minimally displaced fracture may present with complaints of pain and decreased range of motion. The differential diagnosis in these patients includes transphyseal fractures, minimally displaced supracondylar or radial neck fractures, "nursemaid's elbow," and infection. Close examination (often not possible in the child with a grossly displaced fracture) may reveal isolated lateral tenderness. A careful history should be elicited to ensure a clear, immediate, traumatic onset of the pain, as a history of "minor trauma" is often associated with a delay in the diagnosis of an infectious process. Radiographically, it is often difficult to distinguish between transphyseal fractures and lateral condyle fractures. Both may have a posteriorly based Thurston-Holland fragment on the lateral radiograph (Figs. 41–69 and 41–71). The distinction is made by examining the AP radiograph (see Fig. 41–35). In transphyseal fractures the radial head-capitellum relationship remains intact. In displaced lateral condyle fractures the capitellum is laterally displaced in relation to the radial head. Additionally, transphyseal fractures are more likely to exhibit posteromedial displacement and lateral condyle fractures are more likely to exhibit posterolateral displacement.

Radiographic Findings. The hallmark radiographic finding is the posteriorly based Thurston-Holland fragment in the lateral view (Fig. 41–71A). In minimally displaced fractures, the AP radiograph may show little abnormality, although the fracture line may be seen running parallel to the physis (Fig. 41–71B). Oblique radiographs or arthrograms are often helpful in identifying minimally displaced fractures.[316,347,524] Recently, a few groups have reported using MRI to help identify which fractures are at risk for late displacement. However, currently this technique has little clinical value.[229,258]

Classification. There are several schemes for classifying lateral condyle fractures. The best known is the one described by Milch.[342] A Milch type I fracture extends through the secondary ossification center of the capitellum, entering the joint lateral to the trochlear groove. In a Milch type II injury, the fracture extends medial to the trochlear groove, making the ulnar-humeral joint unstable (Fig. 41–72). Unfortunately, although widely known and frequently used, the Milch classification provides little prognostic information regarding treatment and potential complications.[348]

Lateral condyle fractures involve the physis of the distal humerus and therefore can also be classified according to the Salter-Harris classification. Some controversy exists as to the appropriate Salter-Harris classification of lateral condyle fractures. We believe, with Salter, that all of these fractures begin in the metaphysis, cross the physis, and exit through



A B

FIGURE 41–71 **A,** Lateral radiograph of a minimally displaced lateral condyle fracture. The small, posteriorly displaced metaphyseal fragment (*arrow*) is often difficult to see. **B,** AP radiograph demonstrating the fracture line (*arrowheads*) running parallel to the physis. The fracture extends across the physis into the joint.

the epiphysis, and should be classified as type IV injuries.[442,444] However, other authors have classified the Milch type II fracture as a Salter-Harris II injury, arguing that the secondary ossification center of the epiphysis is not involved. We believe the intra-articular, transphyseal nature of these fractures mandates that they be treated as Salter-Harris type IV injuries, with restoration of the articular surface. Regardless, because growth arrest is relatively uncommon following this injury,[438,525] the Salter-Harris classification also adds little useful clinical information.

Unfortunately, the classification that provides the most useful information is not clinically viable. In a cadaver study, Jakob and colleagues reproduced lateral condyle fractures and discovered that the lateral fragment was occasionally "hinged" on intact medial cartilage.[244] This fact explains the clinical behavior of lateral condyle fractures. Minimally displaced fractures with an "intact medial hinge" do not displace further and heal with simple immobilization. However, if the fracture extends completely into the joint, the fracture is at risk for late displacement and potentially nonunion (Fig. 41–73). Thus, the presence or absence of the medial hinge is the key diagnostic factor in lateral condyle fractures. Although a few studies have attempted to identify this hinge and classify lateral condyle fractures accordingly, there is to date no accepted, reproducible, clinically viable method to obtain this information.*

Finally, lateral condyle fractures may be classified as nondisplaced (traditionally less than 2 mm), minimally displaced (traditionally 2 to 4 mm), or displaced (traditionally greater than 4 mm).† We believe this classification provides the most clinically useful information, as it represents the current "best attempt" to identify fractures with an intact medial hinge.

Treatment. The treatment of lateral condyle fractures depends on the amount of fracture displacement. Although there is controversy regarding the treatment of nondisplaced and minimally displaced fractures, there is a consensus that displaced lateral condyle fractures require open reduction and fixation (Fig. 41–74).* Open reduction is performed through an anterior lateral approach. Because the blood supply of the lateral humeral condyle arises from the posterior soft tissues of the distal fragment, it is important that there be minimal dissection of the posterior soft tissues. Occasionally there is plastic deformation of the distal fragment, and so it is important to judge the reduction at the apex of the articular surface rather than by the lateral metaphyseal fragment. Fixation is usually achieved with smooth percutaneous pins, although screws and bioabsorbable pins have been used (Fig. 41–75).[88,228,309,458] Patients are usually immobilized with the elbow at 90 degrees for 4 weeks postoperatively.

The difficulty in treating lateral condylar fractures lies in differentiating "stable nondisplaced" fractures from "potentially unstable, minimally displaced" fractures. Unfortunately, there are currently no clinically applicable means of assessing the stability of the medial cartilaginous hinge. However, careful clinical and radiographic examination may offer important information with regard to the stability of fractures that appear minimally displaced radiographically. Oblique views are often helpful in assessing and follow-

*See references 32, 146, 152, 229, 244, 258, 316, 348, 510.

†See references 24, 32, 88, 146, 154, 347, 348, 388, 510.

*See references 24, 154, 222, 244, 348.

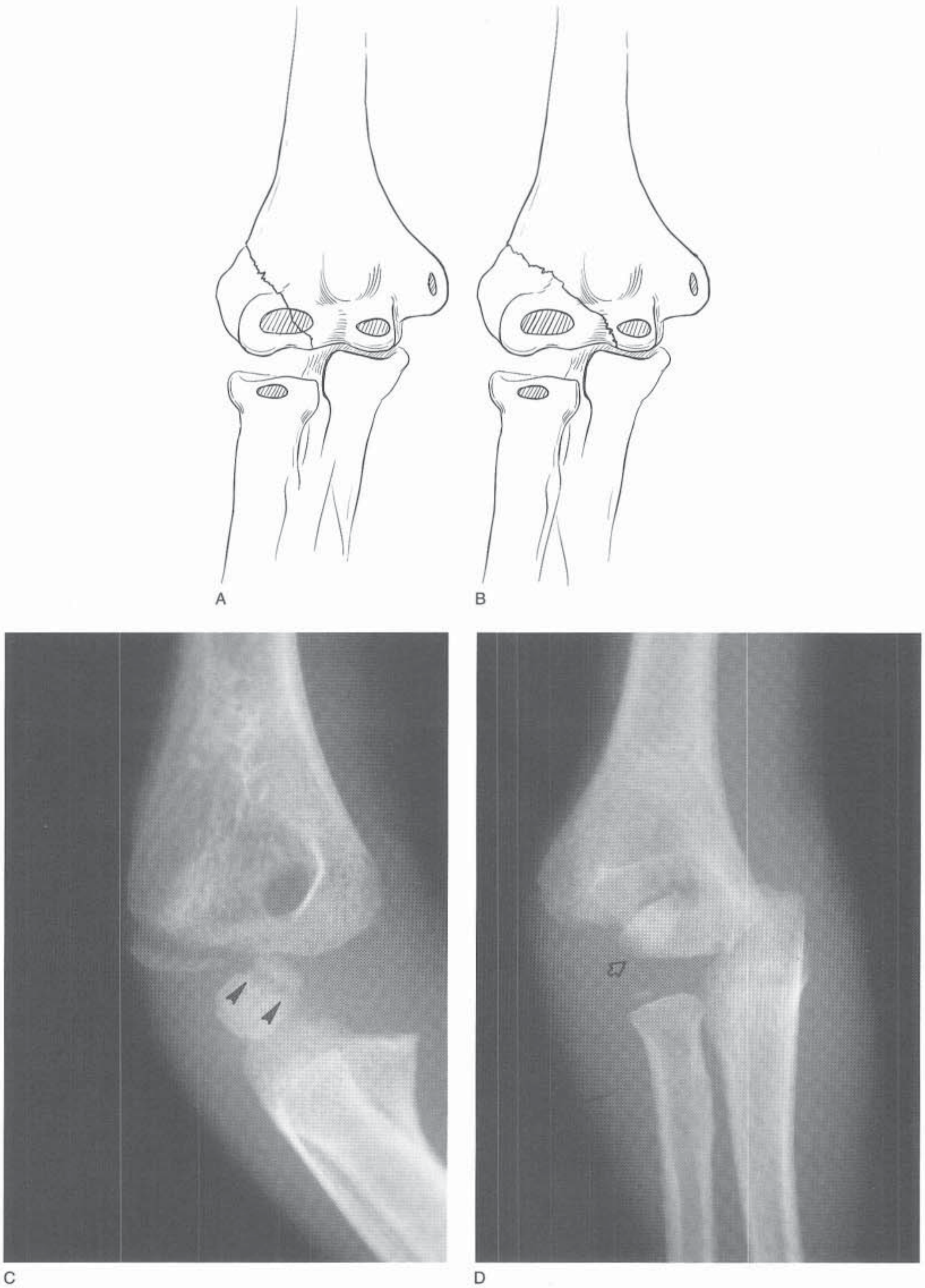


FIGURE 41–72 Milch classification of lateral condyle fractures. **A,** Type I—The fracture extends through the secondary ossification center of the capitellum. **B,** Type II—The fracture crosses the epiphysis and enters the joint medial to the trochlear groove. Thus, the ulnar-humeral joint is potentially unstable. **C,** AP radiograph of a Milch type I fracture. Note that the fracture extends through the secondary ossification center of the capitellum (*arrowheads*). **D,** AP radiograph of a Milch type II fracture of the lateral condyle. The forearm is displaced medially, giving the appearance of an elbow dislocation or a transphyseal fracture. Close examination reveals the radius to be grossly in line with the capitellum. However, the capitellar articular surface is subtly rotated (*arrow*).

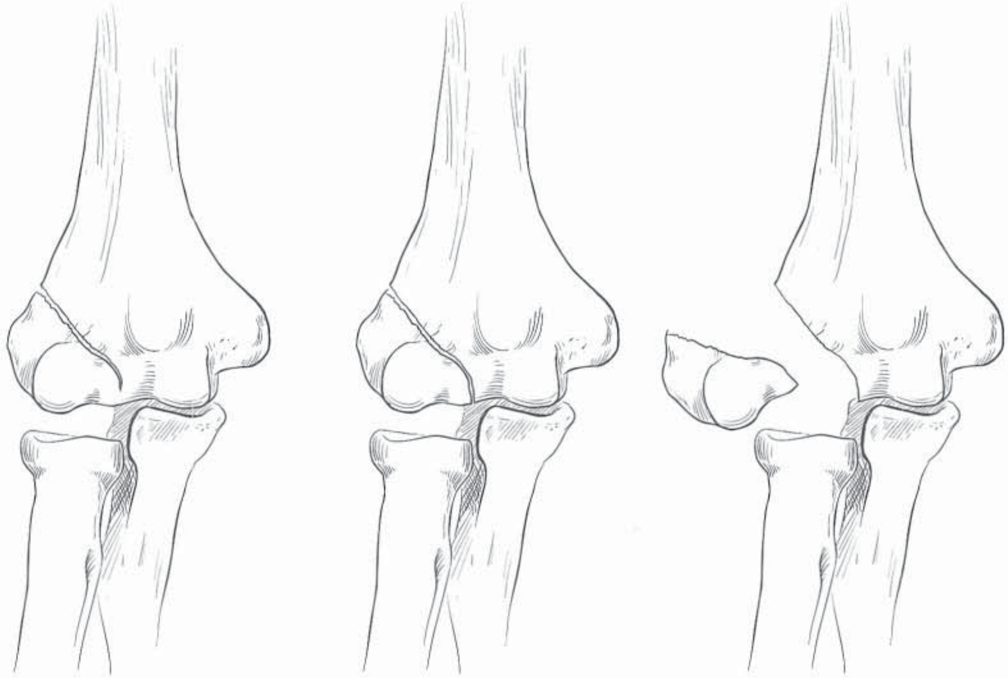


FIGURE 41–73 Classification of lateral condyle fractures based on the presence of an intact articular hinge. **A,** Type A: Fracture extends through the metaphysis and physis, but a portion of the articular cartilage remains intact. These fractures are stable, will not displace, and heal with immobilization. **B,** Type B: Fracture extends completely through the articular surface. Radiographically, this fracture may be impossible to distinguish from A. However, it is potentially unstable and at risk for late displacement and delayed or nonunion. **C,** Type C: Grossly displaced lateral condylar fragment (may be significantly rotated).

ing nondisplaced or minimally displaced fractures. Fracture displacement often appears greater on oblique radiographs. We believe that classification as a nondisplaced fracture requires an oblique radiograph with less than 2 mm of displacement. Significant lateral soft tissue swelling identified radiographically or clinically should alert the surgeon to a potentially unstable fracture. The presence of a lateral ecchymosis implies a tear in the aponeurosis of the brachioradialis and signals an unstable fracture, regardless of the radiographic appearance (Fig. 41–76). Similarly, palpable crepitus between fragments signals an unstable fracture, irrespective of the radiographic appearance.

If the fracture is nondisplaced or if there is other radiographic evidence that the medial articular hinge is intact, we treat the fracture with immobilization in 90 degrees of flexion and neutral rotation. Parents must be forewarned that the fracture can displace in the cast and that close follow-up is mandatory and surgery a possibility. Patients usually return 1, 2, and 4 weeks after the injury for radiographic assessment, which may require removal of the cast or splint. The cast is continued until radiographic healing is evident, usually 4 to 6 weeks. Patients are seen 6 weeks following cast removal to ensure that range of motion has returned. If there was any question regarding union at the time of cast removal, radiographs should be repeated at this time, although they are not routinely necessary.

The management of minimally displaced lateral condyle fractures is more controversial.* A number of authors have reported good results with conservative treatment of minimally displaced fractures. However, these reports all stress the possibility of late displacement and, consequently, potential delayed or nonunion (Fig. 41–77).[32,117,154] A recent report by DeVito and colleagues stressed the feasibility of cast immobilization. Eighty-two of 125 fractures had a fracture gap of 4 mm or less and were initially treated by a closed technique. Nine of the 82 fractures demonstrated late displacement, but only two required surgical treatment.[117] Others have advocated percutaneous fixation of minimally displaced lateral condyle fractures.[154,258,347] Mintzer and colleagues reported good results in 12 patients who had more than 2 mm of displacement and were treated with closed reduction and percutaneous pinning. They recommended arthrography to confirm a reduced articular surface.[347] We believe that treatment decisions for minimally displaced lateral condyle fractures must be made on an individual basis, and we use all three treatment techniques (casting, percutaneous fixation, and open reduction). Parents must thoroughly understand the importance of close follow-up if these fractures are to be treated conservatively. We have a low threshold for examination of these fractures under anesthesia with arthrography if necessary.

Complications. The most common complications following lateral condyle fractures include cubitus varus, lateral spur formation, delayed union, and nonunion, with or without cubitus valgus. Growth arrest and fishtail deformity of the distal humerus can also occur but are rarely clinical problems.

*See references 24, 32, 88, 146, 149, 151, 152, 154, 204, 244, 316, 347, 348, 388, 510, 525.

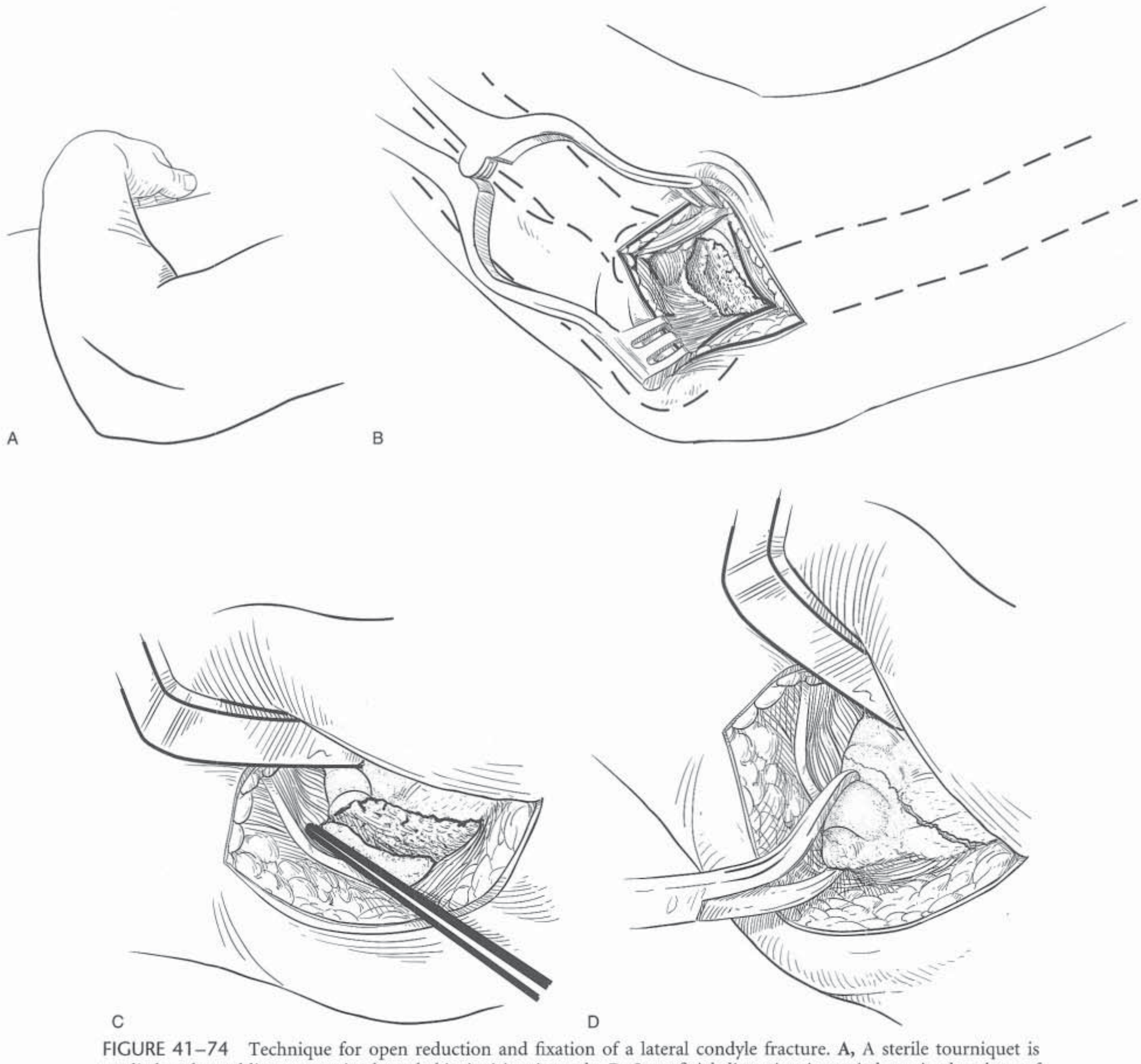


FIGURE 41–74 Technique for open reduction and fixation of a lateral condyle fracture. **A,** A sterile tourniquet is applied and an oblique posterior lateral skin incision is made. **B,** Superficial dissection is carried out in the plane of the fracture hematoma until the distal-lateral corner of the proximal fragment is identified. **C,** Once the metaphyseal side of the fracture has been identified, the dissection is carried across the joint, exposing the medial articular surface. After exposure of the proximal fragment, the orientation of the distal fragment is defined and the soft tissues are sharply released off the *anterior* aspect of the distal fragment, extending distally to the radial head. **D,** After irrigation and debridement of the fracture hematoma, the distal fragment is reduced with a towel clip. It is important to judge the reduction at the level of the articular surface rather than the metaphysis, as plastic deformation or comminution of the metaphyseal fragment may be present.

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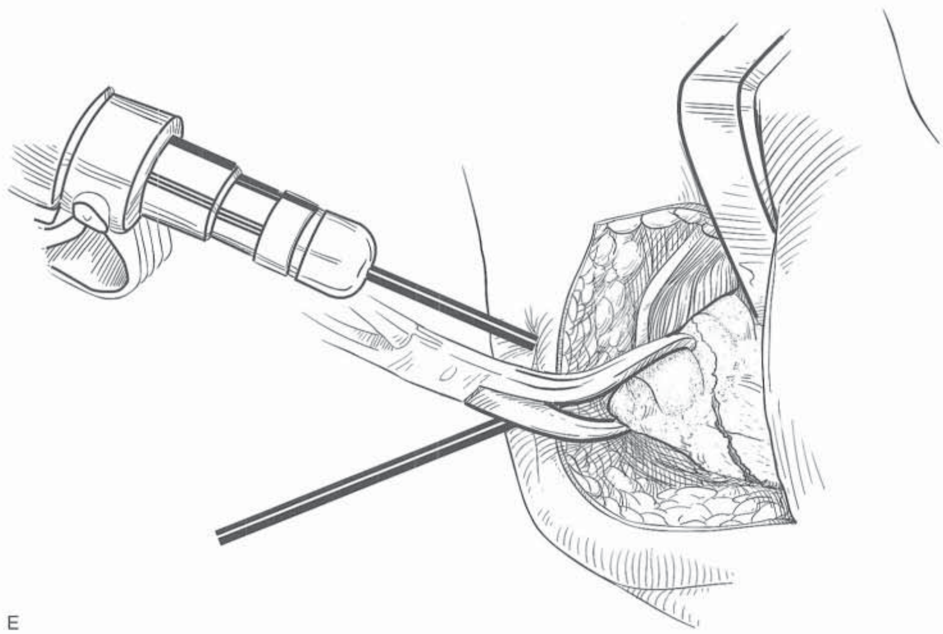


E

FIGURE 41–74 *Continued.* **E,** Pins (usually 0.062 inch) are placed percutaneously to secure the fracture.

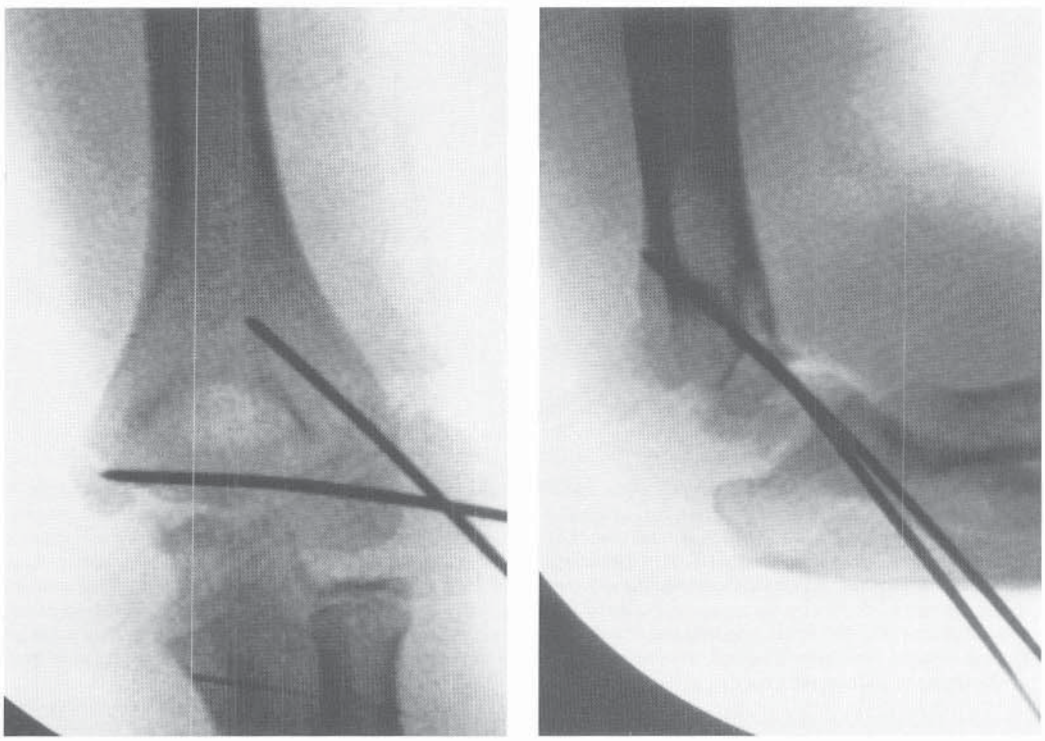
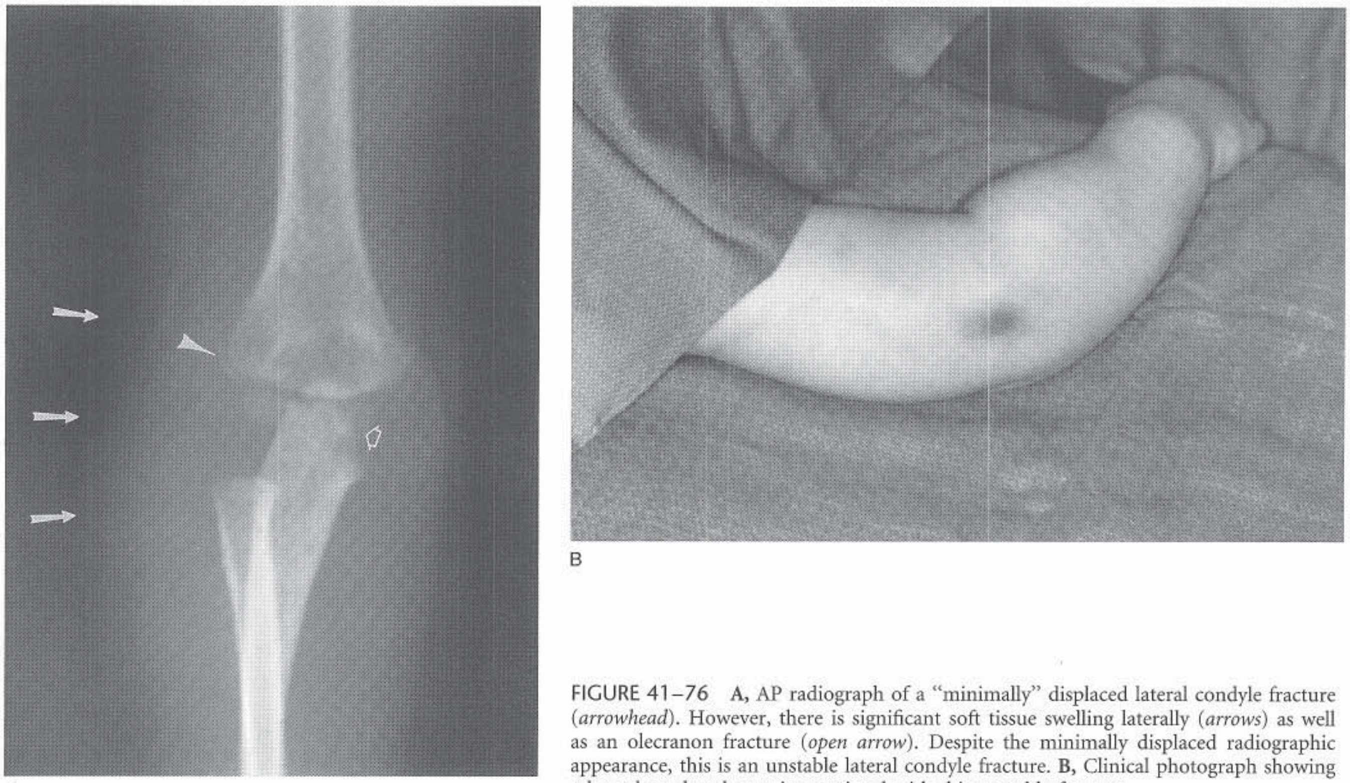


FIGURE 41–75 AP and lateral radiographs demonstrating the technique of percutaneous pin fixation of lateral condyle fractures. The pins are widely divergent at the fracture line, providing maximum rotational stability.



A

B

FIGURE 41–76 **A,** AP radiograph of a "minimally" displaced lateral condyle fracture (*arrowhead*). However, there is significant soft tissue swelling laterally (*arrows*) as well as an olecranon fracture (*open arrow*). Despite the minimally displaced radiographic appearance, this is an unstable lateral condyle fracture. **B,** Clinical photograph showing a large lateral ecchymosis associated with this unstable fracture.

CUBITUS VARUS/LATERAL SPUR FORMATION. Cubitus varus is the most commonly reported complication following lateral condyle fracture, occurring in 40 percent of patients in one series.[154,486] This high incidence represents reporting of both true cubitus varus and lateral spur formation as "cubitus varus." Cubitus varus and lateral spur formation are multifactorial in origin. True cubitus varus may be the result of malunion, growth arrest, or growth stimulation of the lateral condylar physis, or a combination of factors. Lateral spur formation occurs in lateral condyle fractures treated with operative as well as nonoperative techniques (Fig. 41–78). It is probably a result of slight displacement of the metaphyseal fragment in addition to disruption of the periosteal envelope.[486,547]

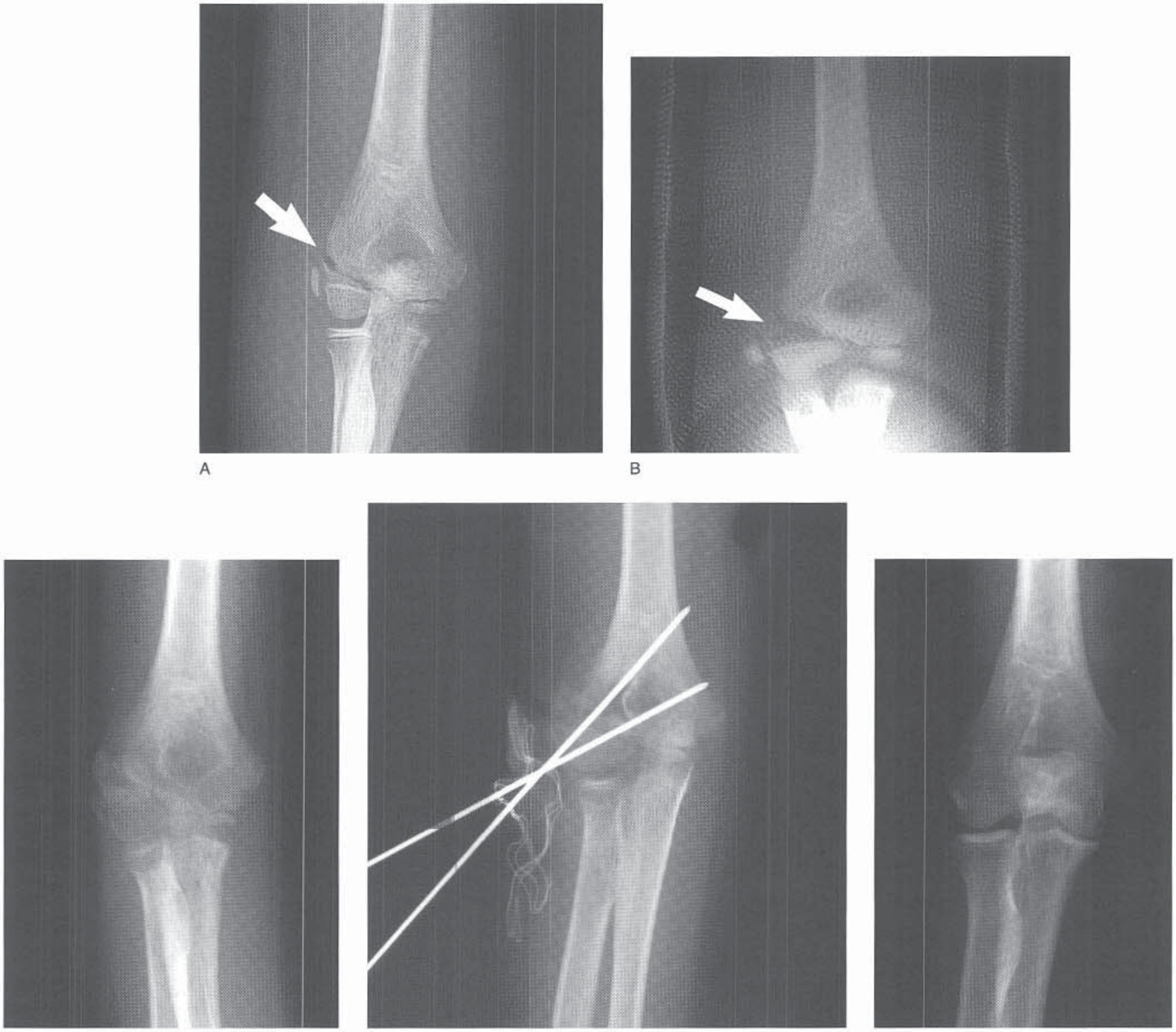
Cubitus varus following lateral condylar fractures is rarely as severe as that following supracondylar fractures. This is because it is usually only a coronal plane deformity and does not have the hyperextension and rotary deformity present with supracondylar malunion. Because it is commonly mild and asymptomatic, cubitus varus following lateral condylar fracture rarely requires treatment. Occasionally a progressive deformity, particularly if involving a growth arrest or a nonunion, requires treatment. Usually, mild varus can be treated by forewarning the parents at the time of initial treatment that their child may have a "prominence" on the lateral aspect of the elbow after the fracture has healed.

DELAYED UNION AND NONUNION. Without question, the most frequent problematic complication of lateral condyle fractures is delayed union or nonunion. Several factors contribute to the difficulty in achieving union of lateral condyle fractures.[152,204] First, the fracture is intra-articular and consequently is constantly exposed to synovial fluid. Second, the lateral condyle has a poor blood supply. Finally, if not immobilized, there is constant motion at the fracture site from the pull of the wrist extensors on the distal fragment.

We use the term "delayed union" to refer to either a minimally displaced fracture that does not heal with 6 weeks of immobilization or an untreated fracture that presents more than 2 weeks (but by convention less than 3 months) after injury. If a conservatively treated fracture appears stable (no progressive displacement), healing usually occurs without further intervention; however, a persistent nonunion will occasionally develop.[204] Thus, it is important to observe these fractures until radiographic union is achieved. If healing does not occur or if progressive displacement develops (see Fig. 41–77), we recommend surgical treatment. Generally, union can be achieved simply by stabilizing the distal fragment with a screw through the metaphyseal fragment. We do not attempt to anatomically restore the articular surface, and bone grafting is not usually required. The surgical approach to a delayed union or nonunion is the same as the surgical approach to an acute fracture (see Fig. 41–74). Care must be taken to ensure that all soft tissue dissection occurs anteriorly to avoid the blood supply of the distal fragment.

The management of late-presenting fractures is controversial. Some authors have reported better results in patients treated with observation rather than delayed open reduction.[119,244] However, a number of authors have recently reported good results with the surgical treatment of late-presenting (2 to 12 weeks) fractures as well as established nonunions.* Although Flynn initially recommended surgical

*See references 109, 149, 152, 153, 174, 317, 462, 540, 547.



A B C D E

FIGURE 41–77 Radiographic example of a minimally displaced fracture, displacing with cast immobilization. **A,** AP radiograph at the time of injury showing a minimally displaced lateral condyle fracture (*arrow*). **B,** One week after injury, significant displacement of the fracture (*arrow*) had occurred. Cast immobilization was continued. **C,** Two months after the injury, a delayed union had developed. **D,** The delayed union was treated with open reduction and stabilization. Note the fracture was not reduced anatomically but was pinned in a position to provide maximal metaphyseal contact. **E,** Six years postoperatively the fracture has healed with minimal fishtail deformity of the distal humerus.

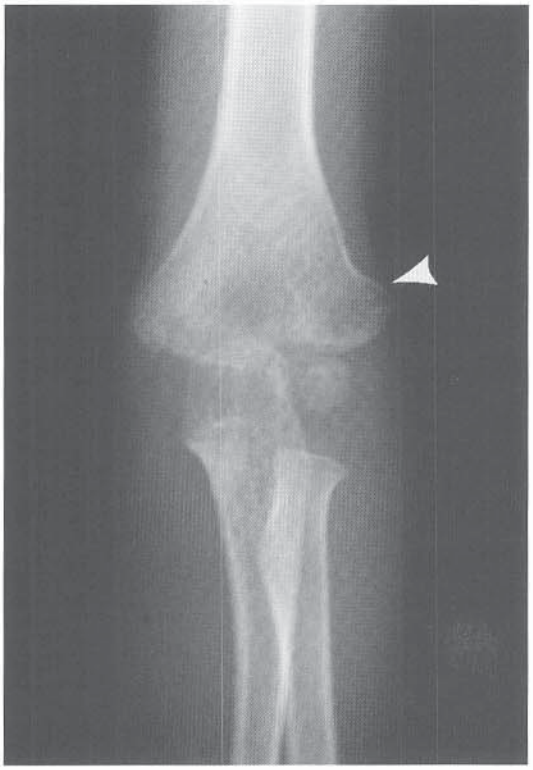


FIGURE 41–78 AP radiograph demonstrating lateral spur formation (*arrowhead*) following operative treatment of a displaced lateral condyle fracture. The prominent lateral spur creates the clinical appearance of mild cubitus varus.

treatment for late-presenting fractures that were "in good position" and had an open growth plate,[149] other authors have described good results in skeletally mature patients with more displaced fractures. All authors warn of the potential for stiffness, osteonecrosis, and fishtail deformity if surgical treatment is undertaken.* We favor surgical treatment for these fractures (Fig. 41–79).

We use the term "nonunion" to refer to a fracture that has not healed within 3 months. Clinically, a nonunion can present with one of three scenarios.† The first is as a painful nonunion. This is the least common. The pain is usually activity related. Older patients may have a feeling of lateral instability and apprehension. We manage these patients with an attempt at osteosynthesis. The goal of surgical treatment is to obtain union of the metaphyseal fragment, not to restore the joint surface. Bone grafting may be required, and the posterior soft tissues must be avoided (Fig. 41–80). The second presentation of a delayed union is as a cosmetically unacceptable valgus deformity. These patients usually have an associated flexion contracture and can be managed with a corrective osteotomy with or without attempts to achieve healing of the nonunion. And finally, patients may present with cubitus valgus and a tardy ulnar nerve palsy.[175,324,344,460] These patients should be managed with ulnar nerve transposition with or without attempts to achieve union (Fig. 41–81).[478]

*See references 109, 149, 152, 153, 174, 204, 317, 462, 547.

†See references 109, 149, 174, 247, 256, 317, 356, 357, 451, 478, 597.

GROWTH ARREST. Although lateral condyle fractures cross the germinal layer of the physis and are classified as Salter-Harris type IV injuries, growth arrest is a rare complication.* In a review of 39 fractures, Rutherford reported only one case of growth arrest.[438] If growth arrest does occur, a progressive valgus or varus deformity may develop. In young patients, this may be treated with bar resection and/or osteotomy. Because of the limited growth of the distal humerus (20 percent of the entire humerus, or approximately 3 mm a year), older patients are probably best treated with completion of the epiphysiodesis and osteotomy.

FISHTAIL DEFORMITY AND AVASCULAR NECROSIS. The etiology of fishtail deformity of the distal humerus is uncertain. Rutherford noted this deformity in nine of ten patients who had unreduced lateral condyle fractures. He hypothesized that it was the result of malunion at the medial extent of the fracture that resulted in growth arrest of the lateral trochlea.[438] However, Morrissy and Wilkins noted it after a variety of fractures of the distal humerus and attributed it to avascular necrosis.[358] In all likelihood, both etiologies occur. Mild deformity following lateral condyle fractures may occur more frequently than reported and is likely to be related to growth arrest.[358,438] More severe deformities are probably the result of vascular changes, often associated with surgical approaches to the elbow (Fig. 41–82).[565]

MEDIAL EPICONDYLE FRACTURES

Fifty percent of medial epicondyle fractures are associated with elbow dislocations. Fractures of the medial epicondyle usually occur between 7 and 15 years of age. They account for approximately 10 percent of all children's elbow fractures.†

Anatomy. The ossification center of the medial epicondyle of the humerus appears between 5 and 7 years of age and unites with the humeral diaphysis between 18 and 20 years of age.[467,487] The common tendon of the flexor muscles of the forearm and the ulnar collateral ligament of the elbow insert on the medial epicondyle. The ulnar nerve runs in a groove in the posterior aspect of this epicondyle. The medial epicondyle is an apophysis and does not contribute to longitudinal growth of the humerus.

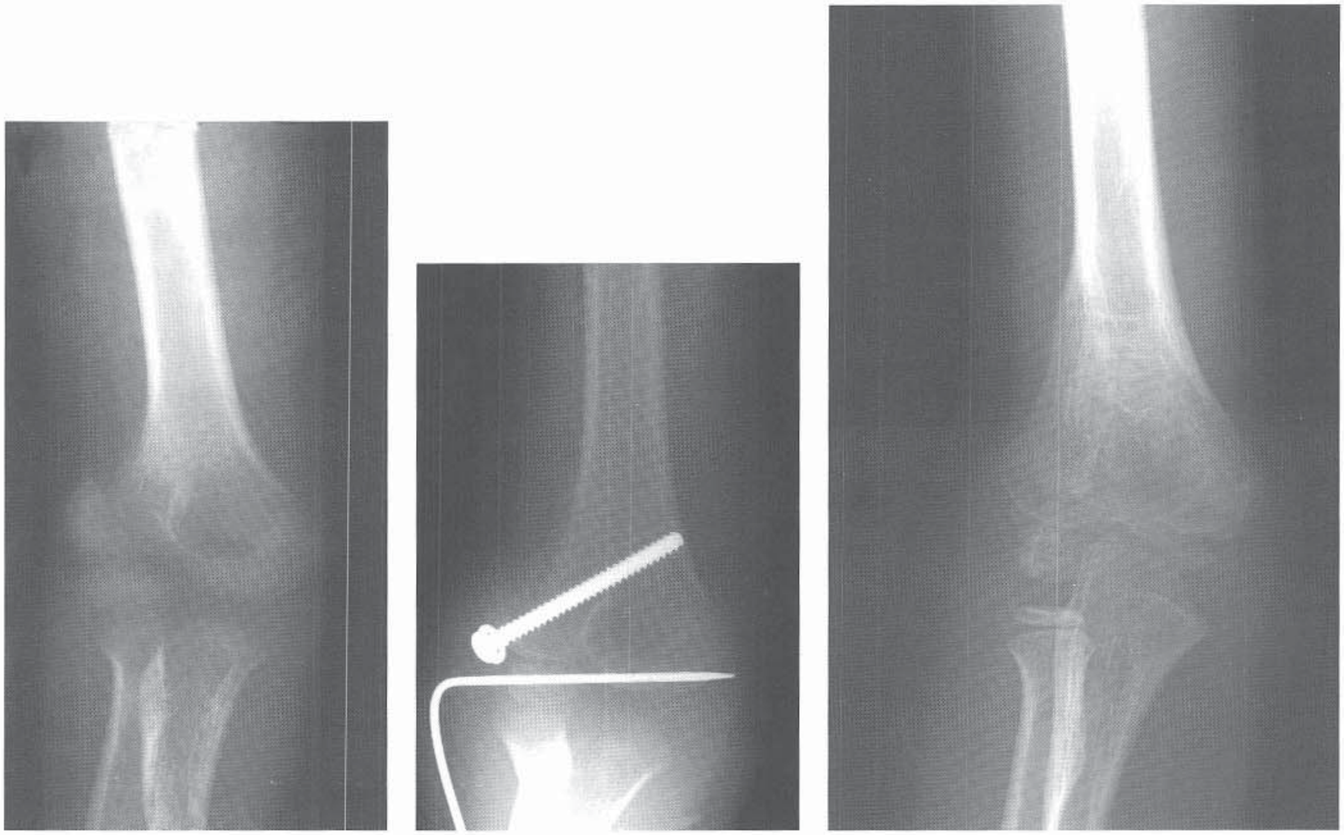
Mechanism of Injury. The mechanism of injury is a valgus stress producing traction on the medial epicondyle through the flexor muscles. The epicondyle may be minimally or severely displaced. If associated with an elbow dislocation, the fragment may become incarcerated in the joint at the time of dislocation or reduction.‡

Diagnosis. The physical findings depend on the degree of displacement of the medial epicondyle. Usually the elbow is held in flexion and any motion is painful. There is tenderness over the medial epicondyle that is exacerbated with valgus stress. Ulnar nerve paresis or dysthesias may be present.

*See references 24, 152, 204, 347, 348, 438, 478, 547.

†See references 38, 129, 283, 284, 322, 477, 553.

‡See references 143, 160, 161, 392, 393, 425, 431, 475, 509, 534.



A B C

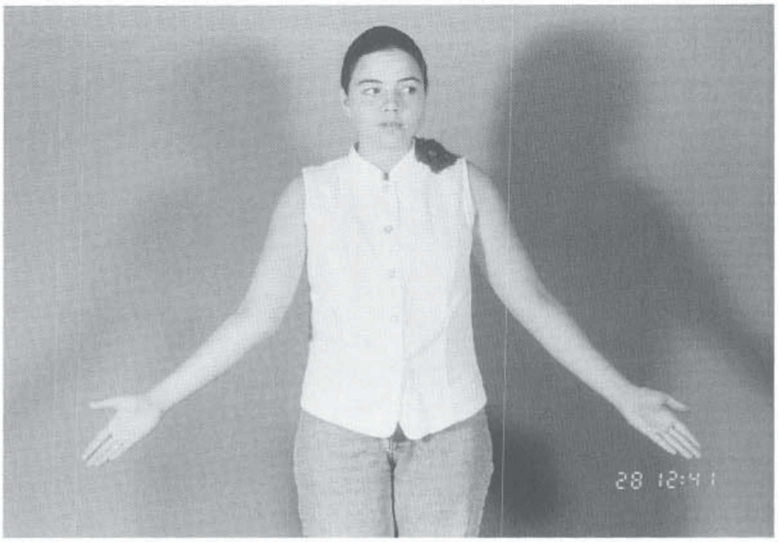
FIGURE 41–79 Treatment of a late-presenting lateral condyle fracture. **A,** AP radiograph obtained at initial presentation, 5 weeks after injury, shows a displaced lateral condyle fracture. **B,** Open reduction with internal fixation was performed. Note the fracture was not reduced anatomically but was placed in a position to maximize metaphyseal contact. A screw was used through the metaphyseal fragment, as delayed healing was anticipated. A percutaneous pin provided initial rotational stability. **C,** AP radiograph obtained 18 months after treatment.

FIGURE 41–80 Symptomatic lateral condyle nonunion. **A,** AP radiograph showing established nonunion of the lateral condyle. The patient had elbow pain with vigorous use of the extremity. **B,** Surgical treatment was directed toward achieving union of the distal fragment to the metaphysis. Articular congruity was not restored. **C,** Six years postoperatively the fracture has united. A fishtail deformity is present (*arrow*).

Radiographic Findings. In older patients (more than 6 or 7 years old) the medial epicondylar fragment is usually easily identified radiographically. However, radiographic interpretation in younger patients may be difficult if the secondary ossification center is not yet ossified. In either case, assessment of minimally displaced fractures may be facilitated with comparison views to establish the "normal" width of the cartilaginous space between the metaphysis and medial epicondyle. Fragments trapped in the joint may be difficult to identify, particularly in younger patients with minimal ossification.[392,467] Although medial joint space widening may be present on the AP radiograph, a noncentrically reduced ulnohumeral joint on the lateral radiograph is often the only radiographic finding. Thus, whenever a medial epicondyle fracture is suspected, it is imperative to obtain a true lateral radiograph of the elbow. The inability to obtain a true lateral radiograph should raise the suspicion of an entrapped medial epicondyle fragment (Fig. 41–83).

Several authors have advocated an AP valgus stress radiograph for assessment of stability after medial epicondyle fracture.[452,559] This radiograph is obtained with the patient supine, the arm abducted 90 degrees, the shoulder externally rotated 90 degrees, and the elbow flexed at least 15 degrees to eliminate the stabilizing force of the olecranon. In this

A



B

FIGURE 41–81 Lateral condyle nonunion producing cubitus valgus and tardy ulnar nerve symptoms. **A,** AP radiograph shows an established nonunion of a lateral condyle fracture. **B,** Clinical appearance of cubitus valgus. The patient was treated with ulnar nerve transposition.

FIGURE 41–82 AP radiograph showing mild fishtail deformity in the distal humerus following uncomplicated treatment of a lateral condyle fracture (see also the fishtail deformities in Fig. 41–80).

position, gravity will create widening on the medial side of an unstable elbow. Because sedation is usually required, we have found this radiograph to be of little clinical use.

Classification. Unfortunately, there is no widely accepted classification of medial epicondyle fractures, and most authors have described unique systems based on what they consider critical information.[559] All of the established classification systems consider whether the fracture is displaced or nondisplaced. However, there is no agreement on what constitutes a displaced fracture.

We believe the important factors in prognosis and treatment include the amount of displacement (we use a threshold of 5 mm of displacement), the presence of associated elbow injuries or fragment incarceration, and the desired athletic endeavors of the patient.[14,120,220,550]

Treatment. There is a consensus that nondisplaced and minimally displaced fractures (less than 5 mm) are best managed with symptomatic treatment. This usually consists of immobilization in a posterior splint, long-arm cast, or sling for 1 to 2 weeks, followed by early active range-of-motion exercises. It is important to warn the parents that the radiographic union may not occur, but that functional results are usually excellent.[120,253,554]

There is also agreement that intra-articular fragments should be acutely removed.[402] Although some authors have cautioned against doing this with closed techniques because of concern that the ulnar nerve could be damaged, we agree with those authors who favor a single attempt at gentle manipulative reduction for acutely (less than 24 hours after injury) entrapped fragments.[425] Closed extraction is accomplished by opening the joint with a valgus stress and then

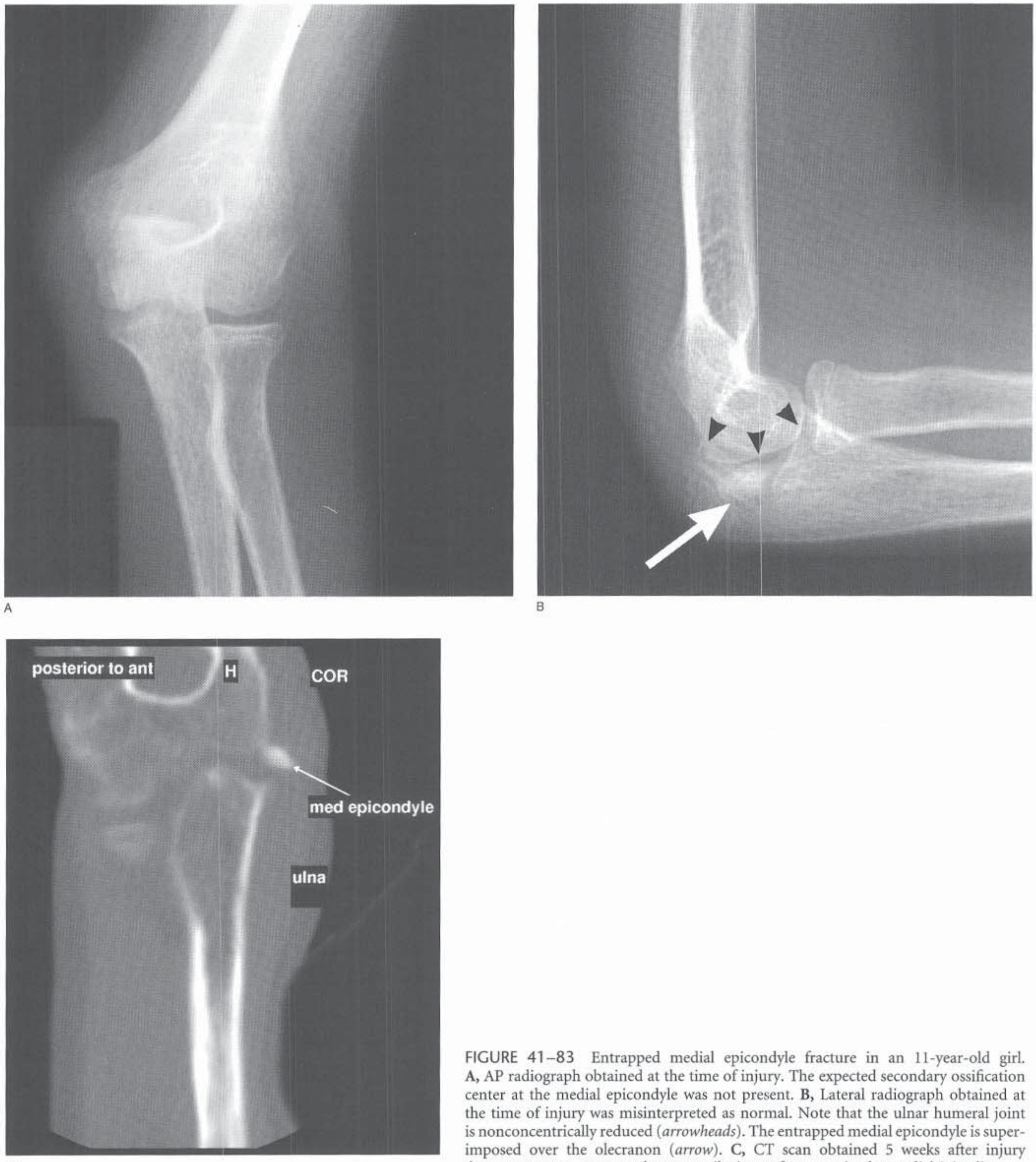


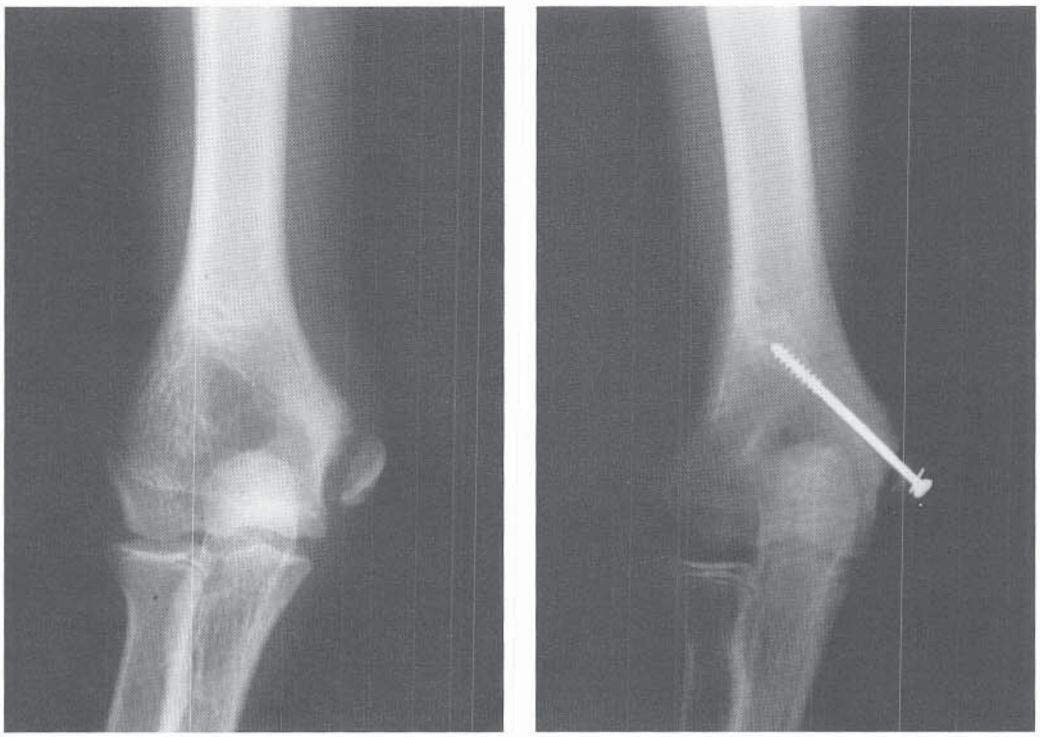
FIGURE 41–83 Entrapped medial epicondyle fracture in an 11-year-old girl. **A,** AP radiograph obtained at the time of injury. The expected secondary ossification center at the medial epicondyle was not present. **B,** Lateral radiograph obtained at the time of injury was misinterpreted as normal. Note that the ulnar humeral joint is nonconcentrically reduced (*arrowheads*). The entrapped medial epicondyle is superimposed over the olecranon (*arrow*). **C,** CT scan obtained 5 weeks after injury demonstrates an entrapped osteocartilaginous fragment in the medial joint line.

supinating the forearm and dorsiflexing the wrist and fingers to stretch the flexors and extract the medial epicondylar apophysis from the joint.[54,450] Other authors have suggested that electrical stimulation of the flexor mass or joint distention with saline may help facilitate extraction. We do not have experience with these techniques.[161,392] If we are unable to release an entrapped fragment with closed techniques, we proceed to an open reduction.

Treatment of displaced (more than 5 mm) medial epicondyle fractures is more controversial. Although a number of studies have reported superior results with closed treatment, these series all included a few patients who developed symptomatic nonunions. Recently, there have been reports of excellent results with open reduction and internal fixation of medial epicondyle fractures.[74,220,391] However, there have also been reports of stiffness and nonunion following operative treatment.[131,474,554] Woods and Tullos have expressed concern that the symptomatic treatment of displaced fractures in the "high-demand" overhead athlete may lead to symptomatic valgus instability because of functional lengthening of the ulnar collateral ligament.[559] Because such late instability can be difficult to treat, they advocate open reduction and internal fixation of medial epicondyle fractures in serious overhead athletes. Unfortunately, it is often difficult to predict whether a young patient with a displaced medial epicondyle fracture will develop into an overhead athlete.

We have had good results with both operative and conservative treatment of displaced medial epicondyle fractures. We treat these injuries on an individual basis after a thorough discussion with the parents. Although some authors have described closed reduction and percutaneous pinning for displaced fractures, we favor open reduction to ensure that the ulnar nerve is not damaged. Open reduction is performed through a medial longitudinal skin incision. The ulnar nerve is identified, dissected free, and retracted posteriorly. The fractured medial epicondyle is identified and is anatomically repositioned with a towel clip. We favor fixation with a partially threaded screw, often using a cannulated system to achieve temporary fixation (Fig. 41–84). Care must be taken in young patients to prevent comminution of the predominantly cartilaginous distal fragment during fixation. After an open reduction we immobilize the elbow in flexion for 1 to 3 weeks, after which we begin active range-of-motion exercises. We occasionally splint the wrist for an additional 3 to 4 weeks after cast removal to prevent active contraction of the flexor muscle mass, which might displace the distal fragment.

Complications. Complications from medial epicondyle fractures include stiffness, ulnar neuritis, missed incarceration, and symptomatic nonunion.[38,220,374,402] Stiffness is the most common complication and is best avoided by avoiding prolonged immobilization. It is important to remember that the soft tissue injury is usually much more significant than the radiographic abnormality. We favor a brief period of immobilization (no more than 3 weeks) followed by early active range-of-motion exercises. Aggressive physical or occupational therapy should be avoided in the early (initial 6 weeks) phase, as it has been shown to lead to increased stiffness. The incidence of ulnar nerve dysfunction varies from 10 percent to 16 percent.[38] If the fragment is entrapped



A B

FIGURE 41–84 **A,** Displaced medial epicondyle fracture in a 14-year-old Little League pitcher. The injury was sustained during pitching. **B,** AP radiograph obtained after open reduction and fixation of the medial epicondyle fragment.

in the joint, the incidence of ulnar nerve dysfunction may be as high as 50 percent.[6]

Traditionally, surgical treatment for late-presenting entrapped fragments has been avoided.[160,431] However, recent studies have shown good results with late extraction of incarcerated fragments. Fowles and associates reported improved range of motion (80 percent normal), decreased pain, and improved ulnar nerve symptoms in six patients treated with surgical extraction an average of 14 weeks after injury.[160] Somewhat surprisingly, there are also long-term follow-up reports showing good results with persistently retained fragments.[431]

Symptomatic nonunion in the high-performance athlete is difficult to treat. Wilkins and associates reported the case of a high-performance adolescent baseball pitcher who had to stop pitching after nonoperative management of a medial epicondyle fracture. We have had some success in establishing union in symptomatic patients. Our approach is to stabilize the fragment with in situ fixation and a local bone graft. We do not attempt to mobilize the fragment and reduce it anatomically. Others have advocated simple excision of the symptomatic nonunion with reattachment of the ulnar collateral ligament. We do not have experience with this technique and prefer an initial attempt at establishing union.

ELBOW DISLOCATIONS

Dislocation of the elbow is a relatively uncommon injury in children. It is frequently associated with fractures, particularly of the medial epicondyle, proximal radius, olecranon, and coronoid process. Elbow dislocations are most common in adolescents and unusual in young children.* An apparent elbow dislocation in a young child should alert the orthopaedist to a potential transphyseal or other fracture. Although most elbow dislocations can be treated with simple closed reduction, it is important to carefully assess the patient and the radiographs to ensure that associated injuries are not missed.

Mechanism of Injury. Elbow dislocations are most commonly the result of a fall on an outstretched arm. The direction of displacement varies according to the direction of the force. The most frequent elbow dislocation is posterior or posterolateral and is usually the result of a fall with the forearm supinated and the elbow either extended or partially flexed (Fig. 41–85).[73,161,287,799] Although less common, anterior, medial, lateral, and divergent dislocations can occur. Anterior dislocations are caused by a direct blow to or fall on the olecranon process. Medial or lateral dislocations usually result from direct trauma, violent twisting of the forearm, or falls on the hand. In divergent dislocations, which are extremely rare, the radius and ulna displace in opposite directions.†

Anatomy. The anatomic constraints to posterior dislocation include the anterior capsule, the coronoid process (which resists posterior displacement of the ulna), and the collateral ligaments. During posterior elbow dislocation the momentum of the body applied to the lower end of the humerus tears the joint capsule anteriorly. The relatively

*See references 185, 237, 283, 432, 447, 524.

†See references 15, 52, 72, 113, 179, 209, 243, 306, 488, 493, 499, 556.

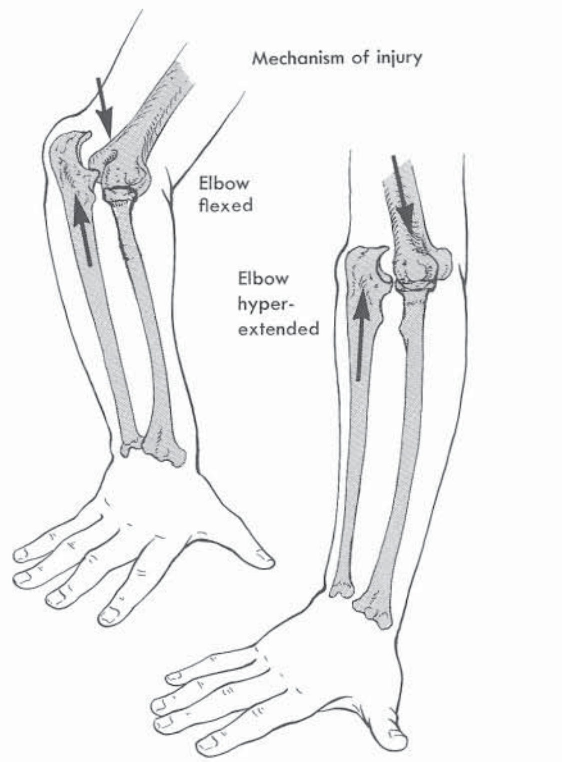


FIGURE 41–85 Elbow dislocations are usually the result of a fall onto a supinated forearm with the elbow in either flexion or extension.

small coronoid is unable to prevent proximal and posterior displacement of the ulna. The collateral ligaments are stretched or ruptured. The radius and ulna, being firmly bound by the annular ligament and the interosseous membrane, are displaced together. The coronoid becomes locked in the olecranon fossa by contraction of the biceps and triceps. In posterolateral dislocations, the biceps tendon serves as a fulcrum about which the distal fragment (the forearm) rotates laterally. The normal cubitus valgus of the elbow also promotes lateral displacement. If only one collateral ligament is torn, one of the forearm bones will dislocate while the other undergoes rotary subluxation.

With posterior and posterior lateral dislocations the ulnar collateral ligament and medial epicondyle may be avulsed. After reduction, the medial epicondyle may remain incarcerated within the joint (see discussion under Medial Epicondyle Fractures). With posteromedial dislocation, fracture of the lateral condyle may occur. Injury to the radial head or neck is another frequent finding with posterior elbow dislocations.

The neurovascular anatomy of the arm plays an important role in the potential complications that may develop following elbow dislocations (see Fig. 41–33). As with supracondylar fractures, the brachial artery and median nerve lie anterior to the humerus and may be injured when stretched over the displaced proximal fragment. The ulnar nerve lies immediately posterior to the medial epicondyle and is particularly at risk with dislocations associated with medial epicondyle fractures.*

*See references 45, 107, 189, 213, 223, 311, 318, 408, 409.

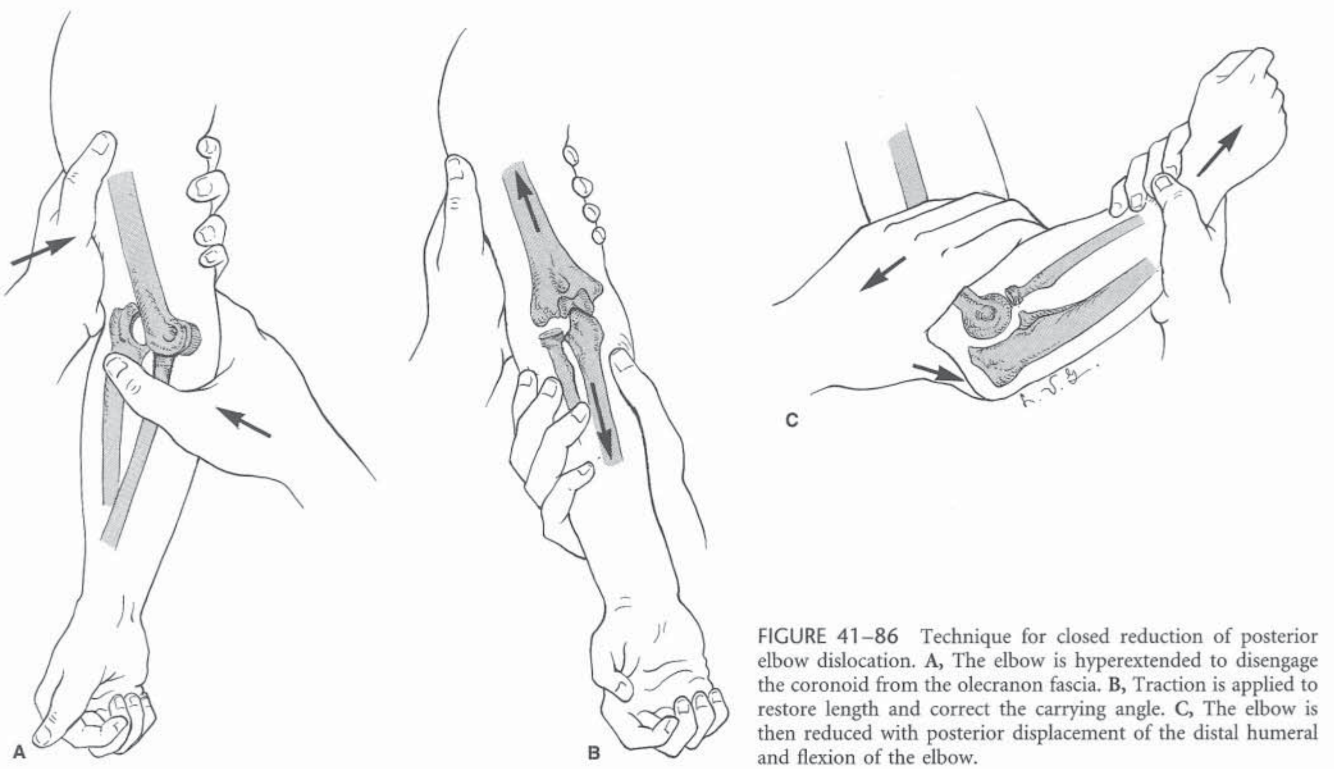


FIGURE 41–86 Technique for closed reduction of posterior elbow dislocation. **A,** The elbow is hyperextended to disengage the coronoid from the olecranon fascia. **B,** Traction is applied to restore length and correct the carrying angle. **C,** The elbow is then reduced with posterior displacement of the distal humeral and flexion of the elbow.

Diagnosis. Immediately following the injury, the patient presents with a painful and swollen elbow, which is held in flexion. Attempts at motion are painful and restricted. From the anterior view, the forearm appears to be shortened, whereas from the posterior view, the upper arm appears to be decreased in length. The distal humerus creates a fullness within the antecubital fossa.

The differential diagnosis includes transphyseal fractures, supracondylar fractures, Milch type II lateral condylar fractures, and Monteggia fractures (see Fig. 41–35). An accurate diagnosis can be made by assessing good-quality AP and lateral radiographs. Radiographs should also be scrutinized to identify any associated fractures, with particular attention to the medial epicondyle, coronoid process, proximal radius, and lateral condyle. Elbow dislocations are classified according to the displacement of the distal fragment.[488]

Treatment. A thorough examination of the skin and assessment of the vascular and neurologic status of the extremity are imperative, as neurovascular injuries are not uncommon.* Reduction of acute posterior dislocations is usually easily accomplished without a general anesthetic.[96,500] We prefer to reduce posterior dislocations with hyperextension and traction followed by flexion (Fig. 41–86).[20,101,200,290] The upper arm is held with one hand and the forearm with the other. The elbow is hyperextended and traction is applied to disengage the tip of the coronoid process from the olecranon fossa. Marked hyperextension of the elbow should be avoided to avoid unnecessary strain on the anterior soft tissues. Traction is continued to restore length. While maintaining traction the elbow is gently flexed. As the olecranon engages the articular surface of the humerus there is often a palpable and audible click. A second technique places the patient prone with the injured limb hanging over the edge of the table. The weight of the arm provides distal traction while the surgeon pushes the olecranon downward and forward with his thumbs.[339]

Anterior dislocation is a very rare injury.[52,85,243,493,499,556] Linscheid and Wheeler reported two cases of anterior dislocation out of 110 elbow dislocations.[299] Anterior dislocations are associated with extensive soft tissue damage and often fractures of the olecranon or the proximal ulna. Reduction is accomplished with longitudinal traction with the elbow in flexion and firm pressure applied distally and posteriorly on the forearm as the elbow is gradually extended. Reduction of the rare medial or lateral dislocations of the elbow follows the principles outlined for treatment of posterior dislocation, that is, traction, correction of coronal plane deformity, and flexion.[488]

Following successful closed reduction, good-quality radiographs must be obtained, including a perfect lateral view to ensure that there are no entrapped intra-articular fragments. We immobilize the extremity in a posterior splint. Because compartment syndrome has been reported following elbow dislocation, we recommend admission to the hospital for overnight observation following reduction.[132] The splint is continued for 1 to 2 weeks. Once the splint is removed, active range of motion is encouraged. We reassess the range of motion 6 to 8 weeks after injury. If there is significant stiffness at this time, formal physical or occupational therapy can be initiated. We avoid earlier (less than 6 weeks post injury) passive range of motion, as it has been associated with increased stiffness. Aggressive range-of-motion exercises are never indicated.

*See references 45, 107, 189, 213, 223, 311, 318, 408, 409.

When associated with a fracture, the dislocation should be reduced and the fracture should be reassessed and managed appropriately, based on the postreduction radiographs. Late-presenting dislocations generally require open reduction.[13,159,287,468,469,490]

Complications. Stiffness is the most common complication following elbow dislocation.[81,161,287,299,413] Other complications include vascular injury, peripheral nerve injury, myositis ossificans, and recurrent dislocation.* Nearly all reports of elbow dislocations, including those in children, list loss of motion as the most common complication. Fortunately, in children, loss of motion is rarely significant from a functional or cosmetic standpoint. Stiffness is to some extent a function of the soft tissue damage at the time of injury. However, there are some variables in the management of elbow dislocations that will affect the range of motion. Stiffness is more likely following prolonged immobilization and early aggressive passive range-of-motion exercises. Thus, we rarely immobilize elbow dislocations for more than 1 to 2 weeks. Following removal of the cast, we immediately begin gentle active motion but do not begin a formal therapy program until 6 to 8 weeks after injury, if necessary.

Both heterotopic bone formation and myositis ossificans have been reported following elbow dislocations. Limited amounts of heterotopic bone commonly form along the course of the collateral ligaments.[299] Myositis ossificans may occur within the brachialis muscle.[426] A delay in the initial reduction and vigorous passive stretching exercises following cast removal have been reported to lead to myositis ossificans.[302] Rest, gentle active range-of-motion exercises, and anti-inflammatory medications such as Indocin or Naprosyn are recommended during the active phase of myositis ossificans. Myositis may spontaneously resolve over time (see Fig. 41–68).

Vascular injury is uncommon with elbow dislocation. It is most commonly seen with open injuries.† Perhaps the most important fact in relation to vascular injuries with elbow dislocation is that the collateral circulation is much more likely to be damaged at the time of injury than in supracondylar fractures. Consequently, most authors have a lower threshold for vascular repair than with injuries associated with supracondylar fracture.‡

Peripheral nerve injury is more common than vascular injury. The ulnar nerve is most frequently injured, usually in dislocations associated with avulsion of the medial epicondyle. Ulnar nerve symptoms most commonly arise when displacement of the medial epicondyle results in compression of the nerve by the fibrous band that binds the nerve to the posterior aspect of the epicondyle.[96,160,161,169] With greater awareness of displaced medial epicondylar fractures, the incidence of ulnar nerve symptoms appears to be decreasing, and the ones that are noted are often transient and improve once the incarcerated medial epicondylar fragment is released from the joint.[169,299,538]

Median nerve injury may take place in three ways (Fig. 41–87).* The nerve may be displaced posteriorly behind the medial condylar ridge and trapped between the distal humerus and olecranon. Second, the median nerve may be trapped between the fractured surface of the medial epicondyle and humerus. If the medial epicondyle is allowed to heal in this position, the median nerve will be encased in bone.[423] Finally, the median nerve can become caught between the trochlea and olecranon during reduction.[198,494] The diagnosis of median nerve entrapment is made difficult by the lack of pain and the delayed appearance of motor and sensory symptoms. Matev described the radiographic appearance of a chronically displaced median nerve, namely a sclerotic depression over the posteromedial epicondyle, a finding now referred to as Matev's sign.[318] Treatment of median nerve entrapment entails immediate surgical release. Chronic entrapment may require reanastomosis and/or nerve grafting and carries a poor prognosis.

Recurrent dislocation is a rare but disabling complication that is difficult to treat. The first case was reported by Albert in 1881.[10] It is most common in young adults who sustained an initial posterior or posterolateral dislocation in late adolescence.[83,328,517] Osborne and Cotterill proposed that the pathologic defect causing recurrent dislocation was laxity of the posterolateral capsule ligamentous complex.[380] Initial treatment should be conservative, particularly in the young patient. We have had some success treating these patients with a prolonged period of bracing. If conservative measures

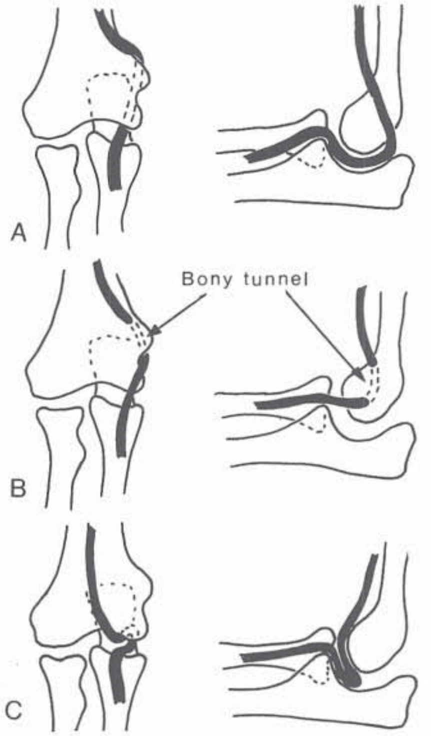


FIGURE 41–87 A to C, Median nerve entrapment following posterior elbow dislocation. See text for description. (Redrawn after Hallett J: Entrapment of the median nerve after dislocation of the elbow. J Bone Joint Surg 1981;63-B:408.)

*See references 45, 83, 107, 169, 189, 191, 213, 223, 302, 311, 318, 408, 409.

†See references 20, 136, 191, 213, 214, 223, 270, 302.

‡See references 23, 132, 136, 191, 213, 214, 223, 243, 270, 299, 302, 489.

*See references 45, 107, 189, 311, 318, 408, 409.

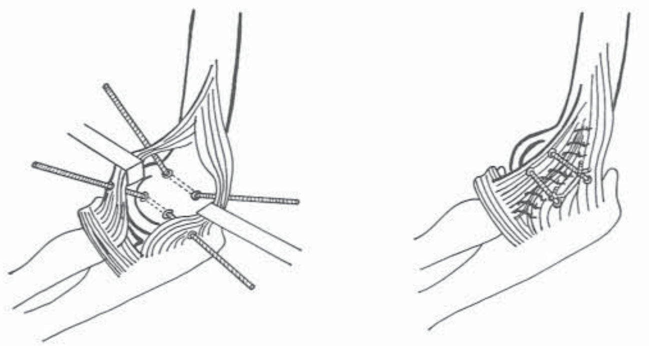


FIGURE 41–88 Technique of Osborne and Cotterill for posterolateral capsular reefing for recurrent elbow dislocation. (From Osborne G, Cotterill P: Recurrent dislocation of the elbow. J Bone Joint Surg 1966;48-B:344.)

fail, we favor the posterolateral capsular reefing described by Osborne and Cotterill (Fig. 41–88).[260,380]

RADIAL HEAD AND NECK FRACTURES

In children, the cartilaginous radial head is resistant to fracture, and children are more likely to sustain fractures of the radial neck than of the head. About half of radial neck fractures are associated with other injuries to the elbow.[128,297,323,355,537] It is important to warn parents that displaced fractures, particularly those in children older than 10, may be associated with loss of forearm rotation.[123,411,419,456]

Anatomy. The radial head is disk-shaped and of greater diameter than the neck, which rotates within the annular ligament. It has a shallow cuplike surface that articulates with the capitellum proximally and the radial notch of the ulna medially. The biceps inserts on its tuberosity immediately distal to the neck. The secondary ossification center of the proximal radius appears as a small sphere between the third and the fifth year of life and fuses with the shaft between the ages of 16 and 18. Occasionally the ossification centers are bipartite, which should not be mistaken for a fracture.[487] Because the entire radial head is covered with articular cartilage, the blood supply to the epiphysis is supplied through the more distal metaphysis and may be injured with complete separation through the neck (see Fig. 39–7).[104]

Mechanism of Injury. Fractures of the radial head or neck may occur as a result of two different mechanisms.[248,367] Most commonly they are the result of a fall onto an outstretched hand with the elbow in extension and valgus. This valgus extension force may also produce other injuries, including avulsion of the medial epicondyle, rupture of the medial collateral ligament, or fracture of the olecranon, proximal ulna, or lateral condyle (Fig. 41–89).[128,173,264,297,456]

Fracture of the radial neck may also occur as a result of dislocation of the elbow. The radial neck may be fractured by impact against the inferior aspect of the capitellum either at the time of posterior dislocation or at the time of spontaneous reduction (Fig. 41–90).[246,372,419,558] Radial head fracture may also occur with anterior dislocation of the elbow, producing anterior displacement of the head.[367,522]

Diagnosis. Radial head and neck fractures rarely present with obvious clinical deformity. In fact, the fracture may not be evident on initial radiographs and may only be noticed when callus begins to be seen radiographically after 7 to 14 days. There may, however, be local swelling and tenderness, or, rarely, ecchymosis over the lateral aspect of the elbow. There is often point tenderness laterally. Although passive flexion and extension of the elbow are restricted in range, they produce less pain than pronation and supination of the forearm, which are extremely painful.

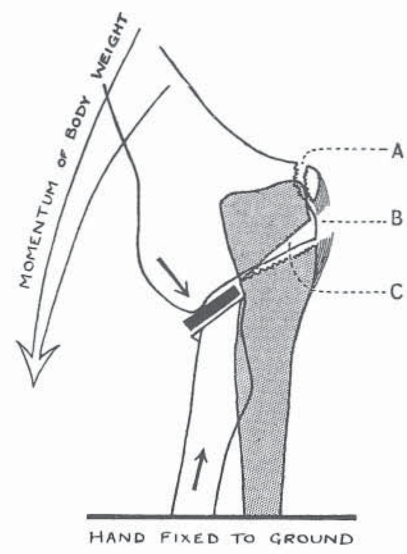


FIGURE 41–89 A valgus hyperextension force to the elbow may produce a radial neck fracture associated with a fracture of the olecranon or medial epicondyle, or less commonly with a rupture of the medial collateral ligament. (From Jeffrey CC: Fractures of the head of the radius in children. J Bone Joint Surg 1950;32-B:314.)

Radiographic Findings. Fractures of the radial head and neck are often subtle and require close examination of good-quality radiographs. When evaluating and treating fractures of the radial neck and head it is important that AP and lateral radiographs of the *proximal radius* be obtained. The child's inability to fully extend the elbow makes it difficult to get a true AP view of an acutely swollen elbow. Thus, if pathology of the proximal radius is suspected, the x-ray technicians should be instructed to obtain an AP radiograph of the proximal radius rather than the elbow (Fig. 41–91). It may be helpful to obtain radiographs with the forearm in different positions of rotation.[371] Careful assessment should be made for associated fractures, particularly of the medial epicondyle and olecranon or proximal ulna.

Classification. Fractures of the radial head and neck may be classified according to the magnitude of displacement, the mechanism of injury, or, for fractures involving the physis, the type of physeal involvement. O'Brien subdivided radial head and neck fractures into three categories based on the degree of angular displacement of the superior articular surface from the horizontal (Fig. 41–92).[372] This classification has proved to be most effective as a guide in both treatment and prognosis.[372,419] In type I fractures the displacement is 30 degrees or less. Type II fractures have between 31 to 60 degrees of angulation. Type III fractures have more than 60 degrees of displacement.

Jeffrey initially recognized two different mechanisms of radial head fracture.[248] Newman later developed a classification system based on the direction of radial head displace-

FIGURE 41–90 Fracture of the radial neck associated with dislocation of the elbow. The inferior aspect of the capitellum acts as a fulcrum, producing a radial neck fracture. This may occur at the time of dislocation or reduction. (From Jeffrey CC: Fractures of the head of the radius in children. J Bone Joint Surg 1950;32-B:3.)

ment.[368] Wilkins combined and modified these systems to classify radial head and neck fractures based on the mechanism of injury and the location of the fracture line.[77]

Approximately half of fractures of the proximal radius involve the physis and half are completely within the metaphysis.[250] Those fractures that involve the physis may also be classified according to the Salter-Harris classification of physeal injuries.[444] Proximal radial physeal fractures are most frequently Salter-Harris type II injuries. Younger children may sustain Salter-Harris type I injuries. Salter-Harris type III or IV fractures involving the radial head and articular surface also occasionally occur.

Treatment. The greatest difficulty in treating radial neck fractures lies in determining which fractures require a reduction and which can be treated by simple immobilization. Reduction may be achieved using closed, percutaneous, intramedullary, or open techniques.[181,268,363] The second dilemma that arises with radial neck fractures is determining whether a reduction is "acceptable" or requires more "aggressive" treatment. While O'Brien's classification system, based on the degree of initial angulation, provides vital information and is the most widely accepted, it does not assess all factors that must be considered when making treatment decisions regarding radial neck fractures. Other factors that must be considered include the amount of translation, the age of the patient, and the time elapsed since injury. Perhaps the most important aspect of treating fractures of the radial head and neck in children is for the surgeon to be aware, and to educate the parents at the time of injury, that significant loss of motion occurs in 30 to 50 percent of patients.[456,501]

Undisplaced or minimally displaced fractures (less than 30 degrees of angulation, minimal translation) may be managed with simple immobilization of the elbow in a sling, posterior splint, or above-elbow cast for 1 to 2 weeks.[456] Because of the limited remodeling potential in children over 10 years of age, we attempt a closed reduction if there is more than 15 degrees of angulation.

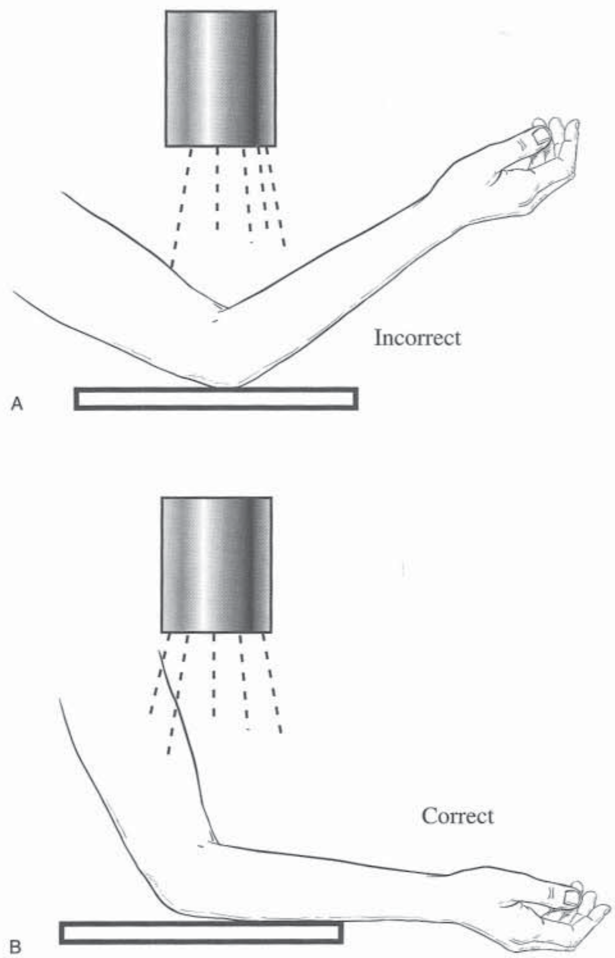


FIGURE 41–91 Technique for obtaining an AP radiograph of the proximal radius. **A,** Because an acutely injured elbow is unable to fully extend, placing the apex of the elbow on the cassette produces an oblique view of both the proximal forearm and the distal humeral. **B,** A true AP view of the proximal radius and ulna is obtained by placing the proximal forearm directly on the cassette.

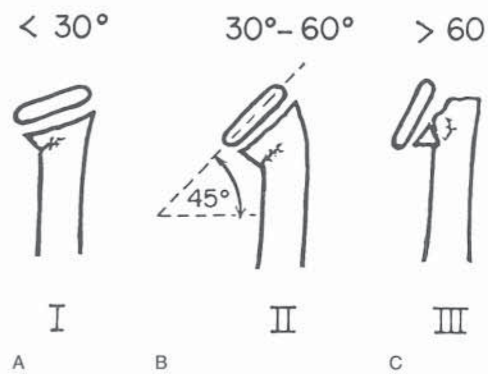


FIGURE 41–92 Classification of radial neck fractures. (The angle measured is the displacement of the superior articular surface of the radial head relative to a perpendicular to the radial shaft.) **A,** Type I fractures are angled less than 30 degrees. **B,** Type II fractures are angled between 30 and 60 degrees. **C,** Type III fractures are angled more than 60 degrees. (From O'Brien PI: Injuries involving the proximal radial epiphysis. Clin Orthop 1965;41:52.)

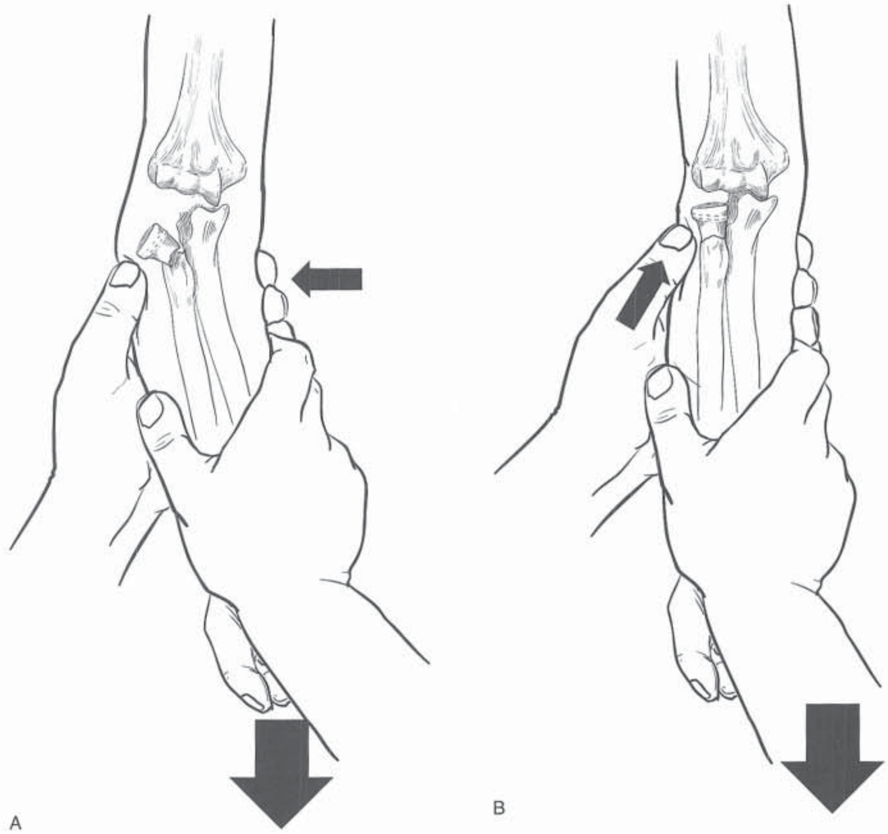


FIGURE 41–93 Technique for closed reduction of the radial head with the elbow in extension. **A,** With the elbow extended, traction and a varus force are applied. The forearm is pronated and supinated to maximize the lateral prominence. **B,** The radial head is digitally manipulated into position. Supination or pronation of the forearm may assist in the reduction.

There are several techniques of closed reduction. Patterson is credited with describing a technique advocated by several subsequent authors.[393] The elbow is fully extended, which usually requires conscious sedation or general anesthesia. An assistant grasps the arm proximal to the elbow joint while the other hand of the assistant is placed medially over the distal humerus to provide a medial fulcrum for a varus stress applied across the elbow. The surgeon applies distal traction with the forearm supinated to relax the supinators and biceps. Although forearm supination may facilitate relaxation of the supinator muscle, it may not be the best position for manipulation of the head fragment. Jeffrey realized that the tilt of the radial head can be anterior or posterior. He believed the forearm should be rotated until the maximal tilt of the proximal fragment is felt laterally.[246] A varus force is then applied across the elbow to open up the lateral side of the joint, and the radial head is digitally manipulated back into position (Fig. 41–93).

Kaufman and colleagues have proposed another technique in which the elbow is manipulated in the flexed position. The thumb is pressed against the anterior surface of the radial head and the forearm is forced into pronation (Fig. 41–94).[264] Reduction has been reported after wrapping the extremity tightly, distally to proximally, with an Ace or Esmarch bandage (Fig. 41–95).[77,269]

In type II (30 to 60 degrees of angulation) and type III (more than 60 degrees of angulation) radial neck fractures we first attempt a closed reduction under conscious sedation or general anesthesia. If we are unable to reduce the angulation to less than 30 degrees, we will usually attempt a percutaneous or intramedullary reduction. A number of authors

FIGURE 41–94 Technique for closed reduction of the radial head with the elbow in flexion. The forearm is forced into pronation, and the operator's thumb is used to digitally reduce the proximal fragment.

FIGURE 41–95 Reduction of a radial neck fracture has been reported following exsanguination of the extremity with an Esmarch bandage with the elbow in extension.

have described using a K-wire to percutaneously "joystick" the proximal fragment into position.[44,123,172,411,427] When attempting a percutaneous "joystick" reduction it is important to avoid injury to the posterior interosseous nerve. The proximal fragment can often be manipulated directly from its subcutaneous position. If the distal fragment requires "lateralization," we insert a "joker" as closely as possible to the lateral aspect of the olecranon to avoid the posterior interosseous nerve (Fig. 41–96). Métaizeau and colleagues described reducing the radial neck by passing an intramedullary pin from distal to proximal (Fig. 41–97).[182,314,337,456] This method has been successful when other manipulative techniques have failed. However, our experience is that percutaneous pin manipulation is technically easier than intramedullary reduction and usually produces equal results.

What constitutes an "acceptable" closed, percutaneous, or intramedullary reduction is unclear. A number of authors have reported poor results after open reduction of proximal radius fractures,[368,414,456,511,542] while others have shown that results correlate with the quality of reduction.* Not surprisingly, younger children (under 10 years of age) have had better results after open reduction than older children.[216,250,419] These retrospective studies all have a selection bias in that fractures treated by an open technique are generally the most severely displaced and highest-energy injuries. Nevertheless, in reporting better results with closed treatment, Rang and associates felt that the results had more to do with method of treatment than with severity of injury.[414] To our knowledge, there are no good studies that compared closed, percutaneous, intramedullary, and open techniques for similar injuries. We believe it is probably wiser to leave some residual angulation (up to 45 degrees) than to introduce further soft tissue trauma with an open reduction.[126,368,530]

Salter-Harris type III and IV injuries, as well as fractures that remain significantly angled following attempts at closed reduction and minimally invasive techniques, require an open reduction. We perform an open reduction through a posterolateral approach with as little dissection as possible. A plane is developed between the anconeus and extensor carpi ulnaris muscles. Injury to the posterior interosseous nerve is avoided by staying posterior and positioning the forearm in full pronation. The capsule is divided and the elbow joint is entered. The orbicularis ligament is spared. Occasionally the head will be subluxed inferior to the ligament. If so, it can usually be reduced with the ligament intact, without difficulty. Fixation is achieved with a K-wire placed percutaneously from distal to proximal across the fracture site. Although there is controversy regarding the need for and technique of fixation following percutaneous or open reduction,[250,267,372,419] there is agreement that transcapitellar pins should be avoided.[147,368,542]

Following successful closed, percutaneous, intramedullary, or open reduction, we usually immobilize the arm in a long-arm cast in neutral position or slight pronation for 2 to 3 weeks. Once the cast is removed we encourage immediate active range of motion.

The management of late-presenting displaced fractures is difficult. Blount set a limit of 5 days, after which he advised against attempting reduction.[54] Others have reported poor results after longer delays.[337,368,430] Obviously, treatment decisions for late-presenting fractures must be made on an individual basis. However, we generally favor a conservative course, remembering that the remodeling potential, particularly in patients less than 10 years old, is great (Fig. 41–98).

The role of radial head excision is poorly defined. Classically, radial head excision has not been advocated in children due to concerns regarding growth disturbance and wrist and elbow deformity.[26] Recently, however, Hresko and associates reported good or excellent results in 8 of 12 patients between 12 and 18 years of age who underwent radial head excision for posttraumatic radiocapitellar pain or stiffness. No patients developed cubitus valgus or wrist pain.[231] Generally, we favor an initially conservative approach to severe injuries of the radial head. Although we have been impressed by the remodeling potential of the radial head, we have also had favorable results with radial head excision in the rare patient with late pain or stiffness following radial head fracture.

Complications. Loss of joint motion is the most common and problematic complication following radial head neck fractures. Rotation of the forearm is primarily affected, with loss of pronation greater than supination. Loss of motion may be caused by joint incongruity (malunion), enlargement of the radial head (overgrowth), avascular necrosis (AVN), fibrous adhesions, or proximal radioulnar synostosis. Loss of motion is more likely with (1) severely displaced fractures; (2) fractures associated with other injuries to the elbow, such as dislocation, avulsion of the medial epicondyle, rupture of the medial collateral ligament, or olecranon fracture; (3) patients more than 10 years old; (4) a delay in effective treatment; and (5) the quality of reduction achieved.[456] The prudent surgeon should be aware of these risk factors and

*See references 246, 250, 397, 419, 501, 511.

FIGURE 41–96 Percutaneous technique for reduction of radial neck fractures. **A,** AP radiograph obtained at the time of injury showing a displaced radial neck fracture and an associated olecranon fracture. **B,** Intraoperative radiograph showing a percutaneous K-wire used to "joystick" the proximal radial fragment into position. Note that a "joker" has been placed along the lateral border of the ulna to help lateralize the distal fragment and reduce the radial neck. **C,** Both the radial and ulnar fractures are percutaneously fixed. **D,** AP and lateral radiographs obtained 18 months after injury. There is slight hypertrophy of the radial head.

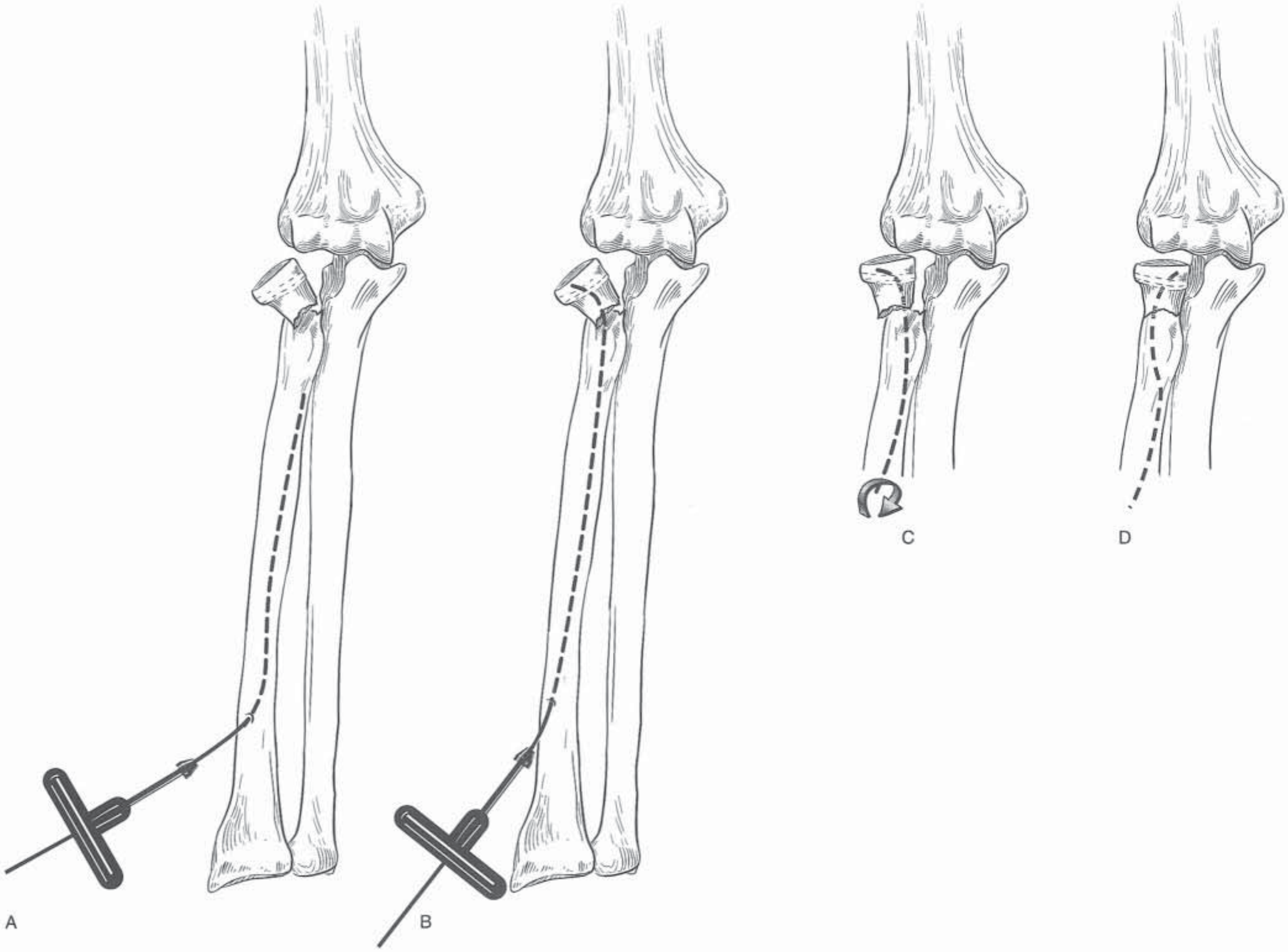


FIGURE 41–97 Métaizeau technique for intramedullary reduction of a radial neck fracture. **A,** A flexible intramedullary wire is introduced through a starting hole proximal to the distal radial physis. **B,** Under image intensification the wire is advanced into the proximal radial fragment. **C** and **D,** The wire is rotated to reduce the proximal fragment.

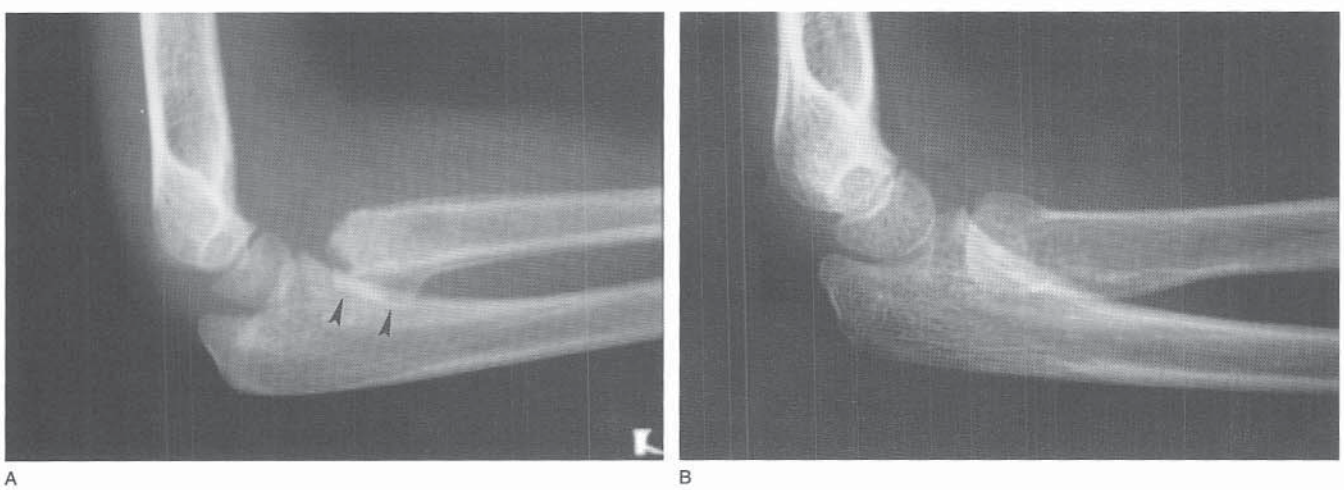


FIGURE 41–98 **A,** Lateral radiograph of the elbow of a 7-year-old girl 4 weeks after injury. The radial neck fracture is angulated 80 degrees (*arrowheads*). There is significant healing, as evidenced by calcification within the intact periosteal sleeve. The patient was treated with observation. **B,** Lateral radiographs obtained 1 year after injury showing significant remodeling.

should forewarn the parents of children at greatest risk of the possibility of loss of forearm rotation.

As with all fractures, malunion results from failure either to achieve adequate reduction or to maintain reduction. Malunion of radial head and neck fractures is most commonly associated with loss of rotation of the forearm. AVN of the radial head develops after radial neck fractures because of its unique blood supply (see Fig. 39–7).[104] AVN has been reported to occur following 10 to 20 percent of radial neck fractures and is almost always associated with significant loss of motion.[250,368] Both synostosis between the proximal radius and ulna[145,372,434] and myositis ossificans within the supinator muscle[522] have been reported to restrict range of motion following radial neck fractures.

Overgrowth of the radial head is presumably due to hypervascularity and stimulation of epiphyseal growth and occurs following up to 40 percent of radial neck fractures. Fortunately, there is rarely any functional deficit.[522] Premature fusion of the upper radial physis has been reported following up to 40 percent of radial neck fractures.[372,419] Theoretically, physeal arrest may produce shortening and valgus; however, clinical problems are infrequent.[368,372,419] Although nonunion of the radial neck has been reported, symptoms are usually mild or nonexistent[453,542] and healing usually occurs when treated by prolonged immobilization.[77,453] Compartment syndrome has also been reported with fractures of the radial neck.[398]

OLECRANON FRACTURES

Fractures of the olecranon are relatively uncommon, accounting for only about 5 percent of elbow fractures.[283] They are associated with other elbow injuries (most commonly the medial epicondyle) in 20 to 50 percent of cases (Fig. 41–99; see also Fig. 41–96).* Surgical treatment is required in 10 to 20 percent of olecranon fractures.†

Anatomy. Several anatomic factors make olecranon fractures less common and less severe in children than in adults. First, because the olecranon is predominantly cartilage, particularly in younger children, there is less chance of a fracture occurring with a direct blow to the olecranon. Second, the thick periosteum and relatively thin metaphyseal cortex of the olecranon predispose it to minimally displaced greenstick fractures (Fig. 41–100).

Mechanism of Injury. Olecranon fractures are most often the result of a hyperextension injury. However, they may also be the product of either a direct blow to the flexed elbow, a hyperflexion injury, or a shear force.[78] Hyperextension injuries are frequently associated with other elbow injuries. The direction of the associated coronal-plane force will determine the corresponding injuries. A valgus hyperextension force may produce an associated radial neck or medial epicondyle fracture (see Figs. 41–96 and 41–99). A varus hyperextension injury may be associated with lateral dislocation of the radial head, a Bado type III Monteggia lesion.

Flexion injuries are usually the result of a fall on an outstretched hand with the elbow flexed. The fracture is the result of a strong eccentric contracture of the triceps, "pulling" the olecranon over the fulcrum of the distal humerus. These fractures are usually transverse (perpendicular to the axis of the ulna), displaced posteriorly rather than anteriorly, and rarely associated with other injuries.

Shear injuries are the least common and are the result of a force to the proximal ulna just anterior to the humeral condyles. The olecranon fractures through metaphyseal bone. The distal fragment is displaced anteriorly and the radioulnar joint remains intact.

Diagnosis. Clinically, an olecranon fracture most commonly manifest as a swollen elbow. An abrasion or contusion on the posterior aspect of the elbow may provide a clue as to the nature of the injury. There may be a palpable defect posteriorly as well as inability to extend the elbow. Once the diagnosis has been made, the patient and radiographs should be closely examined for associated injuries.

Classification. Unfortunately, nearly every series of olecranon fractures uses a unique classification scheme,* and none of these systems provides all the pertinent clinical information. We classify olecranon fractures similar to Graves and Canale[188] and Gaddy and colleagues.[168] Both of these systems describe fractures as either displaced or nondisplaced, although they use different thresholds (Graves and Canale, 5 mm, and Gaddy and colleagues, 3 mm). Graves and Canale also have a third classification for open fractures. We believe the pertinent information required to make sound clinical decisions includes whether the fracture is intra- or extra-articular, whether it is displaced or nondisplaced (we favor Gaddy's threshold of 3 mm), and the presence and significance of associated elbow injuries.

Treatment. Nondisplaced or minimally (3 mm or less) displaced fractures can usually be managed with simple cast immobilization for 3 to 4 weeks. If the fractures are displaced (more than 3 mm), extra-articular, and stable, they can usually be managed with closed reduction and cast immobilization. This is usually the case for the rare shear-type fractures, which are usually quite stable in flexion. Flexion injuries may require immobilization in extension, which is often awkward and uncomfortable. Intra-arcular fractures with more than 3 mm of displacement usually require open reduction and internal fixation. We usually use a standard pin and tension band technique for displaced olecranon fractures (Fig. 41–101). Recently, some authors have described fixation with absorbable implants as an alternative to pins and wires. They note fewer symptoms from hardware with this technique.[78,228] Occasionally, hyperextension injuries associated with other elbow fractures will remain unstable after treatment of the associated fracture. In these instances, we will often stabilize the olecranon with simple percutaneous pinning (see Figs. 41–96 and 41–99). In such cases, arthrography may help ensure an adequate reduction.

Complications. Complications following olecranon fractures are uncommon. The most common complication of olecranon fracture is failure to appreciate a concomitant injury. The other common complication following olecranon fracture is stiffness. Fortunately, this is an unusual finding. Irreducible fractures, loss of reduction, delayed and

*See references 103, 123, 141, 186, 188, 232, 283, 320.

†See references 140, 168, 188, 320, 367, 390.

*See references 78, 140, 168, 188, 320, 367, 390.

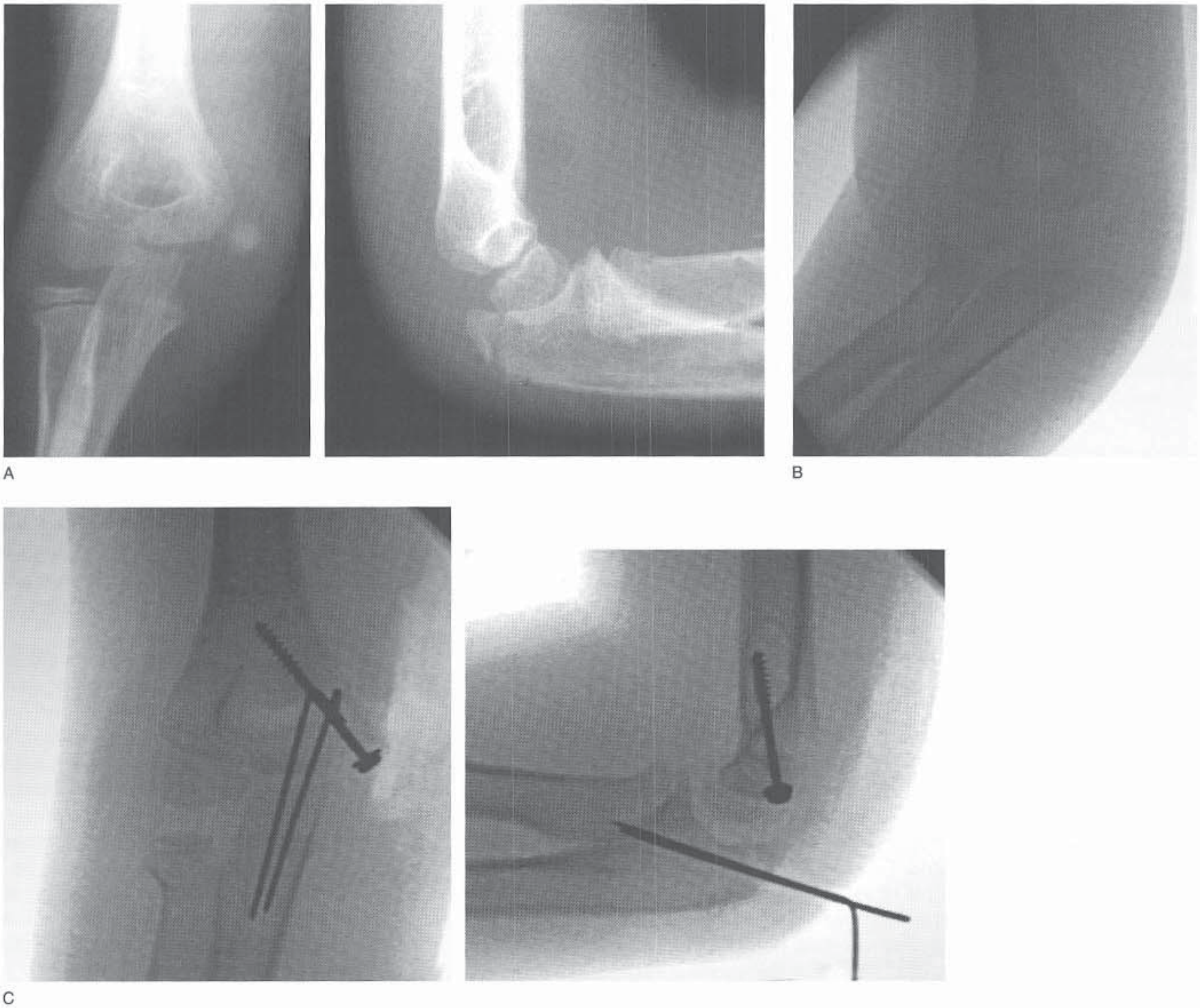


FIGURE 41–99 **A,** AP and lateral radiographs of an olecranon fracture with an associated medial epicondyle fracture, the result of a valgus hyperextension injury (which may have been an elbow dislocation) that spontaneously reduced. **B,** Intraoperative stress radiograph showing significant valgus instability. **C,** The patient was treated with open reduction and internal fixation of the medial epicondyle fragment. The alignment of the olecranon was inspected through the medial incision and the olecranon fracture was percutaneously pinned prior to fixation of the medial epicondyle.

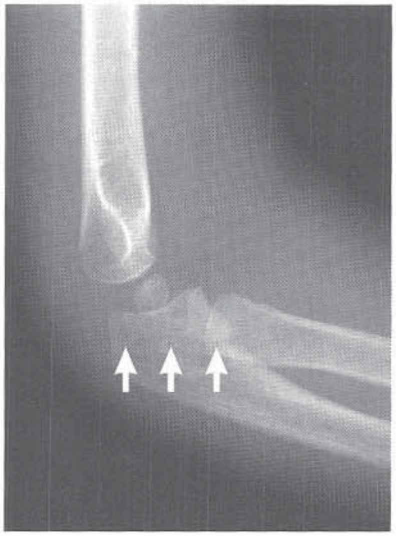


FIGURE 41–100 Lateral radiograph of a buckle fracture (*arrowheads*) through the metaphyseal bone of the olecranon.

nonunion, peripheral nerve injury, and compartment syndrome have all been reported with olecranon fractures.[94,320,568]

UNCOMMON ELBOW FRACTURES

T-Condylar Fractures. Fractures that involve separation of the medial and lateral columns of the distal humerus from each other and from the humeral shaft are referred to as T-condylar fractures. These injuries almost universally result in disruption of the articular surface of the distal humerus and represent a complex reconstructive challenge. These fractures are rare in children. When they do occur, they are usually in adolescents and/or the result of high-energy trauma.[263,389,417] Epright and Wilkins believe that this injury is the result of the olecranon functioning as a wedge to split the distal humerus at the apex of the trochlea.[139] In adults, the force of the olecranon on the trochlea is greatest when the elbow is flexed 90 degrees or more.[334]

A number of classifications exist for these fractures in adults.[245,362,422,568] Toniolo and Wilkins have classified these injuries in children into three types.[513] Type I fractures have minimal displacement, type II fractures have displacement but no metaphyseal comminution and type III fractures have displacement with comminution of the metaphysis.

Treatment is directed toward restoring anatomic articular alignment and reestablishing the distal articular surface with the humeral shaft. In most type I fractures and in some younger patients with type II and type III fractures, this is possible with closed reduction and percutaneous pinning (Fig. 41–102). In type I injuries with an intact soft tissue envelope, simple traction may produce an adequate reduction through "ligamentotaxis." If this is the case, we then percutaneously secure the condyles one to another with a transverse pin or screw. The distal fragment can then be secured to the proximal fragment using the same technique as for supracondylar humeral fractures. If traction alone does not reduce the articular surfaces, they may be manipulated percutaneously with large bone reduction forceps; however, if this fails to anatomically reduce the articular surface, open reduction will be required. In younger patients, the largely cartilaginous distal humeral epiphysis may make assessment of the articular surface difficult. In such cases, stress radiography or arthrography may be helpful in assessing the joint surface.[39]

Most patients with type II and III injuries and patients with type I injuries in whom an anatomic reduction of the articular surface cannot be achieved with closed or percutaneous techniques require an open reduction with rigid internal fixation. A number of different surgical approaches have been described. Although the triceps-splitting approach is the most widely discussed in the literature and the "triceps-sparing" posterior medial approach has gained recent popularity, we favor a posterior approach with an olecranon osteotomy.* We have found this gives wide surgical exposure, allows rigid fixation, and allows early mobilization. Since most of our experience with these injuries has been in older adolescents, we have not had problems or concerns with the proximal ulnar apophysis. Re and colleagues recently reported improved range of motion (particularly extension) in children and adolescents treated with the posteromedial or olecranon osteotomy approaches.[417]

Once anatomic restoration of the distal humeral articular surface has been achieved, rigid fixation of the articular surface to the humeral shaft must be achieved. Numerous reports in the adult literature have analyzed the problems associated with fixation of these fractures. Current recommendations are for double-plate fixation of the distal fragment to the shaft. One plate should be placed posteriorly on the lateral column and one medially. Positioning the plates at right angles to each other provides maximum strength (Fig. 41–103). Compression or pelvic reconstruction plates should be used, but thin "one-third tubular" plates have been found to be inadequate.†

The most common complication of T-condylar fractures is stiffness.‡ The likelihood of some permanent loss of motion is so high with these injuries that we counsel, the parents preoperatively that the goal of treatment is to *minimize* the stiffness. This can best be accomplished by using rigid internal fixation and minimizing immobilization. Recent reports have shown continuous passive motion in the immediate postoperative period to be beneficial, improving range of motion.[417] As with elbow dislocations, however, it is important that early motion be active rather than passive, as "overaggressive" therapy may exacerbate stiffness. Failure of internal fixation, nonunion, and avascular necrosis of the trochlea have also been reported as complications.[263,389]

Medial Condyle Fractures. Fractures of the medial humeral condyle are uncommon injuries. They can be thought of as the mirror image of the more common lateral condyle fracture, not only radiographically but also with respect to classification, treatment, and potential complications. They are thought to be the result of either a direct posterior blow to a flexed elbow§ or an avulsion from a valgus hyperextension injury.[43,158,177]

There are several ways to classify medial condyle fractures. Milch classified medial condyle fractures based on the loca-

*See references 66, 254, 255, 263, 266, 327, 389, 417, 533.

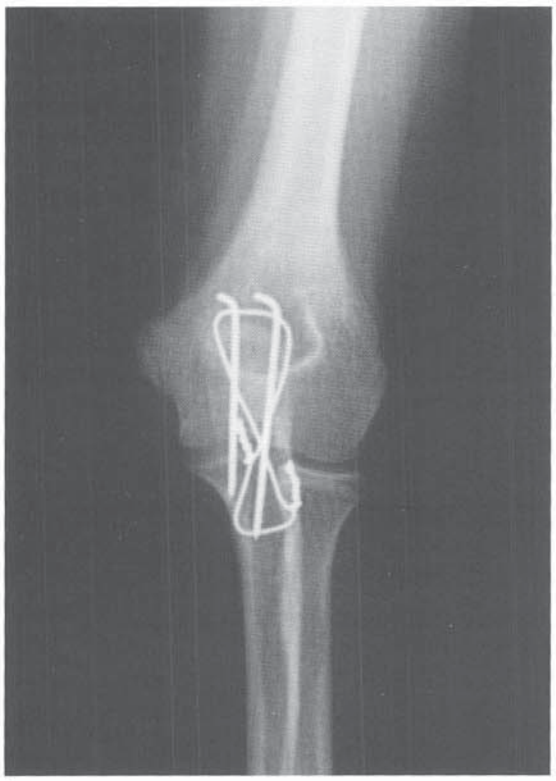
†See references 211, 254, 274, 327, 446, 448, 455, 545.

‡See references 254, 263, 266, 327, 389, 417, 455.

§See references 43, 75, 87, 90, 93, 206, 405.

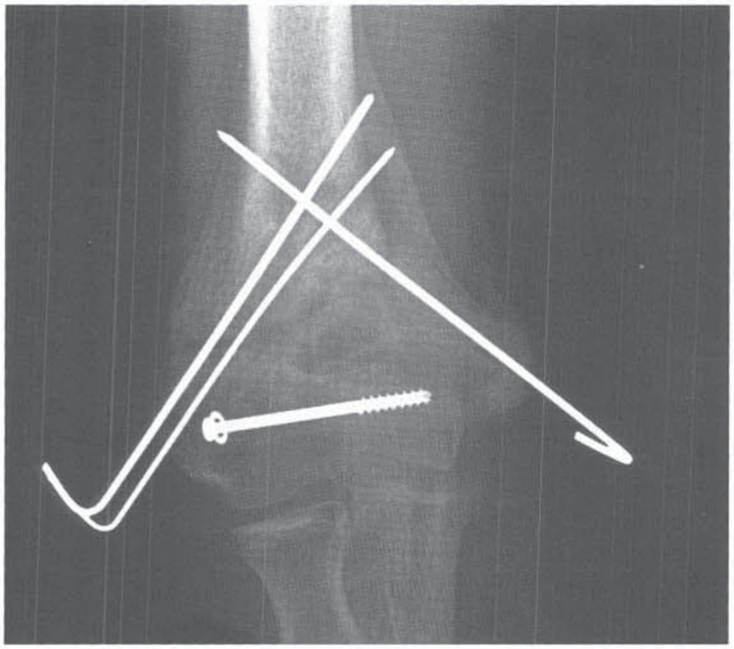
A

FIGURE 41–101 **A,** Lateral radiograph of a displaced olecranon fracture. **B,** Fixation was achieved using pin fixation with an AO tension band.



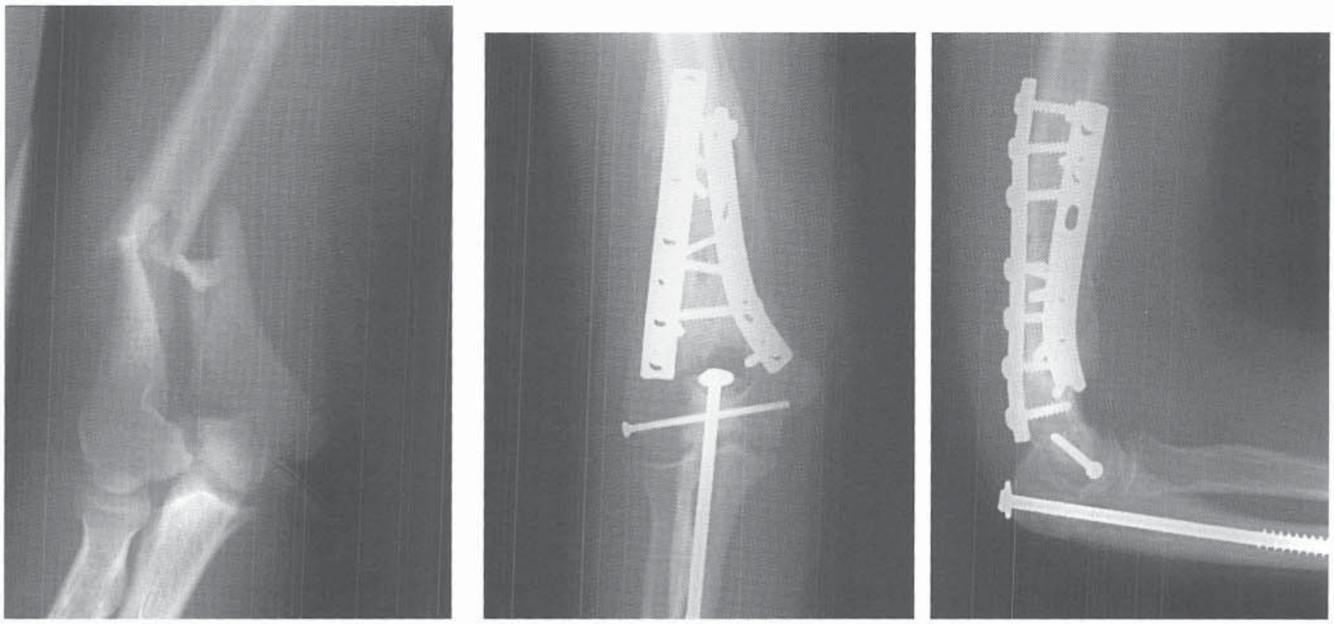
B

A



B

FIGURE 41–102 **A,** AP radiograph of a displaced T-condylar distal humerus fracture. **B,** AP radiograph obtained after reduction. The distal fragments were reduced and fixed with a cannulated screw. The distal fragments were then pinned to the proximal fragment.



A B

FIGURE 41–103 **A,** Displaced T-condylar distal humeral fracture. **B,** AP and lateral radiographs following open reduction and internal fixation through a posterior approach with an olecranon osteotomy.

FIGURE 41–104 Displaced medial condyle fracture. Note the intra-articular displacement (*arrow*).

tion of the fracture line. In type I injuries the fracture exits at the trochlear notch. In type II injuries the fracture extends more laterally through the capitellar ossification center.[343] Medial condyle fractures can also be classified as physeal fractures according to the system of Salter and Harris.[444] Like lateral condyle fractures, medial condyle fractures originate in the metaphysis, cross the physis, and exit through the epiphysis into the joint, making them Salter-Harris type IV injuries. Finally, medial condyle fractures can be classified according to the amount of displacement.[43,177,271,387] We use a modification of Kilfoyle's classification to describe these fractures as nondisplaced (traditionally less than 2 mm), minimally displaced (traditionally 2 to 4 mm), or displaced (traditionally greater than 4 mm).[271]

The treatment of medial condyle fractures depends first on making an accurate diagnosis, which may be difficult in this uncommon fracture.* Once an accurate diagnosis has been made, the treatment is determined by the amount of displacement (Fig. 41–104). Nondisplaced and minimally displaced fractures can be treated with simple cast immobilization. There is insufficient experience with this injury to know how frequently late displacement of minimally displaced fractures occurs. It is known that this fracture, like lateral condyle fractures, may not unite. Thus it is important to follow minimally displaced fractures closely to ensure that further displacement and delayed union or nonunion do not develop. Displaced fractures require open reduction and percutaneous fixation.† Complications following medial condyle fracture include stiffness, ulnar neuropathy, delayed union, and nonunion with cubitus varus deformity.‡

*See references 43, 105, 135, 142, 158, 177, 206, 210, 447, 528.

†See references 43, 141, 158, 177, 235, 271, 387, 405.

‡See references 93, 158, 177, 184, 203, 271, 528

Capitellar Fractures. Fractures of the capitellum are rare in children, occurring most commonly in adolescents.* Because the capitellum is nearly all cartilaginous, it is resistant to stress and difficult to fracture; therefore, a fall on an outstretched hand is more likely to produce a supracondylar or lateral condyle fracture.†

Two fracture patterns have been described. The more common type (Hahn-Steinthal type)[197] contains a significant portion of metaphyseal bone from the lateral condyle and, often, the lateral crista of the trochlea. The second type (Kocher-Lorenz type) is even less common in children.[5] It is nearly pure articular cartilage with little or no subchondral or metaphyseal bone. It may be associated with an underlying osteochondritis dissecans. Recently, anterior sleeve fractures of the capitellum and/or trochlea have been described. Although the sleeve fracture involves more humerus than the capitellum, in principle, it functions as a type II capitellar fracture.[5,125,503] Some authors have described the occasional comminuted fracture as a type III injury.[187]

Although most reports of capitellar fractures have been in adults, a few studies have addressed the injury in children.‡ Treatment guidelines can be gained from both the adult and pediatric literature. Often the most difficult aspect of managing capitellar fractures is making the diagnosis.[465] This is particularly true for type II fractures, which have little bone attached to the articular surface. Although some groups have described closed treatment of capitellar fractures,[305,373] we believe these intra-articular injuries require open reduction and fixation if displaced. Open reduction is usually best accomplished through a posterior or Kocher approach. A variety of implants have been used for fracture fixation, including percutaneous pins, AO screws, Herbert screws, and bioabsorbable pins.§ If the fragment is particularly small or if the articular surface extremely comminuted, excision is a better option than attempts at fixation.‖ In general, the results following capitellar fractures are good, although significant stiffness occasionally develops.[127,314,539]

Coronoid Fractures. Coronoid fractures are most commonly associated with elbow dislocations and therefore are frequently associated with fractures of the medial epicondyle, olecranon, proximal radius, and lateral condyle. They may also occur in isolation as the result of an avulsion from the brachialis. They are rarely displaced and usually require no treatment other than what is appropriate for the associated injuries.

Trochlear Fractures. True isolated fractures of the trochlea are uncommon. The two reports we are aware of are associated with dislocation.[185] There have been a few reports of a concomitant fracture of the anterior trochlea and capitellum.[237,378,503] The treatment of these injuries must be individualized, but it usually requires open reduction and fixation because of the intra-articular nature of the injury.

*See references 91, 95, 127, 130, 157, 187, 249, 292, 305, 373, 406.

†See references 5, 14, 157, 187, 249, 288, 295, 537.

‡See references 86, 127, 130, 292, 421, 437, 451.

§See references 14, 126, 130, 157, 187, 221, 228, 292, 305, 309, 314, 396, 406.

‖See references 14, 130, 157, 176, 331.

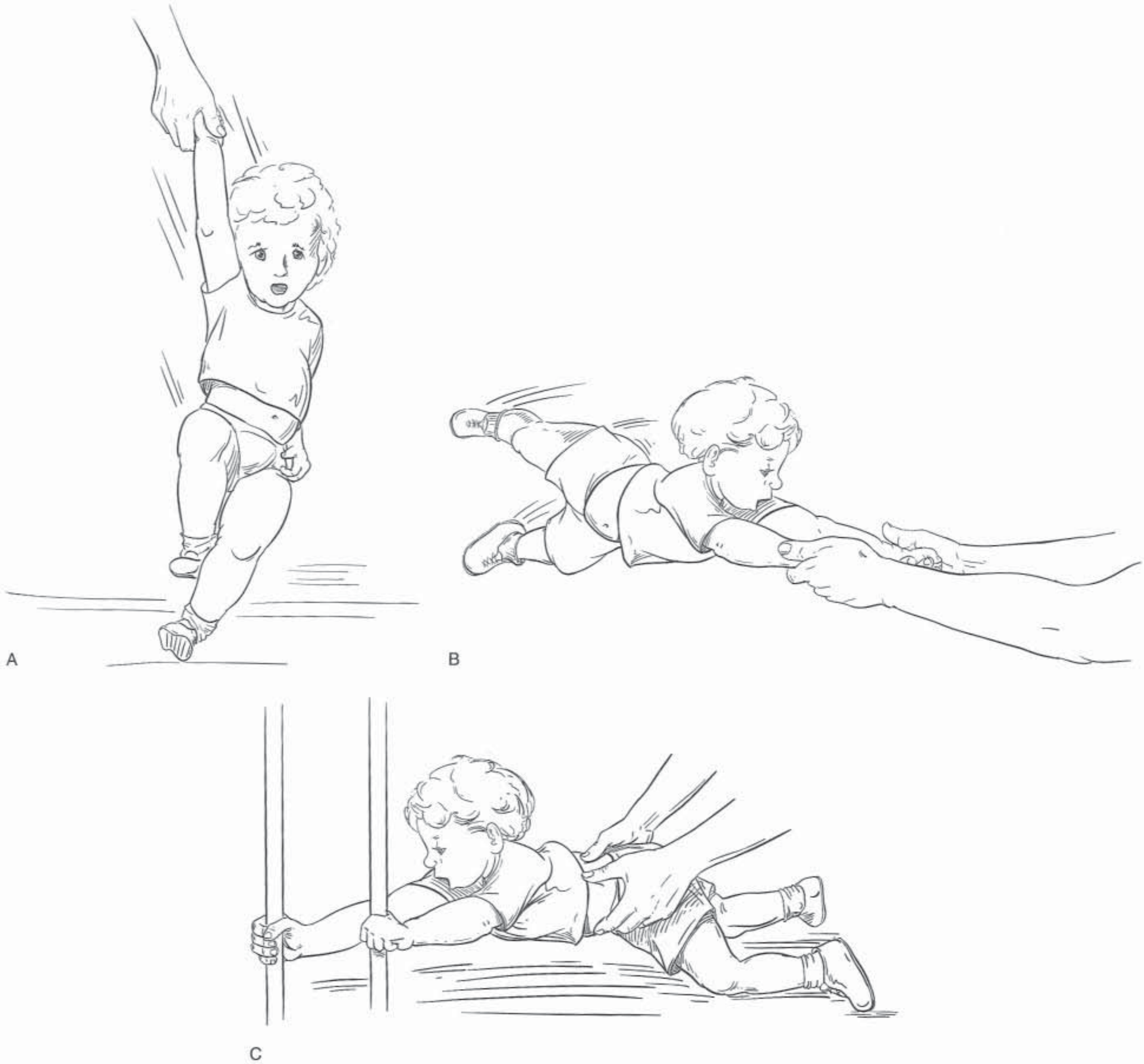


FIGURE 41–105 **A** to **C**, Common mechanisms resulting in nursemaid's or pulled elbow.

Lateral Epicondyle Fractures. In a literature review encompassing with 5,228 fractures of the distal humerus, Chambers and Wilkins could find only one case of fracture of the lateral epicondylar apophysis.[76] Thus, lateral epicondyle fracture may be the least common children's elbow fracture. The irregular ossification of the secondary ossification center makes the diagnosis of lateral epicondyle fractures difficult. The lateral condylar apophysis ossifies laterally to medially, creating a "space" between the secondary ossification center and the metaphysis, which can be misinterpreted as a displaced fracture.[466] To correctly diagnose lateral epicondylar pathology, the physician must carefully evaluate the soft tissues, both clinically and radiographically, as trauma will usually be associated with noticeable swelling.[76] Comparison views of the opposite elbow may also be helpful. The few reports that deal with lateral epicondyle fractures all describe good results with symptomatic treatment despite the development of a fibrous union.[330,375] Entrapment of the fragment has been noted and is the only indication for surgery.[330,539]

ASSOCIATED CONDITIONS

Nursemaid's Elbow (Pulled Elbow, Traumatic Subluxation of the Radial Head). "Pulled elbow" or "nursemaid's elbow" refers to traumatic subluxation of the radial head produced by sudden traction on the hand with the elbow extended and the forearm pronated (Fig. 41–105). Hippocrates is said to have recognized the condition, although the first written description was not until 1671.[155,523]

Pulled elbow is one of the most common musculoskeletal injuries in children less than 4 years old and is rarely, if ever, found in children more than 5 years old. The peak incidence is between the ages of 1 and 3 years.*

Subluxation of the radial head is possible due to the anatomy of the proximal radius.[308,332,439,445,502] The radial head is actually oval rather than circular. When the forearm is supinated, the anterior aspect of the radial head is elevated

*See references 57, 68, 165, 207, 233, 296, 308, 332, 439, 445, 502.

sharply from the neck; thus, if traction is applied with the forearm in supination, the annular ligament is pulled against this sharp bony elevation. However, laterally and posteriorly, the radial head rises rather gradually, so that when traction is applied with the forearm in pronation, the radial head escapes from under the anterior part of the annular ligament, which in turn becomes interposed between the radial head and the capitellum when traction is removed. In children 5 years old or older, subluxation of the radial head is prevented by a thicker and stronger distal attachment of the annular ligament to the periosteum of the radial neck.[332,445,502]

The diagnosis is made from the history and clinical examination. Immediately following the injury, the child cries with pain and refuses to use the affected limb. A click may have been heard or felt in the child's elbow by the person who pulled it. The child holds the elbow by the side in slight flexion with the forearm pronated, and may complain of wrist or elbow pain. If the child is calm and cooperative, passive flexion and extension of the elbow may be possible, but supination of the forearm is limited and voluntarily resisted. Radiographs of the elbow are normal. There is no displacement of the proximal radius from the capitellum and no evidence of intra-articular effusion.[308,332,439,445]

Reduction is often unknowingly performed by the x-ray technician, who passively forces the forearm into full supination in an attempt to obtain a true AP projection of the elbow. If the child escapes such treatment, the radial head is reduced by flexing the elbow to 90 degrees and rapidly and firmly rotating the forearm into full supination. As reduction is achieved, a palpable and sometimes audible click can be felt in the region of the radial head. The child should begin to use the arm in a normal manner within minutes. Immobilization is not necessary following reduction. However, the parents should be educated that recurrence, which occurs in about 5 percent of cases, is preventable by avoiding pulling on the child's hand.

Occasionally a child will present with a "neglected" subluxation that has been present for over 24 hours. These patients may not have immediate relief with reduction and may benefit from a long-arm cast in supination for 1 to 2 weeks. It is important to be certain of the diagnosis prior to immobilizing the arm, as occult elbow sepsis may present with a history of injury and a flexed, pronated arm. Rarely, a child will have multiple chronic recurrences. In addition to thorough education of the caretakers, these children may benefit from 3 to 6 weeks in a long-arm cast with the forearm supinated.

Osteochondroses of the Elbow. Panner first described a lesion in the epiphysis of the capitellum similar to Legg-Calvé-Perthes disease in 1927.[385] In 1964 Smith reviewed the literature and proposed that "Panner's disease" was a self-limiting condition that was nontraumatic in origin.[483] Since that time, a number of different "osteochondroses" about the elbow have been described most, of which seem to be related to repetitive stress.* For discussion purposes, we will consider three different entities: Panner's disease, osteochondritis dissecans of the capitellum, and other overuse injuries of the elbow.

*See references 4, 33, 35, 61, 64, 138, 242, 280, 298, 300, 303, 331, 349, 376, 400, 424, 436, 470, 506, 507, 512, 516, 518, 527, 560.

PANNER'S DISEASE. The entity described by Panner, and subsequently referred to as Panner's disease, affects children less than 10 years old who present with pain and stiffness in the elbow. These patients do not have constitutional symptoms and rarely have a history of trauma. There may be a flexion contracture and diffuse synovitis. Radiographically, the capitellum will show irregular areas of radiolucency with areas of sclerosis. The radial head may be enlarged and appear "skeletally advanced," and an effusion may be noted. Histologic studies of Panner's disease have documented focal areas of avascular necrosis with repair and revascularization. The articular cartilage has been noted to be normal.*

Treatment usually consists of reassurance, restriction of activities, and nonsteroidal anti-inflammatory medications (NSAIDs). Occasionally, extremely symptomatic patients may benefit from a period of immobilization with a splint or cast if the symptoms fail to resolve with conservative measures. We recommend arthroscopy to assess the articular cartilage. If the articular surface is intact, antegrade or retrograde drilling of the epiphyseal subchondral bone may stimulate healing. If there is a full-thickness articular cartilage defect with intra-articular loose bodies, we will remove the loose bodies and drill the subchondral bone either arthroscopically or through an arthrotomy. It should be stressed that surgical treatment for patients with Panner's disease is extremely uncommon.†

OSTEOCHONDRITIS DISSECANS OF THE CAPITELLUM. Osteochondritis dissecans of the capitellum is distinguished from Panner's disease in that it occurs in older children, is usually associated with overhead athletes (most commonly baseball players and gymnasts), and is more likely to require surgical treatment. As with Panner's disease, the presenting symptoms are usually pain, stiffness, and occasionally mechanical symptoms.‡ Radiographically, osteochondritis diseccans of the capitellum cannot be distinguished from Panner's disease (Fig. 41–106) other than by the skeletal age of the patient. Although CT, MRI, and ultrasound have all been used in the management of osteochondritis dissecans, we have not found that these imaging studies influence our clinically based decision process.[65,164,226]

Schenck and colleagues have proposed a mechanism for the development of osteochondritis dissecans of the capitellum from repetitive microtrauma.[449] In a cadaver study, they noted that the central section of the radial head was significantly stiffer than the lateral capitellum. Presumably, the disparity in the mechanical properties of the central radial head and lateral capitellum would increase strain in the lateral capitellum. During high-valgus-stress activities such as throwing, this increased strain may be a factor in the development of osteochondritis dissecans of the elbow.[449]

The initial treatment of osteochondritis dissecans is similar to that for Panner's disease, with an emphasis on activity modification. Patients in whom conservative treatment fails can be treated with arthroscopy for assessment of articular cartilage, followed by drilling, loose body fixation, or excision. Reports of fixation of loose osteochondral fragments

*See references 67, 82, 205, 212, 275, 285, 289, 313, 377, 384, 385, 410, 483.

†See references 67, 82, 205, 212, 275, 285, 289, 313, 377, 384, 385, 410, 483.

‡See references 4, 61, 138, 298, 300, 349, 424, 516, 518, 560.

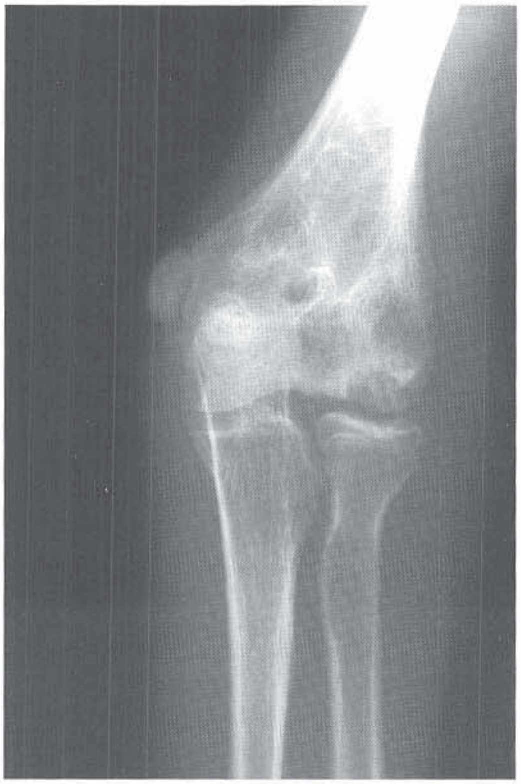


FIGURE 41–106 AP radiograph demonstrating osteonecrosis of the capitellum in a 13-year-old.

using Herbert screws or bone pegs are encouraging.[236,280,376] Results following surgical treatment are generally good,* although some authors report an inability to return to high-level competition.[35,79,242] Despite good short-term results, permanent deformity and disability can develop. A number of studies have documented permanent changes in the radial head, presumably the result of growth stimulation due to hypervascularity. The radial head has also been noted to dislocate over time.† Two long-term studies (17- and 23-year follow-up) report pain and decreased motion in half of patients with osteochondritis dissecans as adolescents.[33,507]

OTHER OSTEOCHONDROSES ABOUT THE ELBOW. The term "Little League elbow" has been used to describe a multitude of lesions about the elbow, most commonly osteochondritis dissecans of the capitellum, but also Panner's disease, osteochondritis of the trochlea and radial head, and epiphysiolysis of the medial epicondyle and olecranon (Fig. 41–107).‡ The casual application of this term is unfortunate in that it accurately describes neither the pathology nor the mechanism. These overuse syndromes can be seen in any overhead athlete. Patients usually present with localized pain that is activity related. Radiographs may be normal or may reveal characteristic changes consistent with osteonecrosis or epiphysiolysis. Treatment consists of NSAIDs and activity modification. Young athletes may require immobilization to ensure compliance with rigid activity restrictions. Once symptoms have abated, a carefully designed, well-controlled return to athletics should be implemented.

*See references 331, 400, 436, 470, 512, 557.

†See references 33, 79, 276, 436, 527.

‡See references 79, 193, 303, 331, 394, 515.

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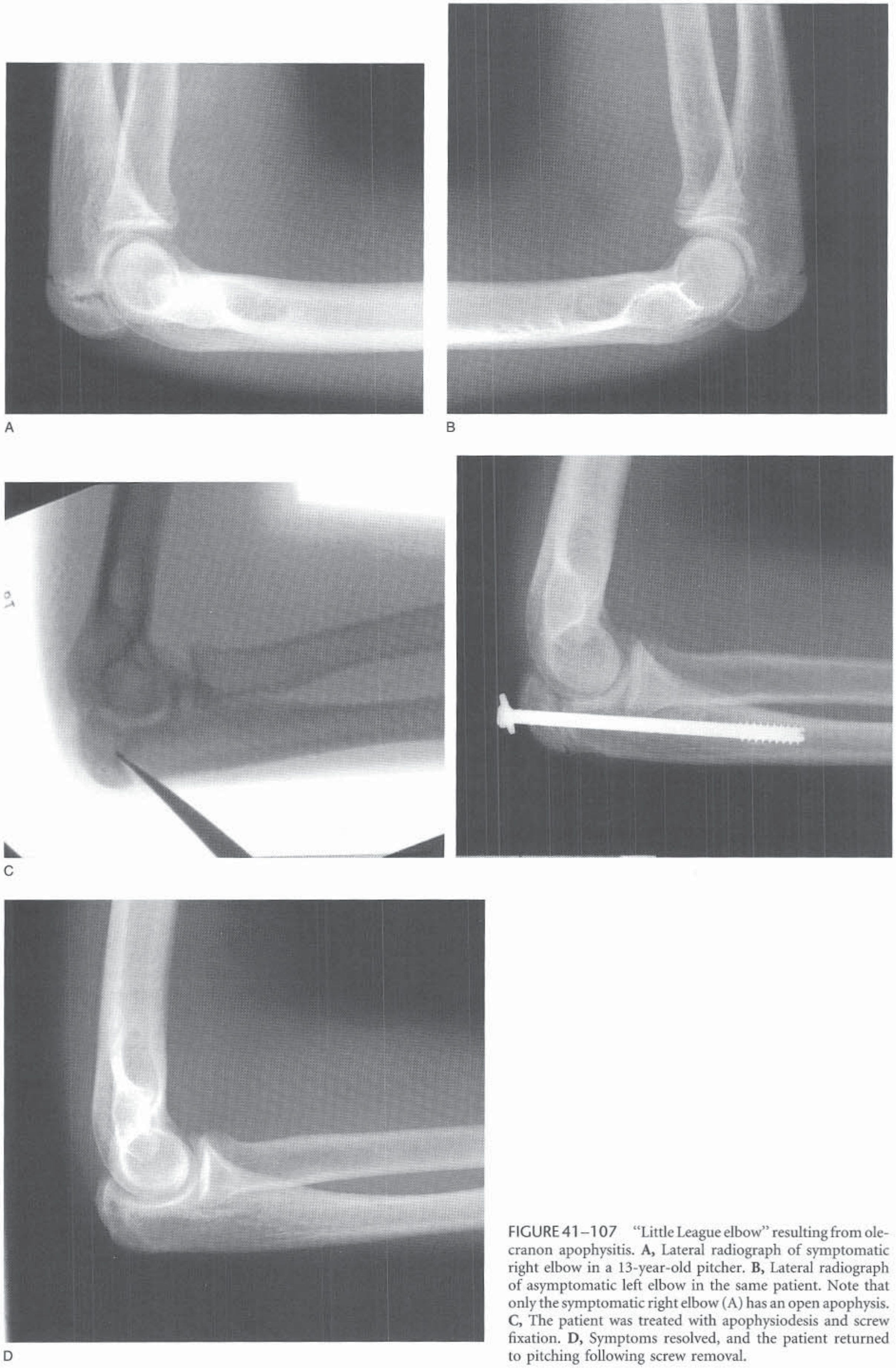

FIGURE 41–107 "Little League elbow" resulting from olecranon apophysitis. **A,** Lateral radiograph of symptomatic right elbow in a 13-year-old pitcher. **B,** Lateral radiograph of asymptomatic left elbow in the same patient. Note that only the symptomatic right elbow (A) has an open apophysis. **C,** The patient was treated with apophysiodesis and screw fixation. **D,** Symptoms resolved, and the patient returned to pitching following screw removal.

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Fractures of the Forearm

MONTEGGIA FRACTURES

In 1814, Giovanni Monteggia described two cases of fracture of the proximal third of the ulna associated with anterior dislocation of the radial head.[184] In 1844, Cooper described anterior, posterior, and lateral dislocations of the radial head with fracture of the ulnar shaft.[62] Perrin is credited with coining the term *Monteggia fracture* in 1909.[214] The eponym *Monteggia lesion* was used by Bado to describe different types of dislocation of the radial head associated with fracture of the ulnar shaft.[16,17] Although the Monteggia fracture is an uncommon injury, it has been the subject of considerable investigation because of the frequency with which its diagnosis is missed and the serious sequelae that may develop without treatment.

Anatomy. The pertinent anatomic considerations in Monteggia fractures include the ligamentous structures, which stabilize the radius and ulna, the muscles, which contribute to the deforming forces, and the neurovascular structures, which may be injured with fracture displacement. The radius and ulna are bound together proximally and distally by strong ligaments and throughout their length by the interosseous membrane. The radial head is maintained within the radial notch of the ulna by the annular ligament. The quadrate ligament, radial collateral ligament, and elbow capsule also provide stability to the proximal articulation of the radius and ulna.

The muscular anatomy of the forearm contributes to Monteggia fractures. In hyperextension injuries, the biceps is a major deforming force, pulling the proximal radius away from the capitellum as the elbow extends. The forearm flexors also provide a deforming force in Monteggia fractures, shortening and radially deviating the ulna.[284]

The unique neurovascular anatomy of the elbow predisposes Monteggia fractures to certain complications. The close proximity of the displacing radial head to the radial or median nerve makes nerve palsy quite common. The fascial compartments of the antecubital fossa and forearm can lead to compartment syndrome following Monteggia fractures.*

Classification. The mechanism of injury varies with the type of Monteggia fracture; thus, it is helpful to discuss the classification of Monteggia fractures before discussing the mechanism of injury. Bado's classic classification is still used today.† Bado's classification is defined by the direction (i.e., anterior, posterior, or lateral) of the radial head dislocation. Radial head displacement is always in the direction of the apex of the ulnar deformity. In *type I* fractures, which are most common, the radial head is dislocated anteriorly. *Type II* Monteggia fractures have posterior dislocation of the radial head.[16,17,83,210,212] *Type III* Monteggia fractures are the second most common. The ulnar fracture is metaphyseal and often greenstick, and the radial head is dislocated laterally.[16,17,136,202,320] If the ulnar fracture extends into the olecranon, there may not be true disassociation between the radial head and the ulna. This fact has led to debate as to the proper classification of this injury.‡ Fracture of both the radius and the ulna with anterior dislocation of the radial head is referred to as *type IV* Monteggia fracture. Some authors have described the *type IV* injury as a variant of a *type I* injury.[16,17,68,259]

Bado described injuries that were "equivalent" to a type I Monteggia fracture based on a similar mechanism of injury, radiographic appearance, or treatment.[16,17] Other authors have subsequently expanded these "equivalent injuries."§ The most common and recognized equivalents are fracture of the ulnar shaft associated with fracture of the proximal radial epiphysis or radial neck,[202] and anterior dislocation of the radial head. Although the latter has been reported as an isolated injury, it is probably always associated with plastic deformation of the ulna.[167] Other uncommon injuries have also been reported as equivalent to Bado type I, II, or III injuries.‖

Letts and associates modified Bado's classification for pediatric patients.[164] They described five types, of which the first three—A, B, and C—are subtypes of Bado's type I anterior dislocation. In *Letts type A* injuries there is anterior dislocation of the radial head due to plastic deformation (apex anteriorly) of the ulna.[167] Both *type B* and *type C* injuries have anterior dislocation of the radial head, type B with a greenstick fracture of the ulna and type C with complete fracture of the ulna. Letts type C injuries include Bado type IV lesions. *Letts types D* and *E* correspond to Bado types II and III, respectively.

Mechanism of Injury. There are three different theories as to the pathogenesis of type I Monteggia fractures. The first theory proposes that fracture results from a direct blow to the posterior ulna.[36,37,184,256] According to this theory, as the ulna fractures and shortens, it puts stress on the radial head, which either ruptures the annular ligament or dislocates anteriorly from it. A second theory, supported in the original work of Bado, is that of hyperpronation.[17,88,208] According to this hypothesis, the body rotates around a fixed and pronated outstreched hand. This produces forced hyperpronation, which leads to fracture of the proximal ulna with anterior dislocation of the radial head. The third theory proposes hyperextension as a mechanism. As a child lands on an outstretched hand, the biceps contracts, which dislocates the radial head anteriorly. Thus, the entire body weight is borne by the ulna, which fractures and displaces anteriorly as a result of the pull of the intact interosseous membrane and the contracting brachialis.[284] Type II Monteggia fractures occur when the flexed elbow is longitudinally loaded; the forearm may be in pronation, neutral position, or in supination.[202,211,212] Type III Monteggia injuries are most likely the result of a varus-extension force at the elbow.[17,79,190,211,274,323]

Diagnosis. A patient with a Monteggia fracture usually presents with an obvious deformity of the forearm and elbow. Rotation of the forearm or flexion-extension of the elbow is painful and restricted. The radial head may be palpable, displaced from its normal position in the direction of dislocation—anteriorly, posteriorly, or laterally. Palpation of the ulnar diaphysis will reveal tenderness and deformity. A thorough assessment of the entire patient must be performed. It is important to be aware of the high incidence of associated ipsilateral extremity fractures in patients with Bado type II lesions.[156,210] A careful examination of the skin and a careful neurovascular assessment should also be performed with particular attention to the posterior interosseous nerve.

Radiographic Findings. The most common problem in the management of Monteggia fractures is failure to properly obtain and interpret good-quality radiographs.[40,79,115,233,310] The importance of obtaining radiographs of the elbow in *all* patients with displaced fractures (complete, greenstick, or plastic deformation) of the ulna cannot be overstated.[68,146,167] A recent report highlighted the potential hazards of "isolated" ulna fractures. Weisman and colleagues described two late-presenting Monteggia fractures with initial radiographs documenting a reduced radial head. In these cases, the radial head presumably spontaneously reduced and redislocated as the ulna angulated in the cast.[310] The diagnosis cannot be made if the appropriate radiographs are not obtained. The surgeon must carefully assess the radial head-capitellar alignment. A line drawn through the longitudinal axis of the radius should pass through the center of the capitellum, regardless of the degree of flexion or extension of the elbow (Fig. 41–108).[256,269]

The only diagnosis in the differential is an ulna fracture associated with a congenital dislocation of the radial head. Congenital dislocations of the radial head are usually bilateral and posterior.[6,168] Although anterior congenital dislocation of the radial head has been described, Lloyd-Roberts and others have written that these probably represent chronic, missed traumatic dislocations.[49,168,181] Radiographically, the congenitally dislocated radial head is posterior, enlarged, elliptical, and slightly irregular. The radius appears long relative to the capitellum, which is flattened.[6,43,168]

*See references 20, 86, 139, 185, 188, 235, 260, 265, 306.

†See references 16, 17, 68, 88, 202, 228, 229, 323.

‡See references 21, 41, 95, 136, 202, 208, 275, 314.

§See references 27, 91, 96, 202, 235, 314.

‖See references 27, 96, 202, 212, 226, 235, 263, 306, 314.

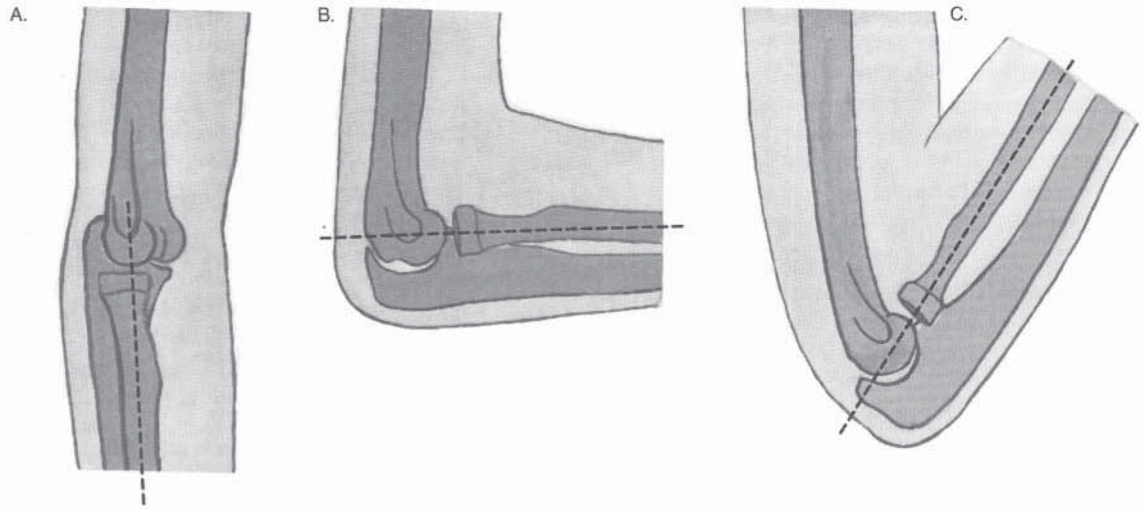


FIGURE 41–108 **A** to **C**, Anatomic relationship of the radial head and capitellum. A line through the longitudinal access of the radius passes through the center of the capitellum, regardless of the degree of elbow flexion.

Treatment

CLOSED REDUCTION. If they are seen and diagnosed acutely, Monteggia fractures in children can usually be managed successfully with simple closed reduction and cast immobilization.* The goal of treatment is to obtain and maintain an anatomically reduced radial head. This can often be accomplished with a less than anatomic reduction of the ulna. We routinely accept up to 10 degrees of angulation of the ulna, provided that a concentric radial head reduction is maintained. Satisfactory results have been reported with angulation of up to 25 degrees.[202,220,224] We usually perform closed reduction under conscious sedation in the emergency department.

Type I fractures are reduced with longitudinal traction and reduction of the ulnar fracture. The elbow is then flexed and the radial head is gently reduced with direct pressure. Following reduction, the radial head is usually quite stable as long as the elbow is kept adequately flexed. The arm should be immobilized with 110 to 120 degrees of elbow flexion and neutral or slight supination.[284] This technique is also used for the uncommon type IV Monteggia fracture, although the "free-floating" proximal radial fragment makes operative treatment more likely, particularly in the adolescent. However, good results have been reported with closed treatment of type IV injuries provided that radial head reduction is obtained and maintained.[17,202,234]

Type II (posterior) Monteggia fractures are reduced with traction to the forearm with the elbow in extension. After the ulnar fracture is anatomically aligned, the radial head is reduced and an above-elbow cast is applied with the elbow in extension and the forearm in neutral rotation.

Type III (lateral) Monteggia fractures are also reduced with the elbow in extension. Reduction is achieved by exerting longitudinal traction on the distal forearm and direct pressure over the radial head and ulna. The arm is immobilized in a long-arm cast with the elbow at 90 degrees and the forearm in supination.[17,79,190,314]

*See references 11, 27, 37, 42, 79, 95, 164, 202, 211, 228, 229, 233, 254, 256, 314

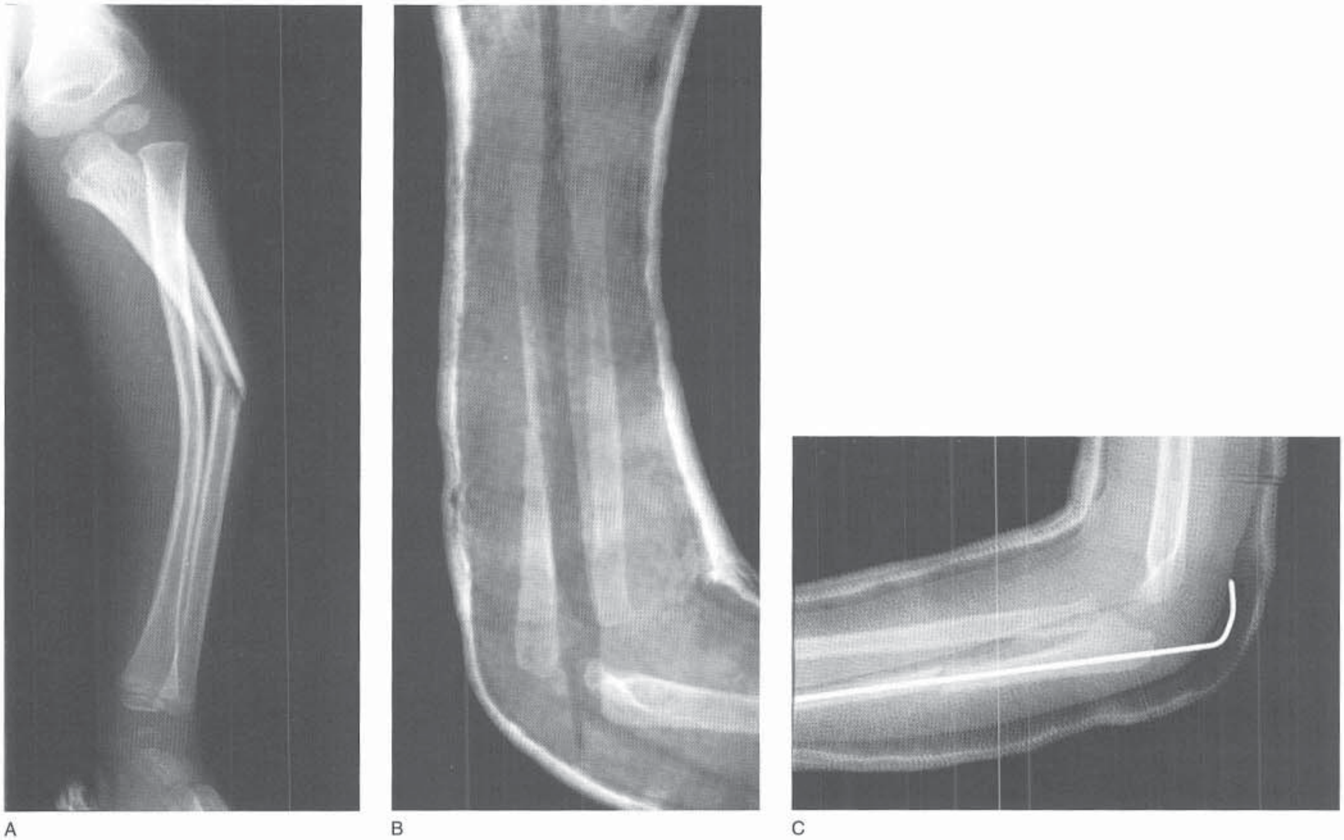
Once an adequate closed reduction has been achieved and a long-arm cast applied, postreduction radiographs should be obtained. These must include a true lateral view of the elbow showing the radiocapitellar joint to be reduced. Radiographs in the cast are obtained at weekly intervals for 3 weeks to ensure that the reduction is not lost as the swelling subsides and the cast loosens.[310] If the cast appears loose on the radiographs, it may be wise to replace it before the reduction is lost. It is imperative that radiographic confirmation of the reduced radial head be obtained in the new cast. After 3 weeks the fracture is "sticky" and reduction is unlikely to be lost. The patient returns at 6 weeks for cast removal and radiographs.

OPERATIVE TREATMENT. Operative treatment is indicated when an anatomic reduction cannot be obtained or maintained by closed methods. If the ulna cannot be maintained in a reduced position, the radial head will often redislocate when the ulnar fracture displaces. In most cases, stabilizing the ulnar fracture will keep the radial head reduced. Ulnar fixation can be accomplished with either pins, screws, or plates (Fig. 41–109). We prefer simple pin fixation because it requires a minimal (or no) incision and avoids the problem of retained hardware.* Once the ulnar fracture is stabilized, a long-arm cast is applied with the forearm in the position in which the radial head is "most stable" (usually supination, although this should be determined intraoperatively under fluoroscopic observation). Radiographs are obtained in the cast 2 weeks later to ensure that the radial head remains reduced. The cast is removed after 6 weeks.

Bado type IV injuries may require stabilization of both the ulna and radius. The radius may be stabilized with open reduction and plating, or with intramedullary reduction and fixation. Following fracture stabilization, cast immobilization is continued for 6 weeks with close follow-up to ensure the radial head does not redislocate.

Occasionally the radial head will not reduce with closed methods because of tissue interposed in the radial notch of the ulna. The possible impediments to closed reduction

*See references 17, 79, 95, 160, 164, 202, 211, 233, 279, 295, 314.



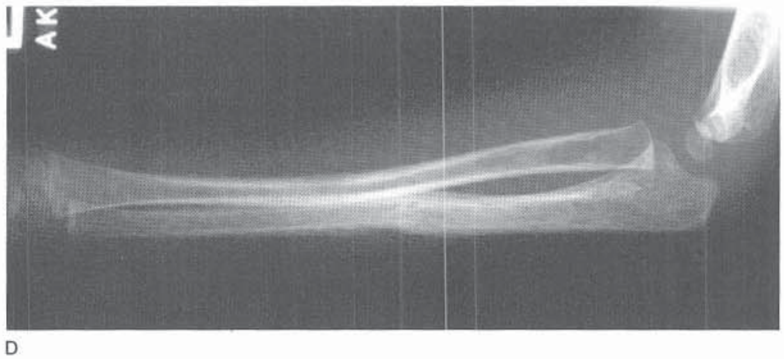


FIGURE 41–109 **A,** AP radiograph of the forearm showing greenstick fracture of the ulna with dislocation of the radial head. **B,** Despite an attempt at closed reduction and casting, the radial head remains anteriorly dislocated. **C,** The radial head is reduced after open reduction and percutaneous pin fixation of the ulna. **D,** The radial head remains reduced following pin removal and fracture union.

include either the annular ligament or a cartilaginous or osteochondral fragment. The annular ligament may be intact or ruptured.[200,284,320] In such instances, open reduction of the radial head is required. This can be performed through a simple posterolateral approach, or through the more extensile approach described by Boyd. For acute injuries we have found the posterolateral approach between the anconeus and extensor carpi ulnaris to be adequate, although it is important to realize that this approach does not protect the posterior interosseous nerve distal to the annular ligament. Thus, if more extensile exposure is anticipated, the Boyd approach should be utilized. In this approach, the incision is extended distally and the supinator is elevated off the ulna down to the interosseous membrane, allowing exposure of the radiocapitellar joint and visualization of the annular ligament as well as exposure of both the proximal ulna and radius as well as the posterior interosseous nerve (Fig. 41–110).[35,37,259] Once the radioulnar joint is exposed, the impediment to reduction can be removed. If the annular ligament remains in continuity, a nerve hook can be used to reduce it over the radial head. If this is unsuccessful, the ligament can be transected and repaired. If the annular ligament is ruptured, primary repair is often possible (Fig. 41–111). If the ligament is not repairable, it may be debrided. Following removal of the impediments to reduction, the ulnar fracture is reduced and stabilized. After fixation of the ulna, we assess the stability of the radial head and usually find it to be adequate. Although some authors have advocated routine reconstruction of the annular ligament, we reserve this procedure for those unusual cases in which the radial head remains unstable despite removal of the impediments to reduction and stabilization of the ulnar fracture. (The technique of annular ligament reconstruction is discussed with management of late-presenting or chronic

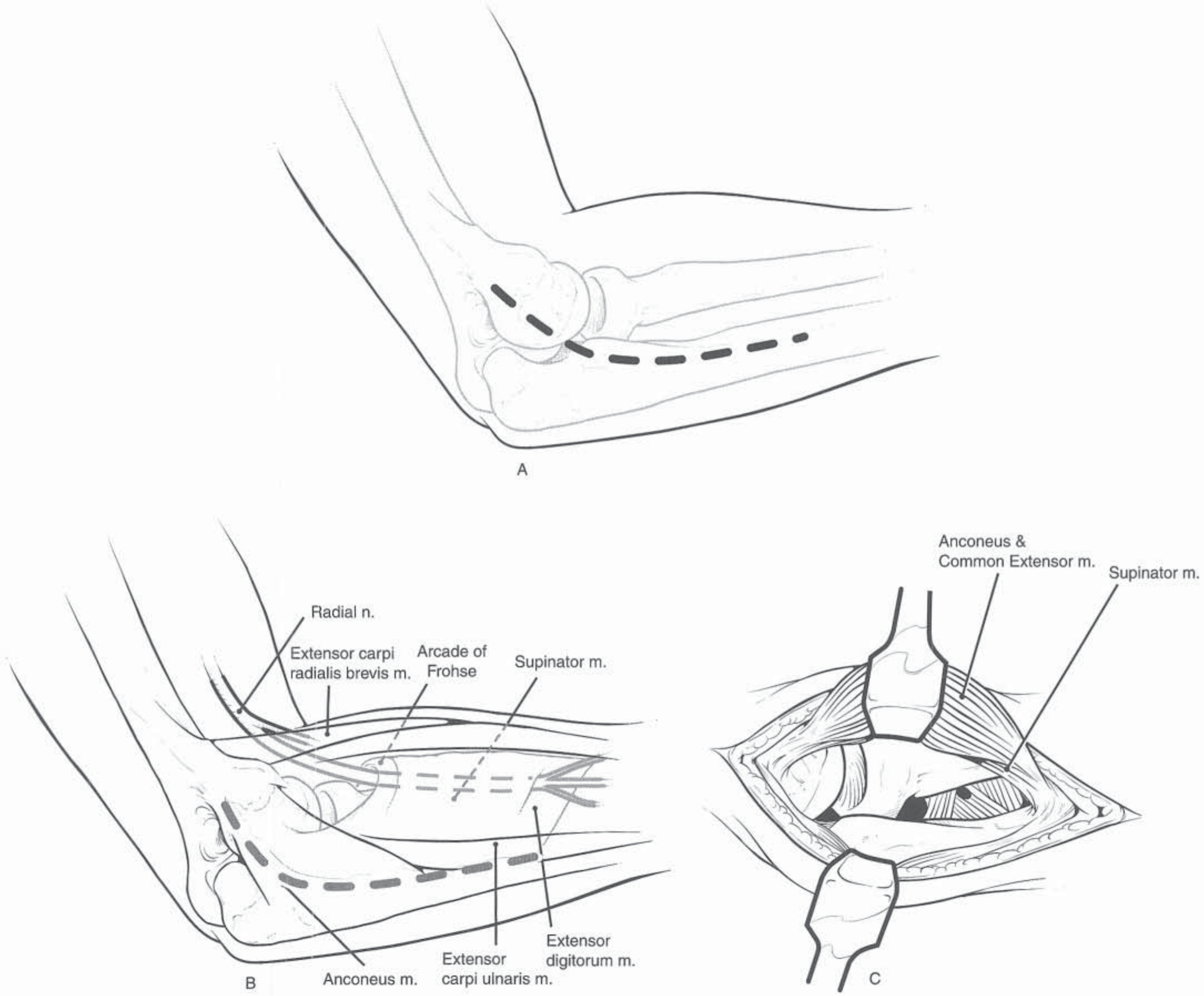


FIGURE 41–110 **A** to **C**, Boyd approach to the radioulnar joint and proximal radius. The insertion of the anconeus and the common extensor and supinator origin are elevated subperiosteally off the dorsal surface of the ulna. The deep fibers of the supinator arising from below the radial notch must be divided close to the ulna. (From Boyd HB: Surgical exposure of the ulna and proximal third of the radius through one incision. Surg Gynecol Obstet 1940;71:86–88, with permission.)

Monteggia fractures.) Following open reduction and ulnar stabilization, the patient is immobilized in a long-arm cast with the arm in the "most stable position" for 6 weeks. A number of authors have suggested a transcapitellar pin to help hold the radial head reduced. These authors stress that the pin must be of adequate diameter to prevent pin breakage. We have seen avascular necrosis of the radial head from a transcapitellar pin that was of "adequate size." We believe the problems associated with transcapitellar pins (breakage, stiffness, osteonecrosis) outweigh their benefits and avoid them at all costs.[195,308]

Complications. The most common and serious complication associated with Monteggia fractures is failure to make the appropriate diagnosis, resulting in a chronic or "neglected" Monteggia fracture. Other potential complications include recurrent radial head dislocation, malunion of the ulna, stiffness, posterior interosseous nerve palsy, and Volkmann's ischemic contracture.

CHRONIC, MISSED, OR NEGLECTED MONTEGGIA FRACTURE. The treatment of a child with a chronic dislocation of the radial head represents a difficult dilemma. On one hand, numerous reports indicate that most children with persistent dislocation of the radial head have minimal or no symptoms in the short term.[191,217,246,266] However, the long-term prognosis for these elbows is less positive. There are multiple reports of adults with untreated Monteggia lesions with pain, instability, and restricted motion.[24,43,168,181] Additionally, tardy nerve palsies have developed in patients with longstanding, untreated Monteggia lesions.[2,15,130,166] The possibility of late complications makes surgical correction at the time of diagnosis an attractive option. However, surgical reconstruction is not simple, and complications are frequent and often

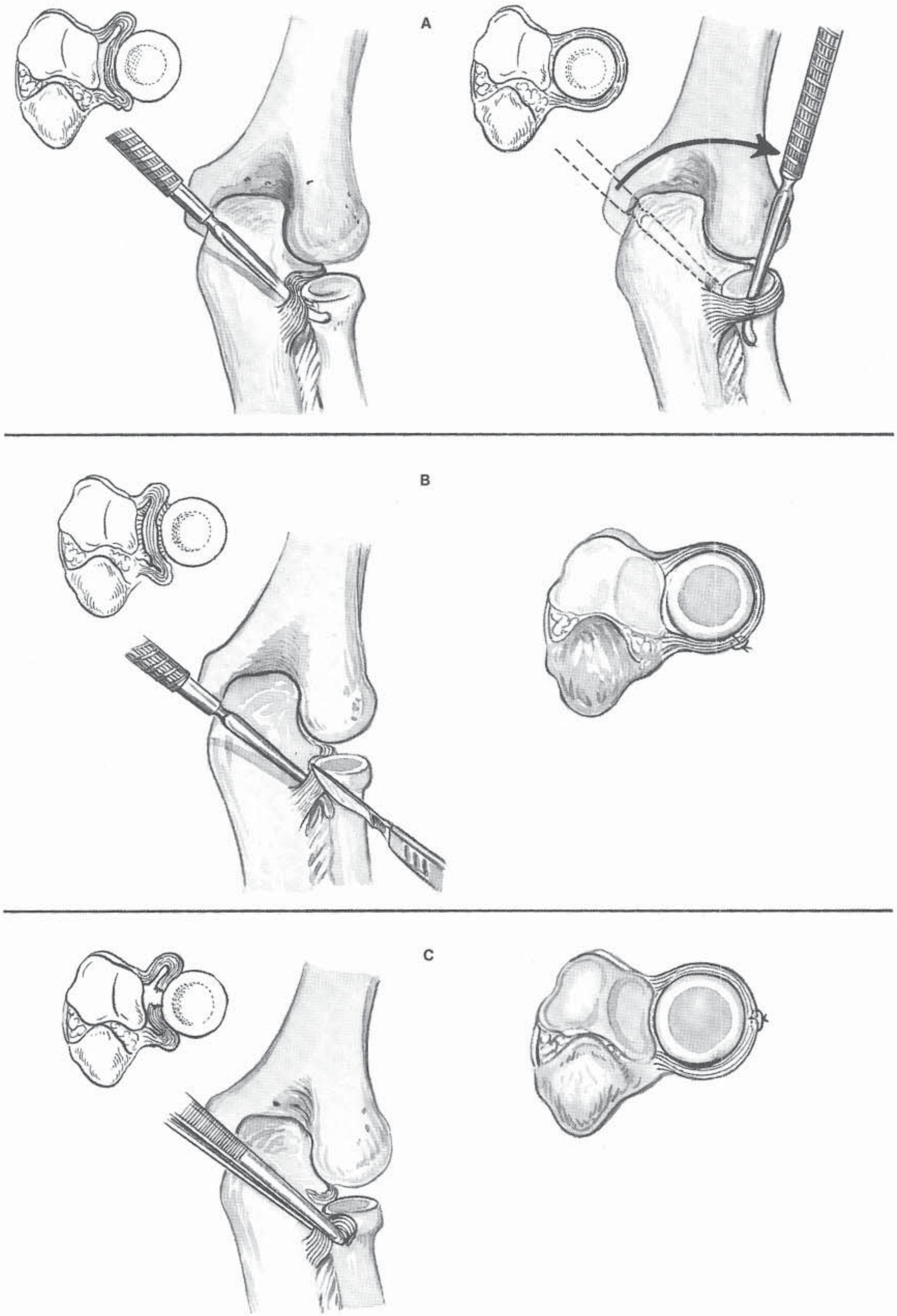


FIGURE 41–111 Techniques for management of the annular ligament following Monteggia fracture dislocations. **A,** An entrapped annular ligament may be reduced with a nerve hook. **B,** If the annular ligament is irreducible, it may be transected and primarily repaired. **C,** A ruptured annular ligament may be primarily repaired or debrided.

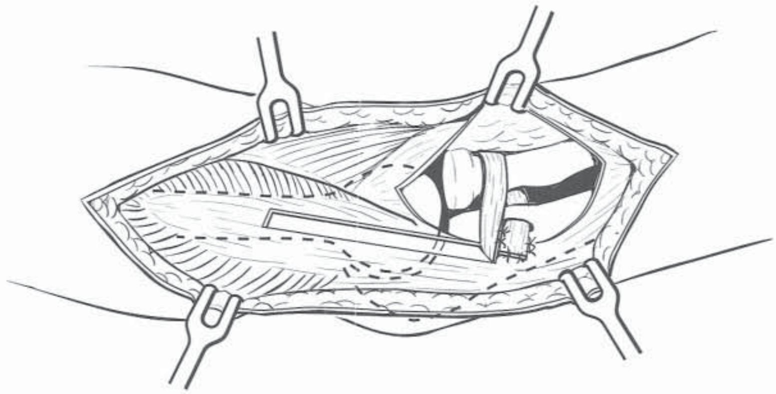


FIGURE 41–112 Bell-Tawse technique for annular ligament reconstruction. If the radial head remains unstable following reduction of the ulna, the annular ligament can be reconstructed using a lateral strip of triceps tendon that is brought around the radial neck and through a drill hole through the proximal ulna.

severe. Although there are many studies that describe the surgical management of chronic radial head dislocation,* relatively few describe the clinical results.[26,76,235,268] The recent report by Rodgers and colleagues at Boston Children's Hospital highlights the frequency and severity of complications. They reported 14 complications in seven patients, including three ulnar nerve palsies, one compartment syndrome, and two instances of loss of fixation. Our experience, while limited, parallels that of Rodgers and colleagues and has led us to take a conservative approach to treating the child with a chronic radial head dislocation. We agree with Fahey and others who have advocated treatment only for symptomatic children, realizing that radial head resection is a safe, reliable procedure for symptomatic adults.[90]

In some cases it is necessary to attempt reduction of the radial head in children with a symptomatic chronic Monteggia fracture. The most common symptoms during childhood include lack of flexion, restricted pronation/supination, and, rarely, unacceptable cosmesis. We favor a Boyd approach to debride the radioulnar joint. After joint debridement, an attempt is made to reduce the radial head. If the radial head is reduced and stable, no further treatment is required and the arm can be immobilized for 6 weeks. If, however, the radial head reduces easily but remains unstable, we proceed with annular ligament reconstruction using the Lloyd Roberts modification of the Bell-Tawse technique (which uses the lateral rather than central triceps tendon) (Fig. 41–112).[24,168] If the radial head is not reducible following joint debridement, ulnar osteotomy at the apex of deformity is performed. If ulnar osteotomy fails to produce an easily reducible radial head, the proximal radius should also be osteotomized. Once reduced, we assess the stability of the radial head. If it is stable through a reasonable range of motion and the osteotomies are rigidly fixed, we do not believe the annular ligament must be reconstructed. If, however, there is any question about the stability of the radial head, we believe the annular ligament should be reconstructed. Given the frequency and severity of complications following reconstruction of chronic Monteggia lesions, we agree with the recommendations of Rodgers and colleagues for exposure of the radial and ulnar nerves as well as prophylactic fasciotomies. Although there are descriptions of radial head reduction via ulnar Ilizarov lengthening, we have no experience with this technique. There is no question that accurate initial diagnosis and appropriate early treatment of Monteggia fractures produce a superior result with significantly fewer potential complications.

*See references 24, 26, 35, 43, 65, 76, 97, 111, 125, 137, 144, 168, 203, 235, 259, 268, 270, 277, 307.

RECURRENCE OF RADIAL HEAD DISLOCATION. This complication most commonly occurs with Monteggia fractures managed with closed reduction and casting and is most commonly associated with failure to maintain the reduction of the ulna.[310] It has been reported in up to 20 percent of Monteggia fractures.[79] When redislocation occurs and is promptly recognized, we usually repeat the closed reduction and stabilize the ulna, usually with percutaneous intramedullary pinning.[233] If significant healing of the ulna has occurred, the management of this problem becomes the same as for the late-presenting or neglected Monteggia fracture. Thus, it is of paramount importance that patients with Monteggia fractures be followed closely so that redislocation of the radial head can be identified and treated in a timely fashion.

MALUNION OF THE ULNA. Minor angulation of the ulna in any plane is well tolerated. Although radial displacement is associated with encroachment on the interosseous space and loss of pronation/supination, we have found this is rarely a functional problem.[220] Ulnar deviation, however, creates a cosmetically unappealing forearm, which may lead to parental or patient dissatisfaction.

STIFFNESS. Stiffness following Monteggia fractures may be the result of simple immobilization, soft tissue (capsular) ossification,* myositis ossificans,[280] or fibrous or bony synostosis between the proximal ulna and radius.[41] Stiffness associated with routine cast immobilization usually improves with active motion in 1 to 2 months. The classic and well-described periarticular ossification is known to resolve over time.† Similarly, myositis ossificans in children usually spontaneously improves in the first year. Myositis is known to be worsened by aggressive passive motion.[194,280] Proximal radioulnar synostosis is a rare complication and is usually seen with fractures associated with significant soft tissue injuries. Resection of the synostosis with interposition material (fat or cranioplast) has been described, with variable results.[41,235]

NERVE PALSY. Transient posterior interosseous nerve palsy occurs in about 20 percent of anterior or lateral Monteggia fracture-dislocations. Fortunately, normal function usually

*See references 24, 136, 166, 168, 266, 269.

†See references 24, 136, 166, 168, 266, 269.

returns within 2 to 3 months of the injury. The anatomic relationships of the proximal forearm help to delineate the location and etiology of radial nerve palsies associated with Monteggia fractures. The superficial radial nerve (pure sensory) branches from the radial nerve just proximal to the fibrous arch at the proximal extent of the supinator muscle (also known as the arcade of Frohse). The posterior interosseous nerve (pure motor) passes beneath the arcade. Therefore, a compressive lesion produces a pure motor deficit while a traction or stretch injury produces a combined motor and sensory deficit.[265] If neurologic function does not return within 3 months, EMG and nerve conduction studies should be performed. If there is no electrophysiologic evidence of reinnervation, consideration should be given to exploration of the nerve. Ulnar and median nerve palsies have been reported with Monteggia fractures, although they are quite rare.[42,265,307,314]

COMPARTMENT SYNDROME/VOLKMANN'S ISCHEMIC CONTRACTURE. Monteggia fractures are associated with significant disruption of the soft tissues about the elbow. Thus, it is not surprising that compartment syndrome may develop following these injuries.* The possibility of compartment syndrome is increased because closed treatment often requires flexion in a cast past 90 degrees. It is imperative that the surgeon be aware of the potential for compartment syndrome and monitor these patients accordingly, particularly those with altered consciousness.

FRACTURES OF THE SHAFT OF THE RADIUS AND ULNA

Fractures of the radial and/or ulnar shafts are relatively common, accounting for 5 to 10 percent of children's fractures.[175,322] Fractures of the shaft of the radius and ulna may occur in the distal third, middle third, or upper third. Fractures are more common distally than proximally.[32,175,230,285,322] One or both bones may be broken. Fractures may be greenstick or complete in both radius and ulna, or may be complete in one and greenstick in the other. Complete fractures may be undisplaced, minimally displaced, or markedly displaced with overriding and angulation. Angulation may be volar, dorsal, or toward or away from the interosseous space. Plastic deformation of one or both bones of the forearm may occur. When only one bone of the forearm is broken, the surgeon should suspect a Monteggia or Galeazzi fracture and obtain radiographs of the wrist and elbow in addition to the forearm. Fractures of the forearm are more easily managed in children than in adults. Closed treatment is usually successful, remodeling is significant, and malunion is uncommon.

Anatomy. The anatomy of the forearm is responsible for some of the unique features of fractures of the forearm. Fractures are more common distally for several reasons. First, although both bones are thick-walled throughout the greater part of their shafts, the cross section of the radius flattens distally. Proximally, it is cylindrical; it becomes triangular in the midshaft and ovoid distally. This geometric change produces a structural weakness in the radius, which has been shown to fracture first in both-bone forearm fractures.[285] Second, the muscular envelope of the proximal forearm provides more protection to the underlying bone than distally, where it becomes tendinous.

The soft tissue anatomy is also important in the production of deformities resulting from the fractures of both bones of the forearm. The actions of the biceps, supinator, and pronator teres and quadratus all affect the position of the forearm following fracture. In proximal third fractures of the forearm, the proximal fragment of the radius is supinated and flexed because of the unopposed action of the biceps brachia and supinator brevis muscles. The distal fragment is pronated by the action of the pronator teres and pronator quadratus muscles. In middle third fractures of the forearm (below the insertion of the pronator teres), the proximal fragment of the radius is balanced in neutral rotation, as the action of the supinator is counteracted by the pronator teres. It is flexed by the biceps. The distal fragment is pronated and displaced ulnarly by the pronator quadratus. In fractures of the distal third of the forearm, the distal fragment is pronated and ulnarly deviated by the pronator quadratus.

Mechanism of Injury. A fall on an outstreched hand is the most frequent mechanism of fracture of the radial and/or ulnar shaft. Evans and others have shown that a fall on a supinated, extended arm will produce a volarly angled greenstick fracture, while a fall on a pronated, extended arm will produce dorsal angulation of a greenstick fracture.[72,87] Both-bone forearm fractures may also be the result of direct trauma. Often these are high-energy, open injuries with significant soft tissue damage. Direct trauma is also involved in fractures sustained when the forearm is raised in self-protection, producing the so-called "nightstick" fracture of the ulna.

Diagnosis. The diagnosis of forearm fractures is generally straightforward. Fractures of the distal third, which are most common, often present with the classic "dinner fork" deformity of the forearm. As with any traumatic injury, a thorough assessment of the entire patient must be completed. Careful attention should be paid to the integrity of the skin, as forearm fractures are the most commonly open long bone fracture in children. It is important to remember that even the smallest "inside to outside" puncture wound represents an operative emergency. These injuries must be treated as open fractures according to the guidelines discussed in Chapter 39. Failure to appropriately treat open fractures can have devastating consequences.

Although pain, swelling, crepitus, and deformity make the diagnosis of displaced fractures obvious, plastic deformation injuries and greenstick fractures may present with minimal findings. In fact, it is not uncommon for children with mild plastic deformation or minimal buckle or greenstick fractures to be seen up to a week after the injury. Often the parents seek care simply because the "sprain" continues to cause minor complaints.

Radiographic Findings. The radiographic diagnosis is usually straightforward. It is important to obtain true AP and lateral views of the forearm, as oblique views may not accurately reflect the displacement (Fig. 41–113). The most important aspect of the radiographic diagnosis is to have complete radiographic assessment of the wrist and elbow. This

*See references 20, 188, 235, 260, 265, 306.

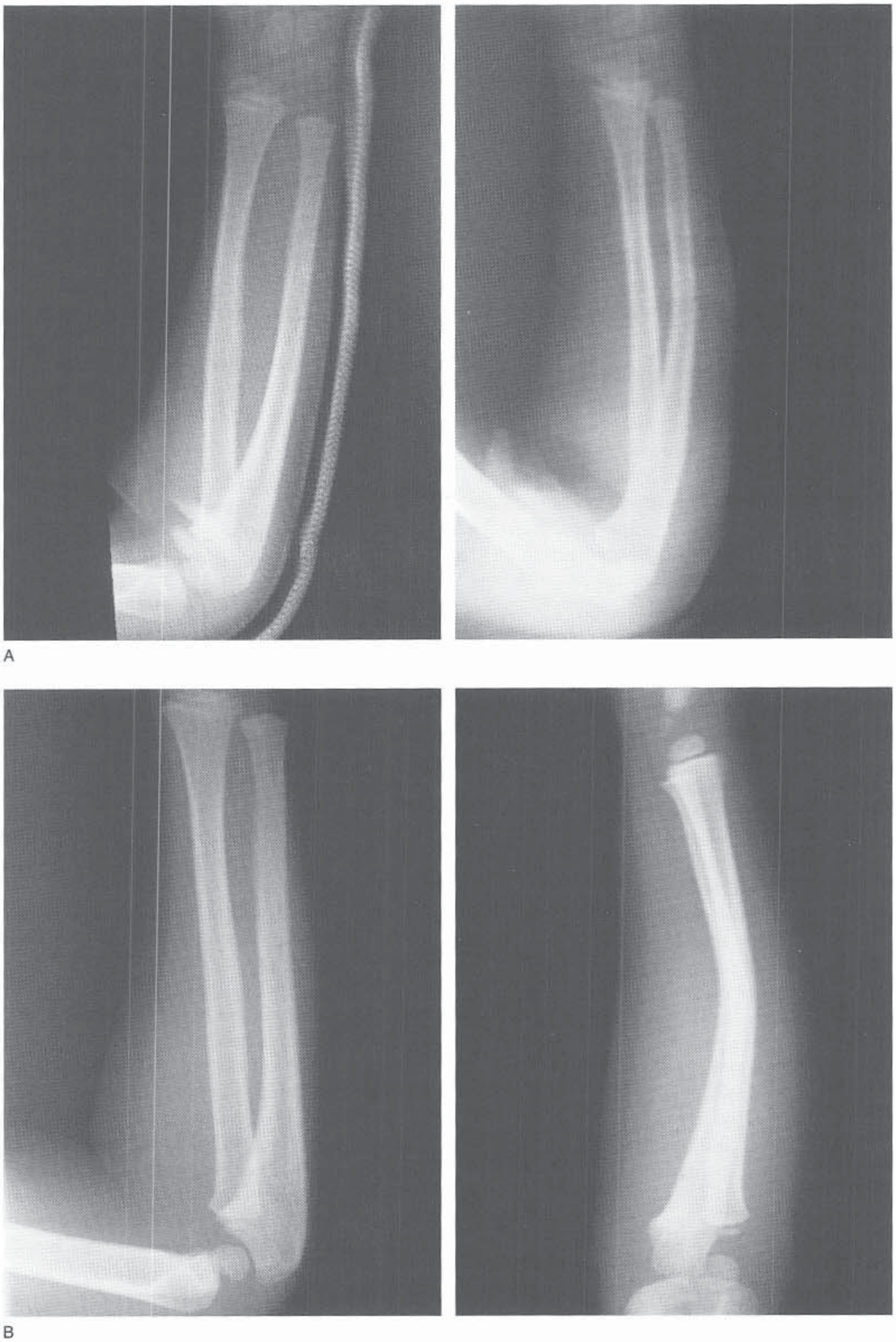


FIGURE 41–113 **A,** Oblique radiographs show what appears to be a minimally displaced fracture through the ulna. **B,** True AP and lateral radiographs reveal significant sagittal plane deformity of both bones of the forearm.

is particularly true when only one bone in the forearm is fractured and the likelihood of a Monteggia or Galeazzi fracture is high.

Classification. There is no established classification system for forearm fractures. Obviously, Monteggia, Galeazzi, and distal metaphyseal or physeal fractures are classified separately. Fractures of the radial and ulnar shaft may be classified according to their completeness—plastic deformation, greenstick, or complete; their location—proximal, middle, or distal third; or the direction of displacement—apex volar, dorsal, radial, or ulnar.

Treatment. Radial and ulnar shaft fractures can almost always be successfully treated with closed reduction and cast immobilization. The indications for operative treatment are few and include fractures associated with a compartment syndrome or an arterial injury requiring repair, open fractures (although after debridement these injuries are often treated with closed techniques), irreducible fractures, failure to maintain an adequate reduction, and skeletal maturity. Our approach to the adolescent with minimal growth remaining is to initially treat the individual as skeletally immature. In our experience, if a closed reduction can be obtained (usually not problematic) and maintained (frequently problematic), delayed union or nonunion is rare.[220] The difficulty in managing the adolescent with a both-bone forearm fracture is in determining how much angulation or displacement can be accepted.

CLOSED TREATMENT. A great deal of the literature on children's both-bone forearm fractures focuses on the appropriate rotational forearm position to adequately obtain and maintain a reduction.* Historically, the classic teaching was that the forearm should be supinated for proximal third fractures, in neutral position for midshaft fractures, and pronated for distal fractures.† Evans later challenged this, recommending supination for dorsally angulated greenstick fractures, pronation for volar greenstick fractures and supination for all complete fractures.[45,89] Evans also advocated using the bicipital tuberosity as a landmark to ensure restoration of appropriate rotational alignment. The bicipital tuberosity should be medial with the forearm in supination, posterior with the forearm in neutral position, and lateral with the forearm in pronation. Evans believed the fracture could be maximally stabilized by matching the distal forearm position to the position of the bicipital tuberosity on the injury film.[89] In practice, we treat the vast majority of both-bone forearm fractures with the forearm in neutral position.

Reduction is usually performed in the emergency department under conscious sedation. Reduction is obtained by exaggerating the deformity, applying traction, and reducing the fracture. Traction can be applied with the use of finger traps, the aid of an assistant, or the surgeon's lower extremity (Fig. 41–114). Once reduced, a well-molded sugar tong splint or cast is applied. If a cast is used, it should be widely split or bivalved in the emergency department. The importance of good casting technique cannot be overemphasized. The reduction is sure to be lost if a poorly molded cast is applied. A good cast must fit snugly, which requires a minimal amount of cast padding as well as a three-point and interosseous mold. Distal "slippage" of the cast (proximal migration of the forearm) will also lead to loss of reduction and can be minimized by ensuring that the arm is immobilized at a sharp right angle and that the ulnar border of the cast is kept straight (Fig. 41–115). Rang and colleagues have advocated that an eyelet passed proximal to the fracture may help limit migration in the cast.[225]

Immobilization of proximal third fractures and of fractures in small, "chubby" arms (usually any patient less than 2 years old) is difficult because of the large soft tissue envelope that must be molded to control the underlying bone. A number of authors have advocated immobilization of these fractures with the elbow in extension (Fig. 41–116).* Although this technique is rarely needed—Gainor and Hardy treated only eight of 130 patients in extension[103]—it can be successful. In an effort to keep the cast from slipping distally, benzoin can be applied to the humeral condyles.

Following reduction and splinting or casting, the patient is discharged with instructions to elevate the arm, "with the fingers above the elbow, and the elbow above the heart." It is important to explain to parents that slings are for comfort after the swelling subsides and should be avoided initially because they maintain the extremity in a dependent position. Patients should return 7 to 10 days after reduction for radiographs in the cast. Displacement in the cast must be appreciated and should be treated when first noted. Most large series report, and our experience supports, that remanipulation is required in 5 to 15 percent of children's both-bone forearm fractures.[53,141] Mild displacement may not require a formal re-reduction but should alert the surgeon to a loose cast that must be replaced. We have found that cast changes done at 10 to 14 days are less painful and the fracture is less likely to displace than if the cast change is done in the first week. If the cast is replaced, it is imperative to repeat the radiographs to ensure the reduction was not lost and that the cast fits snugly. In general, we see patients weekly during the first 3 weeks, as this is when loss of reduction is most likely to occur. If after 3 weeks the cast fits snugly and the reduction remains adequate, the patient returns at 6 weeks after injury for cast removal and radiographs.

What constitutes an acceptable reduction? Unfortunately, the limits of an acceptable reduction are unknown. The goal of treatment of radial and ulnar shaft fractures is to have a normal-appearing arm with a full, or at least functional, range of motion. The only sequelae of "nonanatomic union" that ever become clinically problematic are the cosmetic appearance of the arm and forearm rotation.[29,220,287] Thus, to establish the limits of an acceptable reduction, it is necessary to know the effect of malunion on appearance and rotation.

A number of studies have shown that malunion does not necessarily correlate with loss of forearm rotation. Daruwalla was unable to correlate residual fracture angulation with limitation of forearm movement.[70] Other authors have reported similar findings.† In fact, loss of forearm rotation has been shown to occur in patients with "good" radiographic results following pediatric forearm fractures.[197] These studies suggest that factors other than residual angulation may be responsible for loss of forearm rotation.[128,197,273,327] Complicat-

*See references 34, 50, 66, 87, 89, 101, 180, 218, 311.

†See references 34, 50, 66, 87, 101, 218, 311.

*See references 103, 252, 281, 303, 307.

†See references 70, 127, 128, 197, 218, 311, 327.

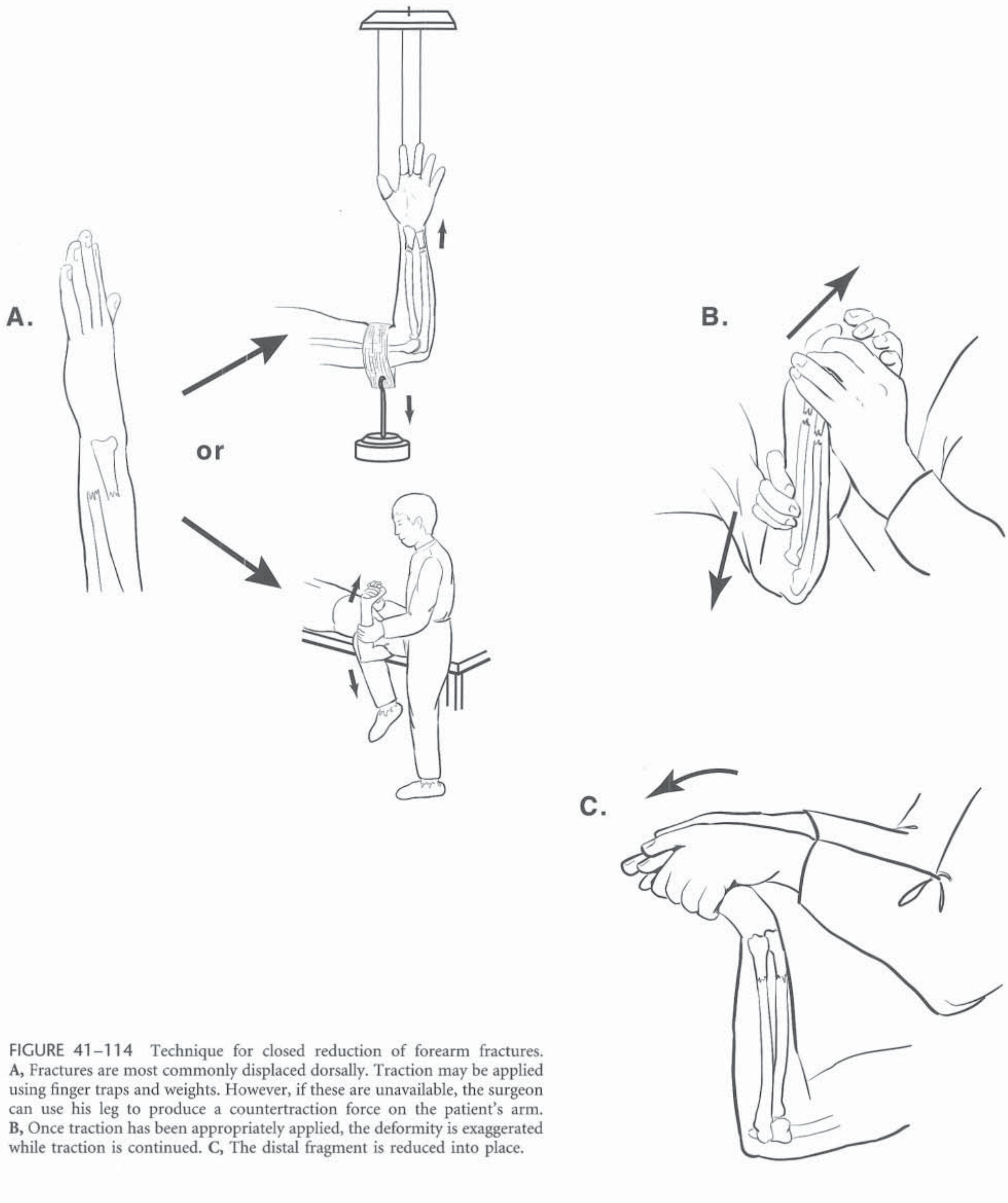


FIGURE 41–114 Technique for closed reduction of forearm fractures. **A,** Fractures are most commonly displaced dorsally. Traction may be applied using finger traps and weights. However, if these are unavailable, the surgeon can use his leg to produce a countertraction force on the patient's arm. **B,** Once traction has been appropriately applied, the deformity is exaggerated while traction is continued. **C,** The distal fragment is reduced into place.

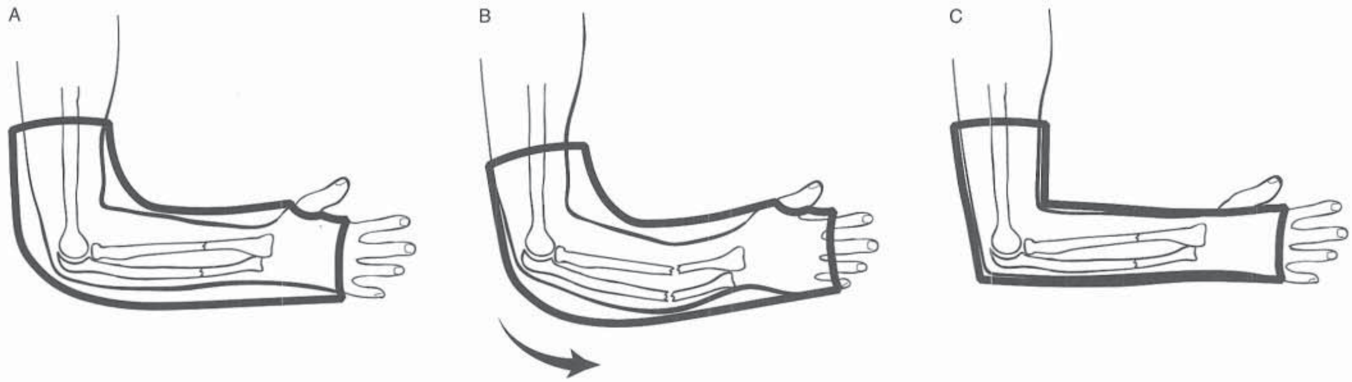


FIGURE 41–115 Proper casting technique. **A,** A poorly molded cast is round at the elbow. **B,** Without a proper mold, the cast can migrate distally, producing ulnar deviation of the distal fragment. **C,** A well-molded cast keeps the elbow at 90 degrees, which prevents distal migration and subsequent deformity.

ing the issue further is the fact that a measurable loss of pronation and supination may not produce a *functional* deficit. Carey and associates documented this in five patients over 10 years of age who lost 20 to 35 degrees of forearm rotation but had no functional limitations.[50]

When discussing the radiographic assessment of malunited forearm fractures, there are several parameters to consider. These include angulation (in both coronal and sagittal planes), rotation, displacement (translation), radial bow, and length. Both cadaver and clinical studies have shown that as much as 10 degrees of midshaft angular deformity does not produce clinically significant loss of motion.[180,247,273] Rotational deformity, however, does produce a corresponding loss of motion that does not remodel over time.[66,101,218,311] Price believes that complete bayonet apposition and some loss of radial bow is acceptable.[198,220] Length

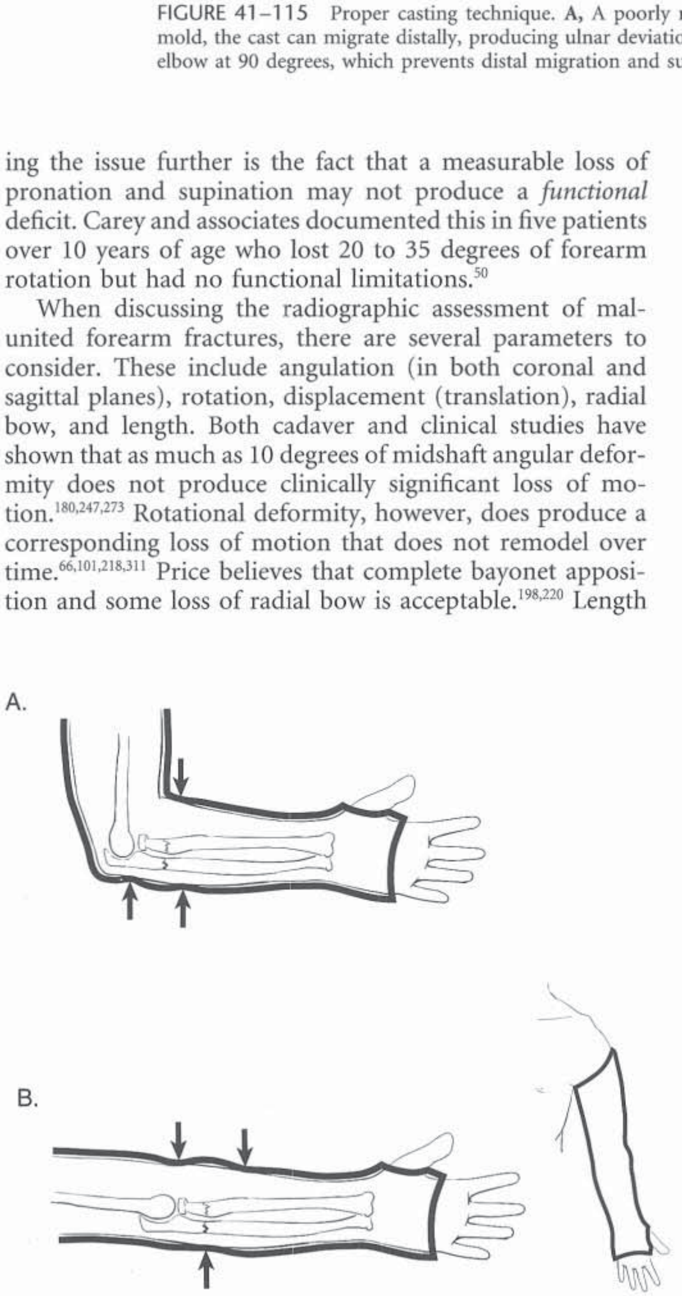


FIGURE 41–116 **A,** Fractures of the proximal third of the forearm may be difficult to maintain in a long-arm cast with the elbow flexed at 90 degrees because it is not possible to obtain three-point fixation. **B,** These fractures can be managed with a long-arm extension cast that allows three-point fixation.

has not been noted to be a problem in fractures of the forearm.[29,73,101,220]

The location of the fracture and the age of the patient also affect the radiographic result. Proximal fractures have been noted in multiple studies to have a worse outcome than distal fractures.* Again, however, the clinical significance of the malunion is unknown. Holdsworth and Sloan noted only three unsatisfactory results in 51 children with malunions of proximal shaft fractures. Consequently, despite the high number of "malunions," they recommended conservative treatment for these fractures. Although children older than 10 have less capacity for remodeling than younger children,† the significance of this fact and its relation to the management of radial and ulnar shaft fractures are unknown.

It is apparent from a review of the literature that malunion following pediatric both-bone forearm fracture is not uncommon.‡ What is surprising, however, is the paucity of reports on the surgical treatment of malunions.[29,33,287] Our review of the literature found only 48 patients less than 16 years old who required surgical treatment for malunion of a radial and/or ulnar shaft fracture. This fact supports our clinical bias that "malunion" of these fractures is a radiographic rather than a functional problem. In fact, we more frequently answer questions regarding the unattractive ulnar bow associated with a malunion than address questions concerning functional limitations (Fig. 41–117). Thus, our experience is that, despite a "measurable" loss of forearm rotation, malunion of forearm fractures, like malunion of supracondylar humeral fractures, is usually a cosmetic rather than a functional problem.

Given the infrequency of functional problems, we favor a generous definition of "acceptable reduction." We consider Price's classic guidelines of 10 degrees of angulation, 45 degrees of malrotation, complete displacement, and loss of radial bow to be reasonable,[220] and we occasionally accept even more deformity.[276] As in all areas of orthopaedics, each case must be individualized. It is important to know that ulnar bowing, particularly in the adolescent girl, may be poorly tolerated cosmetically. Consequently we make a dili-

*See references 30, 66, 70, 105, 128, 135, 218, 276, 290, 327.

†See references 101, 140, 204, 218, 299.

‡See references 25, 29, 30, 33, 53, 67, 73, 98, 100, 101, 117, 128, 140, 141, 148, 149, 159, 180, 198, 220, 230, 252, 253, 287, 299, 326, 327.

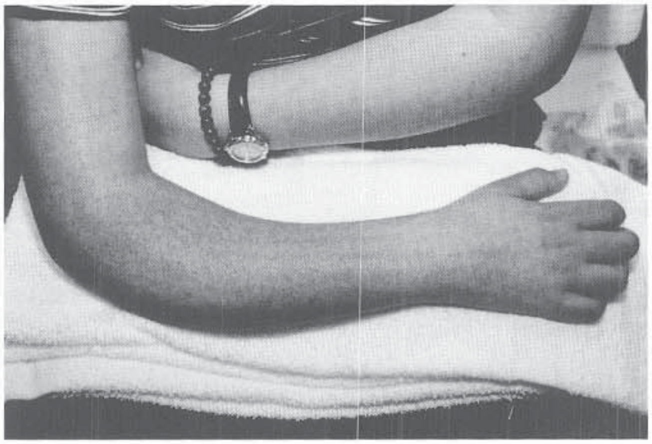


FIGURE 41–117 Significant cosmetic deformity associated with ulnar bowing following a fracture of the proximal third of the radius and ulna.

gent effort to keep the ulna from angulating with either cast or operative techniques.

OPERATIVE TREATMENT. The indications for operative management of pediatric radial or ulnar shaft fractures include dysvascular extremities, compartment syndromes, irreducible fractures, entrapped tendons or nerves, open fractures, and failure of closed reduction and casting. In our experience, the most common indications are open fractures and failure to maintain an acceptable closed reduction (usually in an adolescent). Although our definition of an acceptable closed reduction is discussed above, further discussion of operative indications is warranted. Recently there has been a proliferation of reports of operative management of children's both-bone forearm fractures despite good results with conservative management and few reports of functional problems from "malunion."* A recent report by Jones and Weiner addressed the proliferation of operative management.[141] In their review of 300 forearm fractures, 22 required remanipulation and 12 required pin fixation.[141] Our experience and that of others[253] agrees with their findings, namely, that 90 to 95 percent of forearm fractures can and should be managed successfully with closed techniques. Once the decision has been made to treat a fracture surgically, multiple techniques are available. These include plates and screws, intramedullary rods, and external fixation, either with fixation devices or with "pins and plaster." Oblique cross-pin fixation is usually inadequate for diaphyseal forearm fractures because the bone diameter is small.[316]

Open Reduction and Internal Fixation. Open reduction and internal fixation with compression plate and screws, the standard of care for adult forearm fractures, is also successful in treating children with radial and ulnar shaft fractures.† The advantages of plate fixation include rigid anatomic fixation, which requires minimal postoperative immobilization. The disadvantages include relatively large incisions and problems with retained hardware. We find plate fixation particularly convenient in the management of open fractures, as the exposure has been made during debridement. The issue of retained hardware and subsequent stress risers, either with or without removal, can be minimized by using tubular rather than compression plates. Tubular plates have been associated with implant failure and nonunion in adults, but they are adequate in most children less than 12 years old.

Flexible Intramedullary Fixation. The advent of image intensification has made closed reduction and percutaneous intramedullary fixation an attractive alternative in the management of unstable pediatric forearm fractures. In adults this technique is problematic because of the high rate of nonunion and the need for immobilization in a cast or splint.* However, in immature patients, nonunions are rare, and external immobilization is usually not a problem. Thus, flexible intramedullary fixation can be used to maintain alignment until union occurs.

Classically, intramedullary devices were started distally in the radius and proximally in the ulna. However, Verstreken and associates have pointed out that starting the ulnar pin distally allows the pin to be advanced proximally up the shaft of the ulna, with the elbow in extension and the forearm supinated rather than with the elbow flexed as required with a proximal starting location. This makes obtaining image intensification easier. There may also be fewer problems from symptomatic pin prominence if started distally.[295]

The technique for intramedullary fixation is shown in Figure 41–118. The starting point for both the radius and ulna is the metaphysis just proximal to the physis. Care must be taken not to damage the superficial radial nerve or the dorsal branch of the ulnar nerve. A small bend placed 5 to 10 mm from the end of the rod may help in reduction. The radius is usually harder to reduce and is usually attempted first. In fractures that have failed a closed reduction and are subsequently 1 to 3 weeks old there is frequently early callus within the intramedullary canal. Therefore, we have a low threshold for making a small incision to facilitate reduction of the fracture over the rod. We usually immobilize the arm in a long-arm cast (split in the operating room) for 6 weeks, although good results with no or minimal immobilization have been reported.[160,295,309] The pins may be left outside the skin and pulled at 4 to 5 weeks, or buried and removed in several months. Shoemaker and colleagues noted loss of reduction and deep infection with percutaneous removal of pins at 4 weeks and recommended leaving the pins under the skin, particularly for open fractures, which were slower to heal.[253] Although there seems to be a recent trend toward intramedullary management of children's forearm fractures, it is important to remember that surgical management is not without risks. Cullen and colleagues reported 18 complications in 10 of 20 patients, including hardware migration, infection, loss of reduction, reoperation, nerve injury, significantly decreased range of motion, synostosis, muscle entrapment, and delayed union.[67]

Single-Bone Fixation. Recently there have been reports of successful management of both-bone forearm fractures with stabilization of only one bone.[93,170,198] The rationale is that the stabilized bone allows the other to be manipulated into a reduced position and maintained with a cast. We find this technique attractive because stabilization of the ulna

*See references 25, 56, 67, 93, 113, 118, 134, 170, 206, 231, 253, 292, 305, 324, 329.

†See references 7, 149, 196, 206, 278, 290, 324.

*See references 151, 176, 205, 244, 257, 271.

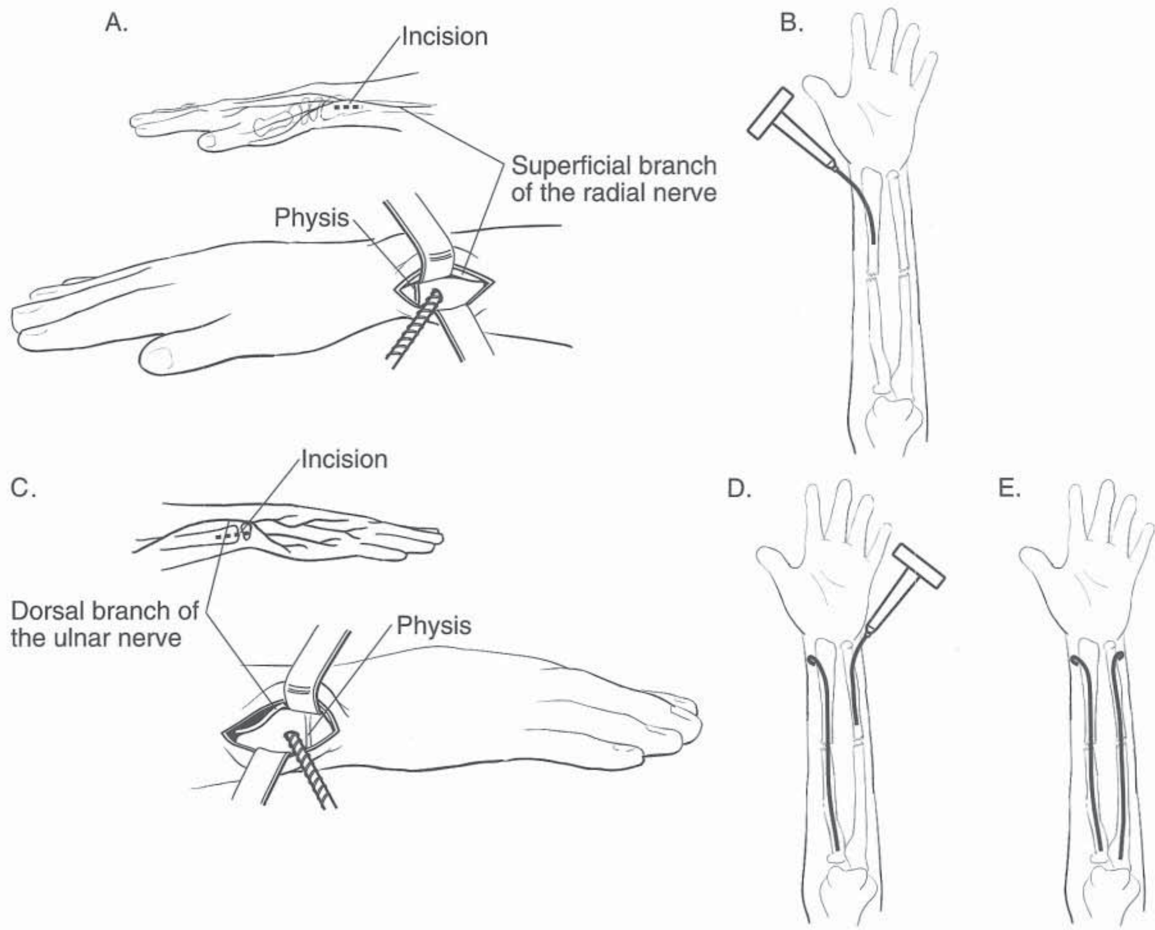


FIGURE 41–118 Technique for intramedullary fixation of forearm fractures. **A,** A distal incision is made over the radius. The superficial branch of the radial nerve is protected and a starting hole is made proximal to the physis. **B,** A flexible intramedullary rod is introduced and advanced to the fracture site. The fracture is then reduced over the rod. The rod is advanced into the proximal fragment to the appropriate length and either buried underneath the skin or left out through the skin. **C,** The dorsal branch of the ulnar nerve is protected for the ulnar starting hole. **D,** A distal starting hole for the ulna makes imaging easier as the fracture can be reduced with the forearm supinated and the elbow extended. **E,** The fracture is reduced over the rod and final positioning is done under image control.

prevents the development of a cosmetically unacceptable bow and provides a fulcrum against which the radius can be maintained in an improved position. This technique is especially useful in treating a fracture 1 to 2 weeks old in which closed treatment has failed. We often have a difficult time achieving a closed intramedullary reduction in these injuries and find that single-bone fixation can be done with a small incision over the ulna, without the need for a second larger incision to reduce and stabilize the radius. This technique is also useful when only one bone has an open fracture (we may use a third tubular plate in such a scenario). Like Shoemaker and colleagues,[253] we have found that some of the reduction of the nonstabilized bone will be lost over time. However, we have not found this to be a clinical problem and believe the benefits of reduced surgical exposure outweigh the risk of minor loss of reduction (Fig. 41–119).

External Fixation. External fixation of children's forearm fractures can refer to management with traditional external fixation devices or to management with "pins and plaster." Formal external fixation devices may rarely be indicated for forearm fractures with massive soft tissue loss, although plate fixation and intramedullary techniques usually provide better fixation and consequently better soft tissue stabilization.[223,249] Pins and plaster have yielded good results in unstable forearm fractures.[141,302]

Complications

REFRACTURE. In most large series, refracture of the forearm occurs in about 5 percent of patients.[128,220,296] Refracture is more likely to occur after greenstick or open fractures.[116,251,253] The high incidence of refracture following plate removal* has led some authors to abandon routine hardware removal in asymptomatic patients.[22,143,182,248] If displaced, refractures can be difficult to reduce and may require surgical stabilization.[13,66,128,220,251] The difficulty in obtaining a closed reduction as well as possible sclerosis of the intramedullary canal may make open reduction and plate fixation a more attractive option than intramedullary fixation for these injuries.

MALUNION. Even with attention to detail and close follow-up, late identified displacement will occur. If the displacement is appreciated less than a month after the injury, we will

*See references 18, 22, 124, 150, 237, 267.

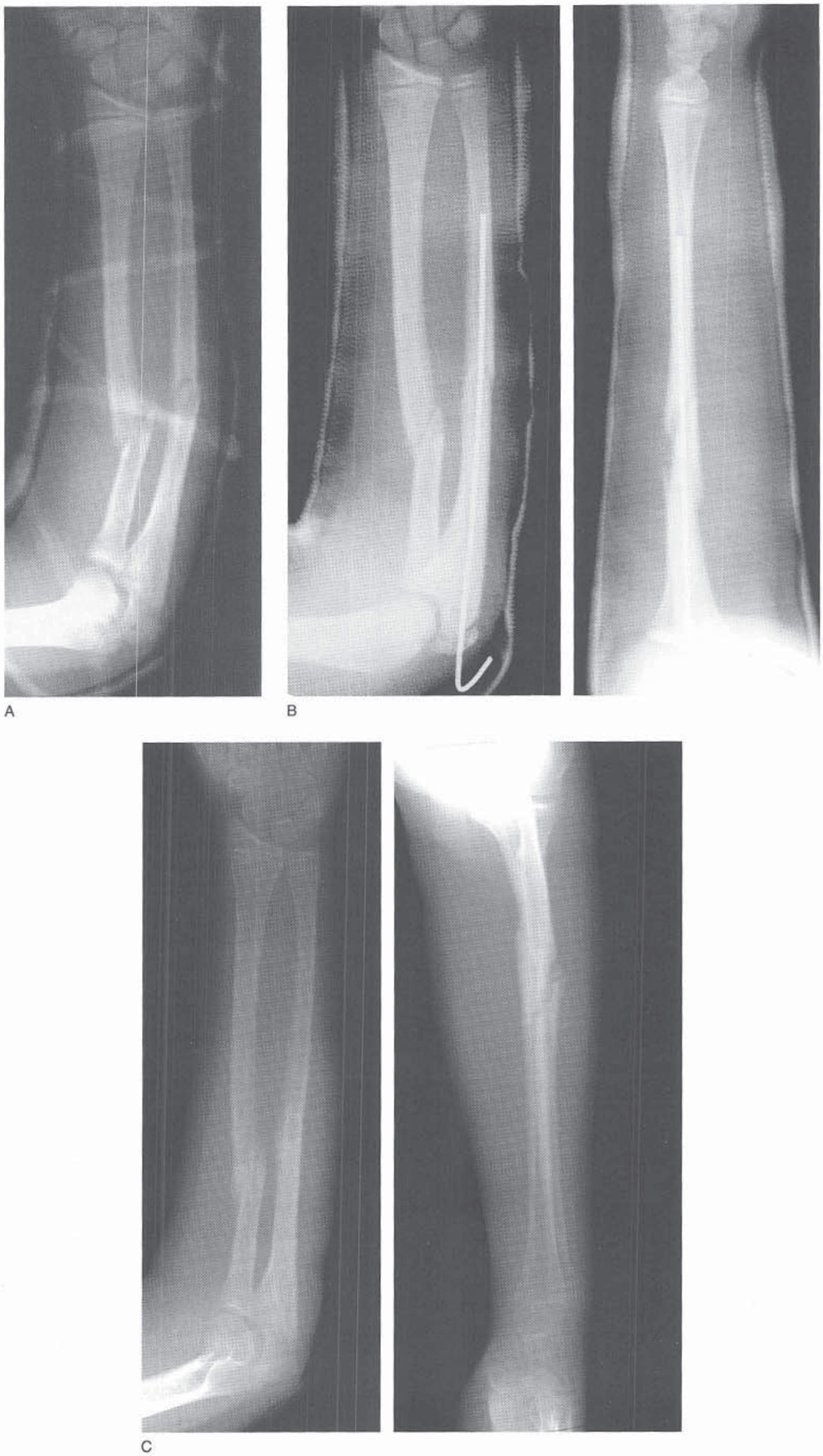


FIGURE 41–119 Single-bone fixation of both-bone forearm fracture. **A,** AP radiograph of a both-bone forearm fracture with the radius fractured proximal to the ulna. Note the ulnar deviation in the cast approximately 2 weeks after injury. **B,** AP and lateral radiographs following open reduction and pin fixation of the ulna. Note that fixation of the ulna has improved the alignment of the radius. **C,** AP and lateral radiographs following cast and pin removal.

remanipulate the arm under general anesthesia and usually stabilize at least the ulna. However, if the malunion is identified later we usually advise the parents that a period of 9 to 18 months of observation is advisable to see how much remodeling will occur. Time must be taken to explain to the parents that remodeling is unpredictable and often surprising. They should be counseled that the atrophy and stiffness associated with immobilization exaggerate the appearance of deformity and that function frequently returns to normal despite the radiographic malunion.[70,127,128,197,218]

Osteotomy to correct malunion is occasionally necessary. The few reports in the literature describe drill osteoclasis and cast immobilization or osteotomy with compression plate fixation.[29,33,287] In addition we have a limited experience with osteotomies through limited surgical incisions with intramedullary reduction and cast immobilization (Fig. 41–120).[52]

DELAYED UNION OR NONUNION. Delayed union or nonunion following children's radial or ulnar shaft fractures is uncommon. It is usually associated with open injuries with significant bone or soft tissue loss. If a delayed union does not progress to union with extended observation, compression plate fixation with iliac crest bone graft has been successful.[116,324]

SYNOSTOSIS. Synostosis following forearm fractures in children is uncommon. It has been reported to be more likely following high-energy trauma, surgical intervention, repeated manipulations, and fractures associated with head injury.[67,239,298] Although there are few reports, the results of excision of a radioulnar synostosis do not appear to be as good in children as in adults.[297]

COMPARTMENT SYNDROME. Compartment syndrome can develop following forearm fractures and may be potentiated by the splint or cast.[123,178,242] We believe it is important to split any and every cast applied to a freshly injured extremity. If there is clinical suspicion of a compartment syndrome, the cast or splint should be split to the skin or removed altogether. The diagnosis and management of compartment syndrome are discussed in Chapter 39.

PERIPHERAL NERVE INJURY. Any of the three nerves of the forearm can be injured with radial and ulnar shaft fractures. Neurologic injury may occur at the time of injury, with closed reduction, or with open reduction. Fortunately, most injuries are related to stretch at the time of injury and recover completely within 2 to 3 months. Entrapment of the median, anterior interosseous, and superficial radial nerve have all been reported. Recovery can be expected following release of entrapped nerves. Although a good neurologic examination can be difficult or impossible to achieve in an anxious child in the emergency room, every effort should be made to assess the child's neurologic status prior to reduction. A definite loss of neurologic function following reduction should lead to exploration of the fracture, particularly if the reduction is nonanatomic.*

OTHER COMPLICATIONS. Muscle entrapment, hematogenous osteomyelitis, and gas gangrene have been reported following forearm fractures.†

*See references 67, 72, 102, 107, 108, 131, 192, 199, 232, 253, 261, 321.

†See references 48, 67, 92, 120, 152, 294.

FRACTURES OF THE DISTAL FOREARM

Fractures of the distal forearm are extremely common in children.* These fractures can usually be managed with simple closed reduction and casting, with excellent results. However, as with all injuries, complications can develop. Careful attention to detail may allow early identification of these complications and prevent them from becoming disabling long-term problems. Fractures of the distal forearm include torus or buckle fractures, greenstick fractures, metaphyseal fractures, physeal fractures, and Galeazzi fractures.

Anatomy. The pertinent anatomic considerations include the bony anatomy, the distal radioulnar articulation, and the soft tissue envelope of the forearm. The secondary ossification center of the distal radius usually appears before the first birthday and the distal ulnar ossification center appears between 5 and 7 years of age. The distal radial physis accounts for 75 to 80 percent of the growth of the radius. This rapid growth may predispose the distal radius to fracture because the distal metaphysis is thin from the continuous remodeling.[5,18,121]

The distal radioulnar joint is a pivot that allows the radius to pronate and supinate around the ulna. There are several components to the distal radioulnar joint, including the triangular fibrocartilage, the ulnar collateral ligament, the volar and dorsal radiocarpal and radioulnar ligaments, and the pronator quadratus muscle. Of these, the triangular fibrocartilage is probably the most important. The triangular fibrocartilage functions to stabilize the distal radioulnar joint against the torsional stresses associated with rotation.[254]

The soft tissues of the volar distal forearm include the flexor tendons, the median nerve, and the ulnar neurovascular bundle. With dorsal displacement of the distal fragment these structures may be injured as they are tented over the proximal fragment. In fact, given the frequency of distal forearm fractures and the usual magnitude of displacement, neurovascular injury is surprisingly uncommon, perhaps because the pronator quadratus protects the volar neurovascular structures. Nevertheless, careful examination is required because median and ulnar nerve injuries and open fractures do occur.[58,116,198,293]

Mechanism of Injury. Distal forearm fractures are most commonly the result of a fall on an outstretched hand. If the wrist is extended or dorsiflexed, as is commonly the case, the distal fragment will be displaced dorsally. Volar displacement of the distal fragment is the result of a fall on a flexed wrist. It is unclear why some falls produce metaphyseal fractures and some produce physeal injuries. Buckle fractures and minimally displaced fractures are thought to be the result of lower-energy injury, while displaced fractures result from falls from a height or with forward momentum (running, riding a bike, and so on).[255] Forearm fractures have been shown to migrate distally with age, with adolescents more likely to sustain distal fractures and younger children more likely to sustain diaphyseal shaft fractures.[5,18,72,285]

Diagnosis. If the forearm has the classic "dinner fork" deformity, the diagnosis is easily made. However, if there is minimal displacement the findings may be quite subtle. In

*See references 18, 121, 153, 158, 216, 230, 315, 322.

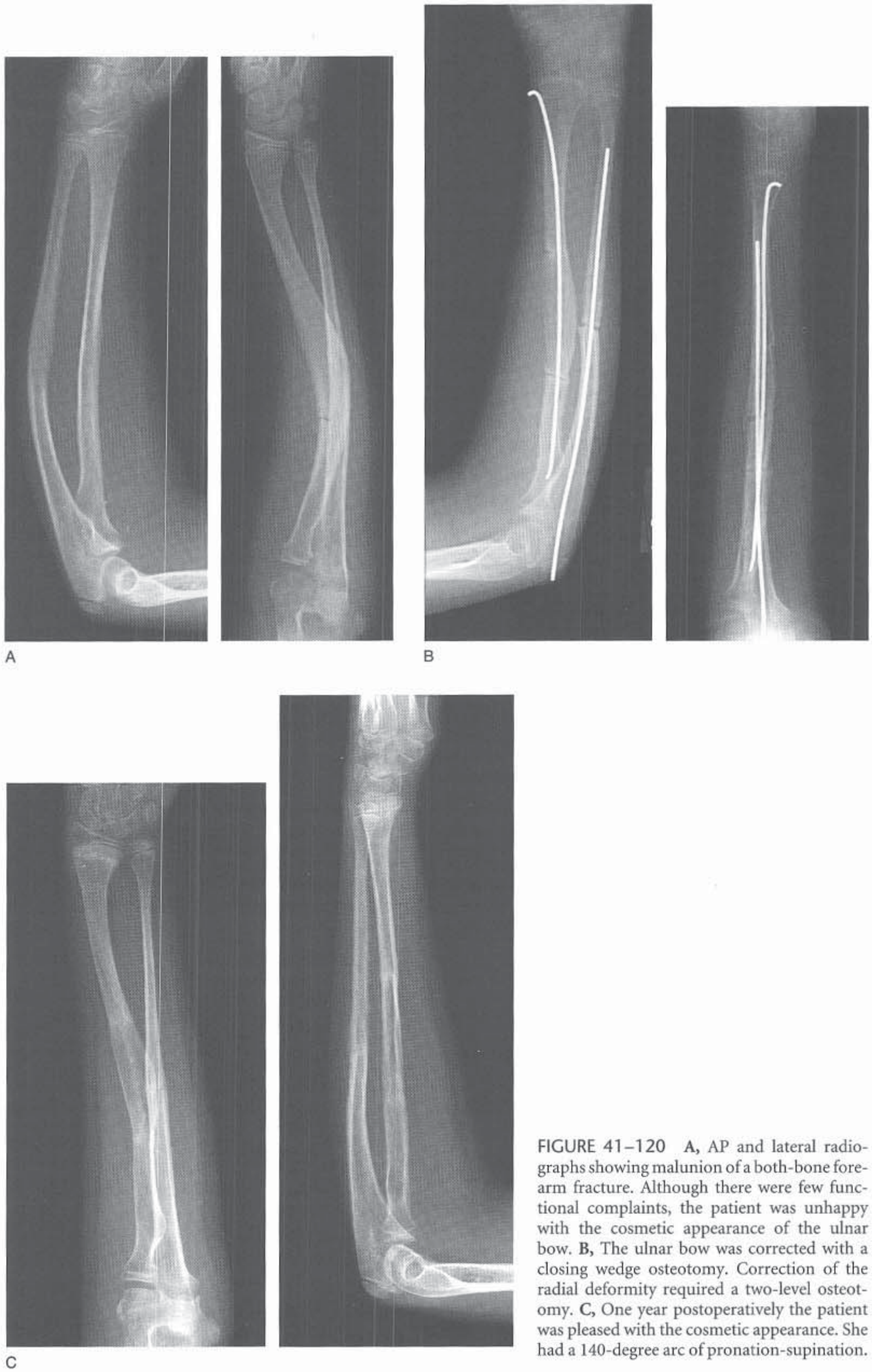


FIGURE 41–120 **A,** AP and lateral radiographs showing malunion of a both-bone forearm fracture. Although there were few functional complaints, the patient was unhappy with the cosmetic appearance of the ulnar bow. **B,** The ulnar bow was corrected with a closing wedge osteotomy. Correction of the radial deformity required a two-level osteotomy. **C,** One year postoperatively the patient was pleased with the cosmetic appearance. She had a 140-degree arc of pronation-supination.

FIGURE 41–121 AP radiograph of a Peterson I fracture of the distal radius. Note the metaphyseal fracture of both the radius and the ulna. There is a longitudinal split from the radial metaphysis to the physis (*arrow*).

fact, patients with buckle fractures often present several days or a week after the injury for treatment of a "sprain" that has not resolved. As always, care must be taken to thoroughly assess the patient for associated injuries. The most common concomitant injuries include scaphoid or other carpal fractures distally and supracondylar humeral fractures proximally.* Careful assessment of the skin and a neurovascular examination should be performed. In dorsally displaced fractures, median nerve symptoms are common and often transient, resolving when the deformity is corrected.[116]

Radiographic Findings. As with all injuries, good-quality radiographs of the entire forearm should be obtained. If there is significant displacement or if only one bone is fractured, AP and lateral radiographs of the wrist and elbow should be included in the assessment.

Classification. We classify distal forearm fractures as buckle (or torus), greenstick, metaphyseal, physeal, or Galeazzi fractures. Metaphyseal fractures can be further classified as nondisplaced or displaced. If displaced, they can be classified according to the direction and degree of displacement. Physeal fractures are most commonly classified according to the system of Salter and Harris.[245] In his classification of physeal injuries, Peterson identified a fracture seen commonly in the distal forearm.[215] A Peterson I physeal injury is a transverse metaphyseal fracture with longitudinal comminution extending into the physis (Fig. 41–121). It is important to identify these fractures, as growth arrest has been reported following such innocuous-appearing injuries.[1,61]

*See references 28, 60, 112, 114, 133, 236, 262, 288, 289, 317.

Although first described by Cooper in 1824,[63] fracture of the distal radius with dislocation of the distal radioulnar joint is known as a Galeazzi fracture, after Riccardo Galeazzi, who described 18 cases in 1934.[104] Galeazzi fractures are rare in children. Letts and Rowhani classified Galeazzi fractures in children based on the position of the distal ulna (dorsal or volar).[165] They differentiated between complete and greenstick fractures of the distal radius. They included injuries with true ligamentous disruption of the distal radioulnar joint and "equivalents"—fractures of the distal radius with separation of the distal ulnar physis. They classified equivalents based on the position of the distal ulnar metaphysis.

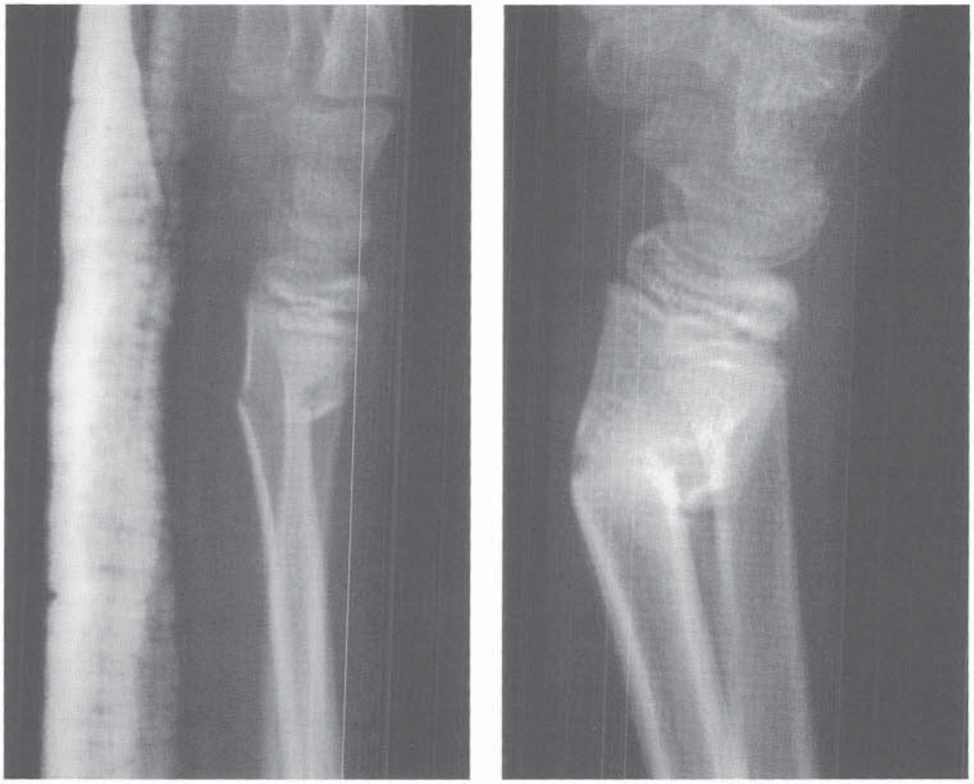
Treatment

BUCKLE FRACTURES. The goal of treatment of buckle fractures is to keep the child comfortable and to prevent further displacement should the child fall on the hand again. Consequently, most buckle fractures can be managed in a short-arm cast. The extremely compliant patient can be managed with a removable Velcro splint. Occasionally a patient will have enough pain on pronation and supination of the forearm to warrant immobilization in a long-arm cast. Perhaps the most important aspect in managing buckle fractures is to be certain of the diagnosis. Minimally displaced metaphyseal fractures can be mistaken for a buckle fracture. These fractures are potentially unstable and will displace further without proper immobilization (Fig. 41–122). Additionally, involvement of the physis (Peterson I physeal injury) may lead to growth arrest and should be noted at the time of injury and followed for 6 to 12 months to ensure that normal growth resumes.[1,9,14,61,78,291]

GREENSTICK FRACTURES. Greenstick fractures of the distal forearm can usually be treated with simple closed reduction and long arm casting. We usually perform closed reduction in the emergency room under conscious sedation. Although a great deal has been written about the position of the forearm after reduction of fractures, we find these fractures very stable once reduced and almost always immobilize them with the forearm in neutral position. Patients are usually seen 1 and 2 weeks after reduction to ensure a snug-fitting cast. When the cast is removed after 6 weeks, the parents should be counseled regarding the increased risk of refracture after greenstick fractures.[128,220,296]

METAPHYSEAL FRACTURES. It is uncommon for metaphyseal fractures of the distal forearm to involve only one bone. The radius is almost always involved as a complete fracture. However, the ulna may have a complete metaphyseal fracture, a metaphyseal greenstick fracture, an avulsion of the styloid, a distal physeal fracture, or plastic deformation. In general, treatment is directed at achieving a stable reduction of the radius, which usually ensures adequate treatment of the ulna.

Nondisplaced metaphyseal fractures need only be immobilized in a short- or long-arm cast for 4 weeks. We choose a long-arm cast for patients with significant pain on pronation and supination. Despite the benign nature of these injuries, careful attention to good casting technique will prevent displacement during treatment. Although mild displacement during treatment usually remodels without functional sequelae, the "worsening" radiographic picture can cause significant parental distress.



A B

FIGURE 41–122 Unstable distal radial buckle fracture. **A,** The distal radius fracture has a "buckled" appearance. However, both the volar and dorsal cortices are fractured. **B,** Angulation of the distal radius following immobilization in a poorly molded splint.

Recognition of the pattern of a displaced fracture may aid in treatment. Displaced fractures may be "out to length" or may have significant shortening of the distal fragment, so-called "bayonet apposition." The reduction is often more difficult if only one bone is shortened. This is often the case with metaphyseal radial fractures, which may be completely displaced and shortened while the ulna is minimally displaced. Fractures are most commonly dorsally displaced, with only about 1 percent of fractures in one large series volarly displaced.[276] Volar displacement usually requires immobilization with the wrist extended. Supination of the forearm will ease application of a cast with a three-point volar mold. For dorsally displaced fractures we usually immobilize the forearm in a neutral position.

Despite recent reports advocating pin fixation for distal forearm metaphyseal fractures,[109,174,222,312] we believe displaced metaphyseal fractures can nearly always be treated with closed reduction and casting under conscious sedation in the emergency room. The technique of reduction is the same as that previously described for fractures of the radial or ulnar shaft, namely traction, exaggeration of the deformity, and restoration of alignment (see Fig. 41–114). Good results have been reported utilizing both short- and long-arm casts to immobilize distal radial metaphyseal fractures.* As with fractures of the diaphysis, we believe careful attention to the quality of the reduction and the cast is more important than whether a short- or a long-arm cast is applied.[53,117] We most commonly use a sugar tong splint at the time of the initial reduction, as it is safe and easy to apply with minimal assistance. Patients can usually be sent home from the emergency room unless there is significant swelling or concern over compartment syndrome or the neurovascular status, in which case they should be admitted for observation. The patients and parents are instructed in elevation and seen 1 and 2 weeks after reduction. This splint is either "overwrapped" or replaced with a long-arm cast 1 to 2 weeks after the injury. If the cast is replaced, it is important to obtain a radiograph afterward to ensure the reduction has not been lost and the cast fits snugly. Immobilization is usually continued for a total of 4 to 6 weeks.

Indications for operative treatment include open fractures, irreducible fractures, fractures associated with compartment syndrome or carpal tunnel syndrome, fractures with severe swelling (for which a snug-fitting cast is ill-advised), fractures with ipsilateral injuries requiring stabilization (most commonly supracondylar humeral fractures, for which a snug-fitting cast is ill-advised), and fractures requiring remanipulation (an acceptable reduction cannot be maintained).* Most commonly, distal metaphyseal forearm fractures are stabilized with a smooth K-wire placed percutaneously from the radial styloid across the fracture into the proximal metaphysis (Fig. 41–123). We attempt to avoid the physis with the K-wire, but find it is often necessary to cross it. Although there are reports of physeal arrest following pin fixation, it is unclear whether the pin or the fracture is responsible for the injury to the physis.[38,132,189,221] We do not believe that a small-diameter smooth pin crossing the physis substantially increases the risk of growth abnormality. Plate and external fixation have also been described.[250,301] We will occasionally utilize single-bone plate

*See references 12, 31, 54, 55, 147, 161, 201, 318.

*See references 28, 109, 141, 198, 262, 325.

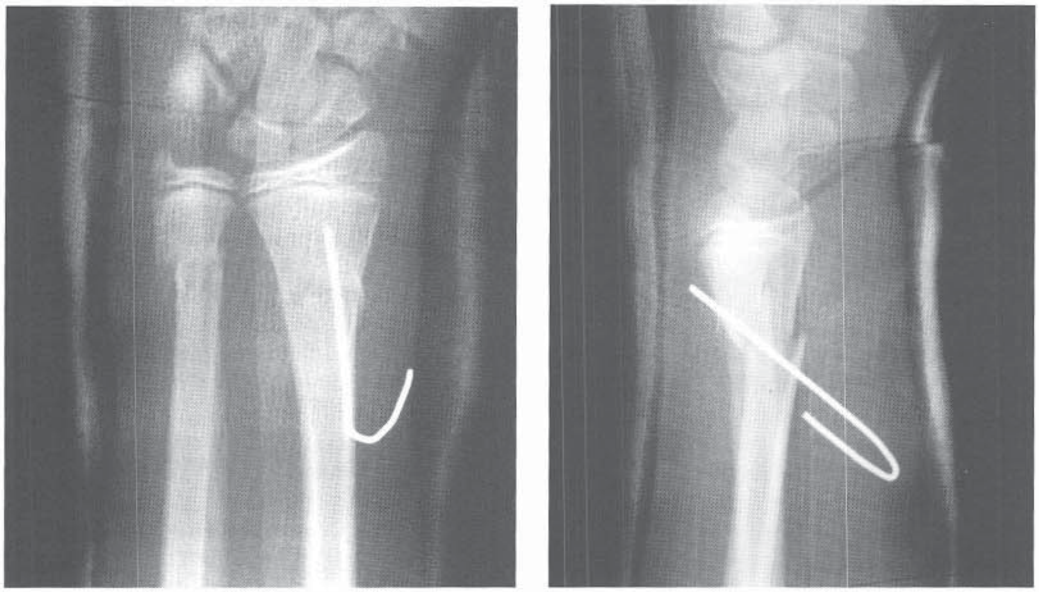


FIGURE 41–123 AP and lateral radiographs of an open distal both-bone forearm metaphyseal fracture that was treated with irrigation, debridement, and percutaneous pinning of the radius. Pin fixation allows the wound to be checked through a window in the cast without concern over loss of reduction.

fixation to stabilize an open fracture, as the debridement often provides adequate exposure for a four-hole tubular plate, providing more rigid fixation than a single K-wire. We have limited experience with external fixation. We reserve external fixation for fractures associated with massive soft tissue injury. It is important that all open fractures, regardless of the size of the wound be managed with thorough debridement and intravenous antibiotics according to the principles outlined in Chapter 39. Fractures may be irreducible owing to interposed soft tissues. For dorsally displaced fractures, the soft tissue is usually the pronator quadratus or flexor tendons.[75,94,129] In the rare volarly displaced fracture, the extensor tendons may become entrapped. Patients suspected of having compartment syndrome or carpal tunnel syndrome should have immediate stabilization of their fractures, as stabilization may help prevent further soft tissue damage and its accompanying swelling. After fracture stabilization, compartment pressures can be measured and managed as discussed in Chapter 39 under the heading Open Fractures. Patients in whom remanipulation is needed are often older and their fractures are more likely to redisplace; consequently, we have a low threshold for pin fixation of these fractures.[56,109,329]

What are the limits of an acceptable reduction? The factors that affect remodeling are discussed in detail in Chapter 39. They include the amount of growth remaining, the age of the patient, the location of the fracture, and the plane of the deformity, with deformity in the plane of motion having greater remodeling potential.* Because of the significant growth (8 mm per year) and the proximity to the physis, as well as the plane of motion, distal radial fractures have a large remodeling potential, particularly in the sagittal plane.† As with any fracture, the "art" of orthopaedics lies in "knowing" the limits of an acceptable reduction. Obviously, each case must be individualized, although a few generalizations may be made. First, translation, or bayonet apposition, nearly always remodels, although these fractures are less stable and may become more angulated. Second, a sagittal plane deformity is more likely to remodel.[72,140,159,213,299] Finally, patients younger than 11 are more likely to remodel distal radial fractures, although older patients may remodel significant deformity (up to 36 degrees in the sagittal plane in a boy age 12 years 11 months has been reported).[140,159,213,299] In general, in a child less than 10, we will accept at least 30 to 35 degrees of sagittal plane angulation and 20 degrees of coronal plane angulation. The amount of angulation that is acceptable decreases with age. However, we will accept 15 to 20 degrees of sagittal plane angulation in a child with as little as 1 year of growth remaining. As for fractures of the diaphysis, surgical treatment of distal radial metaphyseal malunion is extremely uncommon.[29,101,116,220]

*See references 72, 140, 159, 213, 299, 327.

†See references 31, 70, 72, 98–101, 105, 127, 140, 159, 201, 204, 213, 238, 299, 327.

DISTAL RADIAL PHYSEAL FRACTURES. Distal radial physeal fractures are managed similarly to displaced metaphyseal fractures, with a few important differences. First, these fractures heal rapidly, requiring only 3 or 4 weeks of immobilization. Second, their potential to remodel is even greater than that of distal metaphyseal fractures. Third, and most important, attempts at reduction (or re-reduction) after 3 to 7 days may damage the physis, producing growth arrest and consequently less remodeling. Thus, late-presenting fractures and fractures in which the reduction has been lost should not be remanipulated but should be managed in a well-molded cast that prevents any further displacement.*

The one absolute indication for operative management is a Salter-Harris type III or IV fracture. By definition, these fractures are intra-articular and should be treated with anatomic reduction (usually open, possibly percutaneous with

*See references 3, 4, 8, 34, 39, 64, 78, 162.

arthrographic confirmation) and pin fixation. Other operative indications are similar to those for metaphyseal fractures.[163] Distal radial physeal fractures requiring operative fixation can almost always be stabilized with a small, smooth percutaneous K-wire.

DISTAL ULNAR PHYSEAL INJURIES. Although fracture of the distal ulnar physis is uncommon, there are many reports of distal ulnar growth arrest.* Nelson and colleagues reviewed the literature and found 196 fractures of the distal ulna, 33 of which had sufficient follow-up to assess the growth plate. Six of these 33 patients developed a growth arrest of the distal ulna.[193] The reasons for this are unclear. It may be that injuries to the distal ulna are underrecognized and inadequately treated because of concomitant injuries to the ulna. In the series reported by Golz and colleagues, one-third of the 18 patients with ulnar physeal injuries had associated fractures of the ulnar metaphysis or styloid.[110] However, open reduction has not been shown to prevent physeal arrest. Golz and colleagues reported growth arrest of the distal ulna in three of the four patients treated with open reduction.[110] Fortunately, symptoms following ulnar physeal arrest are infrequent.†

Fractures of the ulnar styloid (or epiphysis) have been reported in as many as one-third of distal radial fractures.[264] These avulsions require no treatment and will usually develop into an asymptomatic nonunion.[126] Good results can be achieved with excision of the ulnar styloid nonunion if, in the unlikely event, it becomes symptomatic.[44,172,204]

GALEAZZI FRACTURES. Galeazzi fractures in children are less common than in adults and rarely require surgical stabilization.‡ With disruption of the distal radioulnar joint or separation of the distal ulnar physis, the distal radial fragment may migrate proximally. Although distal radial fracture with separation of the distal ulna has been termed a Galeazzi equivalent, Imatani and associates have pointed out that the intact distal radioulnar joint makes proximal migration of the radius without the ulna impossible and suggest that the more accurate term "pseudo-Galeazzi injury" be used.[138] Interestingly, however, Letts and Rowhani noted a poorer prognosis for the equivalents than for the classic Galeazzi lesions.[165] The worse prognosis may be related to the high complication rate associated with distal ulnar physeal separation.§ The goal of treatment is to prevent migration of the distal radius and stabilize the distal radioulnar joint. In patients with greenstick fractures of the radius and/or ulna and in younger patients with complete fractures, stabilization can usually be accomplished with closed reduction and cast immobilization. Although some authors have recommended supination for dorsally displaced fractures and pronation for volarly displaced fractures, Letts and Rowhani have suggested that all Galeazzi fractures and equivalents be managed with the forearm in supination.[165] Older patients with "true" Galeazzi fractures that cannot be stabilized with closed reduction and casting may require open reduction. We prefer rigid plate fixation to flexible nail fixation for these injuries. If the distal radioulnar joint remains unstable following reduction and stabilization of the radius, consideration should be given to pinning the distal radioulnar joint in position with a transverse K-wire from the ulna to the radius. Open reduction may also be required for Galeazzi equivalent lesions with entrapped soft tissue.

*See references 3, 59, 78, 85, 110, 193, 209, 227.

†See references 3, 59, 78, 110, 193, 209, 227.

‡See references 138, 155, 157, 165, 171, 183, 254, 304.

§See references 3, 59, 78, 85, 110, 193, 209, 227.

Complications. The most common complications following distal forearm fractures include malunion, refracture, growth arrest, peripheral nerve injury, and compartment syndrome. Nonunion, cross union, overgrowth, infection, tendon entrapment, tendon rupture, and reflex sympathetic dystrophy have all also been reported following distal forearm fracture in children. Although radiographic malunion is the most common complication following distal forearm fracture, symptomatic malunion is quite rare.[29,101,128,220] The most frequent symptom is likely to be displeasure with the cosmetic appearance. This may be more likely with the unusual volarly displaced fracture, as there is less soft tissue to cover an apex dorsal deformity. Symptomatic nonunion, although rare, can be corrected with an osteotomy. Traditionally, this has been performed with drill osteoclasis and casting.[29,33] Recent reports, however, have advocated open osteotomy with rigid internal fixation.[287]

Although refracture following distal forearm fractures is less common than with more proximal fractures, it still occurs. It has been noted to be more common following greenstick fractures, open fractures, and hardware removal.[116,169,251,253] Although Price has advocated open reduction and intramedullary fixation of refractures due to the problems maintaining reduction,[219] Schwarz and colleagues reported good results in 14 of 17 refractures treated conservatively. The three patients with poor results all were more than 10 years old.[251] We attempt to manage refractures conservatively but have a lower threshold for operative treatment, particularly if the original fracture was malunited.

Growth arrest is a complication of physeal injury. Although there are reports of arrest following metaphyseal fractures, these injuries probably represent Peterson type I fractures of the physis.[1,61,291] Growth arrest may occur in either the radius or ulna. Despite the frequency of distal radial physeal fractures, growth arrest is relatively infrequent.[9,14,72,78,291] This may be a function of the high velocity of growth from the distal radial physis (8 mm per year) as well as the fact that the majority of these injuries result from relatively low-energy impact. Conversely, ulnar physeal separation is an unusual injury but appears to be associated with a high incidence of growth arrest.* It is important to explain to parents of patients with physeal injuries the possibility of growth arrest, as well as the advantage of early identification and consequently the necessity of follow-up for the asymptomatic patient. We recommend follow-up at 4- to 6-month intervals for at least a year. The treatment of growth arrest is discussed in Chapter 39 under the heading Open Fractures. Generally, options for treatment of distal radial growth arrest include observation, completion epiphysiodesis (with ulnar epiphysiodesis), or bar resection (Fig. 41–124). Ulnar arrest is not amenable to bar resection and, if identified early, is usually treated by radial epiphysiodesis. Unrecognized growth arrest in either the distal radius or ulna may lead to significant ulnar variance (positive or negative).†

*See references 3, 59, 78, 85, 110, 193, 209, 227.

†See references 9, 14, 59, 78, 193, 209, 227, 291.

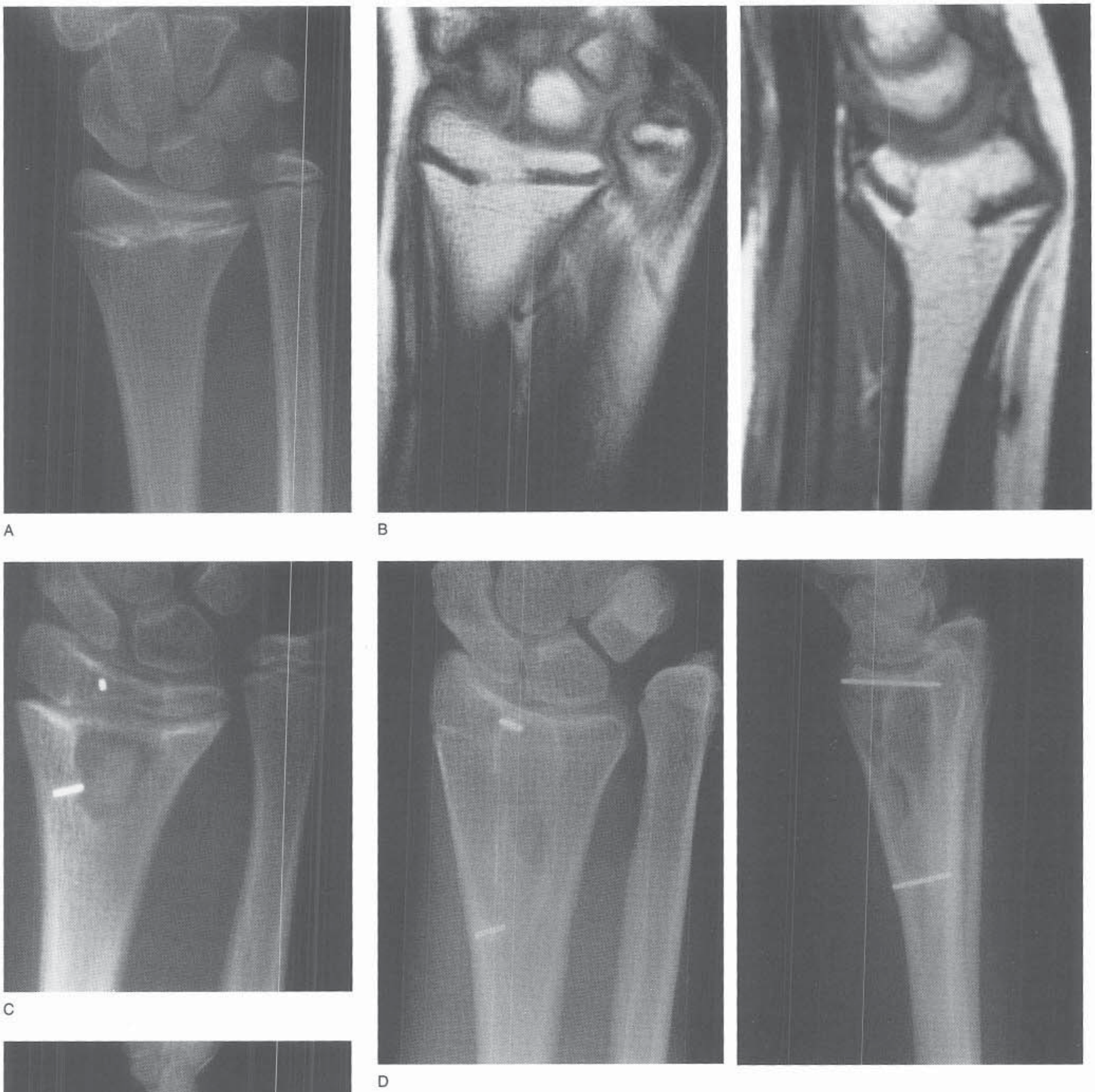
FIGURE 41–124 Chronic overuse injury to the distal radial physis. **A,** AP and lateral radiographs of the right wrist of a 13-year-old gymnast. Note the wide and irregular appearance of the physis. **B,** The radiographic appearance 3 years later, after cessation of gymnastics.

Symptomatic ulnar variance can be treated with lengthening (acute or gradual) or shortening of the appropriate bone.

Peripheral nerve injury is most commonly transient and the result of stretch associated with fracture displacement at the time of injury. It may also be secondary to direct injury, tethering, or entrapment within fracture fragments.[72] The median nerve is most commonly involved, and the symptoms frequently resolve immediately following fracture reduction. Tethering or entrapment can occur at the time of injury or reduction; thus, it is important to obtain a good pretreatment neurologic examination.[67,78,253] Although this may be difficult in an anxious child, many children will comply with a full examination if placed in a parent's lap and slowly reassured by examining the uninjured limb first. Loss of nerve function following a closed reduction is an indication for operative treatment, particularly if the fracture has not been anatomically reduced. If nerve recovery is not evident in 6 to 12 weeks, consideration should be given to electrodiagnostic studies and surgical exploration.

Both compartment syndrome and acute carpal tunnel syndrome can develop following distal forearm fractures.* The hallmark finding in these potentially devastating complications is pain out of proportion to clinical findings. The key to successful management of these injuries is an accurate

*See references 67, 78, 116, 123, 178, 179, 192.



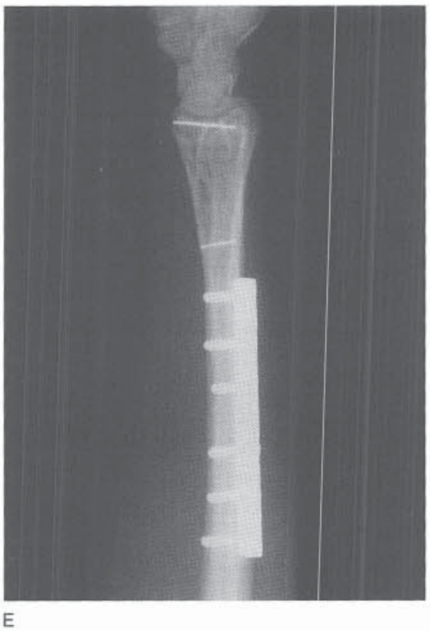


FIGURE 41–125 Physeal arrest (type B) following distal radial fracture. **A,** AP radiograph of the wrist of a 12-year-old girl who had sustained a Salter-Harris type II fracture of the distal radius 6 years earlier. Note the ulnar positive variance as well as the physeal bar in the center of the distal radius. **B,** Coronal and sagittal MR images show the extent of the bar. **C,** The bar has been resected and metallic markers placed in the epiphysis and metaphysis. **D,** AP and lateral radiographs showing resumption of growth as evidenced by an increased distance between the metallic markers. The ulnar positive variance persists. **E,** Lateral radiograph following ulnar shortening to treat symptomatic ulnar positive variance.

and timely diagnosis, which requires a high degree of suspicion and vigilant patient management. The diagnosis and treatment are discussed in Chapter 39.

Nonunion, cross union, infection, and tendon rupture are infrequent in children's distal forearm fractures.[298,324] Nonunion of uncomplicated, closed fractures is uncommon enough that its presence should suggest underlying pathology such as congenital pseudarthrosis or osteomyelitis.[23,145] Interestingly, resection of cross union may be less successful in children than in adults.[298] Overgrowth following distal forearm fractures has not been a clinical problem.[73,328] Although tendon entrapment within the fracture may initially be confused with either nerve injury or compartment syndrome, careful examination usually leads to an accurate diagnosis. Tendon entrapment is not associated with sensory changes or pain and is usually associated with some persistent fracture displacement.[75,152,186]

Reflex sympathetic dystrophy is a poorly defined entity characterized by pain and vasomotor dysfunction. It frequently develops after trauma and in adults is common in the upper extremity. Although reflex sympathetic dystrophy has been reported following distal forearm fractures in children, it is more common in the lower extremities.* In children, reflex sympathetic dystrophy has been shown to respond to conservative measures, including physical therapy, psychological therapies, transcutaneous electrical stimulation, and tricyclic antidepressant medication. We rarely use sympathetic blocks in managing reflex sympathetic dystrophy in children but have found our child psychology colleagues indispensable.[258,313]

Associated Conditions

CHRONIC RADIAL PHYSEAL INJURIES. Recently, overuse injuries of the distal radial physis have been increasingly reported, primarily in competitive adolescent gymnasts.† A recent review revealed radiographic changes in the distal radius of 10 percent of female gymnasts (Fig. 41–125). Additionally, subtle but significant positive ulnar variance has been reported in both skeletally mature and immature gymnasts. Like all overuse injuries, "gymnast's wrist " usually resolves with appropriate activity modification.

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Fractures and Dislocations of the Wrist and Hand

Falling on an outstretched hand usually causes fractures of the forearm bones in children and, rarely, causes carpal fractures until the late teen years. Since the carpus is completely cartilaginous at birth and remains substantially so until late childhood, the cushioning effect of the cartilage protects against carpal fracture in young children. Ossification begins in the capitate between 2 and 3 months of age and proceeds in a clockwise manner to the hamate about a month later. Two years later ossification is seen in the triquetrum. The lunate appears on the radiographs of older 3-year-olds, the scaphoid at about age 5, the trapezoid and the trapezium in the 6-year-old. By the time the child is in the first grade, all but the pisiform are beginning to ossify. This begins much later, in the ninth or tenth year of life. Not until adolescence do the carpal bones of the wrist have an adultlike appearance on radiographs.

Fracture of a carpal bone may occur in small children as part of a massive injury and in this case are almost always associated with other fractures of forearm bones, metacarpals, or other carpals. Later in adolescence, more adult-type fracture patterns may be seen with isolated carpal fractures, which are usually stable. Less common but important, carpal fracture may occur in conjunction with ligamentous injury. In these patients, the injury causes serious instability of the wrist that demands careful treatment. In spite of good treatment these patients usually have residual joint stiffness and weakness.

FRACTURES OF THE SCAPHOID

Fractures of the scaphoid are the most common carpal fracture in adults as well as in children. However, unlike in adults and adolescents, the fracture is rare in young children. It tends to occur in the distal pole as an avulsion-type fracture.[1]

The scaphoid fracture is seen most commonly in males between the ages of 15 and 30.[1] In adolescence as in adulthood, the fracture may be the only radiographic evidence of more extensive, severe trauma which may injure critical ligamentous structures in the wrist. Additional ligamentous injuries in these cases may make the associated fracture unstable, prolong healing, and eventually lead to nonunion. Any evidence of displacement or instability or a history of wrist dislocation should be treated with internal fixation. This is a relatively common injury in the adolescent athlete.

Anatomy. The patient usually is an adolescent boy who gives a history of falling on an outstretched hand in a football game. Commonly the injury is misinterpreted by patient, parent, coach, and trainer as "just a sprain." When such an injury is associated with radial-side wrist pain, the orthopaedist must examine the wrist carefully, since the physical findings are often subtle and critical.

Mild swelling in the anatomic snuff-box is best appreciated by comparing the injured wrist with the uninjured wrist (Fig. 41–126). Tenderness in this area should also be compared with the opposite side. When more massive swelling is present, particularly when it is associated with tenderness over both the scaphoid and ulnar side of the wrist, the surgeon must consider that a perilunate injury may have occurred. This is important, since radiologically the wrist may have little or no sign of this because the perilunate dislocation may have reduced itself prior to the x-ray study.

Radiographic Findings. The radiographic findings in scaphoid fracture may be subtle or, in the first few weeks,

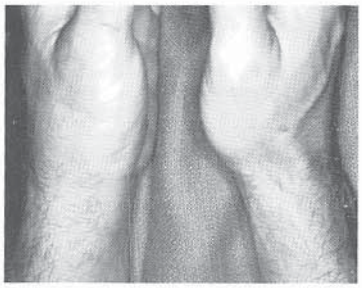


FIGURE 41–126 Subtle swelling in the anatomic snuff-box is more easily demonstrated when the normal side and the injured side are compared side by side.

occasionally absent. It is solid orthopaedic practice to trust the physical examination, and good orthopaedists are wary of patients with well-localized tenderness in the anatomic snuff-box. Nondisplaced scaphoid fractures may not be visible on the initial films. If doubt exists, the scaphoid should be immobilized in plaster and repeat radiographs obtained in 14 to 21 days. In addition, no imaging technique can accurately evaluate the ligamentous injury that may accompany the deceptively benign appearance of a fractured scaphoid. Here the surgeon must rely on a high index of suspicion and the presence of widespread tenderness and swelling on physical examination.

ROUTINE SCAPHOID X-RAY SERIES. When properly done, this series is usually the only imaging study required. Inexpensive and easily carried out, the study requires attention to detail on the part of the x-ray technician. The orthopaedist must insist that at least the following be included:

1. Radial and ulnar deviation PA views with the wrist in about 30 degrees of extension. (This amount of wrist extension is conveniently accomplished by asking the patient to make a fist gently during the examination.)
2. A pronated oblique view of the wrist, PA, with the wrist slightly supinated (about 30 degrees) off the x-ray cassette.
3. A true lateral view of the wrist with the radius and ulna superimposed and in neutral radial and ulnar deviation and neutral extension (this can be verified when the metacarpals are colinear with the long axis of the forearm bones).
4. Comparison views of the opposite wrist in all projections. *The importance of this cannot be overstated.* Subtle changes in the intercalated carpal segment are often normal variants, and without a comparison view of the patient's uninjured wrist they may be erroneously considered pathologic.

A practical way to obtain the scaphoid series is to use two 10 × 12-inch films as follows:

1. Divide the first film into four quadrants and expose the left wrist on the left two quadrants. In the upper quadrant, obtain the ulnar deviation view to "stretch out" the scaphoid, and in the lower quadrant, obtain a radial deviation view to check for scaphoid rotation. Repeat the same views of the right wrist in the corresponding two right quadrants. Now the two wrists can readily be compared with minimal shuffling of x-ray films.
2. Divide the second film into thirds. Place the two lateral exposures of the right and left wrist side by side and the oblique film in the remaining third. Figure 41–127 shows an example of the scaphoid x-ray series.

Additional imaging studies are expensive but may be indicated when displacement of the fracture is expected or in complex wrist injuries. They are not routinely indicated.

TRISPIRAL TOMOGRAPHY. This examination is very useful for detecting small or subtle fractures and fracture displacements. It should be undertaken when there is reason to suspect that such findings may exist. Marked swelling, significant ulnar wrist tenderness, comminuted scaphoid fractures, and intercalated segment instability not present in the normal wrist are indications to use this valuable study. It is also useful in evaluating union of the scaphoid. However, it may occasionally underestimate or overestimate the status of osseous union in these fractures. Unfortunately, trispiral tomography machines and technicians expert in their operation are becoming less available to the orthopaedist. CT is becoming the standard study, and newer, better machines now come close to the exquisite detail of the skillfully done trispiral tomogram.

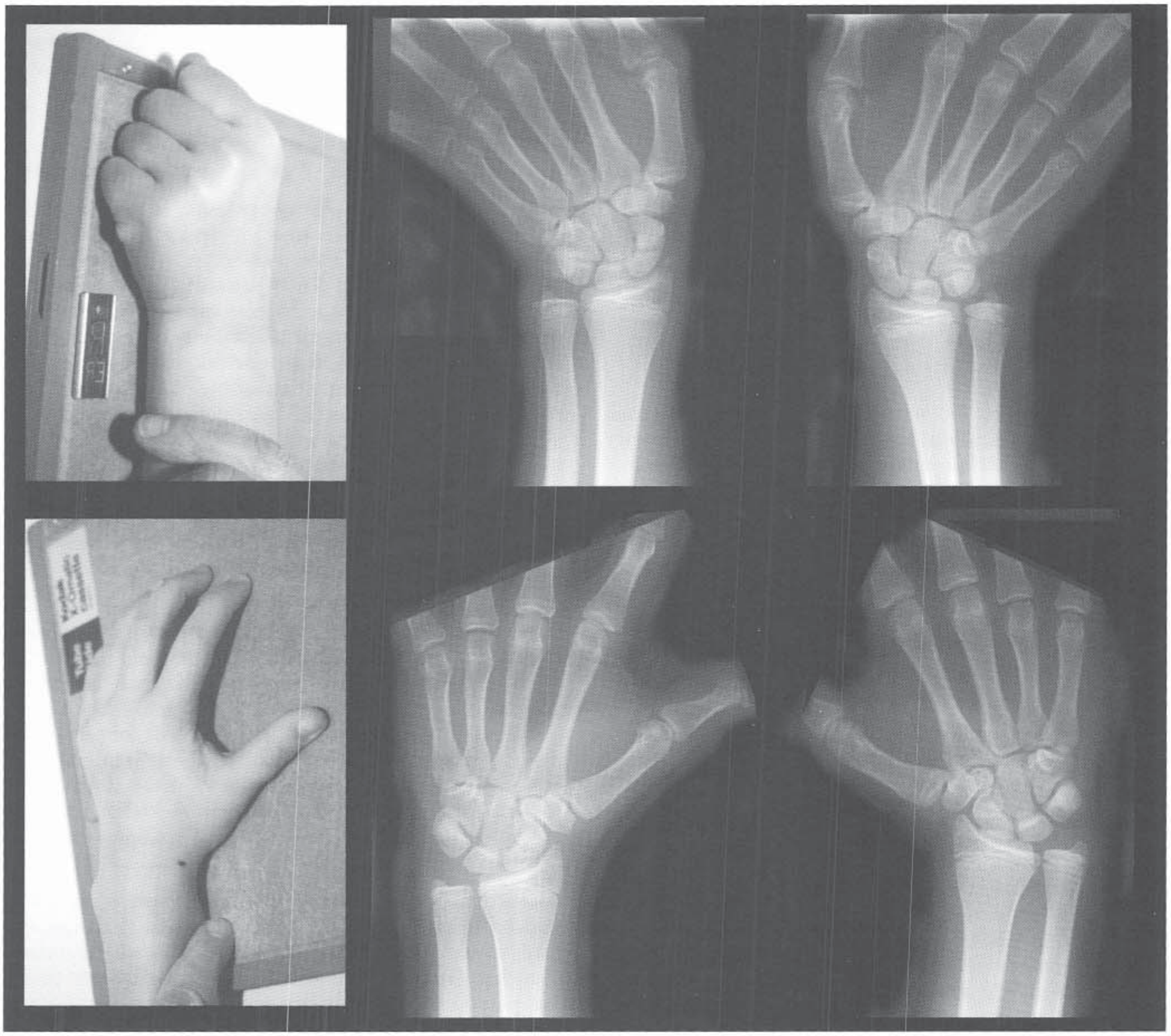
BONE SCANS. Occasionally the standard scaphoid series detailed above fails to demonstrate a fracture but the patient's clinical findings indicate scaphoid fracture and persist after 14 to 21 days of a trial of plaster cast immobilization. In this case, the bone scan is a useful and valuable way to assess the presence of a fracture and hence the need for continuing the plaster immobilization. When the bone scan is normal at 4 weeks, the patient can be assured by the surgeon that the scaphoid is not fractured. An abnormal bone scan is an indication for more advanced imaging techniques such as trispiral tomography or CT.

MAGNETIC RESONANCE IMAGING. There has been considerable abuse of this test for evaluating wrist injuries. This expensive study rarely adds information that changes the treatment of such patients. It is neither a reliable determinant of proximal pole blood supply in this small bone nor does it accurately reveal concomitant ligamentous injury in patients with a scaphoid fracture. MRI may be useful in imaging the mainly cartilaginous carpus of children but it is rarely indicated in the treatment of the adolescent with a fracture of the scaphoid.

Treatment of Scaphoid Fracture

STABLE OR NONDISPLACED SCAPHOID FRACTURES. Treatment with a short thumb spica cast for 4 to 8 weeks is appropriate in younger children. In older adolescents involved in sports, consideration for internal fixation of even nondisplaced fractures may be appropriate in selected cases to allow earlier return to sporting activities. Even with rigid internal fixation, however, it is prudent to protect the patient from overstressing the recently fixed but as yet ununited scaphoid fracture. Usually about 8 weeks is required to obtain adequate osseous union, return of flexibility, and strength before allowing the patient to play vigorous sports without brace or plaster protection.

UNSTABLE OR DISPLACED SCAPHOID FRACTURES. Displacement of even a millimeter on the radiograph is diagnostic of instability, and open reduction with internal fixation is the appro-



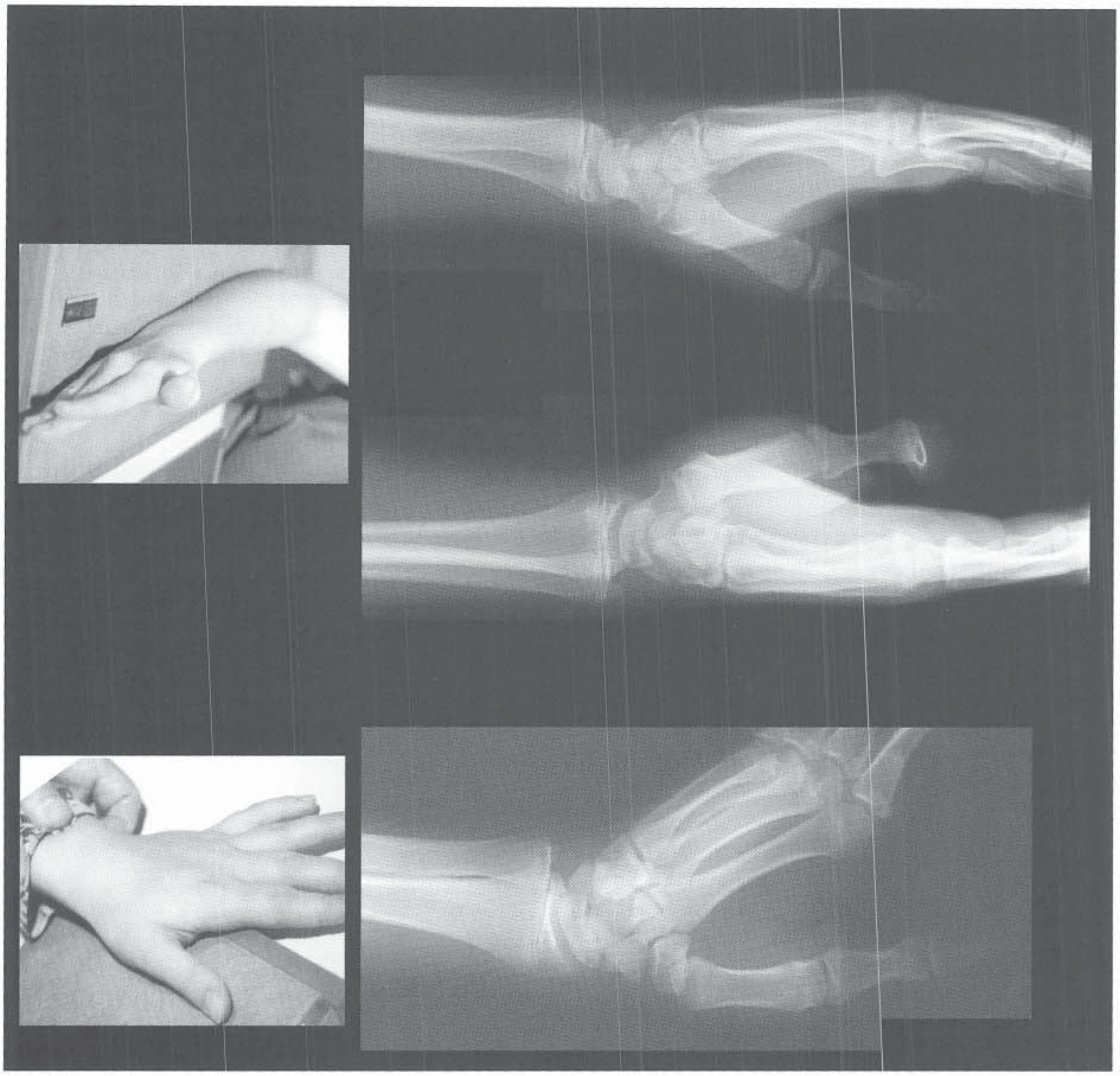
A

FIGURE 41–127 **A** and **B,** The scaphoid radiographic series provides comparison views side by side, a useful and important aid to locating subtle abnormalities. It is made using two 10 × 12-inch films. The clinical photographs show positioning of the wrist on the x-ray cassette. The technique is described in the text.

priate treatment for these scaphoid fractures. Specialized devices such as the Herbert scaphoid screw have been used effectively in this regard. Considerable skill and experience are required to position the internal fixation device properly in this bone. The target area is small and unforgiving. The patient is wisely referred to a surgeon who does this routinely. This is especially true in more unusual cases where a perilunate injury accompanies scaphoid fracture, where the wrist is often very unstable. The open repair of these injuries is one of the most challenging procedures in hand surgery. Wide exposure with incisions on the dorsum as well as anteriorly is needed to achieve adequate ligament repair. These rare injuries are best referred to a hand surgeon for this treatment.

DISLOCATION AND FRACTURE-DISLOCATION OF THE IMMATURE WRIST

Subluxations and dislocations of the wrist can be very difficult to diagnose in the immature carpus because it is unossified. After an injury, if the child's wrist is significantly swollen and unable to flex and extend, and if no forearm fracture is evident, this diagnosis must be ruled out. Bilateral films for comparison are critical; the diagnosis is usually made from a carefully positioned lateral radiograph. For lateral views the wrist must be carefully positioned in neutral flexion and extension with the forearm bones superimposed. The orthopaedist must insist that repeat films be done until a proper study is obtained. On the lateral view in a very



B

FIGURE 41–127 *Continued.* *See legend on opposite page*

young patient, often the axial malalignment of the metacarpals and forearm bones are the only tip-off that can be used to identify this injury. If this is noted in a child, MRI and arthrography are necessary for more complete delineation of these rare dislocations, which in the mature carpus would be obvious on a plain radiograph.

Other Carpal Fractures. Other carpal fractures are rare in children and are usually associated with severe trauma.

FRACTURES AND DISLOCATIONS OF THE HAND

General. Hand fractures in children are usually benign injuries that can be well treated with splinting or casting. The reader is encouraged to review the section on the principles of treatment of acute bony injuries of the hand for the diagnosis and treatment of these common injuries. Only particularly problematic fractures of the hands of children are covered in this discussion. In general, the need for open reduction of hand fractures is the same as in other areas and is dictated by failure to obtain or maintain reduction of the fracture. The Kirschner wire is the mainstay of stabilization in the hand fracture, and there is essentially never a need for plate fixation of a child's hand bone. The K-wire placed percutaneously with image intensifier control is especially useful. Leaving the wire outside the skin but under a cast until healing is secure facilitates removal at follow-up.

Metacarpal Fractures. Although fracture of a single metacarpal tends to be stable and needs only protection while healing, multiple fractures are often unstable. Multiple metacarpal fractures are usually the result of violent crushing injury and often are open. In this case, after appropriate cleansing, temporary K-wire fixation is needed for 4 to 5 weeks.

Occasionally an isolated but malaligned metacarpal defies closed treatment due to angulatory or rotatory malalignment. Rotatory deformities that cause significant finger overlap usually will not correct with remodeling. K-wire stabilization after reduction is effective.

Phalanges

PROXIMAL PHALANX (P1) AND MIDDLE PHALANX (P2). Proximal and middle phalanx fractures that are markedly angulated and displaced may occasionally be irreducible by closed means because of periosteum, tendon, or sheath interpositions. Once released, the reduction is usually easy to obtain but difficult to maintain without supplementary K-wire fixation.

DISTAL PHALANX (P3). This bone is so intimately connected to the nail bed, its germinal matrix, and dorsal skin that a markedly displaced fracture rarely occurs without open injury to the nail bed. The nail plate and any interposed soft tissue must be removed before an accurate reduction is possible. Subsequent stabilization of the phalanx with a longitudinal K-wire continued across the distal interphalangeal joint helps provide both soft and hard tissue alignment. Closure of the nail bed should be done with fine (6-0) absorbable suture.

Intra-articular Fracture. Intra-articular fracture with marked displacement can be managed by open reduction, which is best done in the acute period. If the fracture is well along in healing, sometimes it is best to let the fracture heal and do an osteotomy later (see Fig. 14–47). At other times the fracture may be rotated so much that open reduction is the only hope for salvaging any joint function.

Intra-articular fractures that are not displaced rarely need anything other than protection and closed treatment. If the surgeon considers the fracture pattern unstable, such as an oblique fracture of the condyle of a joint, percutaneous pin fixation is usually adequate. Image intensification and a small power drill make this easier and less likely to displace the fracture.

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Fractures and Dislocations of the Wrist and Hand

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