CHAPTER 33

David L. Skaggs
Steven Frick

Upper Extremity Fractures in Children

INJURIES OF THE SHOULDER AND HUMERUS

The clavicle, scapula, and humerus articulate to form the shoulder. The clavicle is flat laterally, triangular medially, and has a double curve that is convex anteriorly in the medial third and convex posteriorly in the lateral third. The scapula is a large, flat, triangular bone that is connected to the trunk by muscles only and to the clavicle by the acromioclavicular and coracoclavicular ligaments. The spine arises from the dorsal surface of the scapula and forms the acromion laterally. The coracoid process arises from the anterior surface. The clavicle and scapula are attached at the acromioclavicular joint and held in place by the coracoclavicular ligaments. The clavicle connects the shoulder girdle to the axial skeleton at the sternoclavicular joint. This joint is very mobile and allows the clavicle to move through an arc of 60 degrees and accommodate a wide range of scapular rotations. The shoulder girdle articulates with the humerus through the glenohumeral joint. This joint is a ball-and-socket joint that is supported primarily by the articular capsule and surrounding muscle. Thus, the shoulder mechanism functions as a universal joint, allowing freedom of motion in all planes.

Fractures around the shoulder are generally easy to treat and infrequently require reduction or surgical stabilization. The wide range of motion in this region contributes to rapid remodeling and accommodates modest residual deformity.

Shoulder Injuries in Infants. Difficult birth can result in injury to the infant's shoulder (1). The most common injuries are fracture of the clavicle and brachial plexus palsy. The differential diagnosis should also include proximal humeral physeal separation, septic arthritis of the shoulder, osteomyelitis, and nonaccidental injuries. Lack of arm movement in the neonatal period is the most common clinical finding for each of these problems. Pain, swelling, and crepitus may be noted when fracture has occurred. Often, fracture of the clavicle at birth is undetected until swelling subsides, and the firm mass of healing callus is noticed in the midshaft of the clavicle. Parental reassurance and gentle handling are all that are required for managing fracture of the clavicle at birth. Clavicle fracture is occasionally confused with congenital pseudarthrosis of the clavicle. Pseudarthrosis can be distinguished from fracture of the clavicle at birth by the absence of pain and by radiographic features of established pseudarthrosis. Pseudarthrosis also typically occurs only on the right side.

Birth trauma may also result in Salter-Harris type I physeal separation of the proximal humerus. This injury may be difficult to diagnose radiographically because the proximal humeral epiphysis does not ossify until 3 to 6 months of age. Ultrasonography, MRI, or joint aspiration may facilitate diagnosis in questionable cases. Treatment is simple immobilization for 2 to 3 weeks; union and remodeling will occur.

Clavicle Injuries

Clavicle Diaphysis Fracture. The clavicle is frequently fractured in children, and the most common portion injured is the shaft. The mechanism of injury is usually a fall on the shoulder or excessive lateral compression of the shoulder girdle. The subclavian vessels, brachial plexus, and apex of the lung lie beneath the clavicle but are rarely injured at the time of fracture.

Treatment of clavicle shaft fractures in children and adolescents is supportive; reduction is not attempted, except for fractures with extreme displacement. A figure-eight harness and/or a sling may be used until the patient is able to move the arm comfortably. Sports are avoided for approximately 8 weeks. Uneventful, rapid healing is the rule, although displaced fractures may heal with a visible subcutaneous prominence. Parents should be advised that, regardless of alignment, healing will produce a bump that will remodel over the course of several months to years. Indications for surgery are rare but include open fractures, severe displacement with the bone end impaled through the trapezius, and irreducible tenting of the skin by the bone fragments. Even in these severe cases, internal fixation is rarely required. Recently, adults with clavicle fractures that are severely displaced and/or shortened have been found to have dissatisfaction and decreased function after nonoperative treatment (2), resulting in recommendations for operative treatment of fractures with >100% displacement or shortening >2 cm. The treatment of clavicle fractures in adolescents approaching skeletal maturity is evolving, with some recommending surgical treatment for widely displaced or shortened fractures. Some practitioners favor operative treatment in teenage athletes to facilitate rehabilitation and perhaps earlier return to sport, especially in cases where the clavicle fracture is on the dominant side of a throwing athlete. Two recent papers have noted that children and adolescents can be treated successfully with plate fixation with very low complication rates (3, 4). In adolescent patients, a "wait-and-see" approach identified four patients with displaced clavicle fractures who developed symptomatic malunions. All four had good results after osteotomy and plate fixation. Nonunion after clavicle fracture has been reported in adolescents, but it responds to bone grafting and plating (5).

Medial Clavicle Fracture and Sternoclavicular Separation. The medial clavicular ossification center appears at approximately 17 years of age, but the physis does not close until 20 to 25 years of age (6). Therefore, displacements of the medial end of the clavicle are usually physeal separations that mimic sternoclavicular dislocation (7). These are usually Salter-Harris type I or II injuries, although the epiphyseal fragment is not visualized well on radiographs. The direction of displacement can be anterior, superior, or posterior. Posterior displacement by fracture or dislocation can cause dysphagia or respiratory compromise. Physical examination and plain radiography are unreliable in assessing displacement. These injuries are frequently missed, and a high index of suspicion for sternoclavicular injury is needed in patients with pain and tenderness in the region. Apical lordotic radiographs are helpful, but computed tomography (CT) scans best visualize the injury. Anterior or superior displacement is usually treated nonoperatively. Posteriorly displaced medial clavicle fractures or sternoclavicular dislocations are usually treated operatively to relieve compression of mediastinal structures. Some have recommended nonoperative treatment of medial physeal injuries with reliance on remodeling (8), while others have recommended open reduction and repair (9, 10).

OPERATIVE MANAGEMENT OF STERNOCLAVICULAR DISLOCATIONS AND MEDIAL CLAVICLE PHYSEAL FRACTURES

Indications for Operative Management. Posterior or retrosternal displacement of the medial clavicle can cause injury to or compress the great vessels, trachea, or esophagus, and thus reduction is indicated.

Preoperative axial imaging should be carefully assessed for injury to major vessels by the posteriorly displaced clavicle, as lacerations of the pulmonary artery and brachiocephalic vein have been reported (Fig. 33-1). Because of the potential for hemorrhage, it is recommended that reduction be attempted in the operating room under general anesthesia with awareness by a thoracic or a vascular surgeon. Some recommend that a thoracic surgeon be scrubbed in at the time of reduction (8), especially for cases with delayed treatment (>1 week) as the medial end of the clavicle may be adherent to adjacent vascular structures. Fractures with anterior or superior displacement are usually managed nonoperatively.

Closed reduction is attempted in acute injuries by longitudinal traction, abduction, and shoulder extension of the involved arm and is often successful. If reduction is not achieved, direct anterior traction can be applied to the clavicle by hooking a couple of fingers posterior to the subcutaneous midportion, or by percutaneously grasping it with a pointed reduction clamp. In posteriorly displaced dislocations, the reduction can be unstable because of the posteriorly directed

FIGURE 33-1. CT reconstruction demonstrates retrosternal dislocation of clavicle compressing the brachiocephalic vein.

FIGURE 33-2. The patient is placed supine with a bump under the ipsilateral scapula.

slope of the sternal notch. If the surgeon believes a stable reduction is achieved, postoperative axial imaging should be obtained to document maintenance of reduction. Attempted closed reduction is not recommended in late presenting cases. If the reduction is unstable, or with late presentation, open reduction and fixation is performed.

The patient is placed supine with a bump under the ipsilateral scapula (Fig. 33-2). The surgical preparation extends from the midneck to abdomen, and across the chest to include the contralateral acromioclavicular joint. This wide prep allows for emergent access to the chest if needed and allows for palpation of the contralateral clavicle to help assess reduction (Fig. 33-3).

Catastrophic, life-threatening bleeding can potentially occur intraoperatively, but is not reported in the literature. Having a thoracic or vascular surgeon on standby and emergency thoracotomy instruments available is recommended (8, 9, 19) The ipsilateral upper extremity can be prepped into the surgical field if desired to allow traction through the arm and stability testing with range of motion of the shoulder after fixation.

The medial clavicle is approached through a transverse incision extending from the middle third–medial third junction of the clavicle to just past the midpoint of the sternal notch. Subcutaneous dissection is performed through the platysma to the level of the periosteum, and then the periosteum is incised from lateral to medial directly anterior over the clavicle. As the dissection proceeds medially, the periosteum will remain intact and attached to the medial clavicular epiphysis in physeal injuries and should be preserved. In dislocations, the periosteum will often be attached anteriorly to the fibrocartilaginous disc of the sternoclavicular joint.

In acute injuries that are easily reduced, at this point a blunt-tip clamp can be placed around the clavicle and used to manipulate and reduce the medial clavicle (Fig 33-4).

In late presenting cases, the clavicle will be stuck behind the sternum, and vigorous traction to attempt to reduce it is not recommended (Fig. 33-5). Instead, careful subperiosteal circumferential dissection around the clavicle near the middle third–medial third junction can be performed, and a clamp can then be placed around the clavicle more laterally. This will aid in stabilizing the clavicle for careful subperiosteal dissection with an elevator working from lateral to medial. As the dissection proceeds, it is helpful to place small blunt retractors posterior to the clavicle from both above and below, and use them to gently lift the clavicle anteriorly as the dissection proceeds medially. In chronic cases, the displaced medial end of the clavicle can be quite deep behind the sternum, and traction to pull the medial end laterally and anteriorly should not be applied until the most medial aspect of the clavicle is visualized and exposed. During reduction of dislocations, it is important to realize that only about the inferior one-third to one-half of the medial clavicle articulates with the sternal notch.

FIGURE 33-3. The surgical preparation extends from the midneck to abdomen, and across the chest to include the contralateral acromioclavicular joint.

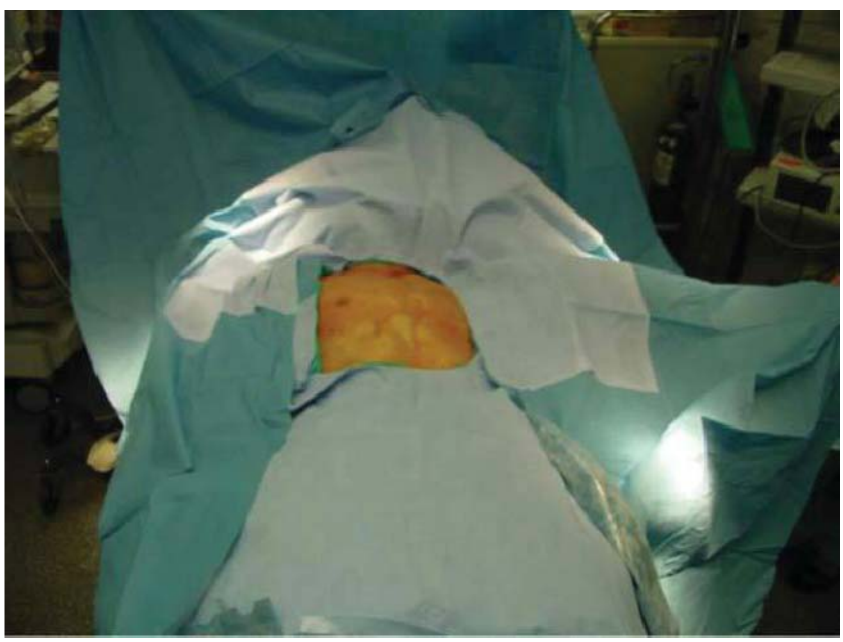


FIGURE 33-4. Intraoperative photograph (with head to left) of blunt-tip clamp around medial right clavicle. The metaphysis is displaced posteriorly and cephalad from the epiphysis, which is visible between the two Senn rake retractors.

Once the medial clavicle is reduced, fixation is recommended to maintain the reduction (Fig. 33-6). Suture fixation, wire fixation, and tendon weave through bone tunnels have all been recommended. Serious complications from pin migration are reported and can be fatal; thus, use of pins is not recommended (8). Because of the excellent healing potential in adolescents, tendon augmentation is not usually needed. For physeal injuries, suture or sternal wire fixation from the metaphysis to the epiphysis (medial clavicular head) is adequate. For dislocations, drill holes through sternum are used with figure-of-eight heavy suture to the anterior medial clavicle. After repair, the adequacy of reduction and stability are assessed under direct visualization. The stability is tested by direct posterior pressure (and range of motion of the ipsilateral shoulder if desired). Intraoperative fluoroscopy is generally not helpful.

The periosteum is often thick and is then closed over the clavicle to augment the fixation. The platysma, subcutaneous layer, and skin are then closed. The patient is placed in a sling for 4 weeks, and for 6 weeks the patient avoids crossarm adduction and heavy lifting with the involved extremity.

Lateral Clavicle Fracture and Acromioclavicular Separation. The mechanism of injury to the distal clavicle is similar to adult acromioclavicular separation. A fall onto the point of the shoulder drives the acromion and scapula distally. This results in distal clavicular physeal separation. This is because the distal epiphysis of the clavicle remains a cartilaginous cap until the age of 20 years or older (6), whereas the acromioclavicular and coracoclavicular ligaments are firmly attached to the thick periosteum of the clavicle. Typically, the lateral metaphysis displaces through the injured dorsal periosteum, leaving the ligaments intact and the epiphyseal end of the clavicle reduced in the acromioclavicular joint (11) (Fig. 33-7). Because these injuries represent physeal disruption with herniation of bone from the periosteal tube, tremendous potential for healing and remodeling exists.

FIGURE 33-5. Three-dimensional CT of chronic retrosternal dislocation of clavicle that crosses midline.

FIGURE 33-6. Lifting the clamp on medial clavicle anteriorly reduces the metaphysis to the epiphysis (beneath Senn rake retractor) prior to figure-of-eight suture fixation.

Treatment of most distal clavicle fractures consists of support with a sling or shoulder immobilizer for 3 weeks. Reduction and fixation are unnecessary, except for the rare instance in which the clavicle is severely displaced in an older adolescent (12).

True acromioclavicular separation is very rare before the age of 16. Fracture or physeal separation of the distal clavicle is more common, and has been called *pseudodislocation of the acromioclavicular joint* (13). Tenderness over the acromioclavicular joint and prominence of the lateral end of the clavicle are present with fracture, physeal separation, and joint separation. Radiographs demonstrate increased distance between the coracoid process and the clavicle, compared with the opposite side. When true joint separation occurs, the injury may be a sprain, subluxation, or dislocation. These have been classified as grades I to VI, depending on the severity of injury to the acromioclavicular and coracoclavicular ligaments (14–16).

Treatment of grades I to III is usually conservative, without attempting reduction. It is unnecessary to determine the degree of separation by stress radiography with handheld weights. A sling or shoulder immobilizer is used for 3 weeks, followed by a graduated exercise program. Even in competitive athletes, shoulder strength and range of motion are typically not impaired after rehabilitation (17–19). In complete separations (type III), the clavicle remains prominent but is usually asymptomatic. The occasional patient who develops late symptoms of pain and stiffness may be relieved by resection of the distal clavicle (18), with ligament reconstruction. In grade IV separations, the distal clavicle is posteriorly displaced through the trapezius fascia, and open reduction and stabilization is recommended (Figs. 33-8 to 33-10).

In grade V separations, the clavicle is displaced 100% to 300% superiorly, and the clavicle lies subcutaneously. In grade VI injuries, the clavicle is displaced inferiorly beneath the acromion or coracoid. In grade V and VI separations, surgical reduction and stabilization is recommended (16).

Scapular Fracture. Fracture of the scapula, although rare in children, should be suspected whenever there is shoulder tenderness or swelling after trauma. These fractures are usually the result of a severe, direct blow of high energy. Therefore, initial evaluation should include a diligent search for more serious chest injuries, such as rib fractures, pulmonary or cardiac contusion, and injury to the mediastinum. If associated with injuries to the clavicle, scapulothoracic dissociation should be suspected, and a careful assessment of the vascular and neurologic function of the ipsilateral upper extremity should be performed. Fractures of the scapula can involve the body, glenoid, or acromion. Avulsion fractures of the scapula have also been reported and are a result of indirect trauma (20). The CT scan is helpful for evaluating scapular fractures and associated injuries.

Treatment of most scapular fractures consists of immobilization with a sling and swathe, followed by early shoulder motion after pain has subsided. The scapular body is encased in thick muscles, so displacement is rare and well tolerated after healing (12). Fractures of the acromion or coracoid require surgery only when severely displaced. Glenoid fractures are the most likely to require reduction and internal fixation. Intra-articular fractures with substantial displacement should be restored to anatomic positions. Large glenoid rim fractures can be associated with

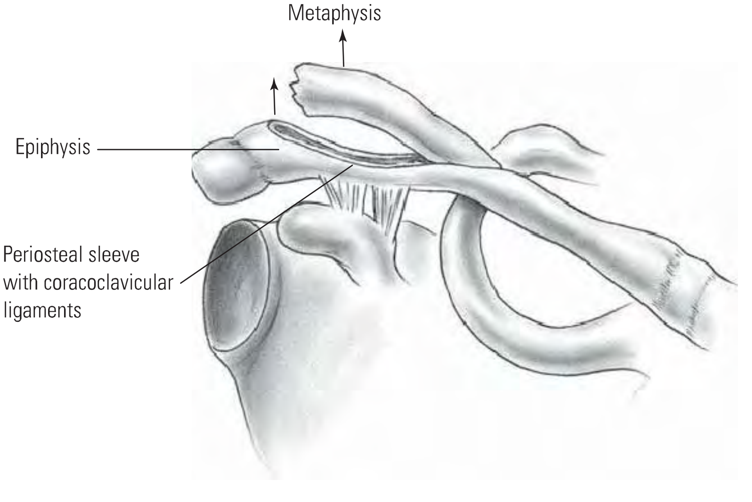
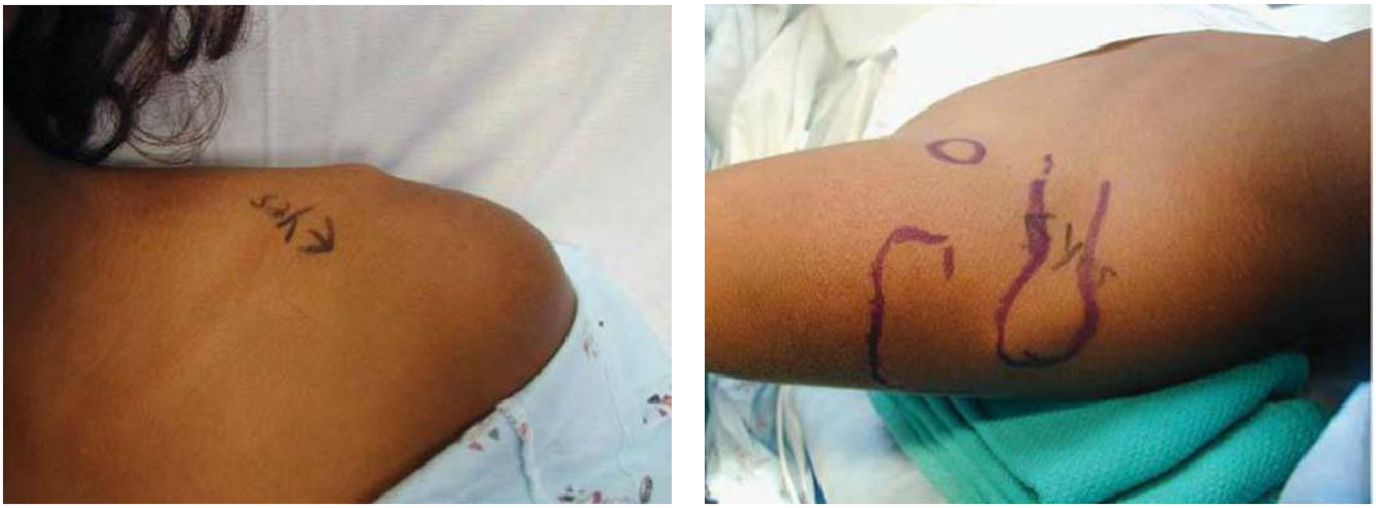


FIGURE 33-7. Lateral clavicle fracture separation. The swelling and dorsal prominence of the clavicle may suggest an acromioclavicular separation. However, the distal epiphysis of the clavicle and the acromioclavicular joint remain reduced. New bone forms from the periosteum, with subsequent remodeling of the prominence. (From Ogden J. Distal clavicular physeal injury. *Clin Orthop* 1984;188:68, with permission.)



A B

FIGURE 33-8. **A:** Clinical photograph from front of a 11-year-old struck by car with type IV posteriorly displaced acromial clavicular pseudodislocation. **B:** Clinical photograph of same patient from back showing posterior displacement of lateral clavicle into trapezius (type IV).

traumatic dislocations. An anterior approach is recommended for anterior glenoid fractures, and a posterior approach is used for scapular neck and glenoid fossa fractures (21).

Shoulder Dislocation. Less than 2% of glenohumeral dislocations occur in patients younger than 10 years (22). Atraumatic shoulder dislocations and chronic shoulder instability are discussed elsewhere in this book. Traumatic shoulder dislocation in the adolescent age group is more common. Approximately 20% of all shoulder dislocations occur in persons between the ages of 10 and 20 years. Most displace anteriorly and produce a detachment of the anteroinferior capsule from the glenoid neck (i.e., Bankart lesion).

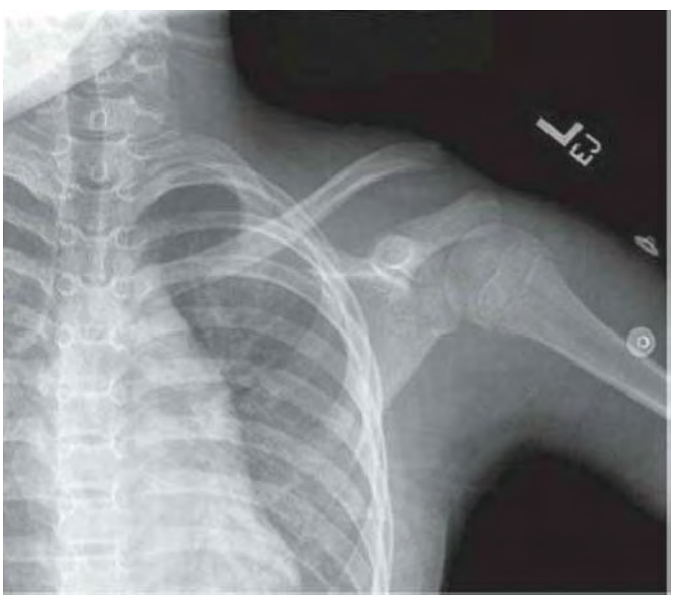


FIGURE 33-9. AP injury radiograph of the patient in Figure 33-8.

Treatment of traumatic shoulder dislocation in children and adolescents is nonsurgical, with gentle closed reduction. This is accomplished by providing adequate pain relief, muscle relaxation, and gravity-assisted arm traction in the prone position. An alternative method is the modified Hippocratic method in which traction is applied to the arm while countertraction is applied using a folded sheet around the torso. After reduction, a shoulder immobilizer or sling is used for 2 to 3 weeks before initiating shoulder muscle strengthening. The most frequent complication is recurrent dislocation, which has an incidence between 60% and 85%, usually within 2 years of the primary dislocation (23, 24). Posterior dislocations of the shoulder may also recur and require surgical stabilization in children (25). A more detailed discussion of this injury and its treatment is found elsewhere in this book.

Proximal Humerus Fractures. Proximal humeral growth accounts for 80% of the length of the humerus. The proximal humeral physis is an undulating structure that forms a tentlike peak in the posteromedial humerus quadrant, near

FIGURE 33-10. AP radiograph of patient after open reduction, suture fixation through clavicle and under coracoid to repair coracoclavicular ligaments, and suture of periosteal tube over clavicle.

the center of the humeral head. The glenohumeral joint capsule extends to the metaphysis medially. Therefore, a portion of the metaphysis is intracapsular. The proximal humeral physis remains open in girls until 14 to 17 years of age and in boys until 16 to 18 years of age.

Mechanisms of injury that would produce a shoulder dislocation in adults usually result in a proximal humeral fracture in children and adolescents. These are usually Salter-Harris type II epiphyseal separations or metaphyseal fractures. Metaphyseal fractures are more common before the age of 10, and epiphyseal separations are more common in adolescents. The distal fragment usually displaces in the anterior direction because the periosteum is thinner and weaker in this region. Posteriorly, the periosteal sleeve is thicker and remains intact. The proximal fragment is flexed and externally rotated because of the pull of the rotator cuff, whereas the distal fragment is displaced proximally because of the pull of the deltoid muscle. Adduction of the distal fragment is caused by the pectoralis major muscle. Remarkably, this is a relatively benign injury because of the rapid rate of remodeling with growth and the wide range of shoulder motion (26, 27).

The long head of the biceps may be interposed between the fracture fragments and may impede reduction (28).

Most of these fractures are minimally displaced or minimally angulated. They are managed in a shoulder immobilizer for 3 to 4 weeks, followed by range-of-motion exercises and gradually increased activity.

Severely displaced fractures pose a greater dilemma for the treating physician. The alarming radiographic appearance invites overtreatment. These fractures are difficult to reduce and maintain in a reduced position by closed methods. Traction and cast immobilization are not recommended because these techniques are inconvenient, cumbersome, and have not been shown to improve results. Current options for management include immobilization without attempting reduction, or reduction under sedation or anesthesia with assessment of postreduction stability, and percutaneous fixation if unstable. Redisplacement after immobilization without pin fixation is common. Authors who have studied these options have concluded that most severely displaced fractures should be treated by sling and swathe immobilization (26, 27, 29). Complete displacement, 3 cm overriding, and 60 degrees of angulation may be accepted in patients who are more than 2 years from skeletal maturity. Up to 45 degrees of angulation can be accepted until physeal closure (28) (Fig. 33-11). Closed or open reduction under anesthesia with percutaneous pinning may be indicated for fractures in older adolescents, open fractures, associated vascular injuries, and severe displacement (12) (Fig. 33-12). Some practitioners also believe that injuries to the dominant arm of a throwing athlete should also be treated with reduction and fixation.

OPERATIVE MANAGEMENT OF DISPLACED PROXIMAL HUMERUS FRACTURES

Indications for Operative Management. The indications for operative management of adolescent proximal humeral fractures are controversial, as some studies report excellent functional outcomes with nonoperative management of displaced and angulated fractures, even in older adolescents (27). Dobbs et al. (28) used >2/3 width displacement (Neer grade III or IV) and angulation >45 degrees in older adolescents (>12 years) as indications for attempted closed reduction under general anesthesia. If a successful reduction could be obtained (to grade II or less displacement and <45 degrees angulation), then stability was tested. If unstable, the fracture was treated with percutaneous pin fixation and immobilization. If an acceptable reduction could not be achieved closed, an open reduction was performed using a deltopectoral approach.

Closed Reduction Method. In most fractures, the distal fragment will be displaced anteriorly through the thinner periosteum, and the proximal fragment will be abducted and externally rotated by its muscular attachments. After adequate analgesia and/or anesthesia, longitudinal traction is applied to the injured extremity, and the distal humeral fragment is flexed, abducted, and externally rotated. Posteriorly directed pressure during flexion on the distal fragment will push it back inside the soft-tissue envelope, and then abduction and external rotation will reduce the fragment. Fluoroscopy is useful to assess the position of the fracture fragments during reduction. Once reduced, an axial load is applied to compress the fracture with the arm still abducted and externally rotated, and the arm is then returned to the patient's side. If the fracture redisplaces to an unacceptable degree with the arm at the side, then repeat reduction and percutaneous pin fixation is warranted. If the fracture remains reduced, the patient is placed in a sling and swathe. For minor amounts of residual varus, an abduction pillow at the side with the sling and swathe may be used.

For unstable fractures and irreducible fractures, the patient should be taken to the operating room for general anesthesia. The patient is positioned supine at the edge of a completely radiolucent table to facilitate fluoroscopy. A bump is placed beneath the ipsilateral scapula. The arm and shoulder are sterilely prepared and draped, and repeat closed reduction is attempted. If an adequate reduction is obtained, it is stabilized with two large pins placed percutaneously. The image intensifier can be brought in from cephalad over the patient's injured shoulder, or from the opposite side if the unit is large enough to rotate around for oblique and lateral views. Because of the risk of migration with use of smooth pins, some prefer pins with threaded tips, and it is recommended to place a large bend in the end of the pins left outside the skin. The axillary nerve is at risk, and runs from posterior to anterior around the proximal humerus in a zone 5 to 7 cm distal to the tip of the acromion. Pins should thus start distal to this, and are placed from the lateral proximal humeral metaphysis and directed up and into the humeral epiphysis. The first pin starts anterolaterally, and then a second pin is placed anterior or posterior to the first, with an attempt to get some divergence or spread of the pins in the epiphysis to enhance stability. Larger pins are preferred (≥0.062 in.) (Fig. 33-13).

FIGURE 33-11. Proximal humeral fracture separation in a boy aged 12 years, 3 months. **A:** The initial fracture displacement was treated with sling and swath. **B, C:** Three months after injury, healing and early remodeling are evident. **D, E:** One year after injury, remodeling continues. **F, G:** Four years after injury, remodeling is complete. **H–J:** The patient has recovered full range of motion, but has a 1-cm arm-length discrepancy.

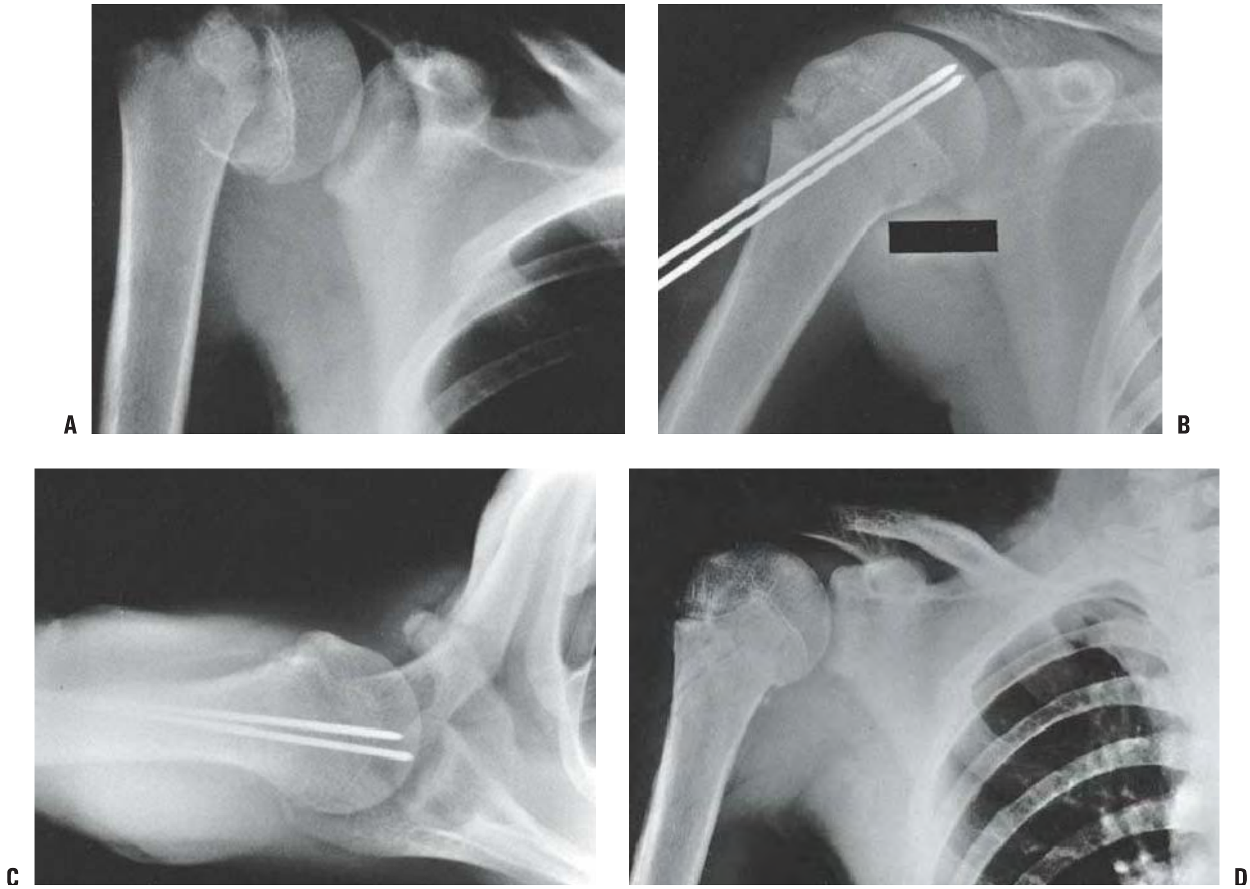


FIGURE 33-12. Salter-Harris type II fracture of the proximal humerus in a 15-year-old adolescent. **A:** Displaced fracture with 70 degrees of angulation. The proximal fragment is abducted and externally rotated because of the rotator cuff attachments. The shaft is displaced proximally by the pull of the deltoid muscle and is generally adducted by the action of the pectoralis muscle. The distal fragment is also internally rotated if the arm is placed in a sling. **B, C:** AP and lateral radiographs after CRPP. The arm is externally rotated and abducted with longitudinal traction to achieve this position. **D:** Final alignment after removal of the pins 4 weeks later.

There often is a posteromedial Thurston-Holland fragment, and if large enough one pin can stay below the physis and engage this fragment. If adequate stability cannot be obtained with pins placed distal and lateral, a proximal to distal pin can be placed lateral to the acromion, through the greater tuberosity, across the fracture, and engage the medial metaphysis of the distal fragment. Some prefer to use cannulated screws for improved bone purchase and less likelihood of implant migration, but there are no comparative studies available. If screws crossing the physis are used, screw removal may be indicated if substantial growth potential remains.

If an acceptable reduction cannot be obtained, an open reduction is performed through a deltopectoral interval approach. The long head of the biceps tendon or periosteum may be interposed obstructing an accurate reduction. After reduction, fixation is achieved percutaneously as noted above (Fig. 33-14).

After fixation, the arm is immobilized with a sling and swathe for 3 to 4 weeks, at which time radiographs are taken to assess healing, and the pins are removed. Graduated range-of-motion and strengthening exercises are begun.

Humeral Shaft Fracture. Fractures of the humeral shaft may occur at birth because of difficult delivery. Other humeral shaft fractures in children younger than 3 years are often the result of nonaccidental injury (30). In any instance of delay in seeking medical attention, inconsistent history of injury, or evidence of concurrent injuries, there is an increased likelihood of inflicted trauma. However, there is no particular pattern of fracture that is diagnostic of child abuse. Fractures seen in older children are usually the result of blunt trauma. The radial nerve is susceptible to injury because it is fixed by the intramuscular septum as it passes lateral to the humerus at the junction of the middle and distal thirds. In fractures with radial nerve palsy, the prognosis for neurologic recovery is excellent. Nerve injury with closed fractures of the humerus should be observed for 3 to 5 months before considering intervention.

Closed management is recommended for most humeral shaft fractures. Infants may be treated with gentle positioning and swaddling, with a small coaptation splint, or the arm may be splinted in extension, using a small splint or a tongue blade and tape. Prompt healing and marked remodeling of angular

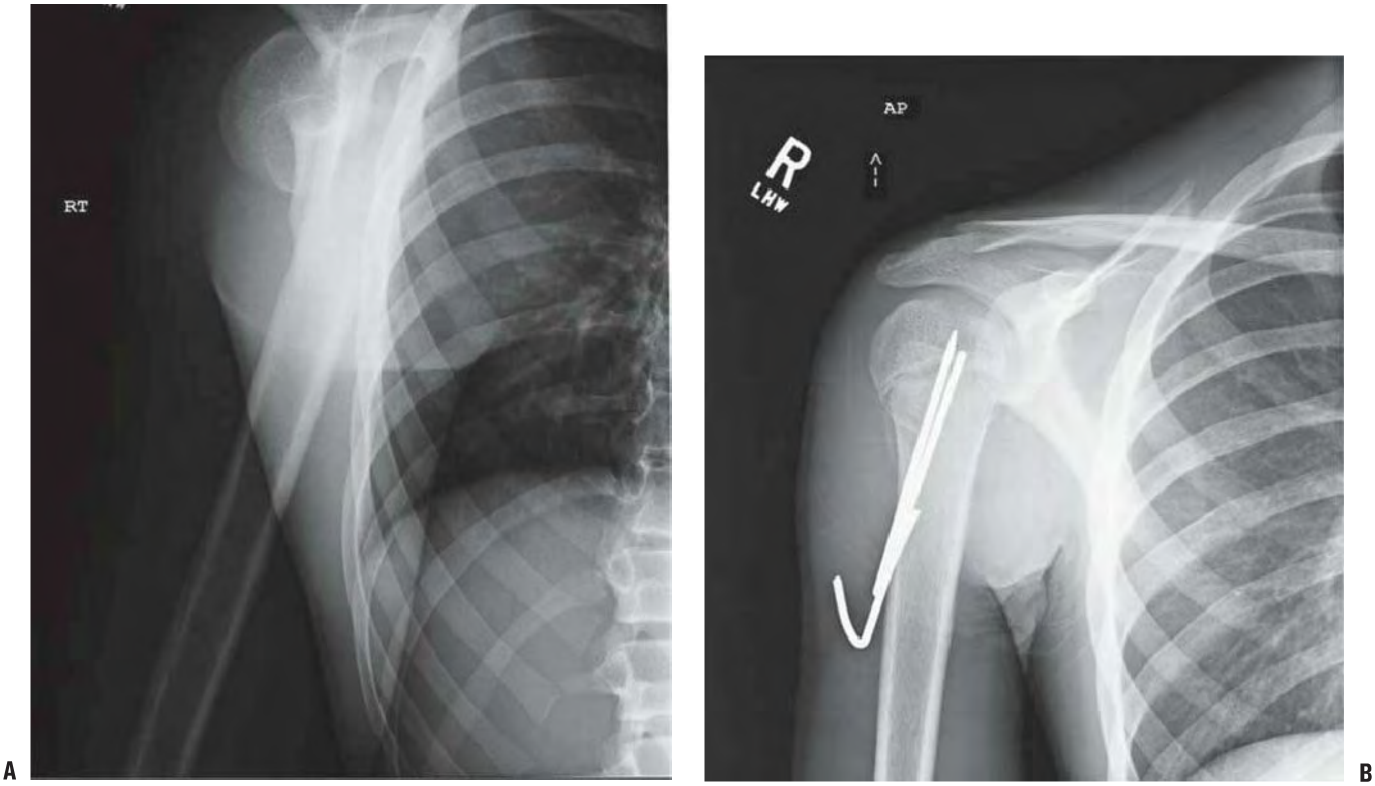


FIGURE 33-13. **A, B:** Radiographs of severely displaced fracture that was unstable after reduction and stabilized with distal to proximal pins, with pins bent outside skin.

deformity and shortening can be expected in infants and young children, with up to 65 degrees of angulation remodeling documented in infants (31). Older children may be treated with a coaptation splint and a sling to maintain alignment of the arm. A hanging arm cast or fracture brace collar and cuff may also be used. Occasionally, an abduction splint or pillow may be used to control varus alignment. In older children and adolescents, complete displacement and 2 cm of shortening are acceptable. In the proximal shaft, one can accept 25 to 30 degrees of angulation. Fracture deformity closer to the elbow is more visible. Up to 20 degrees of angulation is acceptable in the middle third and 15 degrees in the distal third of the humeral shaft (32). Greater degrees of deformity are usually unacceptable cosmetically, although they may remodel without causing functional problems. Indications for surgery include open fractures, multiple injuries, and ipsilateral forearm fractures in adolescents (i.e., "floating elbow"). Fixation techniques include the use of flexible intramedullary (IM) nails and compression plating. Open or comminuted fractures can be stabilized with an external fixator until union is complete or until fracture stability and wound healing permit converting to splint immobilization.

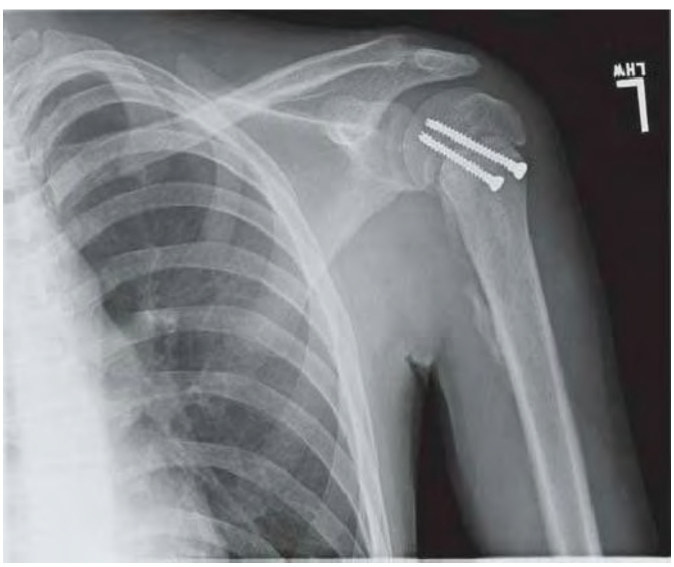


FIGURE 33-14. Rare open proximal humeral physeal fracture treated with open reduction and fixation with two screws, 3 weeks after fixation.

CLOSED REDUCTION AND INTRAMEDULLARY FIXATION OF HUMERAL SHAFT FRACTURE

Indications: Clinical situations where maintaining alignment may be difficult, including multiple trauma, multiple fractures in the same extremity, humeral fracture associated with severe head injury, and pathologic fracture.

The humeral shaft may be stabilized with flexible nails by retrograde or antegrade insertion, and each has its relative indications depending on the location of the fracture. There are a large number of reports of IM nailing of humeral fractures in adults (33–35), but little published in North America on this technique for children.

Retrograde insertion is suitable for fractures of the diaphyseal and proximal humerus. The insertion point for this method is usually through the dorsal surface of the humerus just proximal to the olecranon fossa, but can also be from the lateral column if the IM canal is small and a single nail is used.

Antegrade insertion is accomplished by passing a single rod through a portal in the region of the greater tuberosity. In this technique, either a flexible rod or a more rigid rod can be used. A larger deltoid-splitting incision can be used to create a portal large enough for two flexible rods to be inserted if needed for more stability. This incision requires care to avoid injury to the axillary nerve, the location of which in a child may not be obvious to the surgeon who seldom uses this approach (Figs. 33-15 to 33-21).

Postoperative Care. Usually the reduction is sufficiently stable to permit use of a sling or a shoulder immobilizer; however, a coaptation splint or above-elbow cast may be applied. Healing is usually sufficient within 3 to 4 weeks to initiate range-of-motion exercises. The rods are removed electively after healing is complete.

FRACTURES AND DISLOCATIONS AROUND THE ELBOW

It is wise to assume the worst when evaluating the child with an elbow injury. Only full range of motion, complete absence of swelling, and normal radiographs warrant the diagnosis of elbow sprain or contusion. Any swelling or restriction of movement necessitates thorough evaluation, sometimes with comparison radiographs of the opposite elbow whenever there is doubt regarding normal anatomy. A clinical rule of thumb is that if a child can fully extend the elbow with minimal discomfort, an elbow fracture is unlikely. Small fractures that appear to be avulsions should be accurately diagnosed, because they may indicate a major injury such as an associated elbow dislocation. Arthrography, ultrasonography, and MRI have been used to successfully diagnose occult elbow trauma in children (36–38). These techniques should be considered whenever there is doubt regarding the diagnosis.

Precisely defining the fracture patterns is a challenge in young children because of the large cartilage composition about the elbow. There are also multiple ossification centers that appear at different ages (Fig. 33-22). The capitellum is the first to appear, at 6 to 12 months of age, followed by the radial head and the medial epicondyle at 4 to 5 years of age. The trochlea and olecranon ossify at 8 to 9 years, and the lateral epicondyle appears at 10 to 11 years. The lateral epicondyle, trochlea, and capitellum coalesce to form a single epiphysis by 12 years of age. Ossification centers are intra-articular except for the medial and lateral epicondyles. The radial head, trochlea, and olecranon may appear as multiple ossification centers that may be mistaken for a fracture.

The elbow is a complex joint, and it has three major articulations: the radiohumeral, ulnohumeral, and radioulnar joints. There are two fat pads: one in the olecranon fossa posteriorly, and the other in the coronoid fossa anteriorly. Displacement of the posterior fat pad may be visible on radiographs after elbow trauma. This is a reliable indication of an intra-articular effusion (39). The anterior fat pad is sometimes seen under normal conditions and does not necessarily indicate joint effusion. Most of the distal humerus has good collateral circulation; however, caution should be exercised to avoid disrupting the posterior blood supply of the capetellum and trochlea during surgical exposure of fractures (40). The trochlea and medial condyle are particularly vulnerable to avascular necrosis because they are perfused by nonanastomotic nutrient vessels that enter the bone posteriorly and medially (41).

The clinical carrying angle of the normal elbow is a slight valgus alignment, averaging approximately 7 degrees. There are several helpful radiographic lines and angles that can be measured to determine if there is adequate postinjury alignment; a comparison view of the other elbow may be valuable as a reference (Fig. 33-23). All measurements are subject to the inaccuracies caused by elbow positioning, and this should be kept in mind when making clinical decisions. The Baumann angle is used to assess the varus attitude of the distal humerus, usually after a supracondylar elbow fracture. It is the angle formed between the capitellar physeal line and a line perpendicular to the long axis of the humerus. This angle normally should be within 5 to 8 degrees of the same angle in the contralateral elbow. An anteroposterior (AP) view of the distal humerus, positioned parallel to the radiographic plate, is necessary to reduce the variation of the Baumann angle that occurs when the arm is rotated. Ten degrees of rotation produces a 6-degree change in the angle (42). Sagittal alignment may be determined by the lateral capitellar angle, which indicates the normal forward-flexed position of the capitellum. This angle averages 30 to 40 degrees. The anterior humeral line is an easier means of assessing sagittal alignment. A line along the anterior humeral cortex should pass through the capitellum. While in the past many have said that the line must pass through the center of the capitellum, Herman et al. (43) recently reported that in children <4 years old the line passes through the anterior third 40% of the time, and in children over 4 years 22% of the time. If the capitellum is posterior to this line a displaced supracondylar, lateral condylar, or transphyseal fracture is likely.

Supracondylar Fracture. This is the most common elbow fracture. The usual mechanism of injury is a hyperextension load on the elbow from falling on the outstretched arm. The distal fragment displaces posteriorly (i.e., extension) in more than 95% of fractures. The medial and lateral columns

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Closed Reduction and Intramedullary Fixation of Humeral Shaft Fracture (Figs. 33-15 to 33-20)

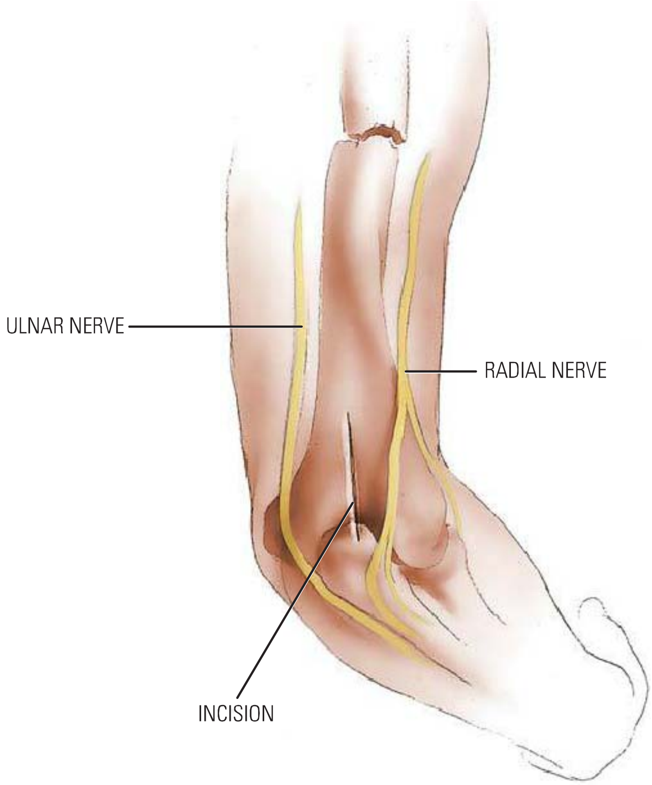


FIGURE 33-15. Closed Reduction and Intramedullary Fixation of Humeral Shaft Fracture. For both the retrograde and antegrade procedures, the patient is placed on a completely radiolucent operating table to allow access for the image intensifier. If the table has a metal edge, the patient is positioned with the injured shoulder in the middle of the table so that the metal does not block the view of the image intensifier. In retrograde nailing, a tourniquet can be used. Before beginning the operation, it is advisable to confirm that the fracture can be reduced and that the image intensifier can visualize the entire humerus. For retrograde nailing with a central entry portal, the arm is positioned across the body. A posterior midline incision is made extending from the olecranon fossa proximally for about 4 to 6 cm, depending on the child's size. The incision is made sharply down through the triceps fascia, and the muscle fibers are split by blunt dissection to expose the posterior surface of the humerus. The only major structure that must concern the surgeon is the radial nerve. In the adult, the nerve lies about 10 cm proximal to the lateral epicondyle, but this distance is proportionally less in the child. The incision should not extend so far proximally that it encounters the nerve unless the surgeon desires to explore the nerve.

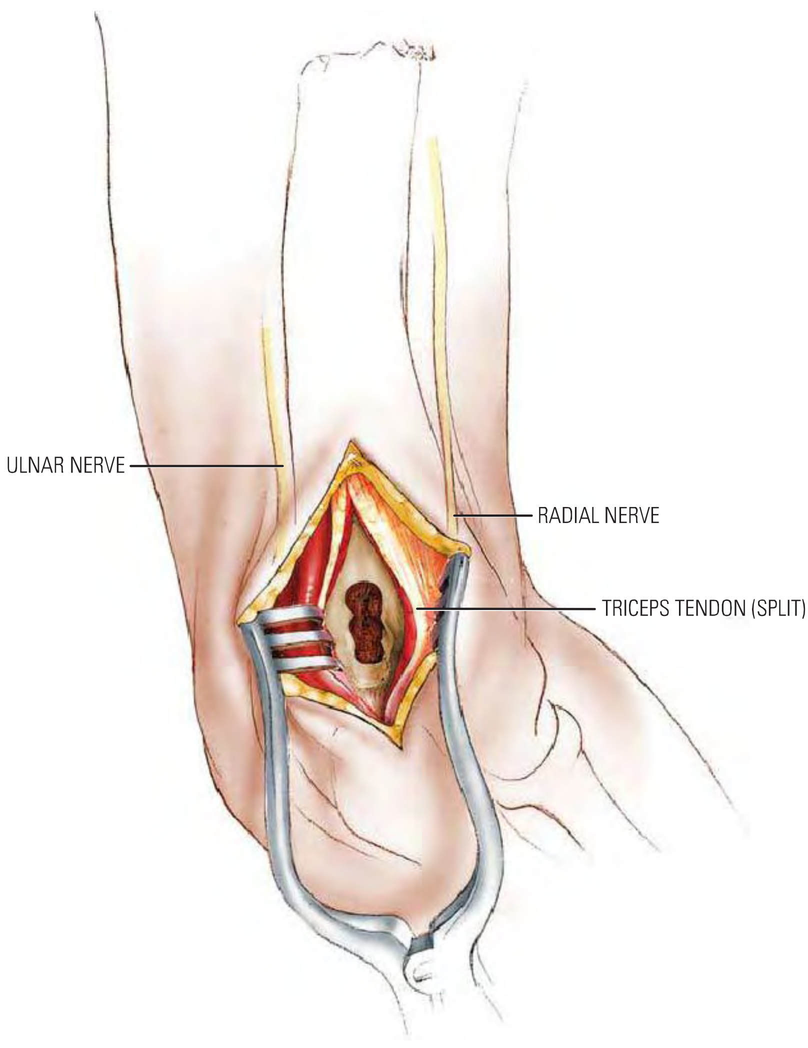
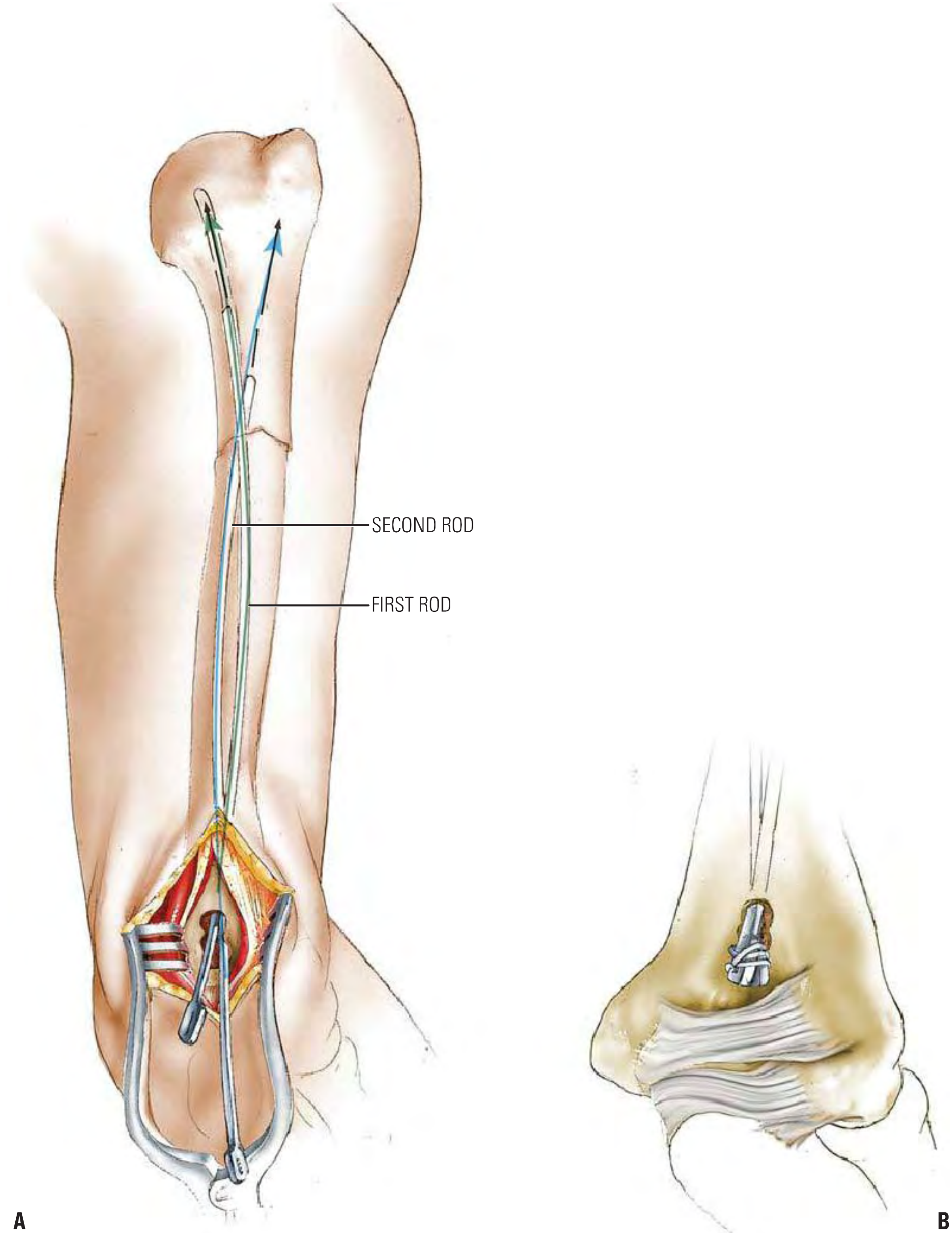


FIGURE 33-16. The superior lip of the olecranon fossa is identified, and a drill hole is made in the cortex far enough above the fossa to enter the medullary canal. In the adult this is 2 to 3 cm, but it is proportionally less in the child.



A B

FIGURE 33-17. The correct size of steel rods is estimated by holding a rod next to the humerus and viewing both with the image intensifier. A small bend is placed in the distal part of the rod. The rod is inserted and driven to the fracture site. The fracture is reduced and the rod driven across into the proximal fragment. If needed for stability, a second rod **(A)** can then be inserted. It is important to have the nails end in different areas proximally to provide stability in rotation. Ideally, one nail end goes into the greater tuberosity and the other toward the articular surface of the humeral head. Positioning of the rod is accomplished using the bend in the rod to drive it during insertion under fluoroscopic guidance. For stainless steel rods with eyelets, a wire can be passed through the eyelets of the rods with the rods 1 cm from final insertion, and then the rods are driven in completely. Only the eyelets should be protruding outside of the cortex. The wire **(B)** is twisted tight, binding the rods together. For titanium nails, the rods are completely seated and then a rod cutter is used to cut them, leaving enough rod protruding for nail removal if desired. A final check with the image intensifier is made to make sure that the nails are positioned correctly and that the fracture is not distracted.

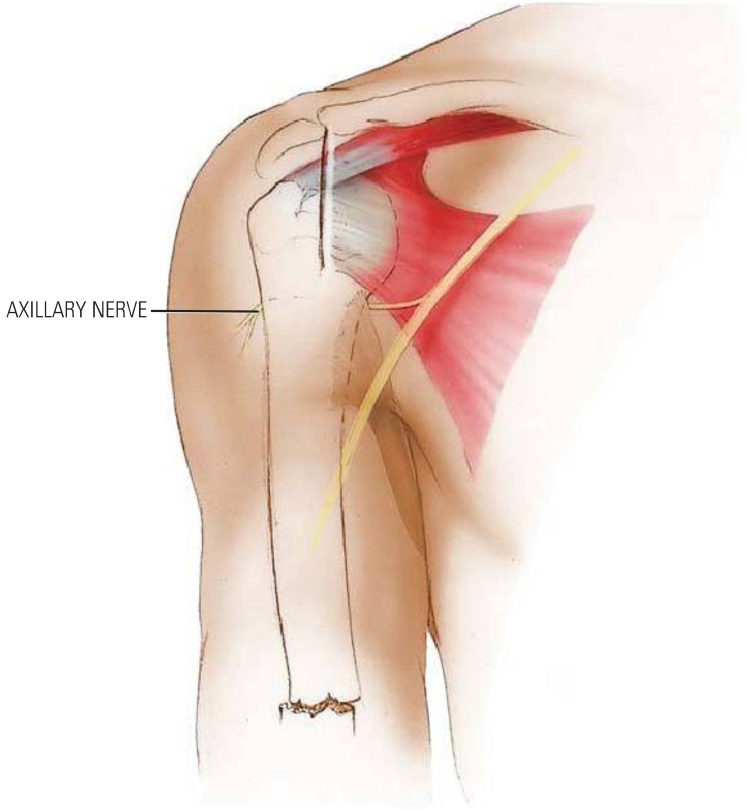


FIGURE 33-18. For the antegrade fixation, a small incision is made over the anterior deltoid. The incision is extended distally from the tip of the acromion for a distance of 2.5 to 3 cm. The main structure to be aware of is the axillary nerve, which crosses at the distal end of this incision.

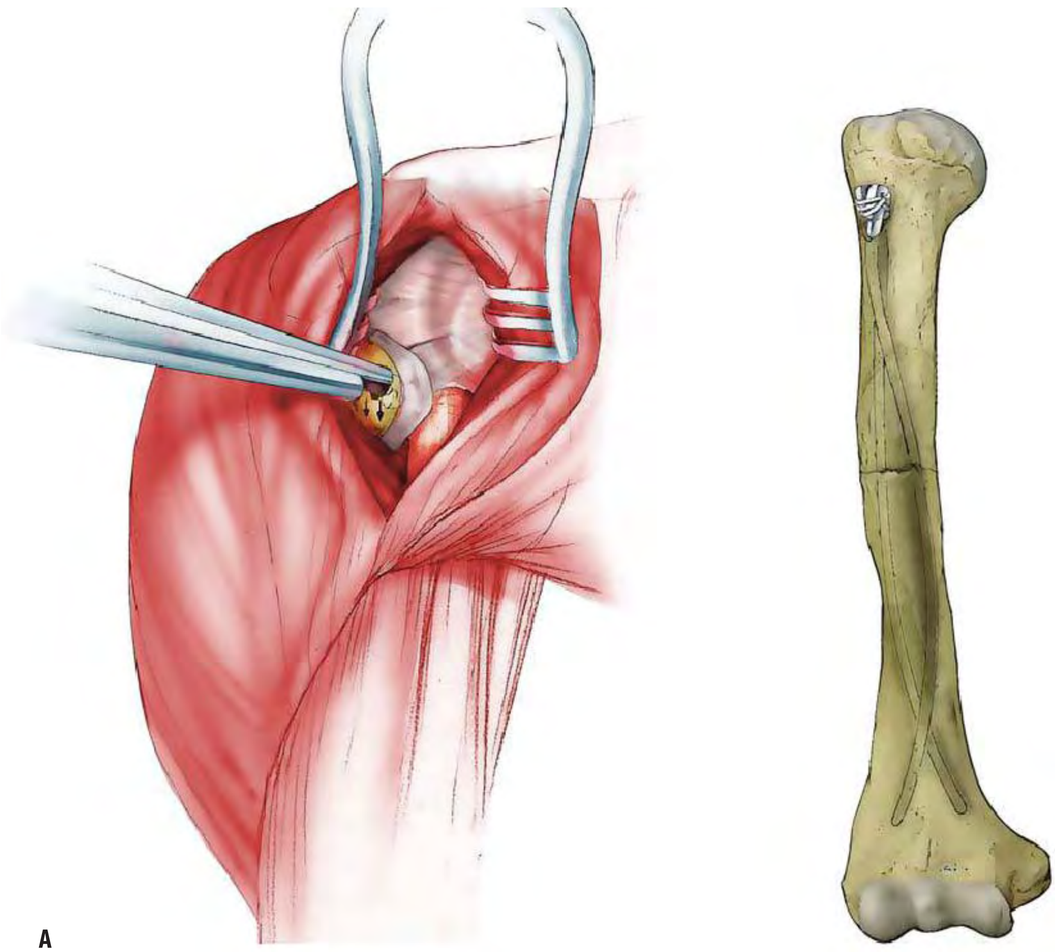


FIGURE 33-19. **A:** The deltoid fibers are split by blunt dissection to expose the periosteum of the shaft, which is opened. A drill hole large enough to admit a rod is made in the anterolateral metaphyseal area of the humerus just below the tip of the greater tuberosity. **B:** The hole is enlarged to accommodate two rods if needed.

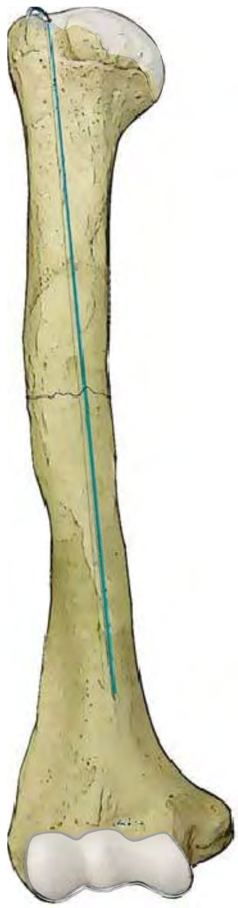


FIGURE 33-20. If speed in completing the procedure is an important factor or only a single rod to help maintain alignment is desired, the incision can be smaller. The rotator cuff is split, and a straight rod is inserted through the tip of the greater tuberosity. This does not provide rotational stability and allows less fixation of the fracture in general, but it helps maintain alignment. Because of the rod-tip location, impingement occurs and the rod will need to be removed.

of the distal humerus are connected by a very thin area of bone at the olecranon fossa. The central thinning and the surrounding narrow columns predispose this area to fracture. As the elbow is forced into hyperextension, the olecranon impinges in the fossa, serving as the fulcrum for the fracture. The collateral ligaments and the anterior joint capsule also resist hyperextension, transmitting the stress to the distal humerus and initiating the fracture (44) (Fig. 33-24). Flexion-type supracondylar fractures result most often from a direct fall onto the olecranon of a flexed elbow.

The classification system most commonly used is that of Gartland, who described three stages of displacement (45): type I, nondisplaced or minimally displaced; type II, angulated with moderate disruption but with a portion of the cortex maintaining end-to-end contact; and type III, completely displaced. A type IV fracture with multidirectional instability resulting from an incompetent periosteal hinge has been described (46). In this fracture, the distal fragment may fall into flexion or extension, and is often determined under anesthesia at the time of surgery. This pattern of instability may be due to the initial injury or may occur iatrogenically during attempted reduction. Fractures with medial impaction may appear to be nondisplaced but may result in cubitus varus attributable to unacceptable angulation (47). After complete fracture, a small amount of rotational malalignment allows tilting of the fragments because of the thin cross-sectional area in the supracondylar region. This may also lead to malunion with cubitus varus or, less commonly, cubitus valgus.

Associated injuries include nerve injuries, vascular injuries, and other fractures of the upper extremity, including the ipsilateral forearm. The incidence of nerve injury is approximately 15%; most often, nerve injury is a neuropraxia that resolves spontaneously within 4 months. The nerve that gets injured is related to the position of the displaced fragment (48). Median nerve injuries, including injury to the anterior interosseous nerve, are more common with posterolateral displacement of the distal fragment. Radial nerve injuries are seen more often with posteromedial displacement. Ulnar nerve injuries are seen most commonly with flexion-type injuries, and ulnar nerve entrapment has been reported in three of six of flexion-type injuries treated with open reduction (49).

Treatment. Nondisplaced or minimally displaced fractures may be treated with an above-elbow cast for 3 weeks. Any medial buckling or impaction of the medial metaphysis may indicate a fracture that requires reduction. This fracture is a diagnostic trap because the collapse of the medial column may be very subtle (Figs. 33-25 and 33-26).

The Baumann angle should be measured, and if >80 degrees, varus is likely present that warrants closed reduction and percutaneous pinning (CRPP). It is difficult to maintain the reduction by cast immobilization alone, and residual deformity will not reliably remodel (47).

Type II supracondylar fractures are usually extension injuries, with an intact or nondisplaced posterior cortex. Type II fractures, in which the capitellum is posterior to the anterior humeral line, have an unacceptable amount of extension. While many of these are stable after closed reduction and casting in 90 to 100 degrees of flexion, just over 20% of fractures treated without operative stabilization may be expected to lose reduction and require delayed surgery (50, 51). Flexing an elbow with a supracondylar fracture increases compartment pressure (52) and decreases brachial artery flow (53). Thus, when 90 degrees or more of flexion is required for maintenance of reduction, percutaneous pinning is recommended. In contrast, a large consecutive series of type II supracondylar fractures treated with CRPP shows predictably good results with no complications other than minor pin tract infections (54). Based on the above data, we recommend CRPP for type II supracondylar fractures in which the anterior humeral line does not touch the capitellum.

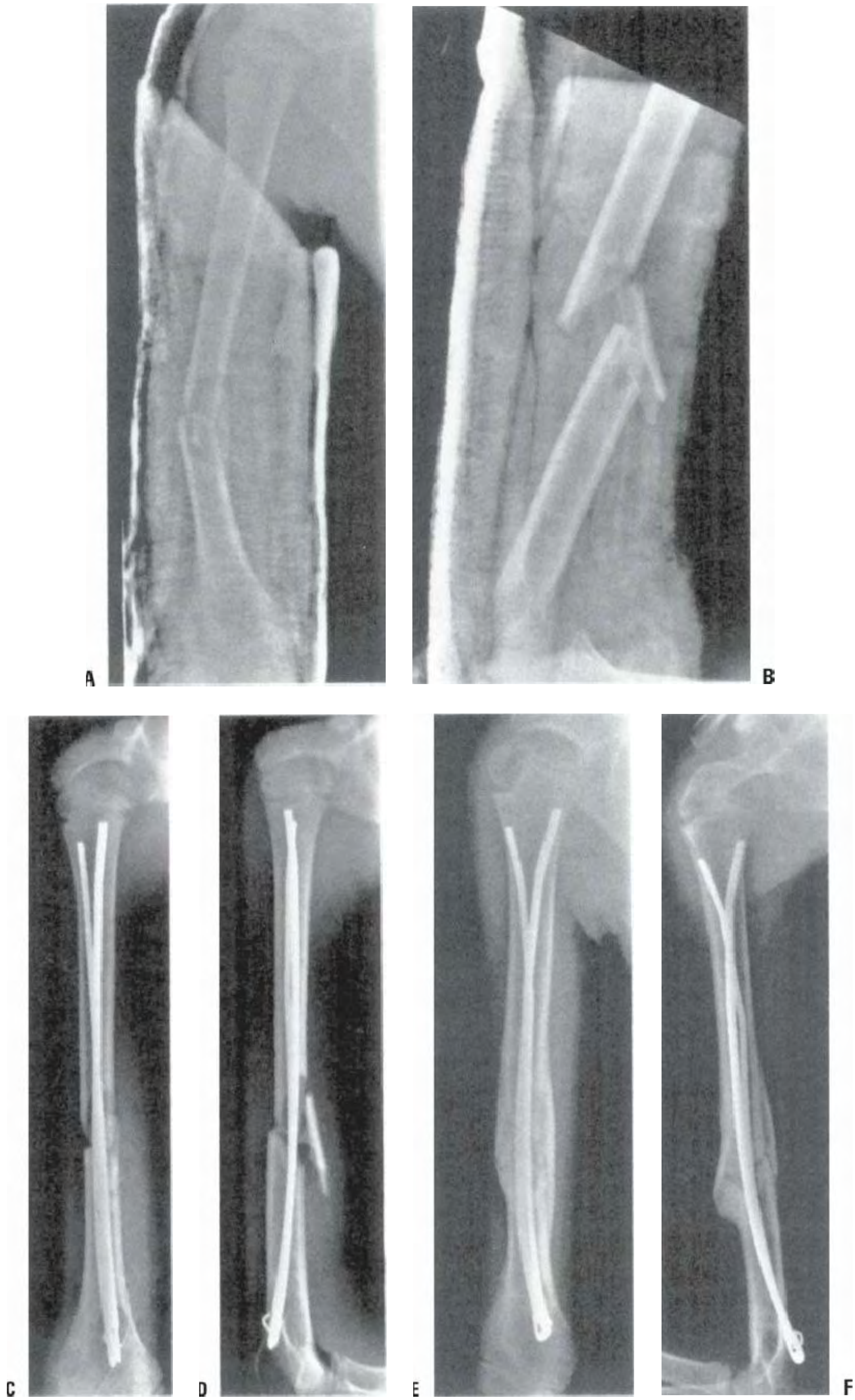


FIGURE 33-21 **A, B:** Radiographs of a 12-year-old boy with multiple trauma, including fracture of the humerus. **C, D:** Radiographs taken at the conclusion of the surgery showing the alignment. **E, F:** Healing after 8 weeks.

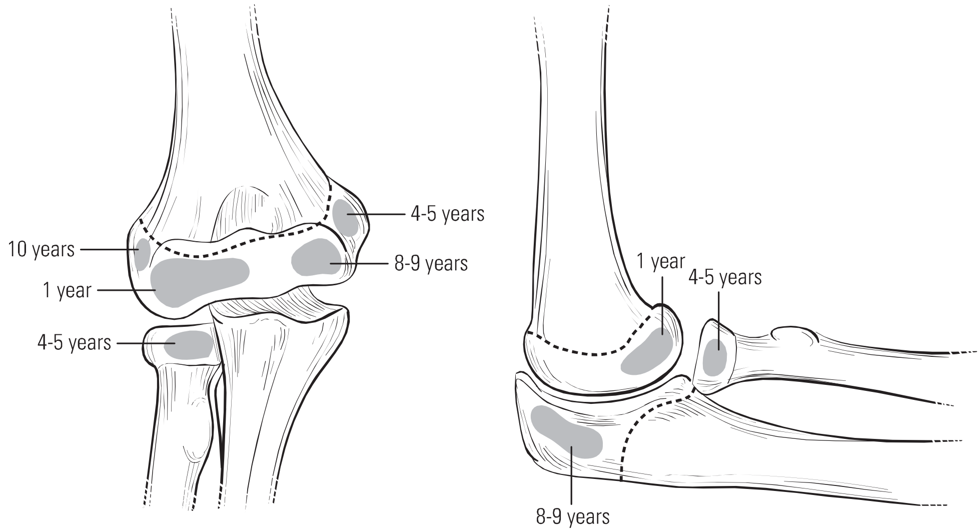


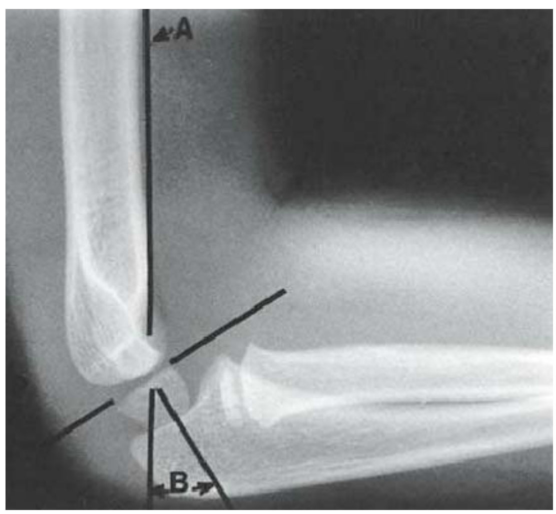
FIGURE 33-22. Secondary ossification centers of the elbow, with a range of ages of appearance. (From Skaggs DL, Flynn JM. *Staying out of trouble in pediatric orthopaedics.* Philadelphia, PA: Lippincott Williams & Wilkins, 2006, with permission.)

Type III supracondylar fractures are displaced with no cortical continuity. The first step is assessment of hand perfusion and nerve function. Neurologic and vascular problems are frequent, and urgent treatment may be required if vascular compromise is present. Primary CRPP is the preferred treatment for type III injuries (55) (Fig. 33-27). Displaced supracondylar fractures treated by closed reduction and casting have a higher incidence of residual deformity than those treated with reduction and pinning (55). Closed reduction and casting also has a higher risk of Volkmann ischemic contracture than treatment with early pinning (55).

Type IV supracondylar fractures are the most unstable type, with the distal fragment able to displace into flexion and extension. A technique for closed reduction of these unstable fractures has been described in which pins are first placed in the distal fragment, and the intraoperative fluoroscopy unit is rotated to obtain AP and lateral images rather than rotate the patient's arm and risk losing reduction (46).

Biomechanical studies have found that two divergent lateral pins have similar or superior stability to crossed pins, and that three pins (either three lateral or two lateral and one medial) are stronger (56, 57). Clinical experience suggests two lateral pins are sufficient for stabilization for type II fractures, and three lateral pins are good for type III fractures (58, 59), but a randomized prospective study of 28 patients using two lateral pins versus cross pins found both techniques were effective in the treatment of type III fractures with no significant differences in outcomes noted

A



B

FIGURE 33-23. Radiographic lines of the distal humerus. **A:** The Baumann angle is formed between the capitellar physeal line and a line perpendicular to the long axis of the humerus. As this angle becomes smaller, more elbow varus will occur. This angle should be compared with that of the contralateral, uninjured elbow with a similar AP view of the distal humerus. **B:** *Line A* is the anterior humeral line, which atypically passes through the middle of the capitellum. *Angle B* demonstrates the anterior angulation of the capitellum relative to the humeral shaft. This is approximately 30 degrees. As *angle B* becomes smaller, the fracture site is moved into extension. Fracture alignment with the capitellum behind the anterior humeral line produces a hyperextension deformity and a loss of elbow flexion.

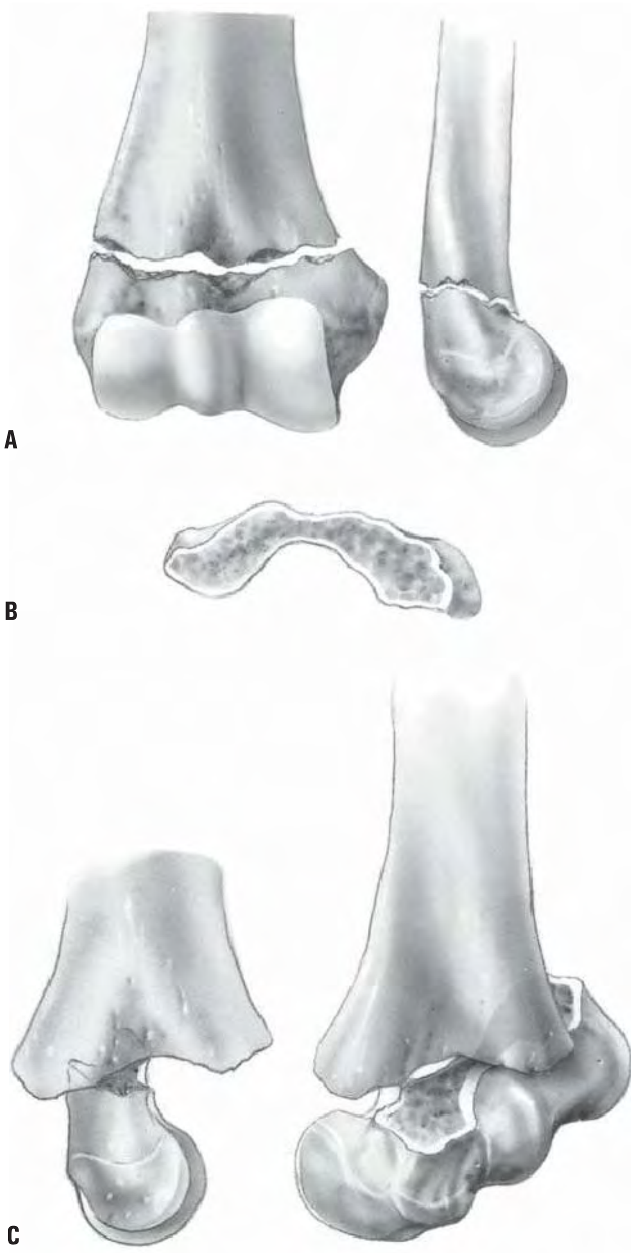


FIGURE 33-24. The typical orientation of the fracture line in the supracondylar fracture. **A:** Sagittal rotation of the distal fragment generally results in posterior angulation, although, less commonly, it can be flexed. **B:** The cross-sectional area through the fracture demonstrates the thin cross-sectional area of the supracondylar region. **C:** Any horizontal rotation tilts the distal fragment. Typically, medial tilting occurs, producing cubitus varus. The lateral projection readily demonstrates this horizontal rotation, producing a fishtail deformity. In this instance, the distal portion of the proximal fragment is obliquely profiled, although there is a true lateral view of the distal humeral fragment.

between groups (59). We prefer laterally placed pins without a medial pin except in unusual circumstances (60). When a medial pin is used, one should be aware that elbow flexion of 120 degrees results in ulnar nerve subluxation anterior

FIGURE 33-25. Medial comminution is a subtle radiographic finding and indicates a more unstable variant that may collapse into varus if not treated appropriately. (From Skaggs DL, Flynn JM. *Staying out of trouble in pediatric orthopaedics*. Philadelphia, PA: Lippincott Williams & Wilkins, 2006, with permission.)

to the medial epicondyle in over 50% of children which increases the risk of damage during pinning (61). When possible, it is advisable to place the lateral pin(s) first to provide provisional stability so that the medial pin can be inserted with the elbow in less than full flexion, placing the ulnar nerve farther posterior (62).

Several retrospective studies suggest the operative treatment of supracondylar fractures may safely be delayed (62, 63), though delay of great than 8 hours in type III fractures may increase the need for an open reduction (64). However, these are all retrospective studies in busy pediatric centers in which surgeons may have appropriately selected

FIGURE 33-26. Note the lateral view does not show significant displacement. This view alone would suggest nonoperative treatment may be sufficient.

FIGURE 33-27. Type III supracondylar humerus fracture. **A:** This type III fracture demonstrates lateral displacement. **B:** The lateral projection also shows flexion of the distal fragment. The treatment of this less common position is the same as that for extension fractures. The posterior periosteum is torn, and hyperflexion of the elbow will excessively forward flex the distal fragment. The elbow is best pinned at slightly <90 degrees of flexion because it is technically difficult to pin the elbow in extension. **C, D:** AP and lateral postreduction and pinning films.

which fractures require urgent treatment. Indications for urgent surgery include a poorly perfused hand, excessive swelling, firm compartments, significant antecubital ecchymosis, a median nerve injury that may mask a developing compartment syndrome, and skin puckering suggesting extensive soft-tissue injury (65).

CLOSED REDUCTION AND PERCUTANEOUS PINNING OF SUPRACONDYLAR FRACTURE OF THE HUMERUS

To understand the importance of accurate reduction, it is necessary to understand both the anatomy of the humerus at the fracture site and the mechanics of how the deformity occurs (Figs. 33-28 to 33-38).

Postoperative Care. Oral analgesics are usually sufficient for pain relief. An increasing need for intravenous narcotics may indicate impending compartment syndrome (66). Immobilization is continued for 3 to 4 weeks, at which time the pins are removed and x-rays may be taken. Invariably, some periosteal new bone extending across the fracture is visible. Fracture callous is often minimal, and this is not an indication for longer casting. Parents are taught range-of-motion exercises and flexion and extension should be normalizing by 6 weeks after the cast is removed, at which time a follow-up visit may be scheduled if there are any concerns (67). It is important to have nearly full return of elbow extension to allow for comparison of the carrying angle of the injured side to the opposite side. Elbow motion may continue to improve over 1 year postoperative at which time 98% should return to normal (68).

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Closed Reduction and Percutaneous Pinning of the Supracondylar Fracture of the Humerus (Figs. 33-28 to 33-36)

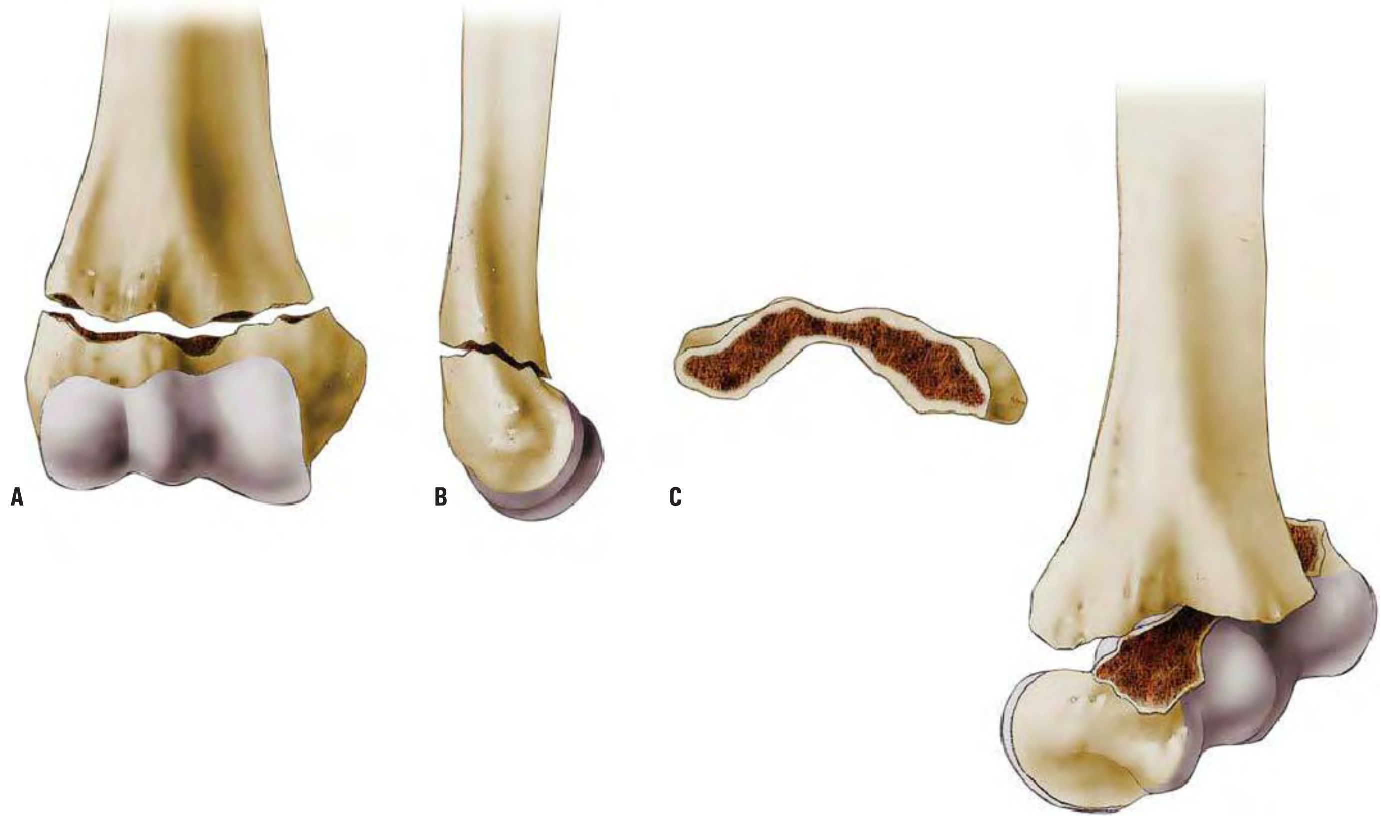


FIGURE 33-28. Closed Reduction and Percutaneous Pinning of the Supracondylar Fracture of the Humerus. The supracondylar fracture of the humerus **(A)** occurs through the thinnest portion of the bone: the area of the coronoid fossa anteriorly and the coracoid fossa posteriorly. A cross section of this area **(B)** demonstrates the medial and lateral bone masses, with the central portion being but a thin strip of bone. If the reduction **(C)** does not achieve and maintain rotational correction, there will not be stability of the reduction and the distal fragment may tilt and angulate, producing deformity. This rotational deformity can be seen clinically in cases of angular deformity. Because of the large range of rotation in the shoulder joint, this rotational deformity is not apparent cosmetically or functionally.

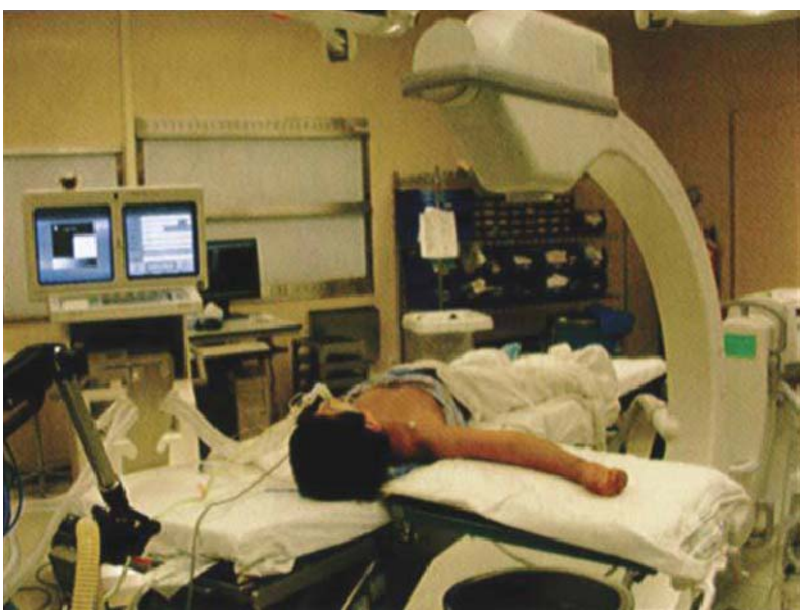
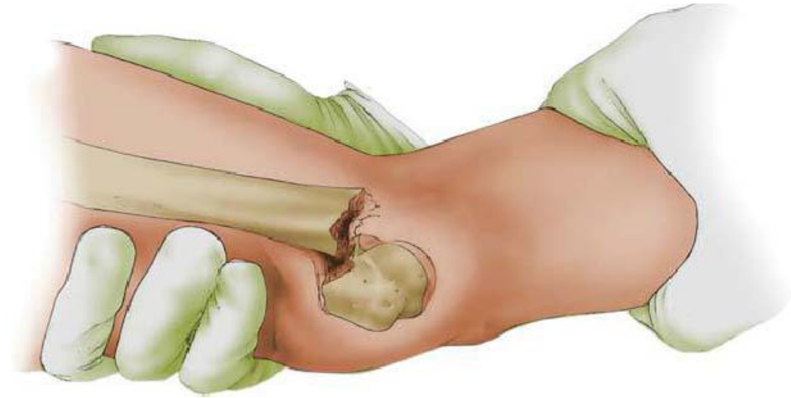


FIGURE 33-29. Proper positioning of the patient, the image intensifier, and the surgical assistant greatly simplifies the procedure. We prefer to use a short arm board though the recording tube of the image intensifier may be used. Having the fluoroscopy monitor on the opposite side of the bed allows the surgeon to easily visualize the monitor. The patient is shifted to the side of the table so that the shoulder is at the edge, and with very small children the head may lie partway on the arm board. The fluoroscopy unit is brought parallel to the operating room table from the foot with the assistant surgeon standing at the end and upper edge of the arm board. The arm is prepped and draped with an extremity sheet.

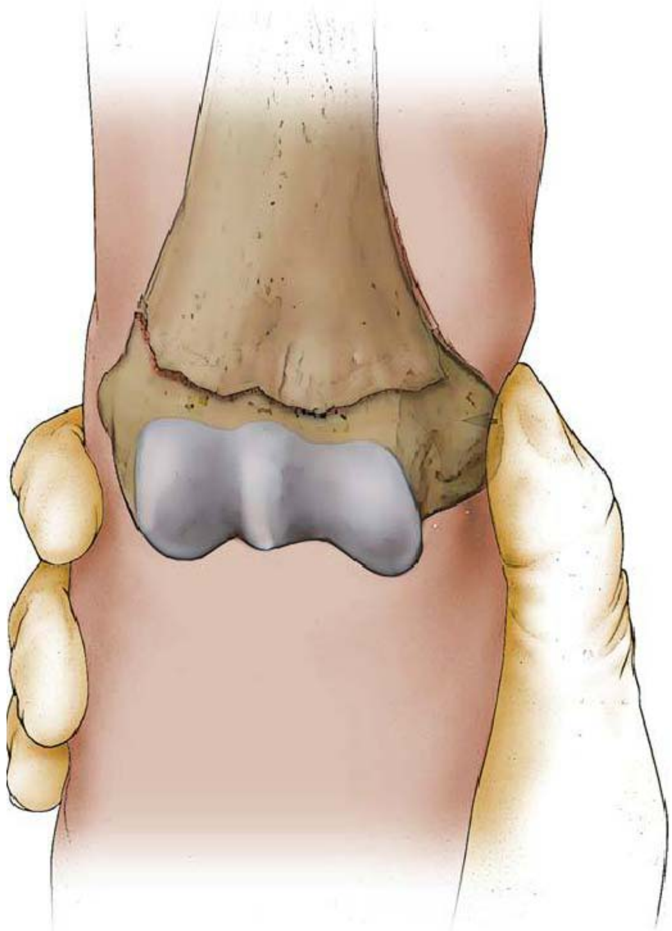


A

FIGURE 33-30. **A:** The first step in the reduction is the application of traction to the arm. With the elbow flexed about 15 degrees to prevent the neurologic and vascular structures from tethering over the proximal fracture fragment, the surgeon applies traction by grasping the forearm while the assistant applies counter traction within an open hand in the axilla. In most extension supracondylar fractures, there is an intact periosteum posteriorly that aids in the reduction by providing a stable fulcrum against which to work. **B:** When the proximal fragment has penetrated the brachialis muscle, the reduction will not be possible until the fragment is disengaged from the muscle. Using a milking maneuver, it is often possible to free the bone. (Part B from Tolo VT, Skaggs DL, eds. *Master techniques in orthopaedic surgery: pediatrics*. Philadelphia, PA: Lippincott Williams & Wilkins, 2008, with permission.)

B

FIGURE 33-31. The second step is the correction of the medial or lateral displacement using the image intensifier during the reduction. This is an important step before the surfaces of the two bony fragments are brought into contact because after they are reduced it is impossible to slide one over the other.



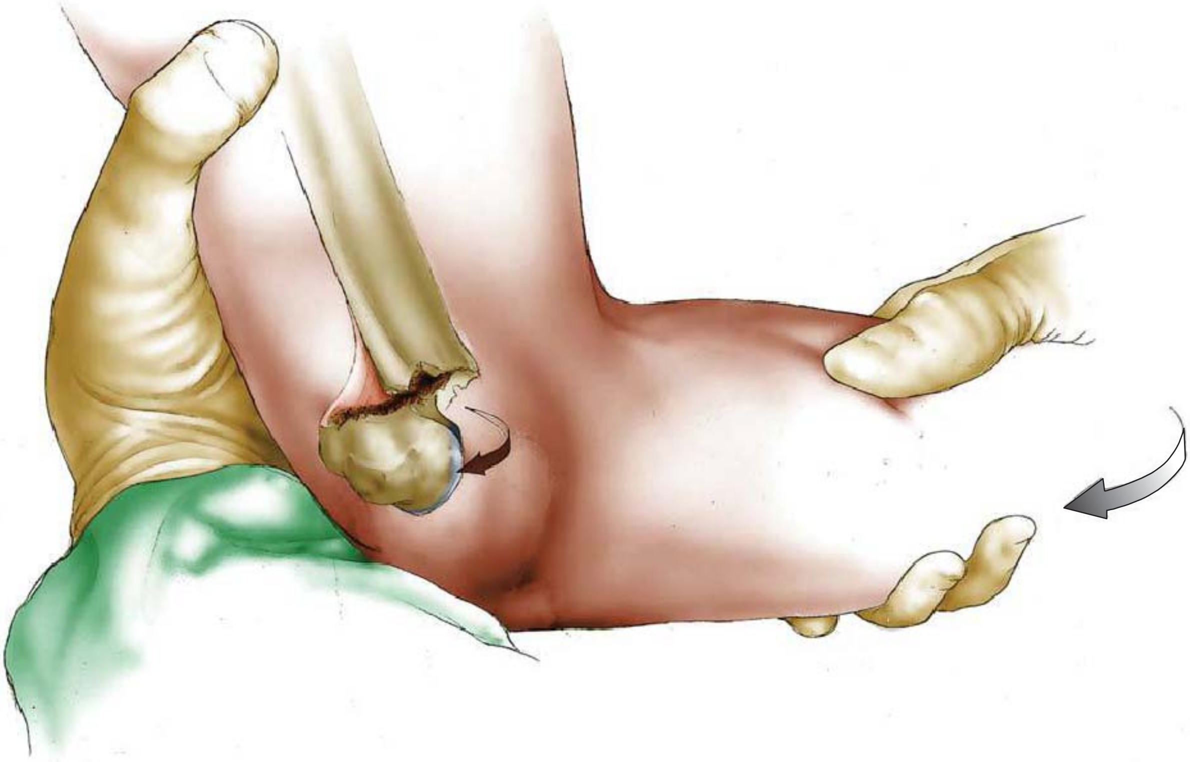


FIGURE 33-32. The third step is to correct the rotation. This must be done before the two fragments are brought into apposition. If the rotation is not correct, the fragments must be disengaged before another attempt at correction of the rotation. In most cases, the distal fragment requires external rotation.

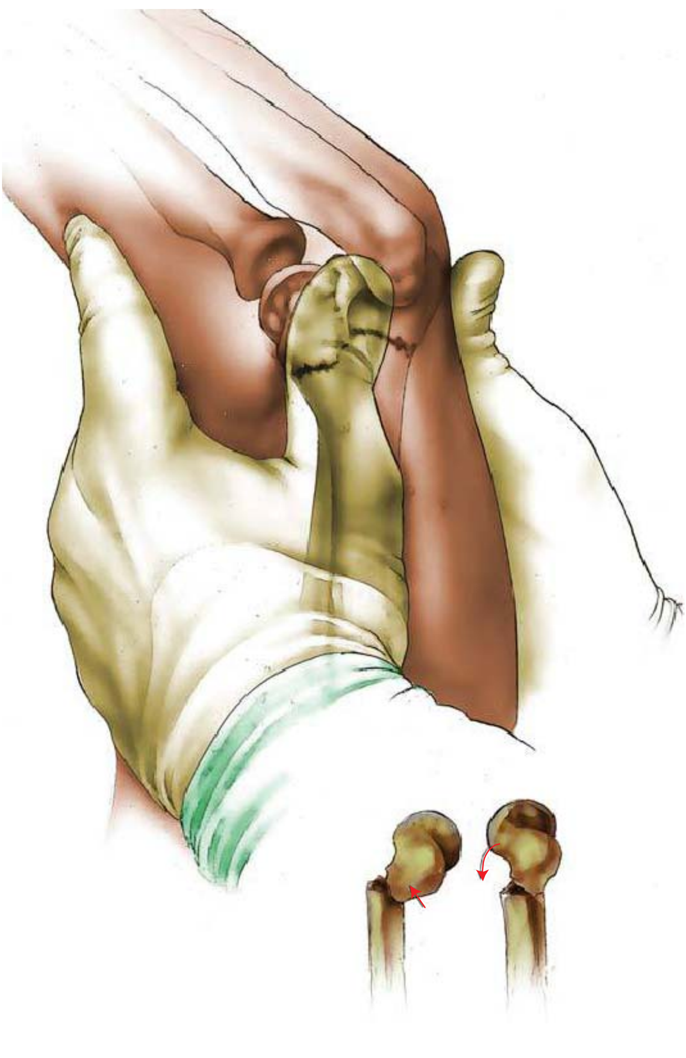


FIGURE 33-33. With the rotation and the medial and lateral displacement corrected, the posterior displacement can be corrected. At this point, the forearm may be pronated (if medially displaced) or supinated (if laterally displaced) to tighten the remaining medial or lateral periosteal hinge. The surgeon then pushes anteriorly on the olecranon and the elbow is then flexed, which reduces the fracture. One may push more on the medial side or lateral side if rotational deformity is present. If the fingers nearly touch the shoulder, it is likely that the extension deformity is fully corrected. The fracture reduction is maintained by keeping the elbow in a hyperflexed position, which may be held with a sterile self-adherent wrap. (From Coban-3M, St. Paul, MN.) If during the reduction maneuver the fracture does not stay reduced, and a "rubbery" feeling is encountered instead of the desired "bone on bone" feeling, the median nerve, brachial artery, or other soft tissue may be trapped within the fracture site. If this occurs, an open reduction may be necessary.

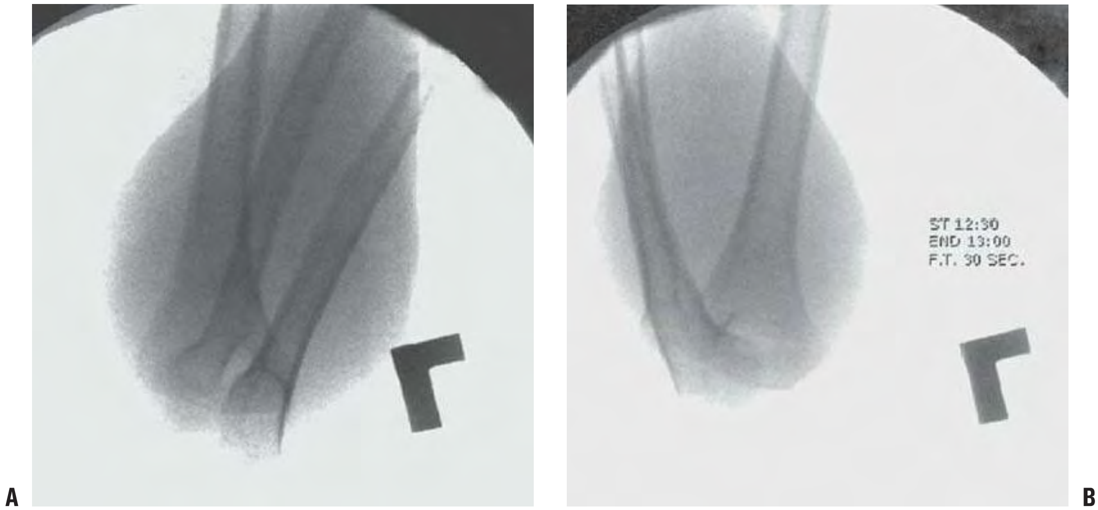


FIGURE 33-34. The reduction is then checked by fluoroscopic images in AP, lateral, and oblique planes. Verify four points to check for a good reduction: (i) the anterior humeral line intersects the capitellum (see Fig. 33-23), (ii) the Baumann angle is >10 degrees (see Fig. 33-23), (iii) the medial and lateral column are intact on oblique views by rotating the arm about 45 degrees in each direction. The AP view is the least helpful because the overlying forearm obscures the bony detail of the humerus, so this should be checked carefully after pins are placed and the arm can be extended. The arm is held acutely flexed while the lateral view is examined. If the diameters of the two fragments at the fracture site are different, malrotation is present. Anatomic reduction is preferred, but this may be difficult to achieve in some cases. We consider the anterior humeral line crossing the capitellum and Baumann angle >10 degrees (or within 5 to 8 degrees of the angle on the contralateral side) to be the most important criteria for acceptable reduction. As long as fixation is secure, it is the authors' opinion that one may accept up to one-third translation of the distal fragment and 30 degrees of malrotation along the axis of the humerus. (From Tolo VT, Skaggs DL, eds. *Master techniques in orthopaedic surgery: pediatrics.* Philadelphia, PA: Lippincott Williams & Wilkins, 2008, with permission.)

FIGURE 33-35. Fracture reduction is maintained by taping elbow in hyperflexed position. The wire may be pushed through the skin and into the cartilage, using the cartilage of the distal lateral condyle as a pincushion that will hold the K-wire in place while you carefully examine the AP and lateral images.

When the reduction is achieved, the percutaneous pins are inserted from the lateral side while the elbow remains hyperflexed. Usually, 0.062-mm K-wires (Zimmer, Warsaw, IN) are adequate for the fixation, though larger or smaller pins may be used depending on the size of the child. (Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.)

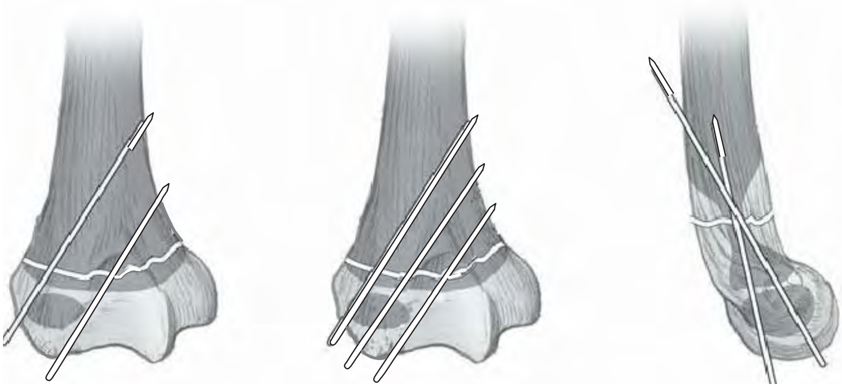


FIGURE 33-36. The aim of pin placement is to maximally separate the pins at the fracture site to engage both the medial and lateral columns. Whether the pins are divergent or parallel, or which pin is placed first is of little importance. Care must be taken to ensure there is sufficient bone engaged in the proximal and distal fragments. It is acceptable to cross the olecranon fossa, which adds two more cortices to improve fixation, but note this means the elbow cannot be fully extended until the pins are removed. In the sagittal plane, to engage the most bone with the K-wire in the distal fragment, the K-wire may go through the capitellum. The reduced capitellum lies slightly anterior to the plane of the fracture; thus, the pin may start a bit anterior to the plane of the fracture and angulate about 10 to 15 degrees posteriorly to maximize osseous purchase. A key element to insure a correctly placed pin is to feel the pin go through the proximal cortex. If this feeling is not clearly appreciated, careful fluoroscopic imaging often reveals the pin did not engage the proximal fragment. As a general rule, we recommend two pins for Gartland-type II fractures, and three pins for Gartland-type III fractures. Even though two good pins are probably sufficient, placing three pins increases the odds of actually having two good ones. While three lateral pins generally provide adequate fixation, an occasional oblique fracture or exceptionally unstable fracture may be amenable to a medial pin. If a medial pin is used, the lateral pin(s) are placed first, then the elbow is extended to about 45 degrees prior to pin placement, as flexion of the elbow often causes subluxation of the ulnar nerve over the medial epicondyle. If the surgeon is uncertain about the location of the ulnar nerve, a small incision over the medial epicondyle may be made. (From Tolo VT, Skaggs DL, eds. *Master techniques in orthopaedic surgery: pediatrics.* Philadelphia, PA: Lippincott Williams & Wilkins, 2008, with permission.)

A

B

FIGURE 33-37. Sterile foam is placed directly on skin. If there is any circumferential dressing placed under the foam, it may be restricting. The elbow is flexed about 45 degrees if swollen to about 75 degrees if not swollen. Fiberglass casting material may be used over the foam as it is lighter, stronger, and allows for better x-rays than plaster casting. (Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.) (From Tolo VT, Skaggs DL, eds. *Master techniques in orthopaedic surgery: pediatrics.* Philadelphia, PA: Lippincott Williams & Wilkins, 2008, with permission.)

FIGURE 33-38. **A, B:** A typical grade III supracondylar fracture of the humerus. Ideally, the lateral pin could be a bit more lateral so as to be in the middle of the lateral column. It is important that all pins are past the proximal cortex by feel; these pins may ideally have been driven in a little further to make certain of this. **C, D:** The AP and lateral views after reduction. Note that the fracture is near anatomic and the alignment is excellent though the Baumann angle is close to 10 degrees, the pins engage the opposite cortex, and both pins are in the distal fragment. (Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.)

Special Case: Flexion-type Supracondylar Humerus Fractures. Flexion-type fractures account for about 2% of supracondylar fractures, and most often arise from a fall directly on the elbow. On the lateral radiograph, the capitellum is anterior to the anterior humeral line. The reduction maneuver consists of elbow extension, which creates a challenge for placement of pins. As in the type IV extension-type fractures, surgical tips include placing the pins in the distal fragment first and rotating the fluoroscopy unit to obtain a lateral x-ray rather than the arm.

OPEN REDUCTION OF SUPRACONDYLAR FRACTURE OF THE HUMERUS

The rare irreducible fracture may be managed with open reduction. An anterior surgical interval is recommended if the neurovascular structures need to be exposed and in general is the most utilitarian. Medial and/or lateral approaches may be used as well if the surgeon is approaching from the side of torn periosteum. The posterior approach should be used rarely because it disrupts any remaining intact periosteum and may disrupt the primary vascular supply to the distal humeral fragment (40, 41) (Figs. 33-39 to 33-41).

Postoperative Care. The postoperative care is the similar as for closed reduction, with an additional week usually necessary for healing. In addition, as there may be an increased risk of stiffness and scarring following an open reduction, range-of-motion exercises should be stressed, with use of formal therapy if needed.

Complications. In the event of a pulseless extremity, prompt reduction of the supracondylar fracture usually restores arterial flow (69, 70) (Fig. 33-42). If the hand is well perfused but pulseless, the great majority of the time fracture reduction is sufficient treatment. In contrast, patients presenting with a pulseless and poorly perfused hand have a nearly 50% chance of requiring vascular surgery and nearly 25% chance of developing a compartment syndrome (71).

Complete vascular disruption is uncommon because the thick local muscle envelope protects the artery. Vascular evaluation after reduction requires differentiation of the pulseless extremity that is pink and viable from one that is cold and pale with vascular insufficiency. The child who has a well-perfused hand but an absent radial pulse after satisfactory closed reduction does not necessarily require routine exploration of the brachial artery (48, 69, 71–73). The pulse usually returns within 48 hours, and collateral circulation is generally sufficient even if it does not. Likewise, the absence of a Doppler-detected pulse at the wrist is not an absolute indication for arterial exploration. When the hand is warm and normal in color with brisk capillary refill and normal oxygen saturation, the authors recommend careful observation in hospital with noncircumferential immobilization and <60 degrees elbow flexion for 48 hours, as we have seen delayed loss of vascular perfusion on occasion in these patients. There is no convincing evidence of a clinical problem with cold intolerance or exercise-induced muscle fatigue for the hand surviving on collateral vascularity, but long-term studies addressing the problem are lacking (73).

For persistent true vascular insufficiency (e.g., avascular, cold, pale hand), especially if there is nerve palsy or inadequate reduction, anterior open reduction is recommended. Frequently, the neurovascular bundle is found kinked at the fracture site, and liberation of the artery restores the pulse. There may also be evidence of brachial artery injury. Vascular reconstruction should be performed if the hand remains avascular despite local measures (e.g., release of tether, lidocaine, warming). The fracture should be stabilized before vascular repair. After reconstruction, there is a significant rate of asymptomatic reocclusion and residual stenosis, although the hand remains well perfused (73).

Nerve injury associated with supracondylar fracture rarely requires exploration (Fig. 33-43). Patients with preoperative nerve injury should undergo reduction and fixation as described. Exploration of the nerve is not necessary when the reduction is anatomic. However, failure to obtain anatomic reduction, especially with a "rubbery" feeling during attempted reduction, may indicate that the nerve is interposed at the fracture site, and exploration may be indicated.

Postoperative neurologic deficit that was not noted preoperatively may represent a preexisting nerve deficit that was undetected at the time of the initial examination (highlighting the importance of a careful preoperative examination), or an iatrogenic injury sustained during reduction. Median and radial nerve injuries most often result from the initial trauma and may be observed when the reduction is anatomic. Postoperative nerve deficits in the setting of a gap at the fracture site may warrant operative exploration. Postoperative ulnar nerve deficits are more often iatrogenic resulting from placement of the medial pin (48, 74, 75). When iatrogenic ulnar neuropathy is suspected, it is the authors' opinion that the medial pin should be removed without exploration. However, if the fracture is not yet healed, be certain to first add more lateral pins to maintain fracture stability once the medial pin is removed. Spontaneous recovery of most neural injuries following elbow fracture is expected within 2 to 6 months. If there has been no recovery of function by 4 to 6 months after injury, then exploration is indicated. The results of late neurolysis or repair are usually favorable in children (76).

Cubitus varus is the most common significant late complication of supracondylar fracture. This deformity typically represents fracture malunion and rarely results from partial growth arrest of the medial condylar growth plate. Malunion may be avoided by careful attention to anatomic reduction and secure fixation at the time of initial management. Cubitus varus is generally considered a cosmetically acceptable deformity, but increased risk of lateral condyle fracture, tardy ulnar palsy, posterolateral rotary instability of the elbow, and posterior shoulder instability has also been reported (77–80).

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Open Reduction of Supracondylar Fracture of the Humerus (Figs. 33-39 to 33-41)

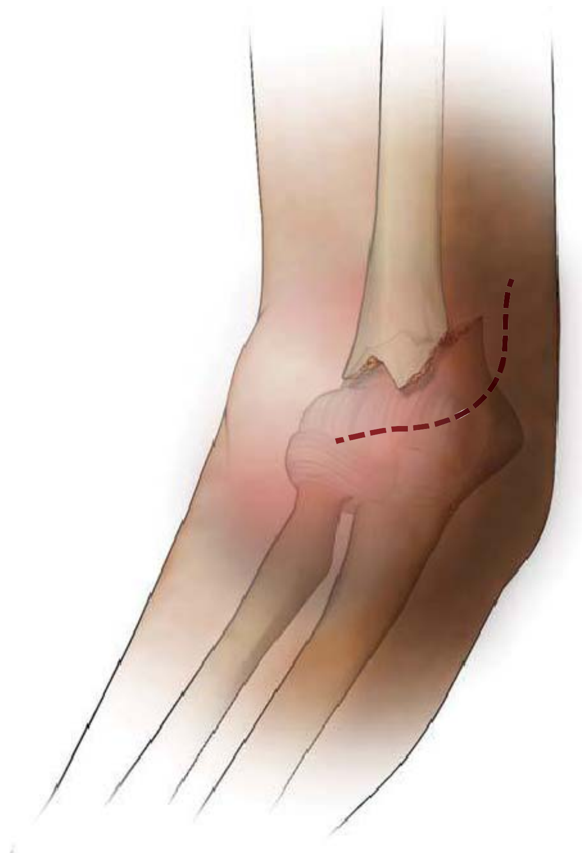

FIGURE 33-39. Open Reduction of Supracondylar Fracture of the Humerus. The incision is transverse in the flexion crease of the elbow about 4 to 5 cm long and may be extended proximally over the anteriormedial aspect of the arm (*dashed line*). Extreme care must be taken in dissecting as the neurovascular bundle may be immediately superficial as it is pushed against the skin by the proximal fragment.

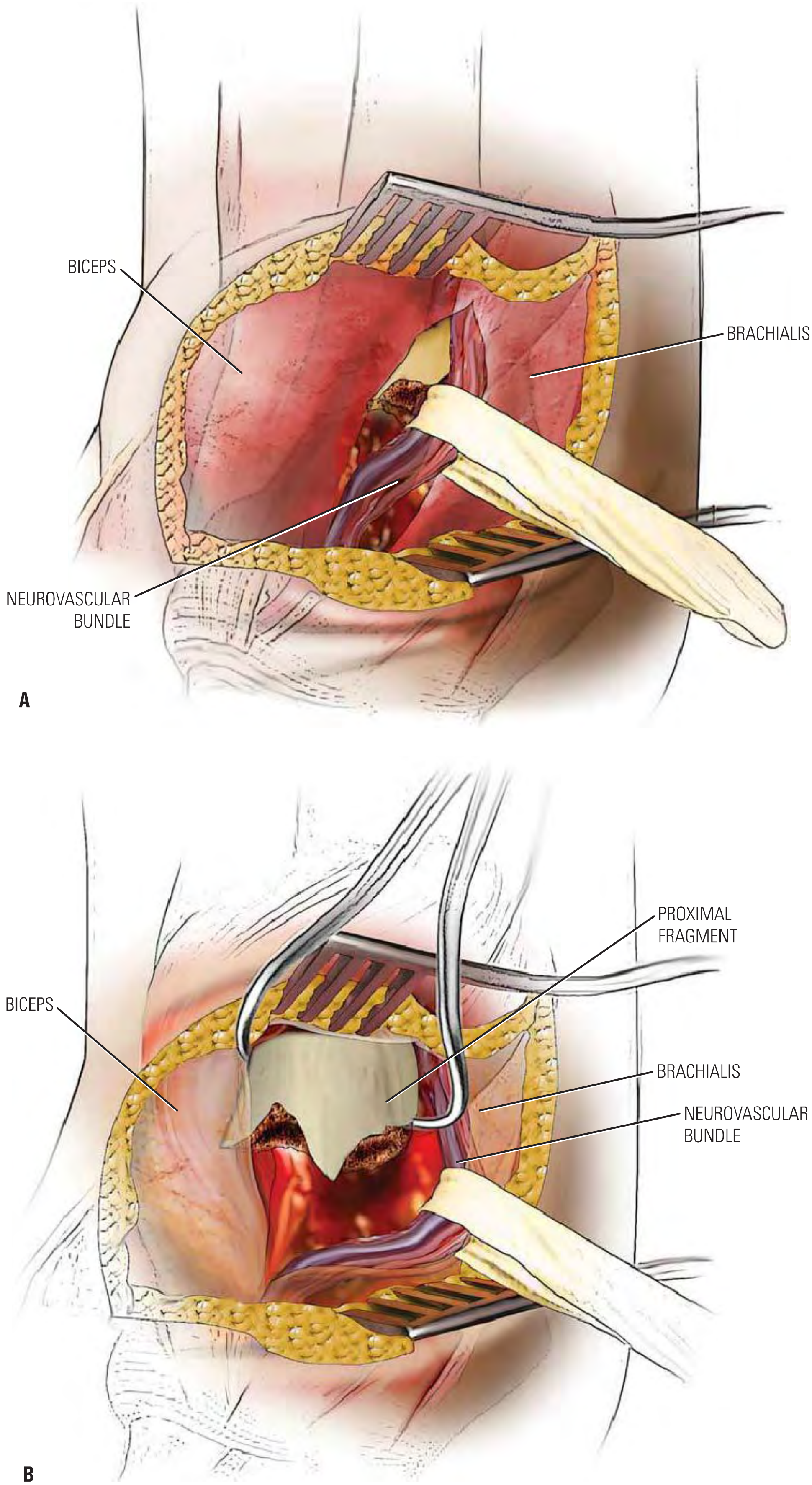

FIGURE 33-40. For purposes of visualization, these figures demonstrate utilizing the entire incision. After exploration of the fatty tissues, the proximal spike of bone is the first structure identified because it is often subcutaneous or covered by only a thin veil of tissue and portions of the brachialis muscle **(A)**. Before proceeding with further exposure of the bone, it is desirable to identify the neurovascular bundle by careful dissection across the anterior aspect of the metaphyseal fragment until the bundle is identified (*dotted line*) If a solid, bone-on-bone anatomic reduction is achieved after simply freeing the proximal fragment of the humerus from the brachialis, and there is no vascular compromise, exposure of the median nerve and brachial artery may not be necessary, but in general this exposure is worthwhile. Just medial to the biceps tendon, the brachial artery may be present, with the median nerve just medial to the artery. The bony spike may be anywhere between these structures. In addition, the traumatized vessels in children are very small and can easily be confused with small veins in the antecubital space. Caution is necessary to avoid dividing important vessels. **B:** In many cases in which there is vascular compromise to the limb, the adventitia of the artery is caught on the proximal spike of bone, acutely kinking the vessel. If not found there, the bundle may lie interposed between the two fracture fragments. If the artery cannot be located in a patient presenting with a pulseless, poorly perfused hand, search for the lacerated ends of the artery that may have retracted.

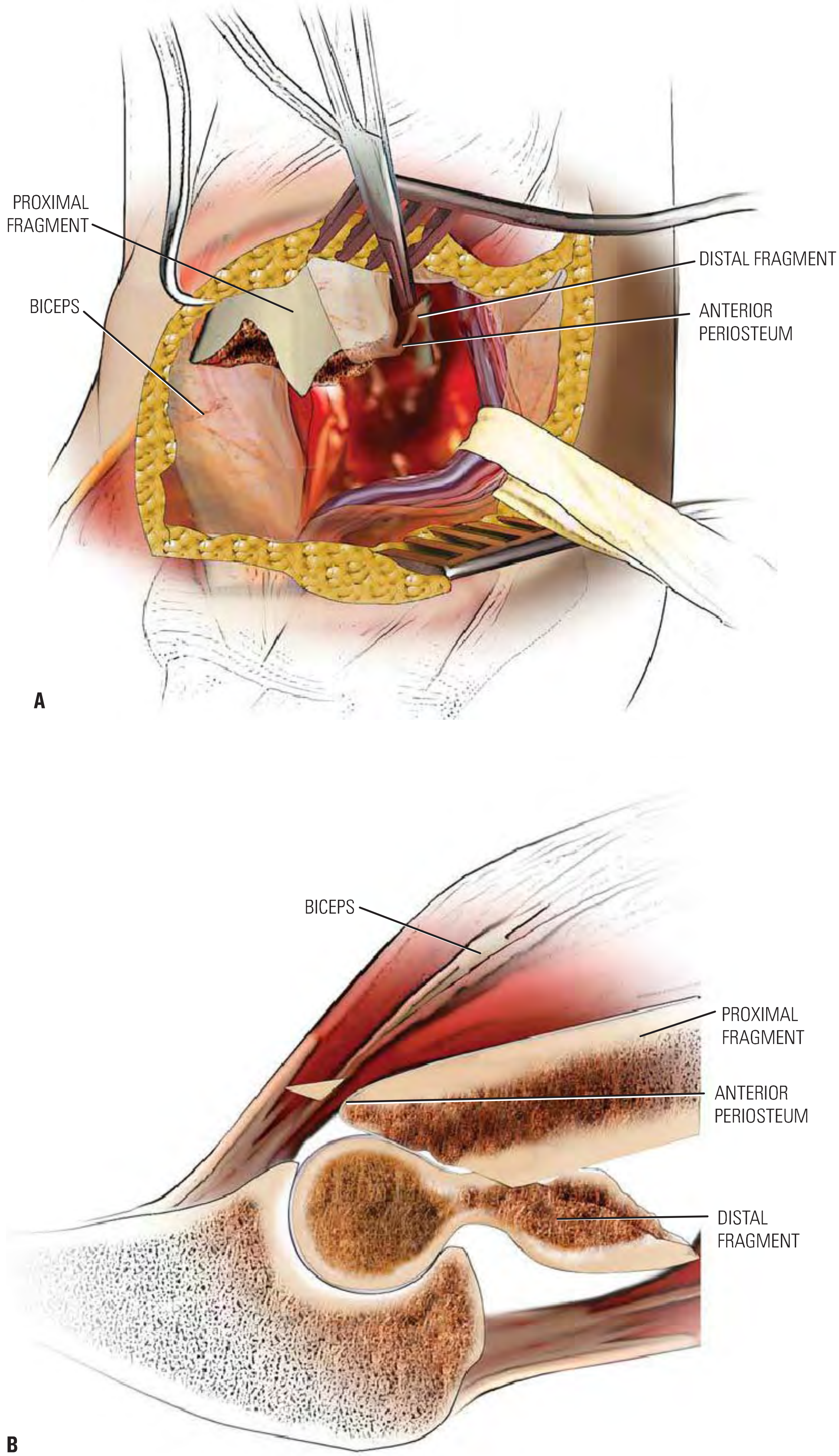

FIGURE 33-41. After the vessel is free and identified, it is gently retracted **(A)**. If the surgeon is certain of the identification of the neurovascular bundle and can retract it far enough for the next step, it is not necessary to dissect it any further. The next step is to identify the distal fragment. This may be the most difficult step for the surgeon who is performing this procedure for the first or second time. The distal fragment is posterior and often deeper than expected; easy to palpate but difficult to visualize. Reduction is often challenging because the periosteum that is torn off the anterior metaphysis of the humerus is folded over the fractured surface of the distal fragment **(B)**. The proximal fragment has essentially "button-holed" through the periosteum, which has closed around the distal fragment and trapped the proximal fragment. This is now the main block to reduction. With the neurovascular bundle safely retracted medially and the proximal fragment retracted laterally, the distal fragment can be exposed. With a forceps or hemostat, the cut edge of the periosteum is grasped and carefully cut along the fractured edge of the distal fragment to open the buttonhole (A). After the buttonhole is freed sufficiently, the distal fragment can be brought anteriorly and reduced. As much of the periosteum is torn, fracture reduction is at times less stable following an open reduction than it is in a closed reduction, so use at least three pins in most cases.

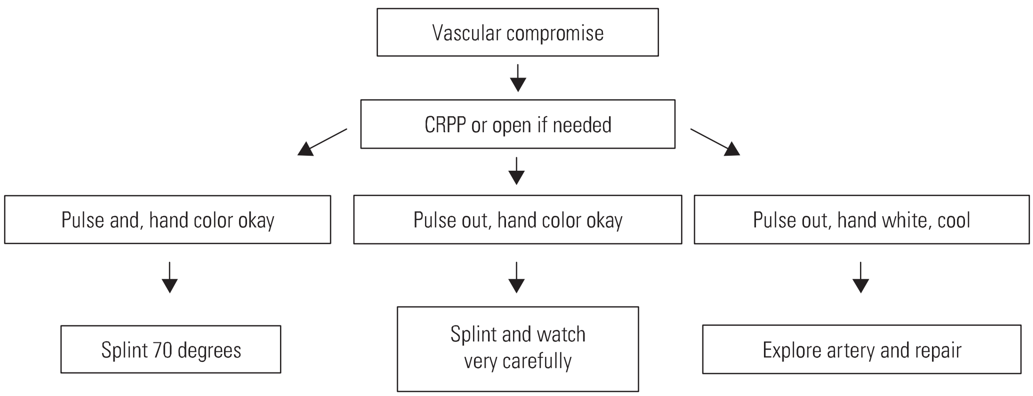

FIGURE 33-42. Management of a supracondylar humerus fracture with vascular compromise. This algorithm shows management of a supracondylar humerus fracture associated with vascular compromise. (CRPP, closed reduction and percutaneous pinning.)

Osteotomy to correct deformity may be performed at any age, but complications are not uncommon (81). Simple uniplanar closing-wedge osteotomies have the lowest complication rates, but lateral condylar prominence may compromise the cosmetic result (81, 82). A variation of a Wiltse osteotomy may obviate that problem, as described below (83).

SUPRACONDYLAR HUMERAL OSTEOTOMY FOR CORRECTION OF CUBITUS VARUS

Careful examination of the contralateral elbow in both planes is an essential step in preoperative planning, perhaps even more important than radiographic markers. Goals of surgery

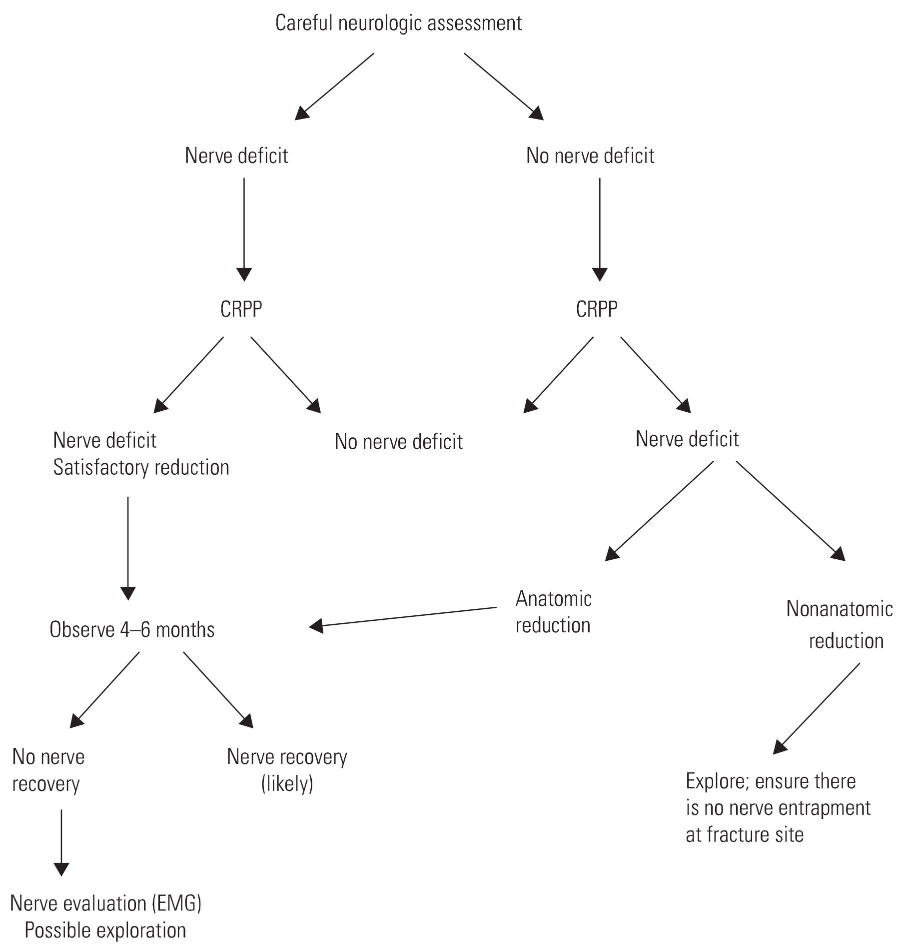

FIGURE 33-43. Management strategy with supracondylar humerus fracture and neurologic deficit. (CRPP, closed reduction and percutaneous pinning; EMG, electromyogram.)

are to make the carrying angle of the injured elbow as close as possible to the normal elbow, so this difference must be carefully measured preoperatively to plan for the angle of wedge to be removed in the coronal plane. Preoperative templating, created from AP radiographs of bilateral upper extremities, determines the angle of wedge to be removed. The difference in elbow extension between elbows clinically is a guide for what angle wedge in the sagittal plane to be removed (Figs. 33-44 to 33-46).

Typical Case. Note improvement in the Baumann angle as well as the position of the capitellum relative to the anterior humeral line (Fig. 33-47).

Floating Elbow. Simultaneous ipsilateral supracondylar and forearm fractures have been termed floating elbow. These injuries often result from high-energy trauma with a resultant increased risk of compartment syndrome (84); for this reason, these injuries are generally considered for urgent fixation. In addition, secondary displacement of the forearm fracture has been reported (85). Percutaneous pinning of both the supracondylar and forearm fractures is recommended if the forearm fracture requires reduction (85, 86). This allows less constrictive immobilization and reduces the risk of redisplacement.

T-condylar Fracture. This is an intra-articular injury in which the capitellum and the trochlea usually are separated from each other, and the two are separated from the proximal humerus. The mechanism of injury is axial impaction. This injury occurs predominantly in adolescents around the time of physeal closure, but it can also occur in younger children.

Treatment of displaced fractures should be aimed at restoring the anatomic alignment of the articular surface. Closed reduction and percutaneous fixation has been reported, with transcondylar fixation followed by pinning or flexible nailing of the supracondylar component of the fracture (87, 88). When open reduction is necessary, a posterior approach is recommended. This can be accomplished by splitting the triceps, reflecting a distally based tongue of triceps, or by olecranon osteotomy (89, 90). Comminution of the articular surface is rare in children, so the triceps-splitting approach is usually adequate without olecranon osteotomy. Extensive dissection of the fragments should be avoided to minimize the risk of avascular necrosis of the trochlea. Transverse fixation of the trochlea to the capitellum is performed first, and this unit is secured to the distal humerus with sufficiently strong crossed pins or cancellous screws. Alternatively, 3.5-mm reconstruction plates are applied to the medial and lateral columns of the distal humerus. When open reduction is performed, internal fixation should be stable to allow motion during the early postoperative period (89, 91). The recommended period of immobilization should be 3 weeks or less to prevent stiffness. The authors prefer rigid internal fixation with early motion (in first few days) for patients who are near skeletal maturity.

Fracture Separation of the Distal Humeral Physis. Fracture separation of the distal humeral physis is seen primarily in infants and young children. The mechanism of injury involves rotatory shear forces, resulting in a Salter-Harris type I or type II fracture pattern. Abuse should be suspected (92). This injury may present a diagnostic challenge because of the lack of ossification of the distal humerus in young children (Fig. 33-48).

Diagnosis of this fracture should be considered in any young child with significant soft-tissue swelling and crepitus on elbow motion. This fracture is most often confused with elbow dislocation and lateral condyle fracture. Elbow dislocation is rare in young children as the physis is weaker than the ligaments, similar to injuries about the distal femur. A lateral condyle fracture in a 2- to 3-year-old child may be confused with transphyseal separation, especially if there is joint subluxation (Fig. 33-49). Arthrography, MRI, or ultrasonography can help confirm the diagnosis of separation of the entire distal humeral physis. Arthrography is a helpful adjunct at the time of definitive treatment to confirm the quality of fracture reduction (Fig. 33-50).

Treatment and complications are similar to those for supracondylar fractures. Closed reduction and immobilization alone may lead to cubitus varus that does not resolve (78, 92). Therefore, fixation with two small-diameter, laterally placed pins is recommended after reduction. Fractures diagnosed after 7 to 10 days should not be manipulated because healing is rapid and growth arrest may result from attempts at reduction. For fractures with late presentation, it is better to wait and perform a supracondylar osteotomy for residual deformity if necessary, rather than risk iatrogenic growth arrest, as remodeling results in acceptable results for most patients presenting late (93).

Lateral Condyle Fracture. Fracture of the lateral condyle is the second most common elbow fracture in children. This injury is usually the result of a fall on an outstretched hand. The peak age range for this injury is 5 to 10 years, but it is often seen in older or younger children.

This is a complex fracture because it involves the physis and the articular surface. It is a Salter-Harris type IV injury in most cases, but a significant portion of the fragment is unossified, especially in children younger than 5 years. Growth disturbance is more common than is generally recognized (94). Fortunately, growth disturbances are usually minor because the distal humerus only contributes 2 to 3 mm of longitudinal growth per year in children older than 7 years (95). The injury is often identified by a thin lateral metaphyseal rim of bone, but the fracture line may continue across the physis, through unossified cartilage, and into the elbow joint. The fracture line may take several paths through the unossified cartilage of the distal humerus, but is most commonly oblique, and with the most displacement evident on an internally rotated x-ray (96).

Determining the exact location and extent of the fracture line may be difficult. When the fracture gap is equal medially

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Supracondylar Humeral Osteotomy for Correction of Cubitus Varus (Figs. 33-44 to 33-46)

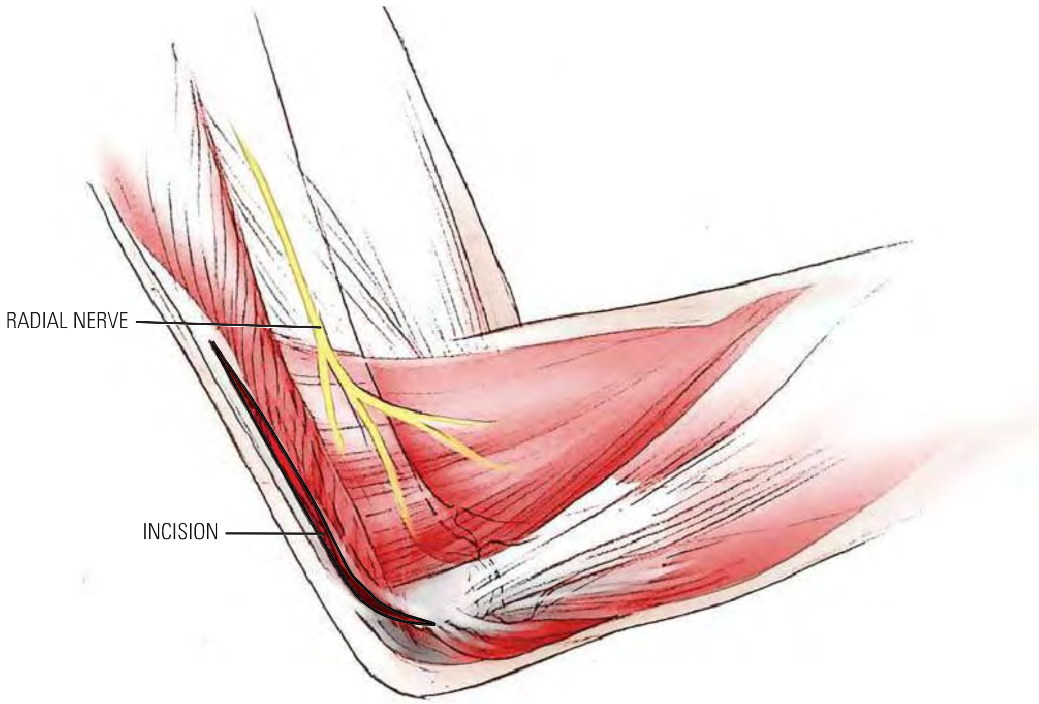


FIGURE 33-44. **Supracondylar Humeral Osteotomy for Correction of Cubitus Varus.** The lateral approach is easiest for this operation. A longitudinal incision, measuring approximately 5 to 6 cm, is made over the distal lateral humerus. The antebrachial cutaneous nerve and its branches are identified and preserved. This approach should be distal to the radial nerve; however, one may look proximally in the wound to make certain it is not in the field.

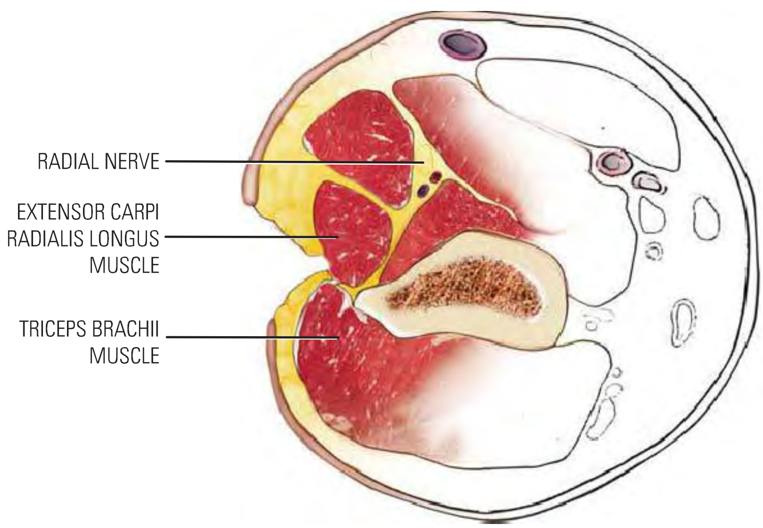


FIGURE 33-45. Dissection is carried out in the interval between the brachialradialis and the triceps muscles. Subperiosteal dissection is performed to expose the distal humerus circumferentially. Posterior dissection distal to the olecranon fossa is avoided to prevent compromising the blood supply to the trochlea. The distal humeral shaft is protected circumferentially with Chandler retractors. With continuous irrigation to prevent the saw blade from becoming hot, a transverse osteotomy is performed just above the olecranon fossa. This osteotomy should be made parallel to the elbow joint in the coronal plane and perpendicular to the humeral shaft sagittal plane. The proximal humerus is now delivered out of the wound to allow for a precise osteotomy with direct visualization.

FIGURE 33-46. The template can be placed on the proximal fragment defining the triangular wedge of bone removed (*arrow A*). Care is taken to leave the lateral most spike of the proximal fragment intact as this will help lock the distal fragment into place and prevent lateral translation of the distal fragment that would otherwise result in a lateral bump, which is cosmetically unappealing. It is during this cut that sagittal correction is obtained. Most commonly, the malunion leads to hyperextension of the elbow. If the elbow extends 20 degrees more than the normal side for example, this cut should be aiming distally 20 degrees from anterior to posterior to correct the sagittal deformity.

A 90-degree triangle should now be removed from the lateral portion of the distal fragment to create space for the lateral spike of the proximal fragment (arrow B). The proximal fragment is now replaced into the wound, and the proximal and distal fragments are brought together in a lock-and-key mechanism *(black curved arrow).*

Three 0.062-in. or 2-mm K-wires are placed across the osteotomy site from lateral to medial. A goniometer is used to measure alignment of the carrying angle of the elbow and elbow flexion and extension are then checked to ensure it is similar to the other side. If needed, the pins can be backed out of the fracture site, and the proximal humerus delivered out of the wound for adjustments to the osteotomy with a saw or rongeur. The wound is irrigated and a small amount of local bone graft from the excised wedge is packed around the osteotomy site. Flexion and extension and varus/valus stability are checked under live imaging to ensure the osteotomy fixation is stable. A long arm cast is applied in about 60 to 70 degrees of flexion with the arm neither supinated nor pronated.

Postoperative care: The cast and pins are removed approximately 4 weeks later in an outpatient setting. Range-of-motion exercises are begun with parents and/or therapy. A sling may be used for protection for an additional 2 weeks.

and laterally along the fracture line, there is a very high risk of displacement due to absence of a cartilage hinge (97). MRI has been recommended when there is doubt about the presence of an intact cartilage hinge (98) though this is not standard practice in most centers. An arthrogram at the time of surgery may also establish that the fracture does not enter the joint. Fractures with initial displacement of 3 mm or more also tend to displace further and have a higher incidence of nonunion (99).

The Milch classification is unreliable and has limited clinical usefulness (94, 100). Postmortem studies by Jakob et al. (101) identified stages of lateral condylar displacement based on movement through a cartilage hinge and the presence or absence of an intact joint surface. Weiss et al. (102) expounded upon these stages and described a classification system based on fracture displacement and integrity of the joint surface that offers treatment recommendations and correlates to postoperative complications (Fig. 33-51). A type I fracture is displaced <2 mm. In a type II fracture, there is ≥2 mm of displacement with intact articular cartilage, as demonstrated by an arthrogram or MRI. In this case, the fracture line extends through the osseous metaphysis, but not all the way through the cartilage of the distal humerus, which may be rather thick and flexible. In a type III fracture, there is ≥2 mm of displacement and the articular surface is not intact. A weakness of this classification system is that an arthrogram or MRI is needed to strictly define the articular surface as being intact; however, practically the authors found that all type II fractures had <4 mm maximum displacement on initial radiographs, and all type III fractures had ≥ 4 mm displacement.

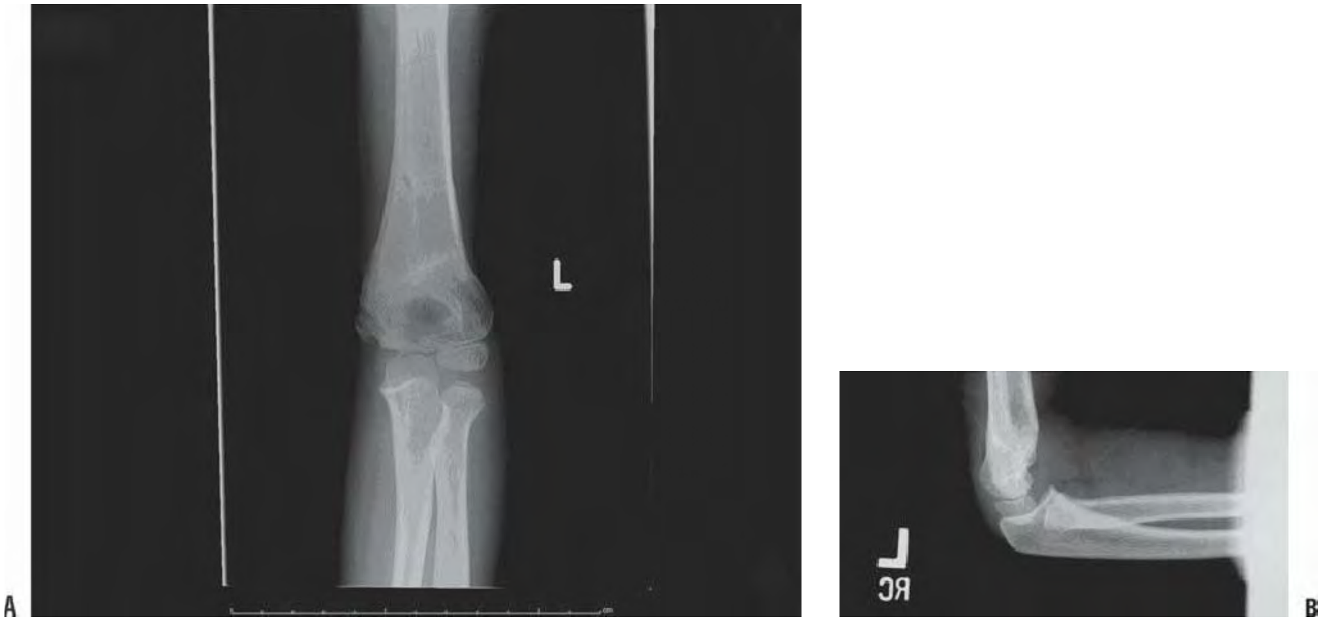
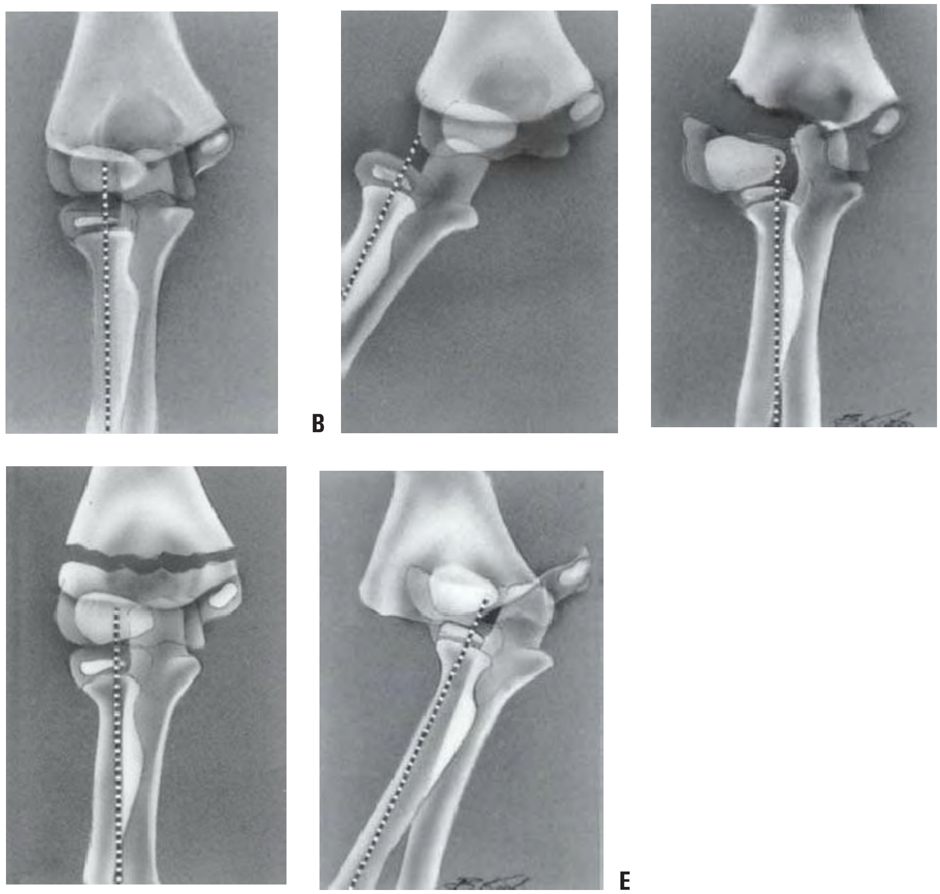


FIGURE 33-47. Note improvement in the Baumann angle as well as the position of the capitellum relative to the anterior humeral line. (Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.)

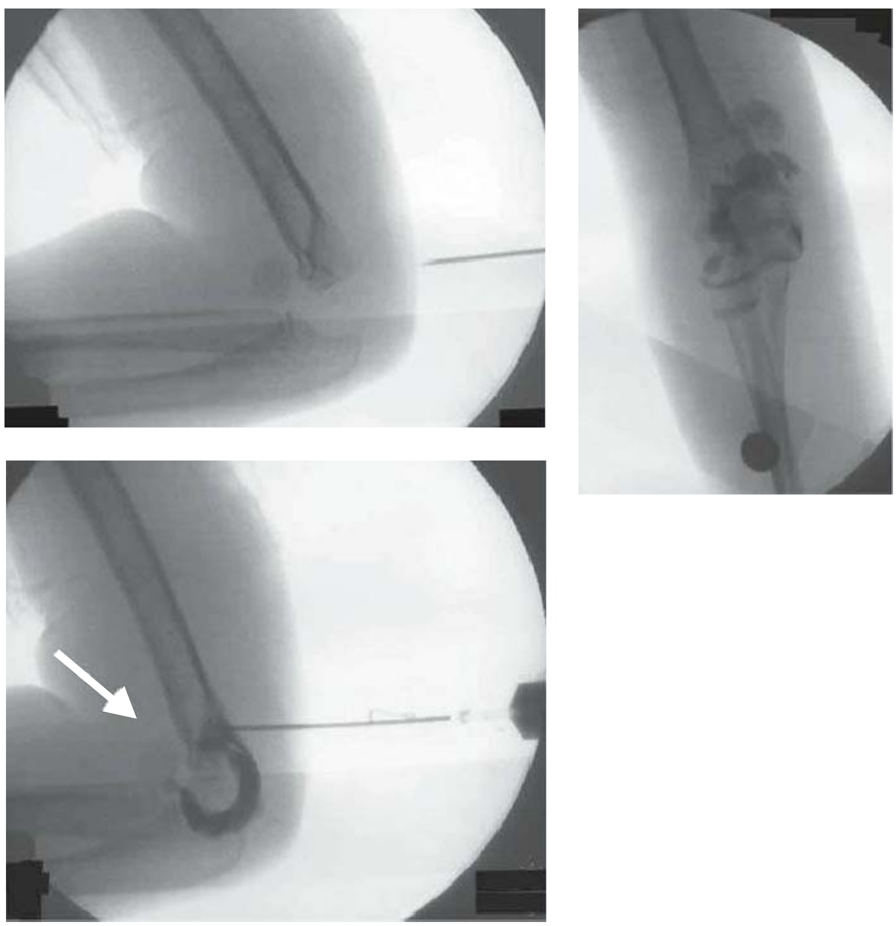
Treatment depends on the degree of displacement and the assessment of fragment stability. Type I fractures (displacement <2 mm) are treated with cast immobilization. Beware that up to 30% of these fractures may have additional displacement within 15 days (103). The authors prefer to assess fracture stability in questionable cases by radiographic follow-up weekly for 2 weeks. It is often necessary to remove the cast to obtain adequate AP, internally rotated oblique, and lateral radiographs

FIGURE 33-48. AP and Lateral view of a 5-month-old with a transphyseal injury. The small fleck of metaphyseal bone may technically make this a Salter 2 fracture, but one should think of this as a transphyseal fracture for purposes of considering child abuse and treatment. (Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.)



A B C D E

FIGURE 33-49. **A:** Normal elbow demonstrating the alignment of the radius with the capitellum. **B:** In a dislocation of the elbow, there is disruption of the radiocapitellar alignment. Most dislocations are posterolateral. **C:** In a displaced lateral condyle fracture, there is again disruption of the radial capitellar alignment. **D:** Supracondylar elbow fracture, in which the radius and the capitellum remain aligned, despite displacement of the distal humeral fragment. **E:** Fracture separation of the distal humeral physis. The radiocapitellar relation is preserved, and typically the distal segment is posteromedially displaced. (Adapted from DeLee J, Wilkins K, Rogers L, et al. Fracture-separation of the distal humeral epiphysis. *J Bone Joint Surg Am* 1980;62:46, with permission.)



A B C

FIGURE 33-50. Arthrogram technique. Although many are trained to use the lateral radiocapitellar joint as the entry point for an elbow arthrogram, the olecranon fossa approach is easier and more reliable on the swollen elbow of a small child. This 6-year-old child presented with distal humeral fracture. The surgeon could not distinguish a distal humeral physeal fracture versus a lateral condyle fracture. In the operating room, 5 mL of radiographic dye was injected into the olecranon fossa. **A:** Lateral image, just prior to injection. **B, C:** AP and lateral image after injection. The distal humerus was clearly delineated as intact, while a lateral condyle fracture fragment (*arrow*) can be seen anteriorly.

FIGURE 33-51. Type I fracture: <2 mm displacement, type II fracture: with ≥2 mm displacement and congruity of the articular surface as proved by arthrogram or MRI, and type III fracture: ≥2 mm of displacement and lack of articular congruity.

of the distal humerus out of the cast (Fig. 33-52), particularly if a plaster cast is used. Gentle cast removal and radiography will not cause displacement if the fracture is inherently stable. Healing for minimally displaced fractures is complete when bridging callus is identified (usually seen posteriorly on the lateral radiograph). This usually occurs by the fourth week of immobilization, but immobilization for up to 12 weeks may be required in some cases (99).

It is the authors preference to treat type II fractures (>2 mm displacement and intact articular surface) with closed pinning after an arthrogram confirms the joint surface is intact as described by Mintzer et al. (104). A technical tip is to perform

FIGURE 33-52. A minimally displaced lateral condyle fracture may be best visualized on the internal oblique radiograph. AP **(A)**, lateral **(B)**, and internal rotation oblique **(C)** radiographs.

the arthrogram through a posterior approach into the olecranon fossa (see Fig 33-50), rather than through a lateral approach; if done through the lateral approach, extravasated dye may obscure visualization of the lateral fracture anatomy. Some suggest lateral condyle fractures displaced 3 mm may have an intact cartilage hinge and heal with cast immobilization (98, 105) though we find it more predictable to pin these fractures initially (Fig. 33-53). Type III (>2 mm displacement, articular hinge not intact) fractures are treated with open reduction and pinning. In obviously displaced fractures, there is no need to perform an arthrogram, and one should proceed directly to open reduction. Establishment of articular congruity is the primary goal of this surgery. Fractures with ≥2 to 3 mm displacement tend to displace further and have a higher incidence of nonunion (99, 103) if treated with casting alone. Careful follow-up for minimally displaced fractures treated without pins is essential, so the surgeon should consider pinning minimally displaced fractures when compliance with follow-up is doubtful (103).

Primary open reduction with restoration of articular congruity is preferred in most cases requiring surgery. In severe cases, the condylar fragment may be rotated 180 degrees. A standard lateral approach is utilized between the triceps posteriorly and the brachialis/extensor carpi radialis longus anteriorly. Incision of the anterior joint capsule facilitates exposure. Soft-tissue stripping posteriorly should be avoided to reduce the risk of avascular necrosis of the capitellum and trochlea. Stabilization can be achieved with two smooth pins crossing the fracture site and exiting the opposite cortex. The pins and cast are removed 3 to 6 weeks after surgery, depending on the extent of healing seen on postoperative radiographs.

FIGURE 33-53. The drifting lateral condyle fracture. **A, B:** AP and lateral radiographs at presentation. This lateral condyle fracture has only approximately 2 mm of displacement on the AP view. No displacement is noted on the lateral view. The child was placed in a long-arm cast and a follow-up 1 week later was recommended. **C, D:** AP and lateral radiographs taken 1 week after injury show further displacement of the lateral condyle fracture with 5 mm of separation of the lateral condyle from the distal humerus. Open reduction and pinning was performed. **E, F:** Radiographs taken in the cast 4 weeks after open reduction and pinning show anatomic alignment and early healing.

OPEN REDUCTION AND INTERNAL FIXATION OF DISPLACED LATERAL CONDYLE FRACTURE OF THE HUMERUS

Postoperative Care. The procedure may be performed on an outpatient basis. Acute swelling and danger of compartment syndrome are less than in supracondylar humerus fractures. The patient returns in 4 weeks and the cast is removed. AP, lateral, and, most important, internal rotation oblique radiographs of the distal humerus are obtained out of the cast. If the fracture gap is narrowing and if there is periosteal new bone bridging the two fragments, the pins are removed. Delayed healing is not uncommon in lateral condyle fractures, in which case the cast should be left in place until healing is seen on x-rays, though pins should often be removed at 4 weeks to prevent infection. Flexion and extension should return almost to normal by 5 weeks (67) (Figs. 33-54 to 33-61).

Management of the late-presenting lateral condyle malunion is an area of controversy. Minor degrees of malunion are well tolerated. Correction of malunion more than 6 weeks after fracture is difficult (101, 106). Remodeling obscures fracture lines and interferes with restoration of anatomic reduction following osteotomy. Excessive stripping of the condyle to facilitate reduction may result in avascular necrosis and greater joint stiffness. Two surgical approaches are described in the literature for management of symptomatic patients with malunion. Supracondylar osteotomy, combined with ulnar nerve transposition, has been performed with satisfactory improvement in function (101). Intra-articular osteotomies, with partial reduction, have also achieved satisfactory results (107).

Nonunion after lateral condyle fracture is seen most often in untreated patients, with displacement of 3 mm or more. Delayed union and nonunion has been attributed to fracture instability, exposure to synovial fluid, and decreased vascularity due to the large articular surface of the fracture fragment. Long-term sequelae of nonunion include ulnar neuritis, progressive valgus deformity, and elbow instability with decreased strength. In established nonunions, the lateral condyle fragment should be fixed in a position that preserves the best functional range of motion, realizing that anatomic restoration is not possible (Fig. 33-62) (99, 107). Bone grafting is recommended to achieve union. The quantity of bone graft needed is small, and can be obtained from the iliac crest, proximal ulna, or distal radius. Collecting graft from the lateral column of the humerus may weaken fixation. Any residual valgus deformity can be corrected with a supracondylar osteotomy. Ulnar nerve transposition may be needed, especially if there are preoperative symptoms (108).

Minor degrees of deformity of the distal humerus are not uncommon following a lateral condyle fracture (94, 109). Asymmetric growth of the lateral condyle or incomplete reduction can produce mild cubitus varus. Fishtail deformity, or deepening of the trochlear groove, may result from central growth arrest or more likely from avascular necrosis. This deformity rarely compromises short-term function, but may predispose to later condylar fracture (94). Corrective osteotomies with nerve decompression or transposition can modify the deformity and symptoms.

Lateral Epicondyle Fracture. Lateral epicondyle fracture is a rare elbow injury that does not involve the articular surface. This ossification center does not appear until the second decade. This injury is often misdiagnosed as an avulsion fracture of the lateral condyle. Treatment is usually immobilization followed by early motion, when comfortable. Displacement >5 mm may lead to joint stiffness. If this occurs, early excision of the displaced epicondyle should be considered.

Medial Epicondyle Fracture. The medial epicondylar apophysis is fractured when a valgus load is applied to the extended elbow. The displacement is encouraged by the pull of the forearm flexor muscle group, which is attached in this region. The medial collateral ligament, which also originates from this apophysis, may play a role in the initial fracture displacement, especially when the fracture is associated with an elbow dislocation. Fracture of the medial epicondyle is largely dependent on age and is related to the ossification of the epicondyle. Ossification begins at approximately 4 to 6 years of age, and fusion occurs at approximately 15 years of age. Early in the process, the medial epicondyle is a part of the entire distal humeral epiphysis. As growth continues, between 9 and 14 years of age this apophysis becomes separated from the main epiphysis, which is when most of these fractures occur. Almost 50% of medial epicondyle fractures occur concomitantly with posterolateral elbow dislocation. The medial epicondyle may be trapped in the joint after reduction. When this occurs, the ulnar nerve may also be in the joint, and vigorous attempts at closed manipulation should be avoided.

Treatment. There is general agreement that surgical intervention is indicated when the epicondyle is trapped in the joint. Otherwise, management is controversial. There are advocates for the closed treatment of this injury regardless of the magnitude of displacement (110, 111). Nonunion is a frequent result of closed management, but the great majority of patients are asymptomatic. Valgus instability to stress testing has been suggested as an indication for surgical stabilization (112). However, most fresh medial epicondyle avulsion injuries will demonstrate instability, so most patients will undergo surgery if this test is used as an indication. Late instability after closed management has been reported, but this complication is rare unless the epicondylar fragment has been excised (111, 112). Excellent results have also been reported after surgical stabilization of moderately displaced fractures (113). Nonsurgical management reliably produces good results almost regardless of displacement or nonunion, so it is the authors' preference to reserve open reduction and internal fixation for medial epicondyle fractures when displacement is >5 to 10 mm (Fig. 33-63). Surgical intervention for lesser degrees of displacement is also considered for competitive athletes in a sport producing elbow valgus stress such as pitching or gymnastics, or in cases of a concomitant elbow dislocation. Many centers are now challenging this conservative view and are recommending a more aggressive surgical approach for these fractures.

Text continued on page 1735

Open Reduction and Internal Fixation of Displaced Lateral Condyle Fracture of the Humerus (Figs. 33-54 to 33-57)

FIGURE 33-54. Open Reduction and Internal Fixation of Displaced Lateral Condyle Fracture of the Humerus. The operation is performed with a tourniquet high on the arm and with the patient supine. The arm should be positioned on a short arm board so that image intensifier views can be obtained to verify the location of the pins: The reduction of the fracture, and in particular the articular surface, is visualized directly, so this is one operation in which a headlight is helpful. An incision is made directly over the lateral condyle, about 5 cm in length for small children, and proportionally larger in older children. The landmarks of the lateral condyle can be difficult to identify in the younger child with a swollen elbow, and one wants to avoid dissecting too proximally to avoid the radial nerve.

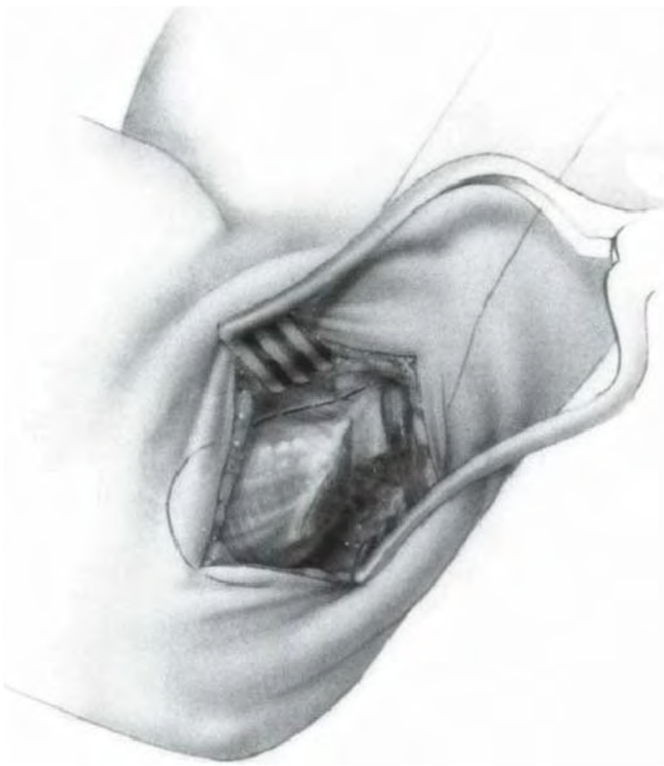


FIGURE 33-55. The incision is made through the skin and the subcutaneous tissues. Beneath the skin, a majority of the dissection is often already done by the injury. Resist the urge to cut fascia, and in displaced fractures you will usually find for a rent in the fascia and muscle with your finger that will bring you right to the fracture site and joint. The rent in the muscle and fascia may have to be extended for visualization. Remove fracture hematoma with irrigation. A Chandler retractor or Army–Navy retractor across to the medial edge of the joint improves visualization. A key step in visualization is dissection of the distal most soft-tissue attachments from the lateral portion of the capitellum, releasing the anterior capsular attachments to visualize the anterior capitellum. The intact joint surface on both sides of the fracture should be seen to achieve an accurate reduction. Finally, in preparation for the reduction, the periosteum is trimmed from the distal fragment to allow visualization of the cortical surface so that accurate apposition to the proximal fragment can be achieved. Avoidance of dissection on the posterior aspect of the fragment is imperative to avoid interference with its blood supply.

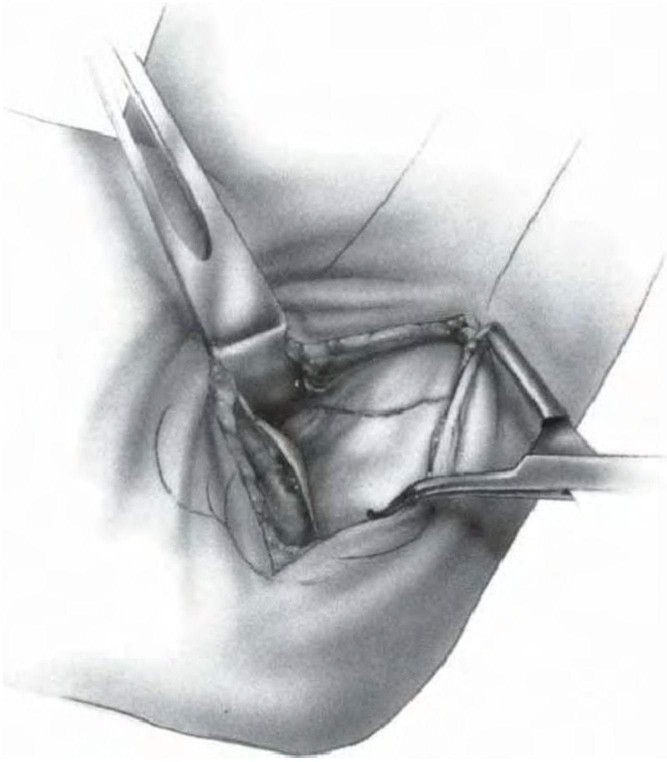
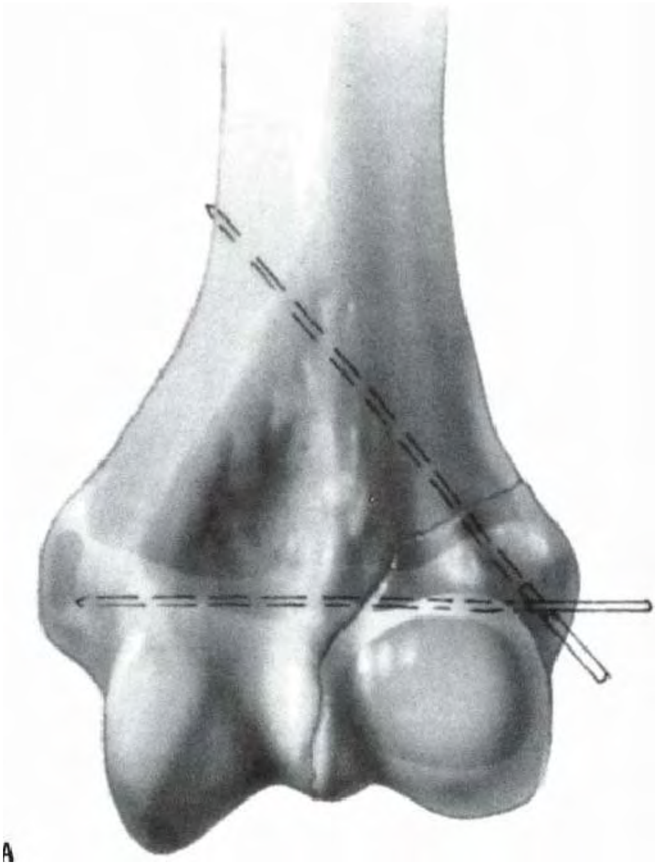


FIGURE 33-56. The fracture fragment is often quite rotated and displaced and surprisingly difficult to reduce. The fragment can be grasped with a sharp towel clip or a pair of small fracture reduction forceps and manipulated into position. Flexion of the elbow as well as wrist extension to reduce tension on the origin of the wrist extensors on the fracture fragment may help. After the fragment is reduced, it can be held in place with a forceps, freer elevator, dental tool, etc. When the articular surface is perfectly reduced the metaphyseal portion may be a little off, as plastic deformation may have occurred in the fragment. Reduction of the articular surface is the goal—a small metaphyseal gap will fill in with time.


A

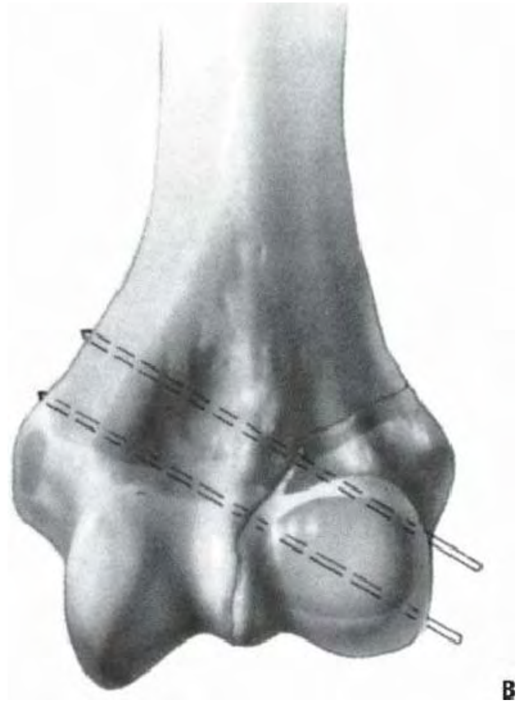
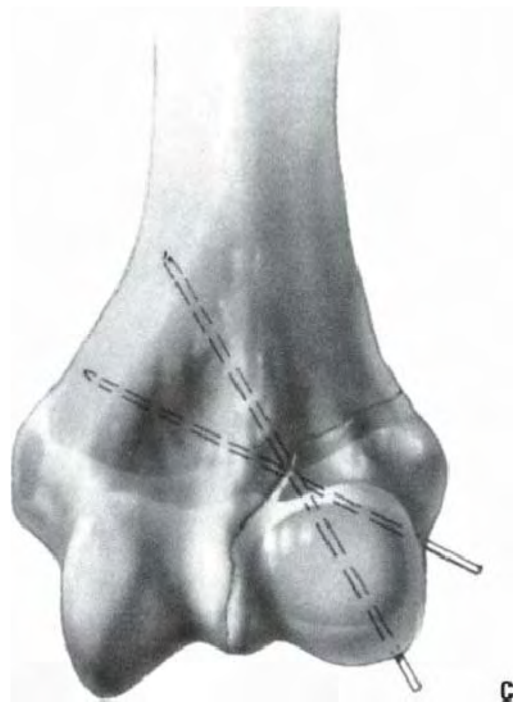

B

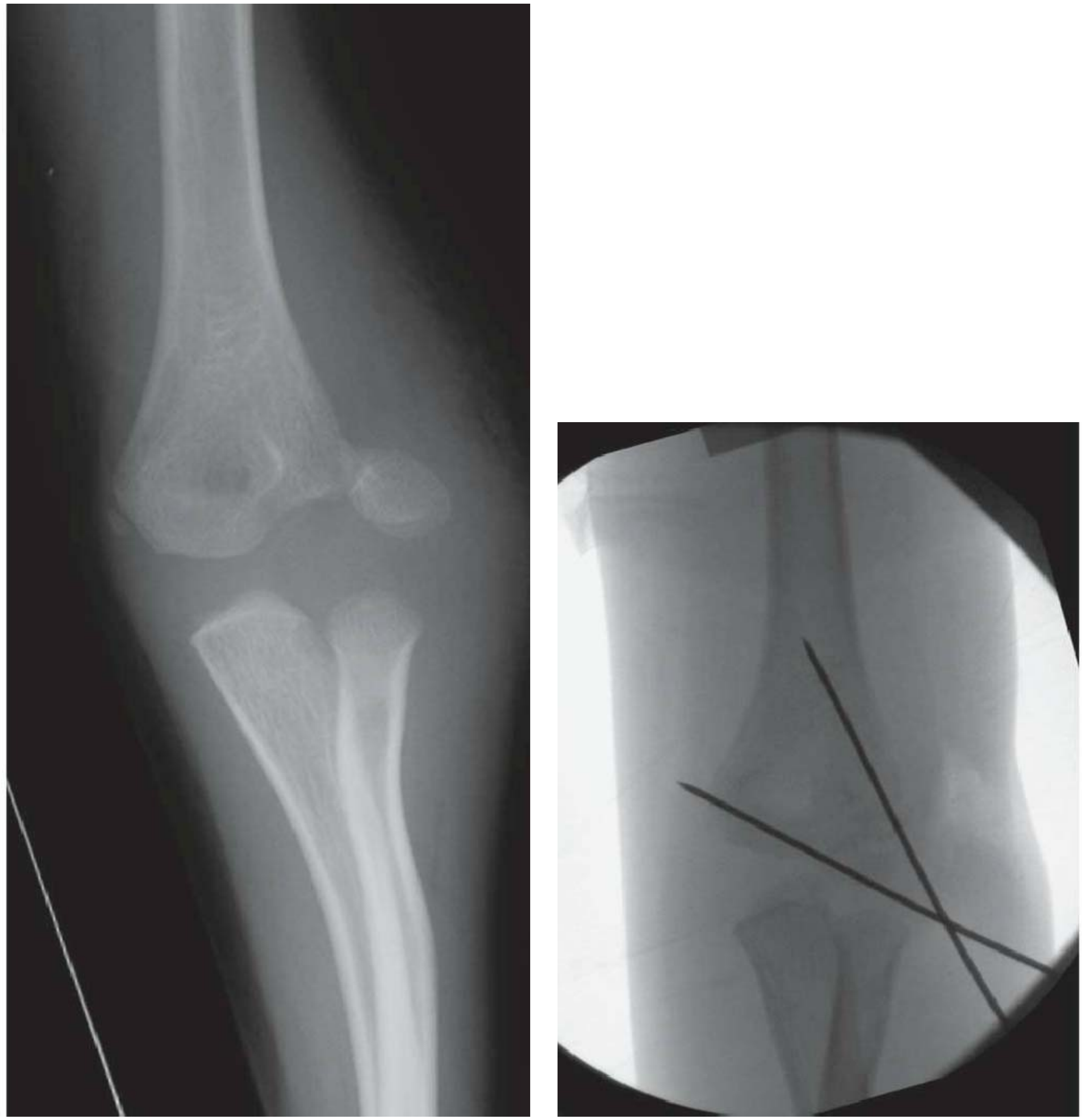
FIGURE 33-57. Pin placement is crucial because this is a small fragment that has strong forces trying to displace it. Similar principles in pin placement for supracondylar fractures apply in this fracture as well. Separate the pins at the fracture site, the proximal pin should be through cortex for firm fixation, and if uncertain use three pins. In the ideal fixation, the pins traverse the fracture site at nearly right angles, spread apart at the fracture site as far as practical. Theoretically if the pins are divergent, it will prevent a fracture gap as the fragment could slide distally over parallel pins. Practically, parallel pins are easier to place especially in small children. Pin configuration **(A)** is not desirable as the horizontal pin is wholly within cartilage and does not provide adequate fixation. Pin configuration **(B)** is desirable. Pins that cross at or near the fracture site **(C)** should be avoided because they provide little rotational stability.


C

In adolescents, fragment fixation can be accomplished with a cannulated bone screw. When reducing this fracture, it is important to understand that the fragment tends to rotate anteriorly from its posteromedial origin. Stable fixation allows early postoperative range of motion. Preadolescents may require fixation with smooth Kirschner wires (K-wires) and cast immobilization for 3 weeks to minimize the risk of growth arrest of the apophysis.

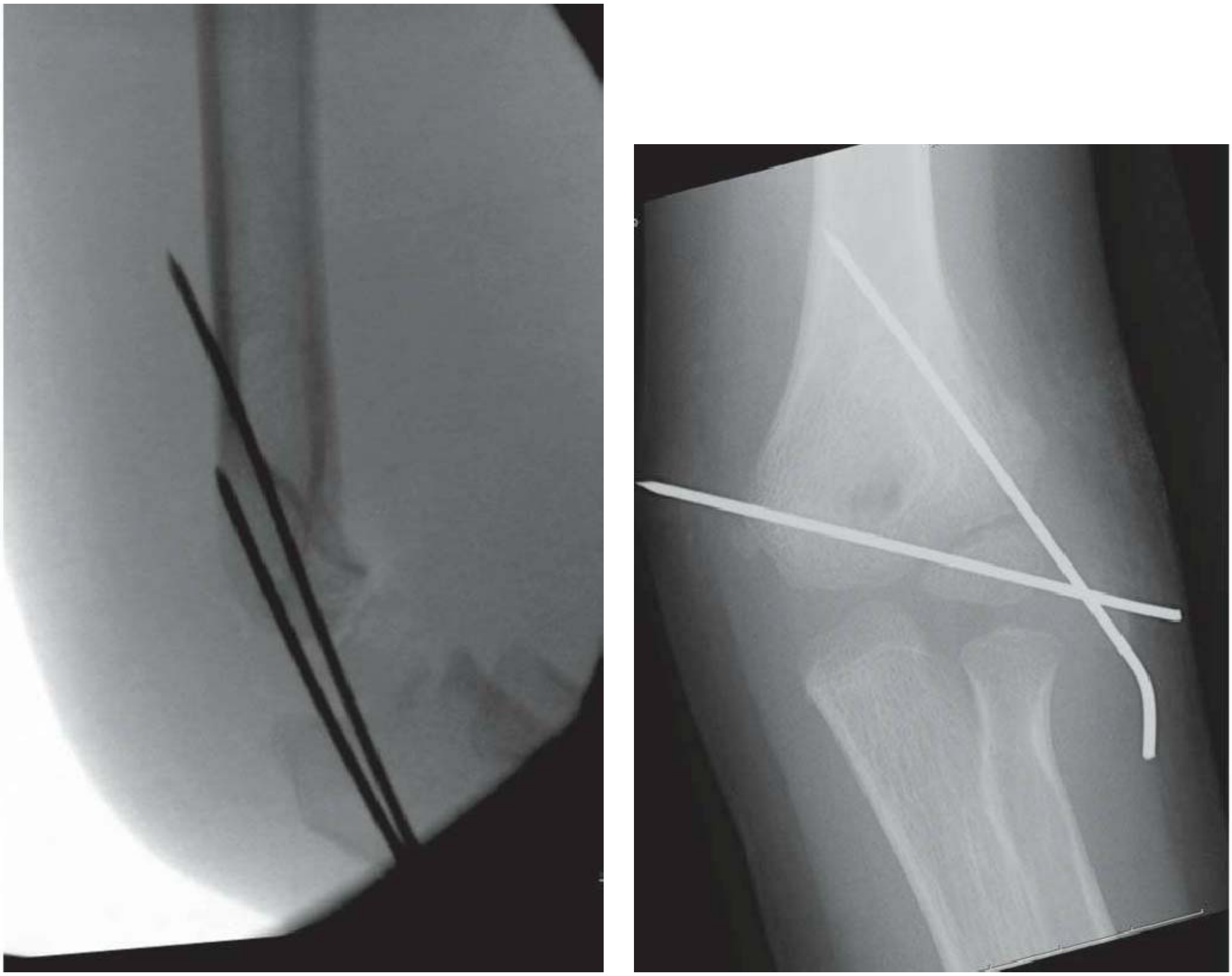
OPEN REDUCTION AND INTERNAL FIXATION OF FRACTURES OF THE MEDIAL EPICONDYLE

Postoperative Care. The surgery can be performed as an outpatient procedure electively within a few days of injury. If performed at night, the patient is discharged the next morning. After 3 weeks, the cast is removed and AP and lateral



A B

FIGURE 33-58. **A:** AP radiograph of a displaced lateral condyle fracture. **B:** Intraoperative AP view on the image intensifier screen. Note that pins are separated at the fracture site and divergent. From this view, one cannot be certain the proximal pin is through proximal cortex.



C D

FIGURE 33-58. *(Continued)* **C:** Lateral intraoperative image demonstrating the proximal pin is through proximal cortex. **D:** The fracture 4 weeks after surgery. The early callus is an indication that it is safe to remove the pins. (Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.)

FIGURE 33-59. Lateral condyle fracture with suboptimal pin configuration with distal pin not engaging cortex proximal to fracture site.

radiographs are obtained. Appearance of periosteal new bone usually indicates that the pins can be pulled out and motion started. The patient is instructed to continue to wear the sling for an additional 2 to 3 weeks until motion improves and healing is more complete. Gentle motion is begun in 5 days if a screw is used (Figs. 33-64 to 33-66).

Medial Condyle Fracture. Fracture of the medial condyle of the humerus is an unusual injury. Medial condyle fracture may be misdiagnosed as medial epicondyle avulsion in children between the ages of 5 and 7 years, because the epicondylar ossification center is visible on radiographs approximately 2 years before the trochlea ossifies. If a child with an unossified trochlea presents with a swollen elbow, it is important to examine the radiographs for a chip or flake of bone from the metaphysis, which indicates medial condyle

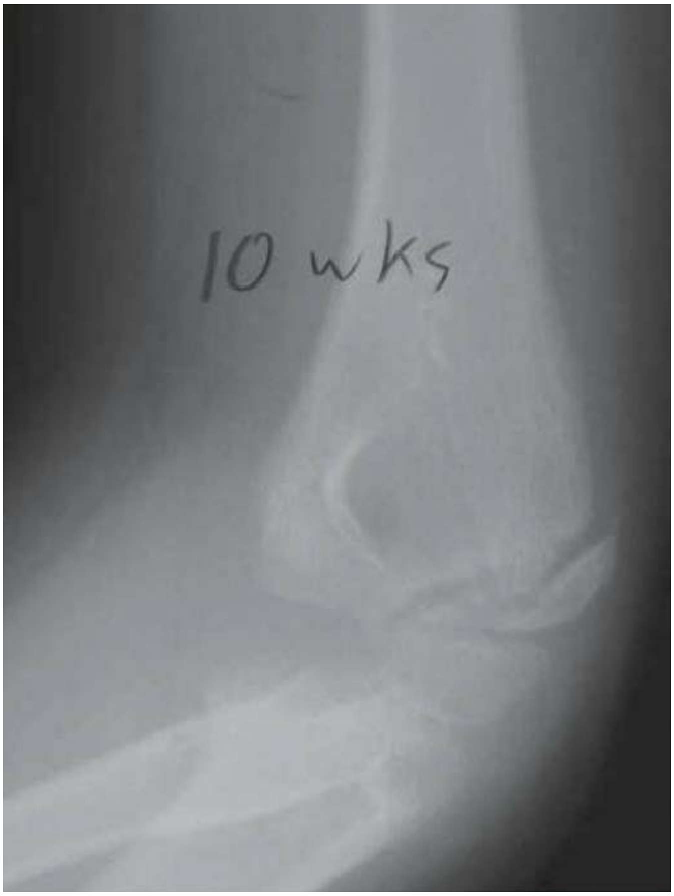


FIGURE 33-60. Despite 10 weeks of immobilization, there is no significant healing, and there is very poor range of motion.

fracture. The mechanism of injury is similar to that for medial epicondylar fracture, but medial condyle fracture is a much more serious injury, because it involves the articular surface. If the condyle is displaced more than 2 mm, open reduction and internal fixation is recommended (114).

Radial Neck Fracture. Fractures of the radial neck are most common in children in the 7- to 12-year age group. Approximately 50% are isolated injuries; associated fractures, most commonly of the proximal ulna, are found in the other 50% (115). Associated injuries should be treated independently as indicated for that particular fracture. Radial neck physeal fractures are predominantly Salter-Harris type I or II injuries, but many are metaphyseal. The radial head is largely cartilaginous and is rarely injured in children. The mechanism of injury is usually valgus stress, with compression of the radial neck from a fall on the extended elbow. Fracture displacement can result in angulation and translation, with or without complete separation of the radial head from the shaft. Angulation after union may remodel, especially in younger children. Union with translation may limit motion because of a cam effect that prevents the radial head from rotating in a circle. Approximately half of the children who sustain fractures of the radial neck will have some permanent limitation of forearm rotation. Factors leading

FIGURE 33-61. Fracture underwent a second surgery at 10 weeks. A screw was used to provide compression and allow early motion. Note the screw does not cross the physis or the olecranon, so it does not require later removal unless it is bothering the patient. (Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.)

to a poor prognosis are age >10 years, angulation >30 degrees, displacement >3 mm, delayed treatment, associated injuries, and open reduction (116, 117).

Treatment depends on the age of the child and the amount of angulation and translation. The plane of maximum angulation can be determined by multiple radiographic views or by fluoroscopy. When angulation is >30 degrees or translation is >3 to 5 mm, closed reduction usually should be attempted because anatomic alignment is associated with better outcome. However, closed reduction may fail, and one must decide whether to accept suboptimal alignment or to resort to open reduction, with increased risks in each case. Age is important in this situation (117). Another factor in deciding whether to proceed with a percutaneous or open reduction is how much pronation and supination is possible after a closed reduction. If there is <60 degrees of

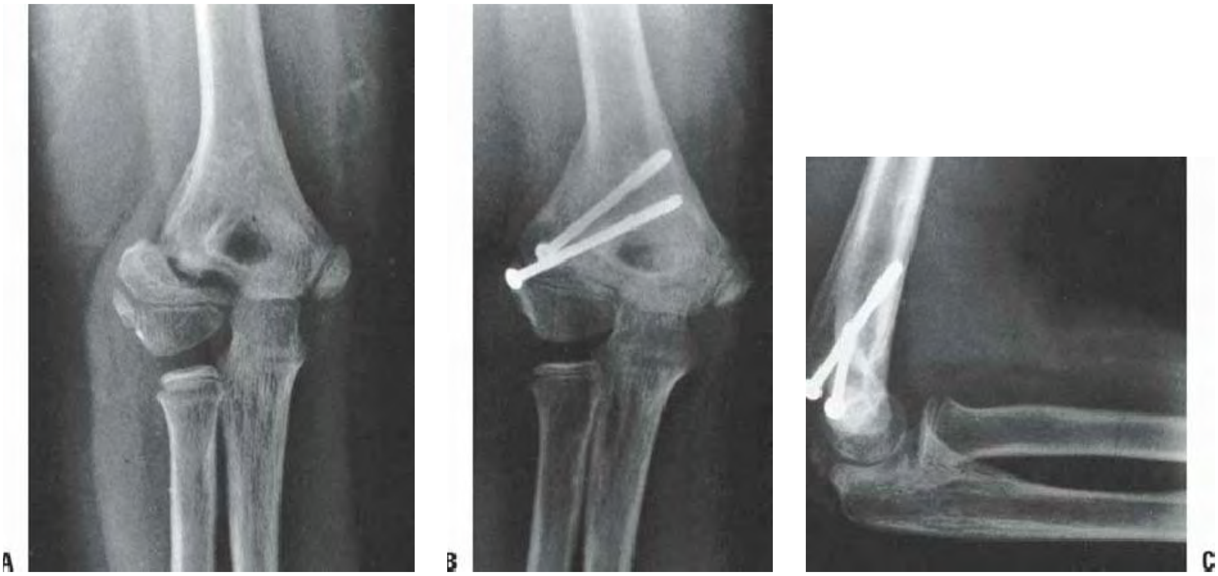


FIGURE 33-62. Nonunion of the lateral condyle. **A:** AP view of a child who sustained this fracture 4 months earlier. Symptoms consisted of pain and decreased range of motion. **B:** AP projection after stabilization of the condylar fragment with bone screws and bone grafting of the nonunion. **C:** Lateral projection.

FIGURE 33-63. Medial epicondyle fracture with elbow dislocation. **A, B:** AP and lateral views of the elbow showing an elbow dislocation with associated medial epicondyle fracture. **C, D:** Intraoperative images after reduction of the elbow dislocation and open reduction of the medial epicondyle fracture with interfragmentary screw fixation.

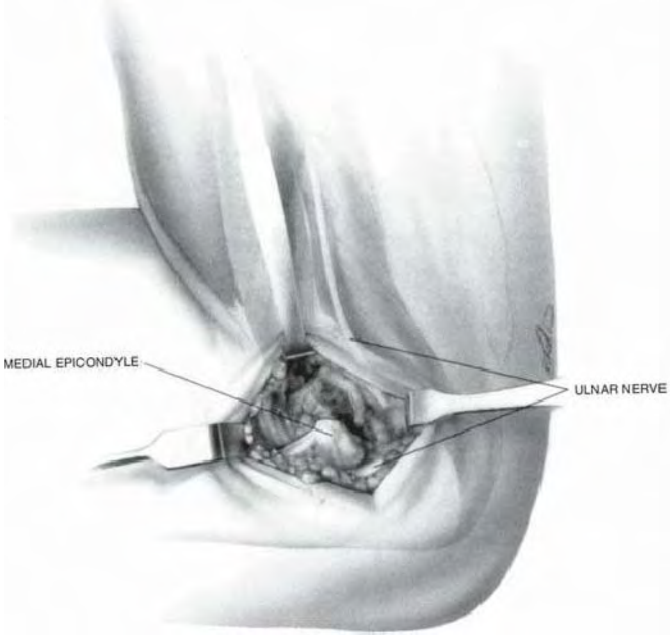


FIGURE 33-64. Traditionally, the patient is supine with the arm extended on a hand table. Alternatively, prone positioning with the shoulder internally rotated and the hand and forearm on the lumbar spine will place the medial epicondyle in an easily accessible position. A small longitudinal incision is made just anterior to the medial epicondyle that can be extended to identify the ulnar nerve if needed. After the skin and the subcutaneous tissues are divided, the fracture is hidden only by hematoma, which should be evacuated. The fragment can be grasped with a sharp towel clip or a small fracture clamp to pull it distally, allowing irrigation of the joint and exposure of the surfaces of the fracture with a small periosteal elevator. Although it is not necessary to identify the ulnar nerve if there are no symptoms preoperatively, it is essential to know its general location and that it is not at the fracture site. The nerve does not have to be disturbed to reduce and fix this fracture. It usually lies along the posterior margin of the fracture.

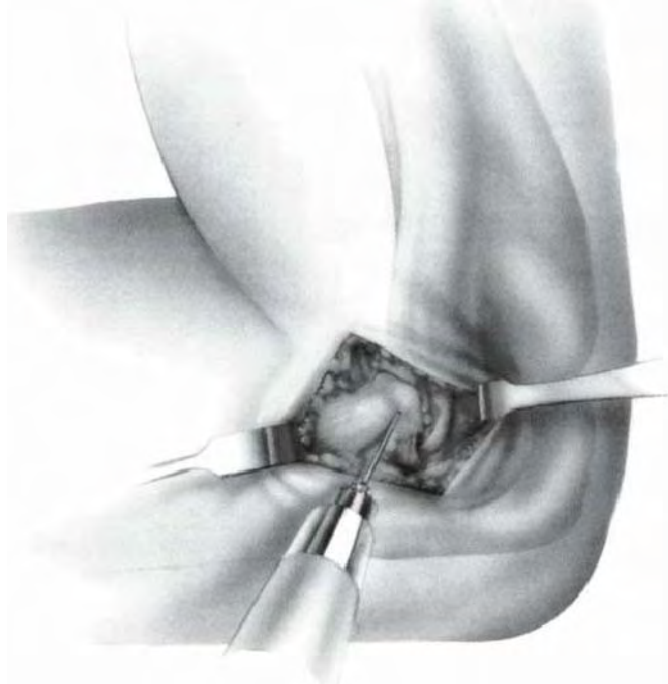


FIGURE 33-65. The fracture is reduced with the towel clip. Wrist and elbow flexion helps minimize distractive soft-tissue forces on the fragment. The fragment is fixed with an appropriately sized cannulated screw or two K-wires. A screw will allows compression and early motion, but may be prominent and require later removal. We prefer a screw for larger patients and athletes likely to stress the fracture early, as well as in cases of elbow dislocations to allow early motion. K-wires can also provide excellent fixation and can be removed easily in the physician's office after 3 to 4 weeks. It is relatively easy to pass the wires through the skin, separate from the incision. The assistant holds the fragment in place with the clamp in one hand while approximating the skin edges with the other so that there will not be undue tension on the skin around the wires after the incision is closed. The wires may also be placed through the incision and cut long, and the skin is pulled over the wires, allowing them to puncture through the skin at the appropriate spot. The wires are advanced to engage the opposite cortex. When the proper placement is confirmed, the wires are bent over outside of the skin. Sterile felt is placed around the pins to protect skin and prevent pin migration. As this is an extra-articular fracture and the main purpose of surgery is to restore the origin of the medial elbow ligaments and the flexor-pronator muscle origins, perfect reduction is not needed. Thus, an alternative, easy method to reduce and stabilize the fracture if the fragment is large enough for a lag screw follows: (a) drill a 2.5-mm pilot hole for the screw under direct visualization up the distal humerus medial column through the exposed cancellous bone at the fracture prior to reduction, (b) drill a hole through the center of the medial epicondylar fragment, (c) place a 25 to 35 mm partially threaded 4-mm screw through the medical epicondylar fragment until the threads exit the fractured surface, and (d) then place the threaded tip of the screw in the pilot hole of the distal humerus medial column and tighten the screw to reduce the medial epicondylar fragment. Elbow flexion and forearm pronation during screw tightening will make it easier. After wound closure, the arm is placed in a long arm cast. Sterile foam may be placed in the antecubital space to allow for any swelling. The circular cast can be lighter, stronger, and more comfortable than the usual splint.

both pronation and supination, one may attempt percutaneous reduction. If there is <45 degrees pronation and supination following attempted percutaneous reduction, one may proceed with an open reduction—accepting less deformity in those nearing skeletal maturity. How much displacement to accept is also rather subjective, but to offer rough guidelines for a child younger than 10 years (Fig. 33-67), the authors will accept up to 45 degrees of angulation and 33% translation before resorting to open reduction. In a child older than 10 years, up to 30 degrees of angulation and 3 to 5 mm of translation may be accepted.

Multiple manipulation techniques for closed reduction have been described, and because of the poorer results described after open treatment, knowledge of all methods is useful in attempts to achieve an acceptable closed reduction. The Patterson technique consists of traction and varus stress, combined with digital pressure over the radial head. Another method involves an assistant pushing the radial shaft laterally with two thumbs while the elbow is extended, and the radial head is pushed medially by the

FIGURE 33-66. **A, B:** A dislocated elbow with a medial epicondyle fracture. The medial epicondyle fragment is in the joint. **C, D:** The results after open reduction and fixation with a small screw. It is important that the screw has good purchase. This may be accomplished by engaging the opposite cortex with cortical screws, or using a cancellous screw. A washer may be used in cases of small fragments in danger of splitting with screw compression.

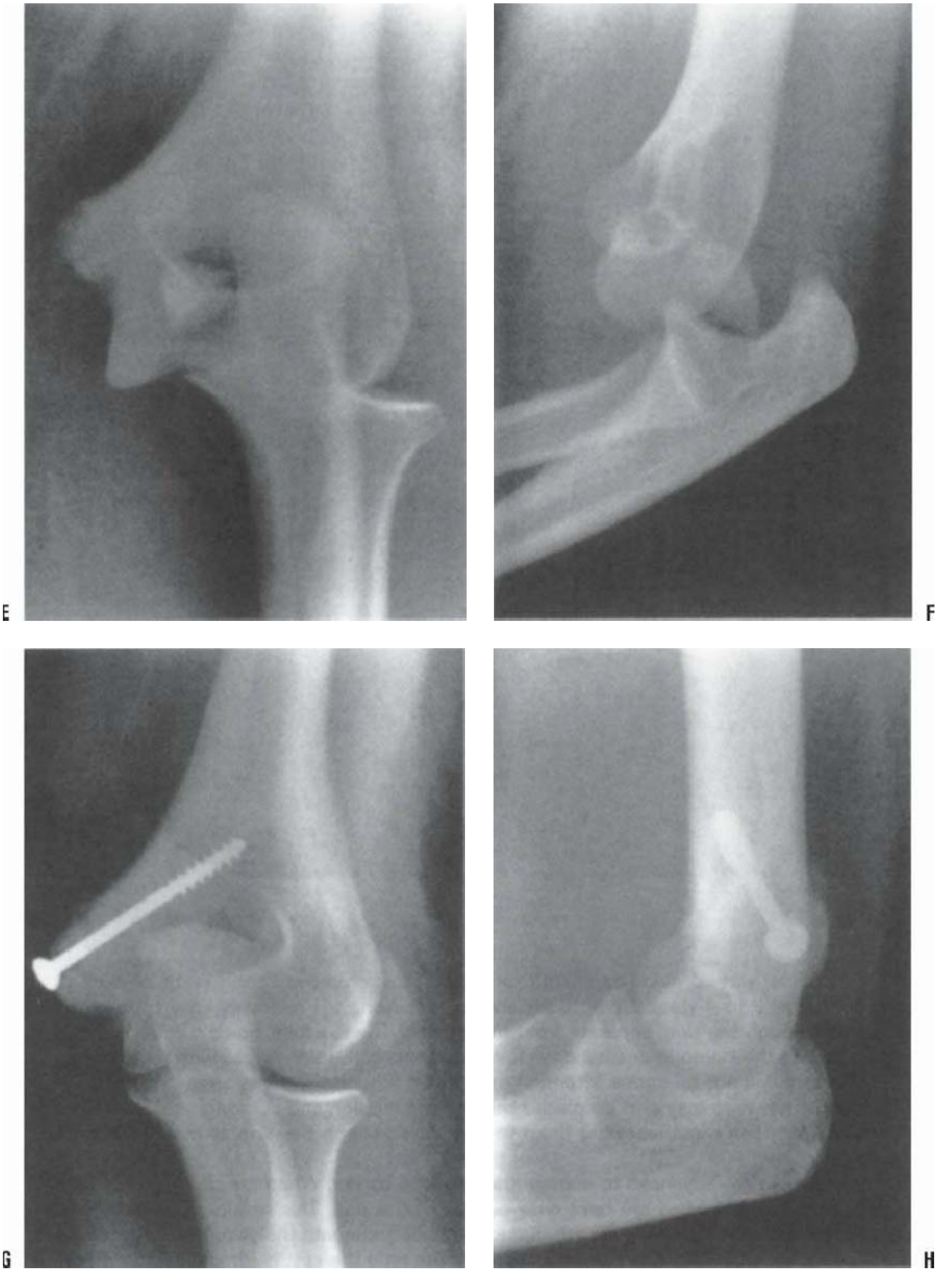


FIGURE 33-66. *(Continued)* **E, F:** The AP view of a younger child with a displaced medial epicondyle fracture. **G, H:** Fixation with two nonparallel 0.62-mm K-wires. The nonparallel configuration of the wires makes displacement or pulling out unlikely. They are easily removed in the physician's office. (A–D: Reproduced with permission of Children's Orthopaedic Center, Los Angeles, CA.)

FIGURE 33-67. Impacted radial neck fracture in a boy who is 6 years and 5 months old. **A:** Angulation measures 30 degrees. **B:** Nine months later, alignment is normal without treatment. The child regained full range of motion.

surgeon (Fig. 33-68) (118). Kaufman et al. (119) described pressing the surgeon's thumb on the anterior radial head while the forearm is maximally pronated as the elbow is at 90 degrees flexion. Monson reported placing the forearm in 90 degrees of supination to produce an apex anterior deformity in the typical laterally displaced fracture. Posteriorly directed pressure is then applied to the proximal radial shaft to reduce the deformity (120). Wrapping the arm firmly in an Esmarch bandage produces compression and elongation forces, which may also reduce the fracture. Alternatively, a percutaneous pin introduced proximally or a flexible IM wire introduced distally can be used to manipulate and stabilize the proximal fragment (121–123). A percutaneous pin can also be placed into the fracture and used to lever the radial neck and head back on the distal fragment. Open reduction is performed when these methods fail to produce an acceptable reduction. Another indication for open reduction is a displaced Salter-Harris type IV fracture involving more than one-third of the articular surface. Fixation may be achieved with IM fixation from the distal metaphysis (Figs. 33-69 and 33-70) or by K-wires or small screws placed obliquely across the fracture. A transarticular pin through the humerus should usually be avoided. Percutaneous fixation is removed in 3 to 4 weeks to begin elbow range of motion.

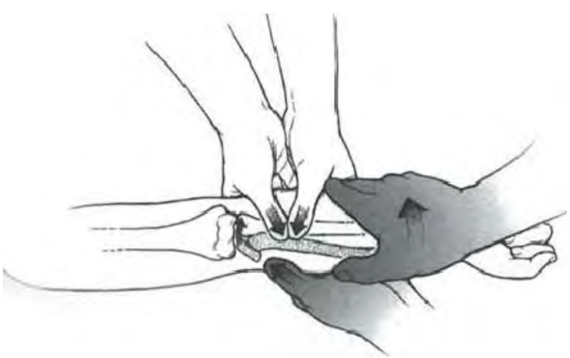


FIGURE 33-68. Displaced radial neck reduction technique using manipulation of the proximal radius with the elbow extended and hand supinated. (From Neher CG, Torch MA. New reduction technique for severely displaced pediatric radial neck fractures. *J Pediatr Orthop* 2003;23:626–628.)

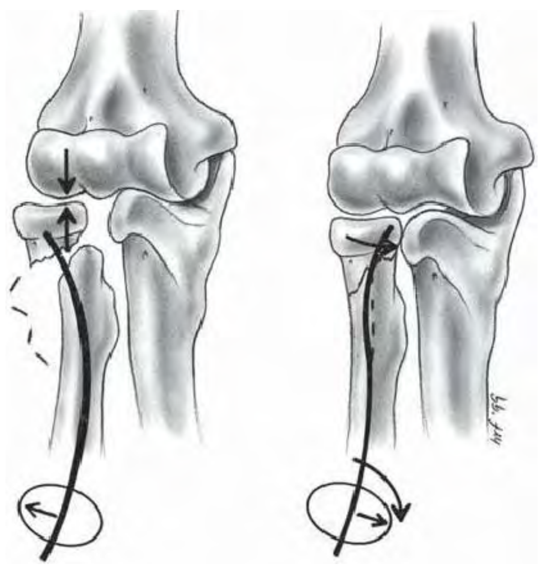


FIGURE 33-69. Radial neck fractures may be reduced by introduction of a percutaneous wire from the distal metaphysis. The wire is rotated after it engages the proximal fragment. (From Gonzalez-Herranz P, Alvarez-Romera A, Burgos J, et al. Displaced radial neck fractures in children treated by closed IM pinning (Metaizeau technique). *J Pediatr Orthop* 1997;17(3): 325–331.)

FIGURE 33-70. Monteggia-equivalent fracture treated with IM reduction and fixation. **A, B:** AP and lateral view of a Monteggia-equivalent fracture with a displaced, oblique ulna fracture and completely displaced radial neck fracture, but intact radiocapitellar joint. **C, D:** The ulna was fixed with an IM nail, and the radial neck fracture was reduced and pinned using the Metazeau technique (shown in Fig. 33-30). **E, F:** Late follow-up after implant removal shows good alignment of the ulna and radiocapitellar joint. (Case courtesy of Ken Noonan, MD.)

CLOSED, PERCUTANEOUS, AND OPEN REDUCTION OF RADIAL HEAD AND NECK FRACTURES

The consensus in the literature that the results of open reduction for this fracture are worse than the results of closed reduction may be because these initial fractures were worse. There is also the belief, however, that the surgery itself, along with the usual methods of internal fixation, contributes to the poor results. For this reason, the technique of percutaneous reduction, initially attributed to Wilkins (124), described by others (125, 126), and recently popularized (127, 128), is a method of reduction that may be superior to open reduction for most fractures that fail closed reduction. Percutaneous reduction is a viable choice because many radial head fractures, once reduced, are stable without internal fixation, which is true with open reduction as well (129).

Regardless of the severity of the fracture and the amount of displacement, the procedure is begun with an attempt at closed reduction because any improvement in the position of the fragment makes the percutaneous reduction easier (Figs. 33-71 to 33-79).

Postoperative Care. After reduction, the wound is closed and a cast is applied as with a closed fracture. Depending on the stability and the amount of remaining soft-tissue attachments, the cast may be left in place for 3 to 6 weeks, although the sooner the motion is started, the better. Because avascular necrosis and delayed healing may occur, the surgeon may decide on longer immobilization if no soft-tissue attachments remain or resorption of the fracture site is seen.

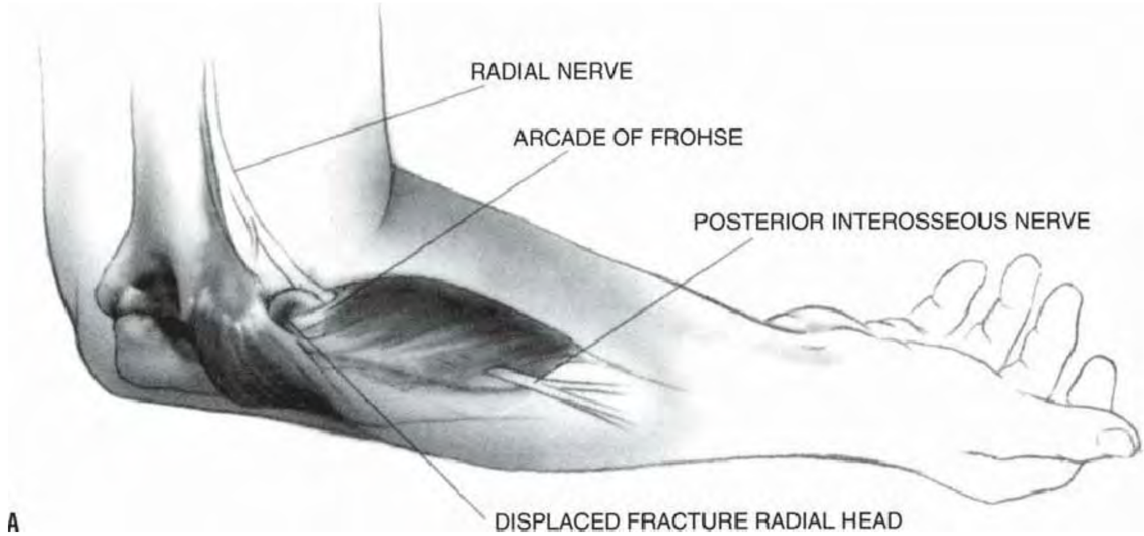
Complications. Complications of this fracture and its treatment include loss of forearm rotation, radioulnar synostosis,

Text continued on page 1750

Closed, Percutaneous, and Open Reduction of Radial Head and Neck Fractures (Figs. 33-71 to 33-79)

FIGURE 33-71. Closed, Percutaneous, and Open Reduction of Radial Head and Neck Fractures. The closed reduction of this fracture is ideally accomplished using an image intensifier so that the radial head can be rotated to visualize the maximal deformity. Multiple techniques for closed reduction are described. The first is that described by Kaufman et al. (119). This technique is easier, does not require a skilled assistant, and has a fairly high success rate. In this technique, the elbow is flexed to 90 degrees to relax the capsule. The surgeon holds the arm at the wrist while the opposite hand is used to effect the reduction. This is done by rotating the forearm while the thumb of the other hand palpates the radial head. The arm is rotated until the maximum deformity is palpated, and then the thumb is used to manipulate the radial head back into position. Continuing forearm rotation while pushing quite firmly is often effective.

FIGURE 33-72. If the Kaufman method fails, the method described by Patterson can be attempted (130). In this technique the elbow is extended, the forearm is supinated, and a varus stress is applied to the elbow while the surgeon attempts to reduce the fragment. If reduction is successful after these methods, the arm should be rotated through a range of pronation and supination while viewed under image intensification to be sure that the reduction is stable. This also determines the residual angulation, and the surgeon can observe the range of motion. Sixty degrees of pronation and supination is usually acceptable.



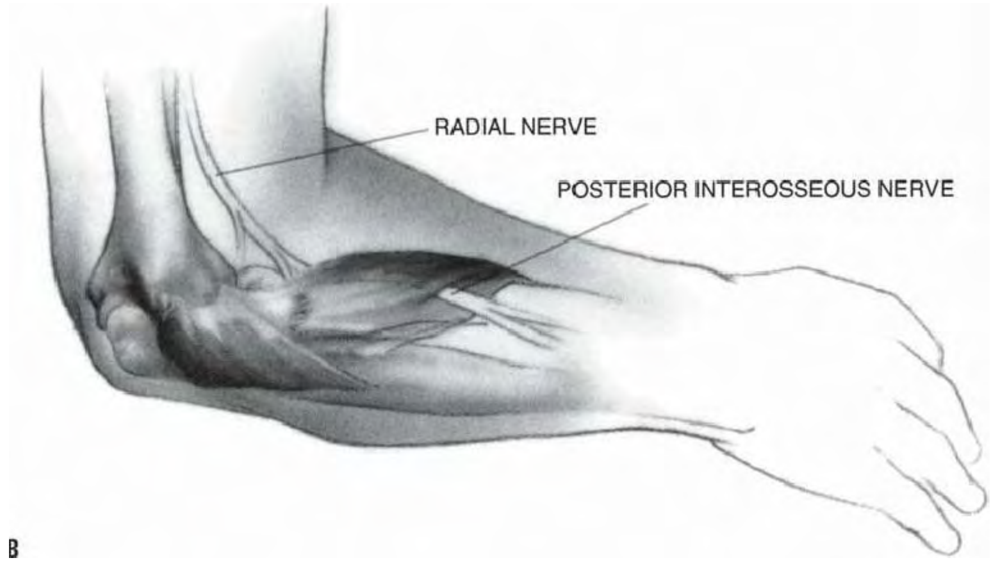
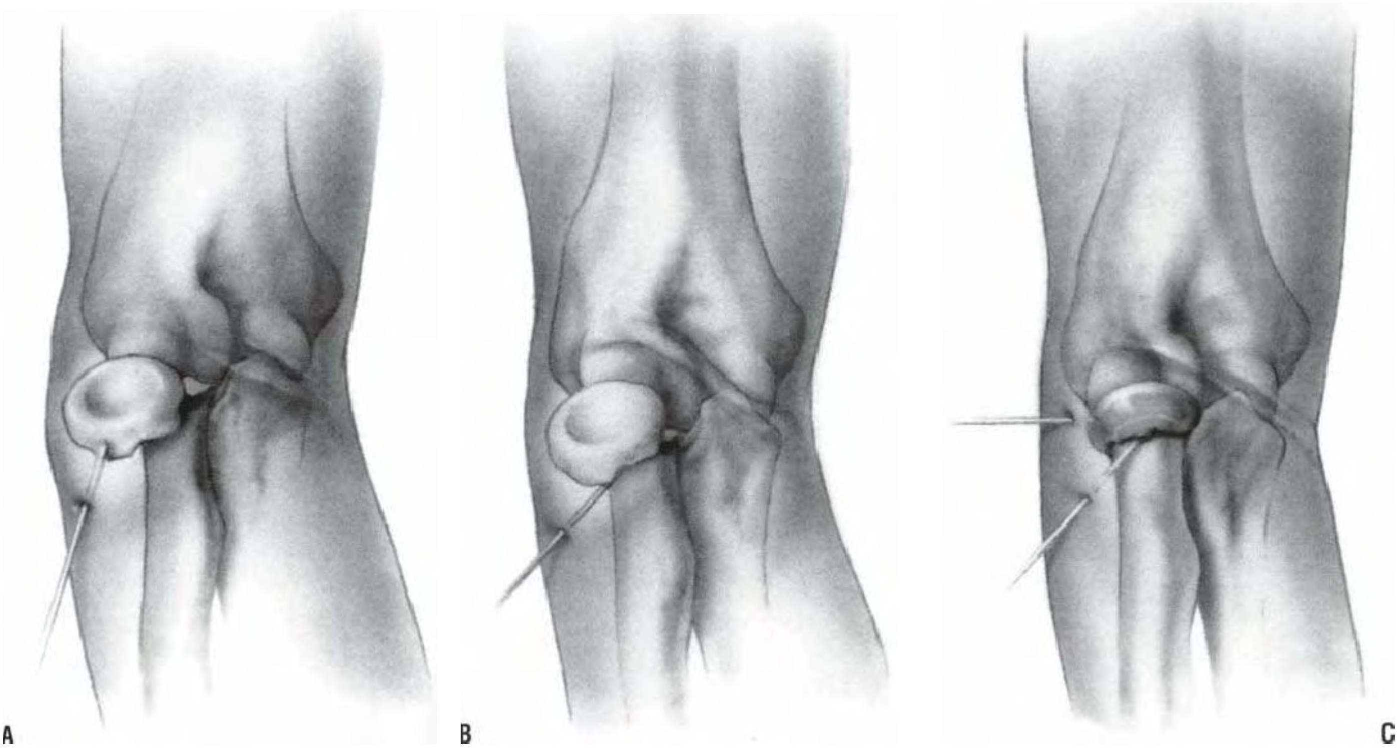


FIGURE 33-73. If closed reduction is not successful, the next step should be reduction by the percutaneous technique. This step usually requires a general anesthetic. The patient is positioned at the edge of the operating table with the arm on a radiolucent arm board. A tourniquet is not necessary. The only equipment necessary is a small blade to make an entry wound and Steinmann pins of sufficient size to resist bending. The main anatomic consideration is the location of the posterior interosseous nerve. This nerve, a branch of the radial nerve, enters the arcade of Frohse just distal to the fracture site. When the forearm is supinated **(A)**, the nerve lies posteriorly, and when the forearm is pronated **(B)**, the nerve lies anteriorly. The entry site should be at the point of maximal displacement, in pronation or supination to keep the nerve out of harm's way. The entry site is distal to the fracture and can be determined by using the image intensifier to line up the Steinmann pin in the desired position and with the desired angle to the radial head fragment.



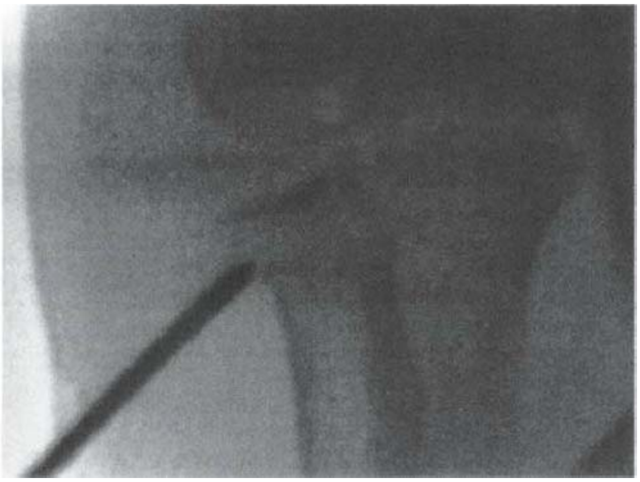
A B C

FIGURE 33-74. The technique can be used with leverage on the fragment or direct pushing on the fragment. Often both these procedures are necessary. With the image intensifier, the Steinmann pin is inserted. The forearm is rotated until the image is at a right angle to the plane of displacement (i.e., the maximal angulation is seen). The fragment **(A)** can be pushed proximally. The pin **(B)** is inserted into the fracture site, and the fragment is levered upward to bring the fracture surfaces closer to a more parallel plane. When this is achieved **(C)**, the fragment is pushed back into place by the surgeon's opposite thumb, a second Steinmann pin, or the same pin.

A

B

FIGURE 33-75. The AP **(A)** and lateral **(B)** views of a 12-year-old girl with a severely displaced radial head fracture. Note the associated olecranon fracture that frequently accompanies radial head and neck fractures. This required no treatment apart from immobilization. Closed reduction under general anesthesia was not successful because of the severe displacement. The K-wire



C

D

E

FIGURE 33-75. *(Continued)* **(C)** pushes the radial head back into position. Four weeks later **(D, E)**, the cast was removed. The patient regained full motion. Another method of semiclosed manipulation of the fracture was described by Metaizeau (237) and is popular in Europe (238) (see Fig. 33-69). A flexible IM nail is inserted in the distal radial metaphysis and advanced to the fracture site. Using the bend in the tip of the nail, the nail is advanced under fluoroscopic control into the radial neck fragment, and then the rod is rotated to reduce the fracture. The technique has the advantage of both reducing and stabilizing the fracture, and excellent results have been reported.

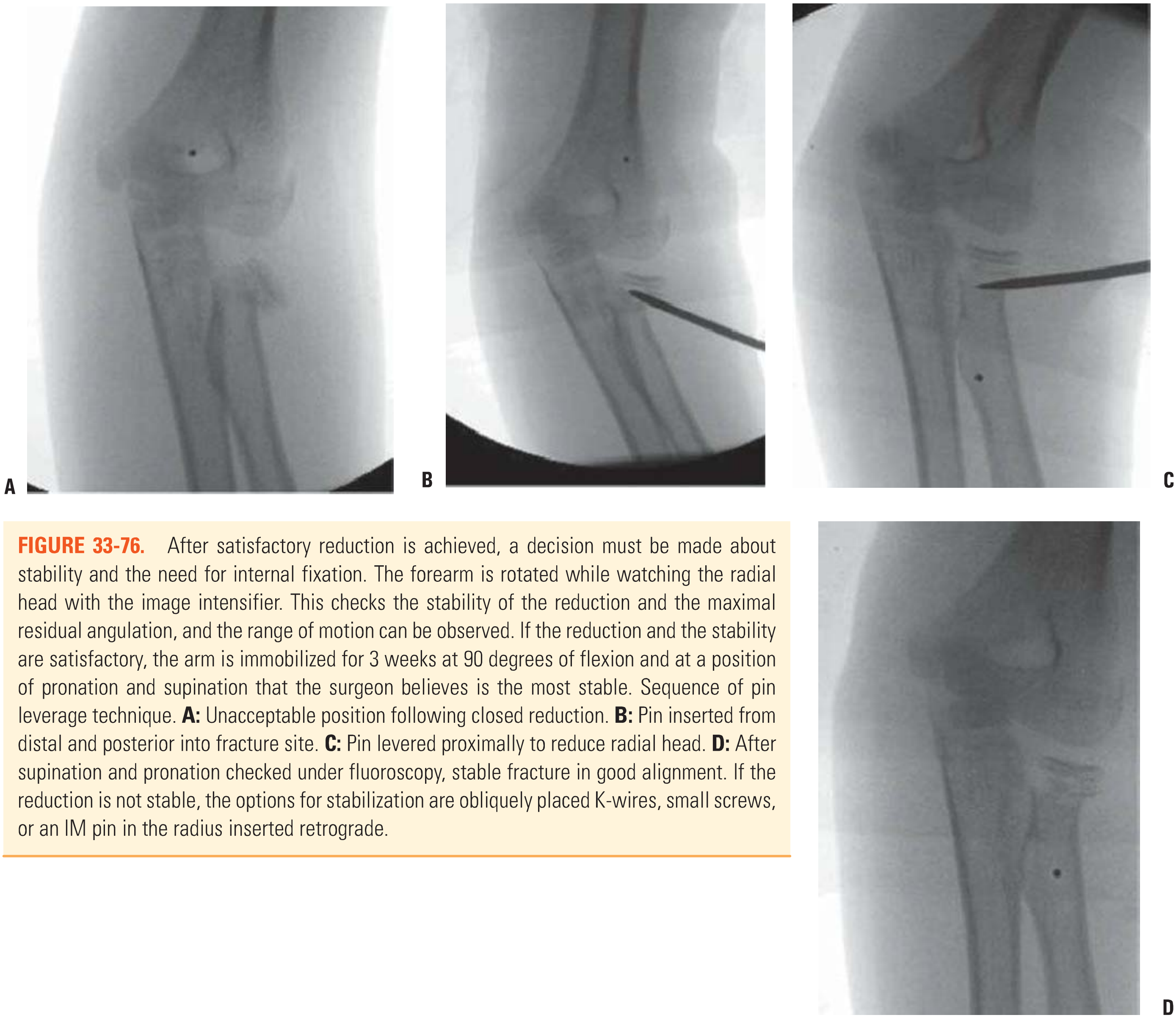


FIGURE 33-76. After satisfactory reduction is achieved, a decision must be made about stability and the need for internal fixation. The forearm is rotated while watching the radial head with the image intensifier. This checks the stability of the reduction and the maximal residual angulation, and the range of motion can be observed. If the reduction and the stability are satisfactory, the arm is immobilized for 3 weeks at 90 degrees of flexion and at a position of pronation and supination that the surgeon believes is the most stable. Sequence of pin leverage technique. **A:** Unacceptable position following closed reduction. **B:** Pin inserted from distal and posterior into fracture site. **C:** Pin levered proximally to reduce radial head. **D:** After supination and pronation checked under fluoroscopy, stable fracture in good alignment. If the reduction is not stable, the options for stabilization are obliquely placed K-wires, small screws, or an IM pin in the radius inserted retrograde.

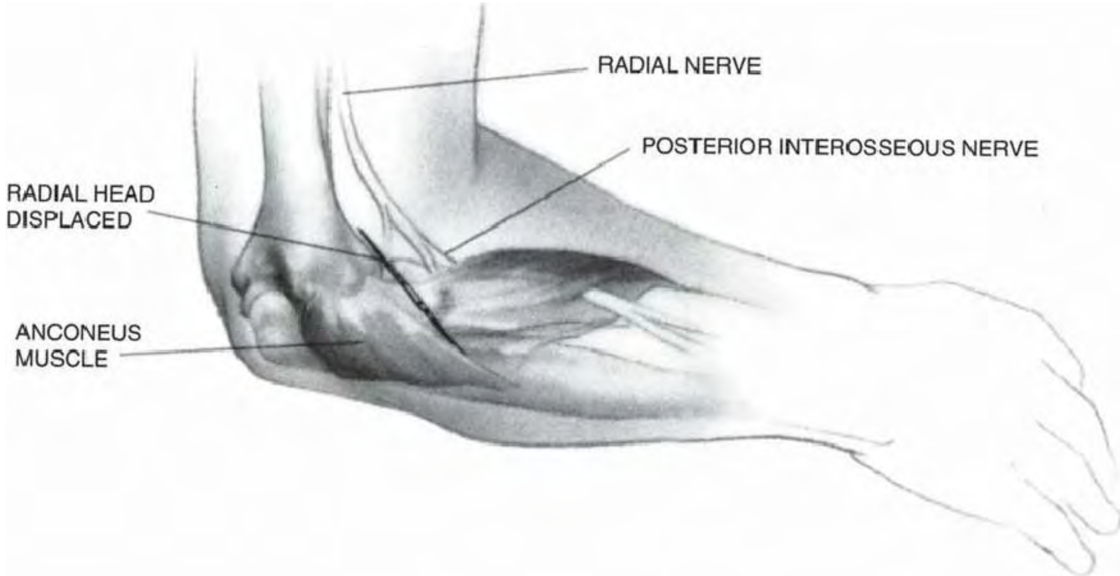


FIGURE 33-77. If the above methods fail to achieve a satisfactory reduction, open reduction is necessary. This usually occurs in fractures that are completely displaced and often angulated 90 degrees or more, with the radial neck lying laterally and the radial head articular surface facing directly lateral. The classic posterolateral approach to the radial head is ideal for open reduction. The patient is positioned either supine or prone. The arm is pronated to place the posterior interosseous nerve anteriorly out of the way of the surgical dissection. With the elbow flexed 90 degrees, a straight incision is made, beginning on the lateral epicondyle of the humerus. The incision angles distally toward the ulna, crossing the head of the radius.

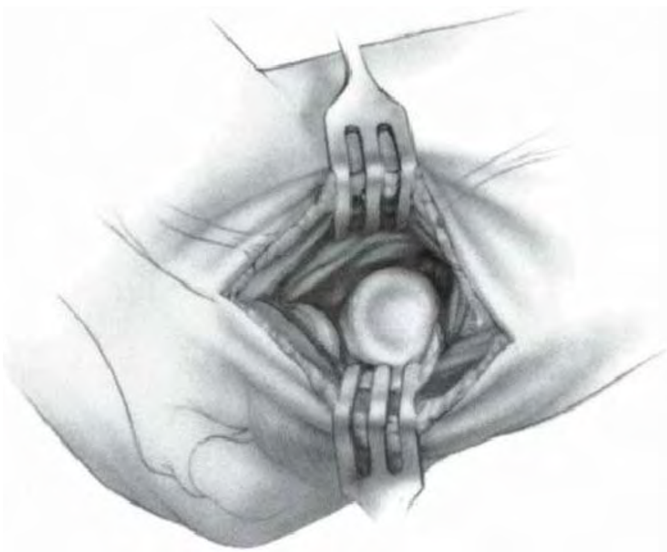


FIGURE 33-78. The fascia is incised in line with the incision. The interval sought is that between the anconeus muscle posteriorly and the extensor carpi ulnaris muscle anteriorly. The origin of these muscles blends on the humeral epicondyle; therefore, it is easier to find the interval distal. The interval can be widened by sharply dissecting some of the fibers of the extensor carpi ulnaris from the epicondyle. Finding the capitellum under the capsule and then working distally will aid in keeping exposure in the correct plane. After the radial head is exposed, an effort to reduce it should be made with as little disturbance to the soft-tissue attachments as possible. If the radial head is outside of an intact orbicular ligament, the ligament must be divided and repaired. After the radial head is reduced, the forearm should be pronated and supinated to determine the stability of the reduction. It is usually stable due to fracture interdigitation, in which case no fixation is used. If it is unstable, however, fixation of some type is necessary. Placement of a pin through the capitellum, across the radial head, and into the radial neck should be avoided because the complications from this fixation are high (129, 131). Obliquely placed pins are the most common fixation method used.

FIGURE 33-79. Two obliquely placed pins, from proximal lateral edge of radial head fragment to the medial cortex of the distal fragment, in patient reduced by Wallace method above. The wires can be left long outside the skin and bent for later removal, or cut flush with the bone to avoid the need for subsequent surgical removal. If there is a metaphyseal fragment, fixation with small screws is a good choice, and if they are small enough (e.g., 1.5 mm) and placed such that they will not interfere with growth, they can be left in place.

injury to the posterior interosseous nerve, nonunion, premature physeal arrest, and avascular necrosis of the radial head (116, 117). These complications are observed without treatment, unless they are progressive or disabling.

Radial Head Dislocation. Traumatic isolated dislocation of the radial head is a rare injury. The radial head dislocates anteriorly. Most of these injuries actually represent occult Monteggia injuries, with plastic deformation of the ulna and anterior dislocation of the radial head (Fig. 33-80). Treatment consists of closed reduction and immobilization, with the elbow in flexion and supination.

Occasionally, a child with a previously undiagnosed congenital radial head dislocation falls and injures the elbow.

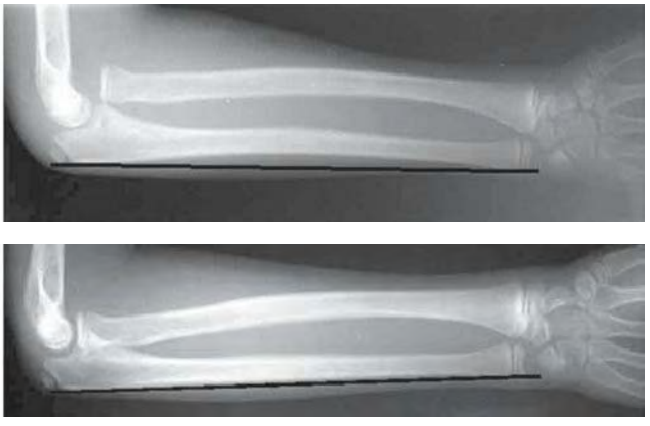


FIGURE 33-80. Dislocated radial head with plastic deformation of the ulna. **A:** A 10-year-old boy presented with elbow and forearm pain after a fall. Radiograph shows complete dislocation of the radiocapitellar joint with plastic deformation of the ulna (note the anterior bow of the ulna demonstrated by a line drawn along its subcutaneous border). **B:** Contralateral, uninjured arm. Note the straight subcutaneous border.

Congenital dislocation of the radial head is distinguished from traumatic dislocation by the fact that congenital dislocation is usually in a posterior direction, and the articular surface of the radial head is convex or flat, rather than having the normal concave contour. The lack of forearm rotation has often not been recognized by the family previously.

Nursemaid's Elbow. Nursemaid's elbow, or pulled elbow, is a very common injury in children between 1 and 4 years of age. Typically, the child is being held by the hand and suddenly falls, or is pulled upward. Pain is variable. The child will not move the arm and will hold it with the elbow slightly flexed and the forearm pronated. Radiographs are not indicated initially and are normal because the injury consists of subluxation of the annular ligament, rather than true joint subluxation (132) (Fig. 33-81). When longitudinal traction is applied to the child's pronated arm, the annular ligament slips off the radius and rides up onto the broader radial head and/or into the joint, like a turtleneck pulled over one's head. The child is unwilling to move the elbow until the stretched annular ligament is reduced.

There are many effective reduction maneuvers such as flexing the elbow above 90 degrees, then fully and firmly supinating the forearm while pressing firmly on the radial head with a thumb. A click or a snap is often felt as the ligament snaps back into place. Occasionally, it is necessary to fully pronate, and then supinate, the forearm to achieve reduction. This is especially true for delayed cases. The child should begin to move the arm within a few minutes after reduction. If this is not the case, then radiographs should be obtained to rule out occult fracture, and the arm may be immobilized in a splint for 2 to 3 days. Normal use of the arm should be expected within 1 day after splint removal. Recurrences are not uncommon and are treated in the same manner as the initial injury. Eventually, children outgrow this condition, and long-term sequelae have not been reported.

Olecranon Fractures. Olecranon fractures are uncommon in children. Up to 50% of the time, an olecranon fracture is associated with other injuries (133). The most common mechanism of olecranon injury is an avulsion or a flexion injury that disrupts the posterior periosteum and fractures the cortex (Fig. 33-82). Extension injuries leave the posterior periosteum intact, but often result in angulated fractures and associated fractures attributable to varus or valgus forces acting on the extended elbow. Olecranon fractures may also result from a direct blow that causes comminution but minimal displacement because the periosteum remains intact. Children with osteogenesis imperfecta can present with an olecranon sleeve fracture (Fig. 33-83).

If displacement is minimal, treatment consists of splint or cast immobilization for 2 to 3 weeks. When displacement is >4 mm in metaphyseal bone, or there is a >2 mm joint step-off in the anterior two-thirds of the coronoid fossa, closed reduction is recommended. Open reduction with internal fixation is performed when closed reduction fails, or when maintenance of reduction is difficult because of fracture instability

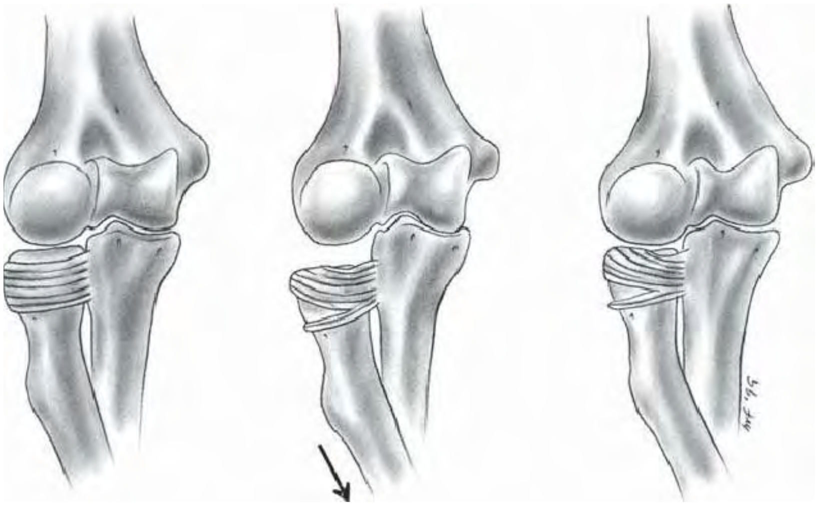
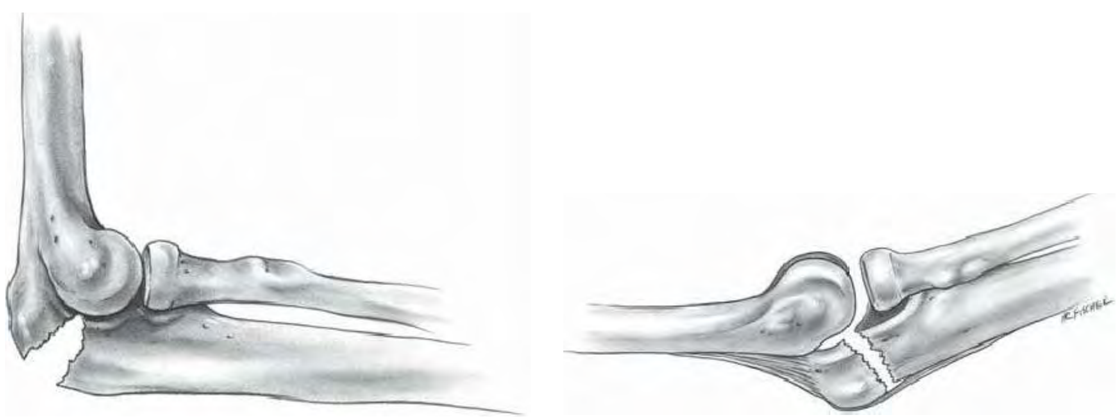


FIGURE 33-81. Pulled elbow, or "nursemaid's elbow," occurs as the radial head moves distally. The annular ligament is partially torn and displaced onto the radial head. (From Rang M. *Children's fractures*, 2nd ed. Philadelphia, PA: JB Lippincott, 1983, with permission.)

(134–136) Internal fixation is achieved by standard osteosynthesis, using the AO tension band technique or a modification, which involves placing the distal wire hole anterior to the axis of the IM K-wires (137). This provides additional compression forces across the articular surface of the olecranon (Fig. 33-84). In younger children, heavy nonabsorbable suture may be used in place of the figure-eight wire because healing is rapid, and this obviates the need for later wire removal if the pins are left subcutaneous and pulled out in the office. An alternative is to place two divergent compression pins or screws through percutaneous incisions (138).

Elbow Dislocation. Elbow dislocation is a relatively uncommon injury in young children; the peak incidence is in the second decade of life. Often there is an associated fracture, most commonly of the medial epicondyle, but occasionally of the coronoid process or the radial neck. Elbow dislocation is predominantly a male injury (70%) involving the nondominant arm (60%), with the great majority being posterior dislocations. The most common pattern is posterolateral displacement of the proximal radius and ulna articulation from the humerus, without disruption of the radioulnar articulation (139).



A B

C

FIGURE 33-82. Olecranon fractures. **A:** Avulsion or flexion injury is most common and requires reduction in extension. Internal fixation is frequently necessary to maintain reduction. **B:** Extension-type fracture leaves the posterior periosteum intact and may be reduced by flexing the elbow. **C:** Comminuted fractures result from a direct blow and may be minimally displaced.

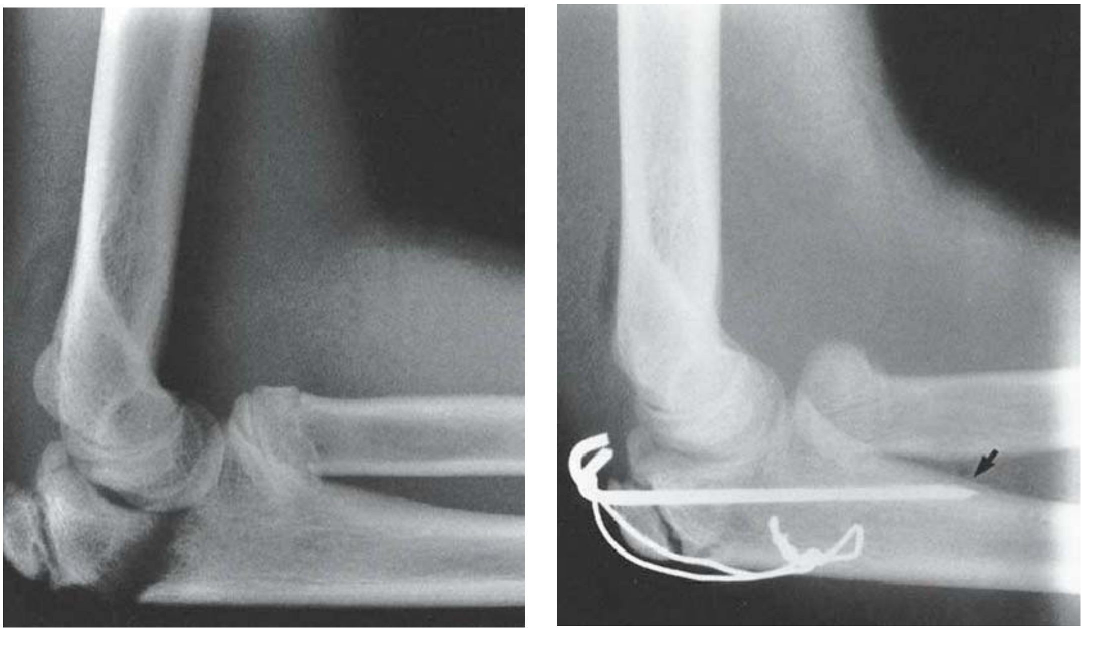
FIGURE 33-83. Olecranon sleeve fracture. This lateral radiograph taken at the time of injury shows an olecranon sleeve fracture in a 10-year-old child with a mild osteogenesis imperfecta.

Reduction is usually achieved in the emergency department, after establishing pain control and muscle relaxation. The reduction maneuver consists of pushing the olecranon anteriorly in the flexed elbow, similar to reduction of a supracondylar fracture, or longitudinal traction. The surgeon should be aware of possible interposed soft-tissue or bony fragments, including the ulnar nerve or medial epicondyle. A posterior splint is applied for 5 to 10 days; thereafter, elbow range of motion is initiated to minimize the risk of fixed contracture.

Complications. The most common complication is loss of motion. This can be minimized for stable reductions by initiating early motion 5 to 10 days after injury, though some have recommended a mean of 24 days of immobilization (139). Stiffness, in the absence of fracture, usually resolves within 6 to 8 months. The authors recommend static stretching devices if range of motion has not returned to a functional range (30 to 100 degrees) by 4 months after dislocation. When avulsion fractures are absent, surgical release of contracture may be required if the range of motion is less than functional 8 months or more after injury (140, 141). Neurapraxia involving the median or ulnar nerves occurs in approximately 10% of dislocations and usually resolves within 3 months.

FOREARM AND WRIST FRACTURES

Fractures of the forearm and wrist are common in children, accounting for 30% to 40% of all fractures in children (134, 142). There may be an increasing incidence of distal forearm fractures related to increased body mass, decreased bone mineral content, and changing patterns of activity such as rollerblading (143). Most forearm fractures occur in children older than 5 years. The location of the fracture advances distally with increasing age of the child, probably because of the anatomic changes in the metaphyseal-diaphyseal junction that occur with maturity (144). The younger child's radius is more elastic and has a gradual transition of the diameter of



A

B

FIGURE 33-84. Olecranon fracture. **A:** Lateral projection showing displaced intra-articular olecranon fracture. There is also an impacted radial neck fracture. **B:** Treatment with standard tension band technique. The slight variation from standard fixation is to capture the anterior cortex of the ulna with the K-wires (*arrow*).

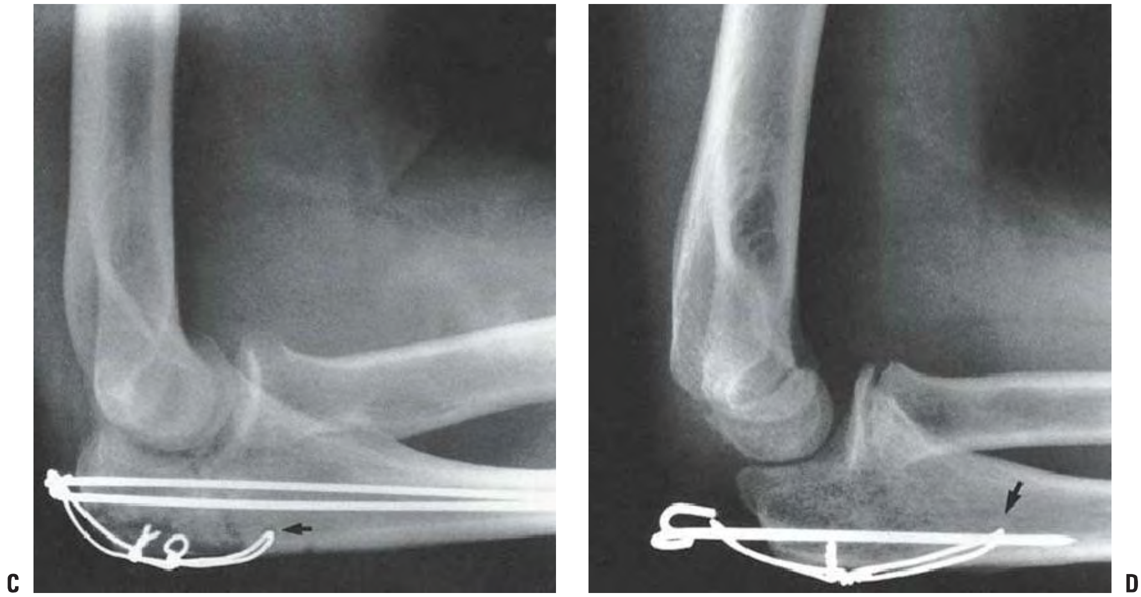


FIGURE 33-84. *(Continued)* **C:** Standard AO technique, used in a similar case, with parallel IM K-wires with the tension band transverse hole inferior (*arrow*). **D:** Modified AO technique performed by placing the transverse hole anterior to the K-wires (*arrow*). The compressive force is anterior to the pin, which prevents the articular surface of the semilunar notch from gapping. Ideal joint compressive forces are obtained with placement of the K-wires down the middle axis of the ulna and the transverse hole anterior to this axis.

the radius from shaft to metaphysis, whereas the transition in diameter is more abrupt at the metaphyseal–diaphyseal junction in the older child. The distal forearm is the site of 70% to 80% of fractures of the radius and ulna. Most of these are nonphyseal. Physeal separations are more likely in early adolescence because of the more adult shape of the radius, which concentrates stress closer to the epiphysis. In 10% to 15% of patients, forearm fractures are associated with elbow fractures. This highlights the importance of a thorough clinical and radiographic examination of the injured extremity.

Anatomically, the forearm is unique. The ulna is a fairly straight bone with a triangular cross section. The radius has a more complex, curved shape with a cylindrical proximal portion, a triangular middle portion, and a flattened distal third. The radius rotates around the ulna during forearm supination and pronation. There are three areas of soft-tissue interconnection between the radius and the ulna. Proximally, there is the radioulnar articulation, which is stabilized by the annular ligament. Centrally, the shafts of the two bones are connected by the interosseous membrane, which is wider distally. The fibers run obliquely from the ulna distally to the radius proximally. This helps transmit force to the ulna during load-bearing activities. Distally, the triangular fibrocartilage complex stabilizes the radioulnar joint by means of the ulnar collateral ligament and the volar and dorsal radiocarpal ligaments. The proximal and distal radioulnar joints are most stable in supination, and the interosseous membrane is widest with the forearm in a position of 30 degrees of supination. Because of these interconnections, both bones are often injured at the time of fracture, especially in diaphyseal fractures. When only one bone is broken, there may be damage to the proximal or distal radioulnar articulation.

Forearm and wrist fractures are usually classified into three major categories: fracture dislocations, fractures of the midshaft, and distal fractures. Fracture dislocations include the Monteggia and Galeazzi lesions. Midshaft fractures of the radius and ulna tend to follow three injury patterns: plastic deformation, greenstick fracture, and complete fracture. Distal fractures are either metaphyseal fractures or physeal separations. Each type of injury presents unique features with regard to mechanism of injury, recognition, and management.

Forearm Fracture Dislocations. The combination of forearm fracture with joint dislocation is less common than other types of forearm fractures. Misdiagnosis may result if radiographs of forearm fractures fail to clearly demonstrate the elbow and wrist joints. The peak incidence occurs between 4 and 10 years of age. The Monteggia lesion is more common and involves dislocation of the radial head. The usual mechanism of injury is a fall on the hyperextended arm. The Galeazzi lesion is uncommon in the skeletally immature and involves fracture of the radius with dislocation of the distal radioulnar joint, or distal ulnar physeal fracture.

Monteggia Fracture Dislocation. The Monteggia lesion should be suspected with any pediatric forearm fracture, including plastic deformation and minimally angulated greenstick fractures of the ulna. When the posterior border of the ulna deviates from a straight line on a true lateral radiograph, dislocation of the radial head should be suspected (145). A true lateral radiograph of the elbow provides the best assessment of the radiocapitellar joint. In the normal elbow, a line drawn down the long axis of the radial shaft will pass through the capitellum regardless of the position of flexion or extension of the elbow or radiographic view (146) (Fig. 33-85). Congenital dislocation of the radial head is distinguished from traumatic dislocation by the facts that congenital dislocation is usually posterior and the articular surface of the radial head is convex. At times, an MRI may help define the convexity or concavity of the radial head as well as the presence of inflammation/hemorrhage suggesting an acute injury. In contrast, anterior dislocation of the radial head is common with Monteggia fracture dislocation (147, 148).

Bado devised a classification system of four basic types of injury and several equivalent lesions. Type I involves anterior radial head dislocation (i.e., ulnar deformity apex anterior), which accounts for most childhood Monteggia injuries (Fig. 33-86). Type II fracture is the least common and entails posterior or posterolateral radial head dislocation. In type III lesions, the radial head is dislocated laterally, and the ulna fracture is usually in the proximal metaphyseal region. Type III injury accounts for 25% to 30% of pediatric Monteggia injuries. Type IV fracture dislocations involve anterior dislocation of the radial head, in combination with fracture of the radius and ulna. This may be considered a variant of the type I lesion. There are numerous Monteggia equivalents that represent a multitude of variations. For example, the ulna fracture may be combined with a radial neck fracture rather than a simple radial head dislocation (see Fig. 33-70). Segmental fractures and plastic deformation of the ulna are other forms of Monteggia-equivalent injury.

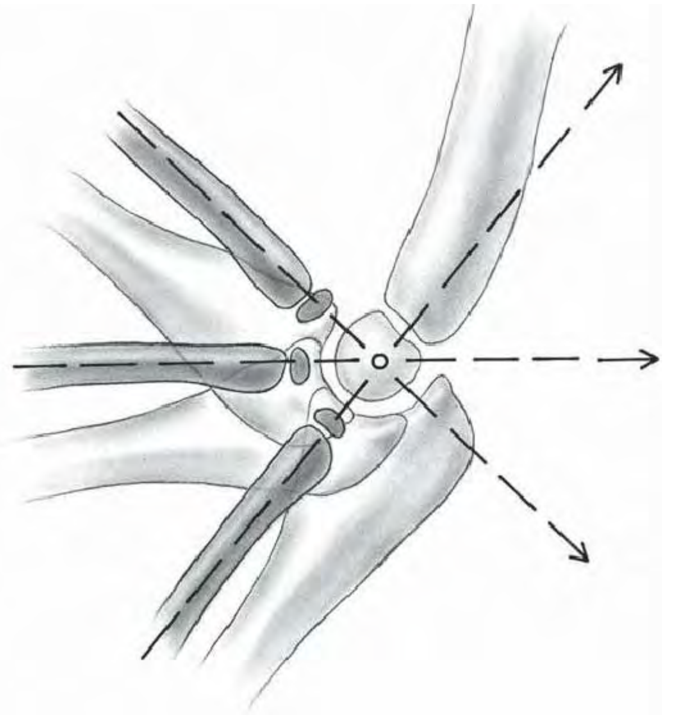


FIGURE 33-85. A true lateral radiograph of the elbow joint allows assessment of the integrity of the radiocapitellar joint. A line drawn down the long axis of the shaft of the radius will bisect the capitellum in all positions of flexion and extension. (From Smith F. Children's elbow injuries: fractures and dislocations. *Clin Orthop* 1967;50:25, with permission.)

A B C D

FIGURE 33-86. Type I Monteggia fracture reduced and stabilized with an IM nail in the ulna. **A, B:** AP and lateral radiographs of a type I Monteggia fracture with an unstable, widely displaced, oblique fracture of the ulna and an anterior dislocation of the radial head. **C, D:** AP and lateral views after closed reduction of the radiocapitellar joint and stabilization of the ulna fracture with a titanium elastic nail.

Treatment depends on the character of the ulnar fracture because stable, anatomic reduction of the ulna can maintain anatomic reduction of the radial head. Most Monteggia injuries in children younger than 12 years can be managed successfully by closed reduction and above-elbow casting. For a type I injury, the elbow is flexed >90 degrees with the forearm supinated. For a type II injury, the radial head may be best located in elbow extension and forearm supination (148, 149). Type III injuries are treated with a varus reduction, but are often difficult to treat with casting alone. Weekly follow-up with good quality elbow radiographs is suggested for 2 to 3 weeks to detect any recurrent radial head subluxation. Transient nerve palsies, most commonly of the posterior interosseous nerve, occur in approximately 10% of patients.

Surgical intervention is indicated when the reduction is unstable. Instability requiring surgical stabilization is more likely when there is an oblique fracture, or a very displaced fracture of the ulna (150) or delay in treatment. The percutaneous insertion of an ulnar IM pin is a simple and effective way to manage this problem. Alternatively, the ulnar shaft can be plated if the fracture pattern seems likely to shorten or angulate. On rare occasions, when the radial head is not reduced after correction of ulnar length and alignment, open examination of the joint is indicated. Interposition of the annular ligament or an intra-articular osteochondral fragment may be found. Transcapitellar pinning of the reduced radial head should be avoided whenever possible.

Complications. Delayed diagnosis is the most frequent complication associated with Monteggia fracture dislocations. Patients presenting <3 weeks after injury with persistent dislocation may be treated by closed reduction. If the ulna can be reduced and stabilized, the radial head will usually reduce and remain stable. Open reduction is indicated if closed reduction fails, which is usual when the injury is more than 4 weeks old. Chronic Monteggia injuries have been surgically treated by open reduction with elongation and bending ulnar osteotomy (151). Following excision of the interposed fibrocartilaginous mass, the annular ligament can be reconstructed from remnants of the ligament, from a strip of triceps fascia, or from other tissues (152). If open reduction for the treatment of a missed Monteggia fracture is performed when the patient is <12 years of age or within 3 years after the injury, good long-term clinical and radiographic outcomes can be expected (151, 153).

Galeazzi Fracture Dislocation. The classic Galeazzi lesion is a fracture of the distal third of the radius, without fracture of the ulna, and is associated with dislocation of the distal radioulnar joint. This is an uncommon injury in children. The triangular fibrocartilage complex is disrupted, and the distal ulna is dorsally displaced, as viewed on a lateral radiograph. Injury to the distal radioulnar joint is frequently overlooked, and persistent joint subluxation is responsible for poor long-term results (154). The Galeazzi-equivalent injury is much more common in children with open growth plates and consists of a fracture of the radius with a physeal fracture of the distal ulna (155). Treatment consists of closed reduction of the radius and ulnar physis with above-elbow casting in full supination or neutral position. Open reduction may be necessary if the ulna is buttonholed through periosteum, blocking reduction. Occasionally, it is necessary to place a smooth K-wire across the joint or the fracture to maintain reduction. Long-term problems with this injury include premature physeal arrest with ulnar shortening and loss of supination (156). Generally, reduction of the radius with concomitant reduction of the distal radioulnar joint and cast immobilization leads to good results even if the Galeazzi injury is not recognized (155).

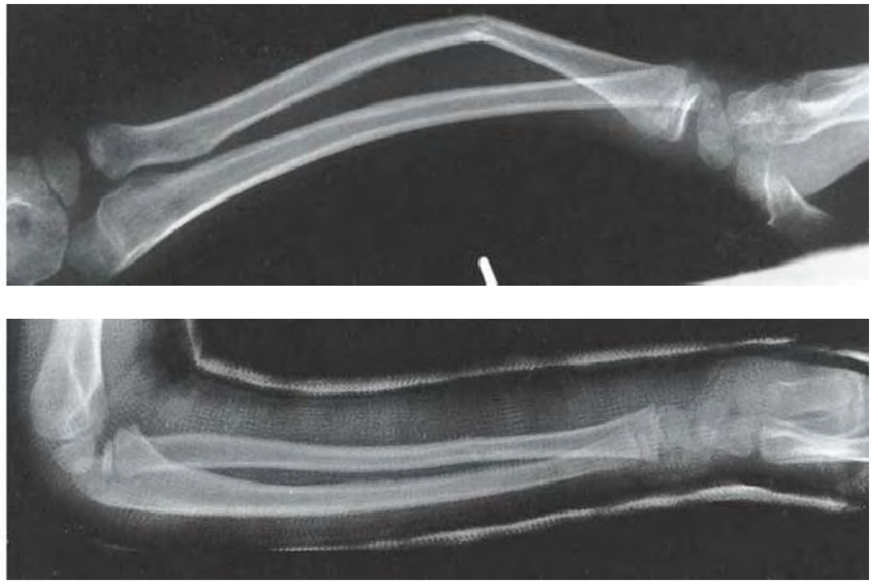
Midshaft Forearm Fractures

Plastic Deformation. Plastic deformation, or traumatic bowing, of the forearm is possible because of the elastic properties of young children's bones. This injury represents a series of microfractures that are not seen on radiographs. Bowing of both bones may occur, but plastic deformation of one bone is often associated with complete or incomplete fracture of the other forearm bone. Swelling and pain are usually less severe with plastic deformation than with complete fractures. This often facilitates examination. Reduction is recommended when deformity is cosmetically unacceptable, or there is >45 degrees loss of forearm rotation, which is difficult to assess in the painful fresh fracture. Remodeling capacity of this type of fracture is limited after 6 years of age. In children younger than 6 years, 15 to 20 degrees of angulation can be accepted, but more than 10 degrees angulation in older children may not remodel (157, 158).

Treatment of plastic deformation usually requires general anesthesia because a prolonged corrective force must be applied to permanently straighten the bone. The position of immobilization follows the principles outlined in the discussion of greenstick fractures, which follows.

Greenstick Fractures. A complete fracture of one cortex and plastic deformation of the opposite cortex characterize greenstick fractures. Most greenstick fractures represent a rotational malalignment, in addition to angular deformity (159). Apex-volar greenstick fracture is the most common type, and results from excessive supination forces applied to the distal segment, combined with axial load. The child presents with the palm facing the apex of the fracture deformity (Fig. 33-87). Apex-dorsal deformity results from excessive pronation force

FIGURE 33-87. Coupled relation of rotation and angulation. This fracture demonstrates volar angulation. The mechanism of injury was falling on the outstretched hand. When the fractures of the radius and ulna are at different levels, angulation cannot occur without rotation. Note the AP appearance of the elbow and the lateral projection of the wrist. This deformity is corrected with pronation of the distal fragment.



A

B

FIGURE 33-88. Coupled relation of rotation and angulation. **A:** The radiograph shows deformity with pronation of the distal fragment and dorsal angulation of the radius. The ulna has undergone plastic deformation. When a single bone angulates, it must rotate around the other. **B:** Alignment is restored with supination of the distal fragment. The lateral projections of the elbow and the wrist are now matched.

applied to the distal segment; the child presents with the palm facing down, relative to the apex of the fracture deformity (Fig. 33-88). Occasionally, greenstick fractures of the radius and the ulna are caused by a direct force producing angular deformity without much malrotation. Reduction is often indicated when shaft angulation is >15 to 20 degrees in a child younger than 10 years, or >10 to 15 degrees in an older child (160, 161), accepting more deformity distally and less proximally. Judgment is required because the rotational component of greenstick fracture of the forearm diaphysis does not always correlate with the amount of angulation. Reduction is indicated if forearm deformity was immediately obvious at the time of injury, or when there is rotational deformity of 45 degrees or more in children younger than 10 years, or 30 degrees or more in older children.

Treatment of greenstick fractures requires adequate pain relief for a reduction attempt that is usually successful. Reduction is accomplished by reversing the injury mechanism. Apex-volar deformity (apex of fracture in the direction of the palm of the hand) is reduced by pronating the wrist while applying pressure to the volar surface of the forearm. Apex-dorsal deformity (apex of fracture in the direction of the dorsum of the hand) is reduced by supinating the wrist while applying pressure to the dorsal surface of the forearm. Completing the fracture of the opposite cortex is unnecessary, although this may facilitate reduction and often occurs during the reduction maneuver. After reduction, the arm is immobilized in a well-molded sugar-tong splint or a split long-arm cast. Three-point pressure is important for the maintenance of reduction. Weekly follow-up is recommended for 2 to 3 weeks after reduction. Four to six weeks of immobilization are usually adequate.

Complications. Refracture occurs in 5% to 7% of forearm fractures, but may be more common following greenstick fractures (162). This may be due to impaired healing of the fractured side because the intact cortex may lead to a smaller fracture hematoma and reduce motion that stimulates periosteal new bone formation. A longer period of immobilization may be indicated if radiographic union is uncertain or delayed. A recent study found location of the fracture in the proximal and middle third of the forearm to be the only risk factor for refracture (163).

Complete Shaft Fractures. Complete fractures of the forearm result from higher energy trauma than do greenstick fractures. The proximal segments usually assume a position dictated by muscle forces because the muscle actions are unrestrained by an intact cortex. When the fracture is in the proximal third, the proximal fragment is frequently in supination due to the unrestrained actions of the biceps and supinator muscles. When the fracture is more distal, the pronator teres has a neutralizing effect on the proximal fragment, causing it to assume a position of neutral rotation (159).

Managing these fractures can be troublesome, but nonunions and serious complications are rare regardless of method of management. The principal concerns are the possibilities of residual deformity and loss of forearm rotation. Closed reduction is recommended for low-energy minimally displaced fractures, but IM fixation is an increasingly popular solution for the management of unstable fractures in children older than 8 years.

Guidelines for the closed management of complete forearm fractures are based on the following observations:

1. Younger children with more distal fractures have the best prognosis (160, 164, 165).
2. Bayonet apposition in the middle and distal third of the shaft does not compromise forearm rotation (166, 167).
3. Rotational alignment of the radius is more critical than the rotational alignment of the ulna (159, 168). Alignment with 45 degrees of malrotation in the radius can be accepted in younger children (165, 166).
4. Midshaft angulation of 15 degrees or less is acceptable in children younger than 8 years (160, 169).
5. Midshaft forearm fractures in children older than 8 years should be maintained with 10 degrees or less of angulation (166, 170).

6. Residual loss of supination (fixed pronation) is more difficult to accommodate than loss of pronation. When in doubt for complete fractures, immobilize the forearm in neutral or moderate supination (171).
7. Immobilization with the elbow extended may help maintain reduction for proximal-third fractures that are unstable in flexion. Elbow extension also helps maintain reduction for most children younger than 4 years. Incorporate the thumb to avoid cast slippage (172).
8. Gentle molding can make improvements in alignment, either in a new cast or by remanipulation for 1 to 3 weeks after injury (173, 174).

When performing closed reduction, pain relief and muscle relaxation are desired because more than one attempt may be necessary. Conscious sedation or regional (i.e., Bier or axillary block) anesthesia is often effective, and can be performed in the emergency department. If unsuccessful, general anesthesia may be needed. The reduction technique typically involves increasing the angular deformity, applying longitudinal traction to lock in place and straighten the fracture, and then correcting any malrotation by supinating or pronating the forearm. If this is unsuccessful, it is often helpful to apply traction by using finger traps for a period of 10 minutes before another attempt is made. Observing the bone widths at the fracture site and matching their contours on radiographs is one method to assess rotational alignment. Comparison radiographs of the opposite extremity, in various degrees of rotation, may also be helpful in determining rotational alignment (165). Alternatively, the position of the bicipital tuberosity may serve as a guide to rotation because the bicipital tuberosity is 180 degrees opposite the radial styloid and thumb (159).

Postreduction casting in an above-elbow cast or splint should maintain a straight lateral border along the ulnar side. A flat interosseous mold along the volar forearm should create an oval shape to the cast. Fracture stability is improved with at least 50% bone apposition. If one bone disengages, shortening may occur, followed by increasing angulation. This may respond to remanipulation or require surgical stabilization. Weekly re-evaluation is recommended for the first 3 weeks in potentially unstable fractures. Union is usually complete in 4 to 6 weeks. Nonunion is rare, and closed treatment can produce excellent results in more than 95% of patients when the fractures can be maintained within the guidelines stated previously (166, 171, 175, 176) (Fig. 33-89).

Surgical intervention with internal fixation is indicated for unstable fractures (Fig. 33-90) and when closed management has failed. Internal fixation can also facilitate management and can improve results for refractures with displacement, most open fractures, and unstable floating elbow injuries (162, 177–181). IM fixation is usually preferred for children and adolescents (182–186). Fixation is achieved by insertion of a small-diameter, flexible pin; a 1.5 to 2.5 mm diameter is sufficient for most cases (182). The ulnar pin can be inserted proximally, just lateral to the tip of the olecranon, or distally in the flare of the ulna. The radial pin is inserted in the distal metaphysis, avoiding penetration of the growth plate. Transphyseal pinning through the distal radius has also been reported without physeal arrest (183, 187). When the entry point is metaphyseal, an oblique drill hole is made in the metaphyseal cortex, and the wire is introduced into the medullary canal. Following insertion, the pin is tapped or gently rotated into the medullary canal until it passes the fracture site (Fig. 33-91). Often in fractures with >100% initial transla-

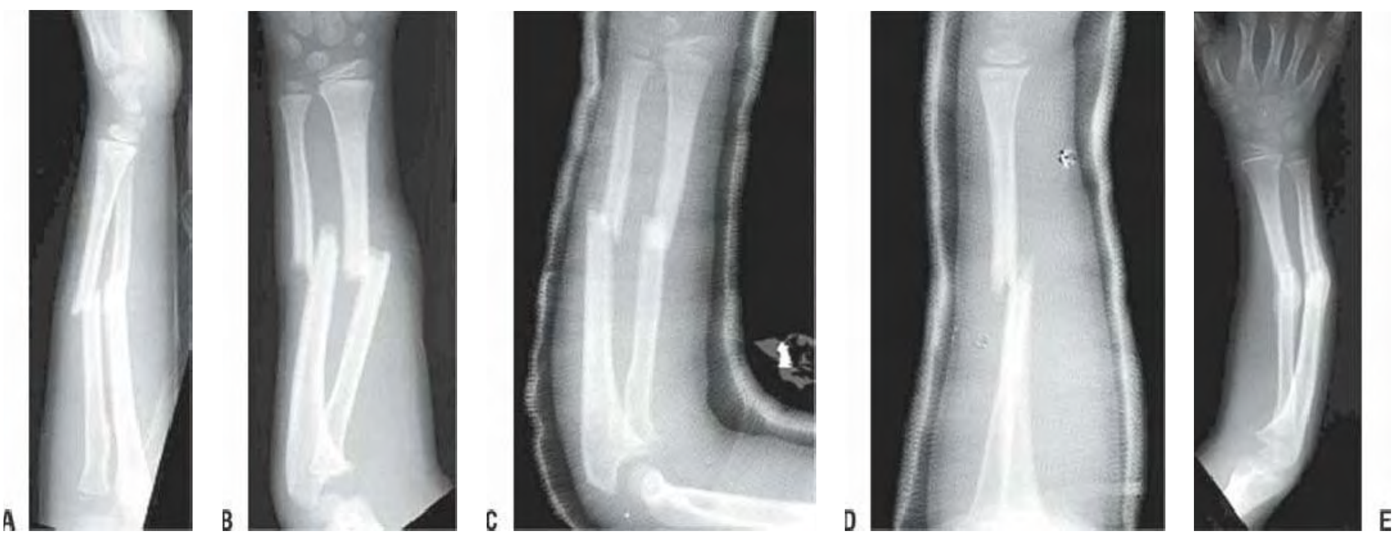


FIGURE 33-89. Malunion and remodeling of a diaphyseal radius and ulna fracture in a 7-year-old boy. **A, B:** Initial AP and lateral views of the forearm; the completely displaced radius and ulnar fracture were treated with closed reduction and casting. **C, D:** These radiographs were taken 1 week after reduction. There is acceptable angulation of the ulna (approximately 15 degrees) and bayonet apposition of both bones, seen on the lateral view. Note that there is no molding of the cast—in particular, note that the cast lacks a straight ulnar border.

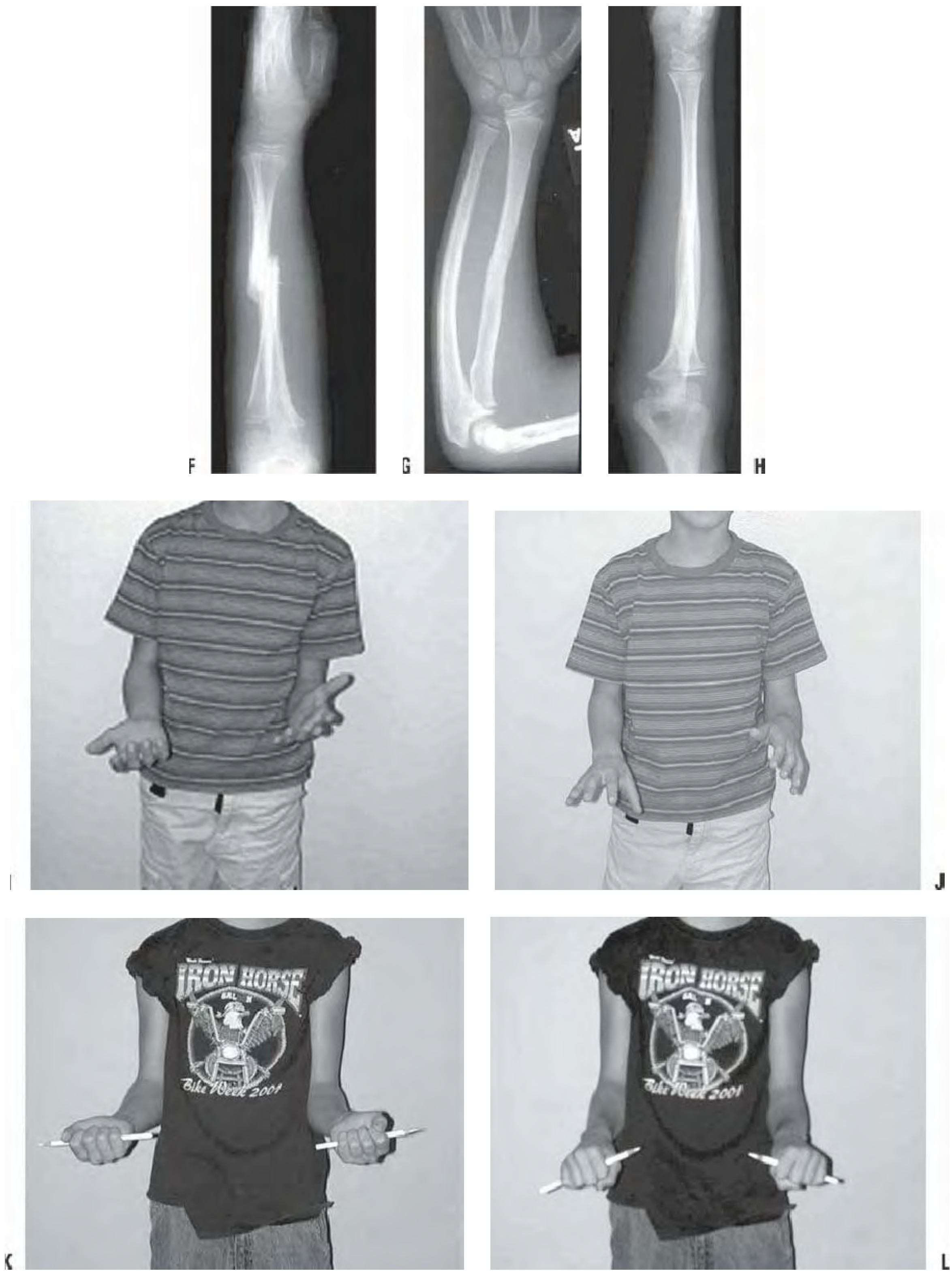


FIGURE 33-89. *(Continued)* **E, F:** These AP and lateral radiographs of the forearm at the time of cast removal 6 weeks after injury show considerable angulation on the AP and shortening with bayonet apposition on the lateral. **G, H:** Three years later, there is extensive remodeling, although the ulnar bow persists. **I, J:** Clinical pictures after cast removal show 45 degrees of pronation and supination. **K, L:** Six years after the injury, pronation and supination are symmetric with the uninjured side.

FIGURE 33-90. Treatment of a high-energy, unstable radius and ulna fracture with single bone IM fixation of the radius. **A:** AP radiograph of the left forearm of a 12-year-old boy who fell 20 ft while skiing. Although this radiograph shows satisfactory bayonet alignment of both the radius and ulna, his fracture was so unstable and his forearm was so swollen that the surgeon opted to use single-bone fixation of the radius and a splint rather than closed reduction and a well-molded cast. **B, C:** AP and lateral view of the forearm taken 8 weeks after a titanium elastic nail was placed in the radius. Neither fracture site was opened. Both bones have healed in satisfactory alignment.

tion, it is necessary to perform a limited open reduction at the fracture site to facilitate passage of the wire (187). Tourniquet time should be kept to a minimum, and multiple attempts at closed pinning should be avoided in order to decrease the risk of compartment syndrome (188). Both bones may be stabilized, but just the ulna is sufficient in many cases (189, 190). One may leave pins under the skin for 3 to 5 months because of the possibility of delayed union and also to reduce the risk of refracture (184), or leave the pins superficial and remove them in clinic at 3 to 4 weeks when fracture callus is present (191). Supplemental casting is recommended until union is satisfactory, approximately 6 weeks after fixation.

Plating is rarely used in children and adolescents, but this technique may be indicated for comminuted fractures, or for adolescents who are close to skeletal maturity. Plating requires more dissection and has the disadvantage that hardware removal may become necessary later, with longer surgical time and the added risk of neurovascular injury and refracture (184–186, 192).

INTRAMEDULLARY FIXATION OF FOREARM FRACTURE

IM nailing of forearm fractures is not a new technique. Reports of the use of K-wires for this purpose date back to the 1920s (193, 194). In the 1950s, special nails were developed for this purpose (195). Although these methods proved superior to closed reduction in adults, they were replaced by compression plating. IM fixation has gained popularity in pediatric patients because of the rapid healing and potential remodeling

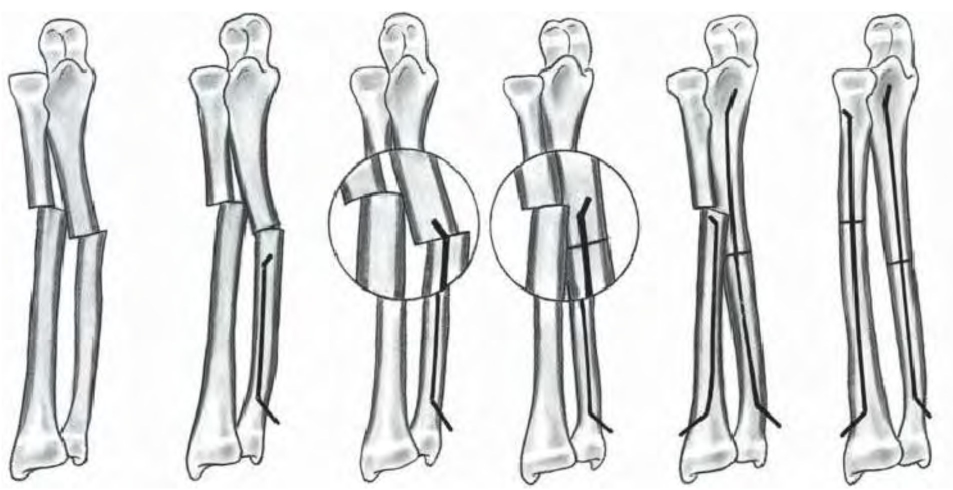


FIGURE 33-91. Surgical nailing procedure for flexible IM nails. The ulnar wire can be introduced digitally, as shown, or through the olecranon. (From Verstreken L, Delronge G, Lamoureux J. Shaft forearm fractures in children: intramedullary nailing with immediate motion. A preliminary report. *J Pediatr Orthop* 1988;8:450, with permission.)

in children's fractures, combined with the need for less surgical dissection for insertion (182, 196, 197). The anatomic alignment is less precise after treatment with IM rods than with plates; however, the amount of malalignment is well within the accepted range for children's fractures (198).

All sizes of bone are encountered while treating children of different age groups; thus, a variety of flexible nails sizes are available. The surgeon can also work with K-wires or Steinmann pins of appropriate size and flexibility for the child's bones. More rigid rods in the ulna impart rigidity and strength and usually are easy to insert because of the straight path of the canal.

IM fixation can be used as the sole means of immobilization of the fracture (197, 198), or it can be used to maintain alignment as an adjunct to cast treatment (182). It is not suitable for fractures of the radius distal to the narrow portion of the diaphyseal shaft because the large medullary canal allows too much displacement of the fragments.

Theoretically, the first bone to be reduced should be the one that is easiest to reduce and fix because it imparts greater stability and restores length, both of which facilitate reduction of the second bone. The ulna is usually the easiest bone to reduce because it is subcutaneous and easily palpated. Frequently, the radius is so well aligned or can be manipulated by rotation into a reduced position after fixation of the ulna, such that it does not need to have an IM rod placed.

Finally, not all fractures that require open reduction are best treated with IM fixation. Fractures treated late for loss of position may not permit the easy passage of a rod. In more mature adolescents, there might be a problem in balancing the problems of plating with the delayed healing that may occur with IM rods (191, 199). In these circumstances, open reduction with plate fixation is often the best treatment (Figs. 33-92 to 33-97).

Postoperative Care. Depending on the rigidity of the fixation and the surgeon's preference, the patient can be left without a cast or can be immobilized with a cast. Some authors report prompt healing when each bone is instrumented with a rod and no external immobilization is used (182, 197). We favor immobilization. Immobilization is discontinued when there is radiographic evidence of sufficient healing, usually at 6 weeks. The pins can be removed when healing is complete as an outpatient procedure.

Complications. Malunion is the most common complication of closed management, but remodeling may be surprising and function may return to normal despite malunion (166, 170, 175, 201). A 6 to 12 month period of observation is recommended when deformity is <20 degrees. Shaft deformities >30 degrees associated with limited forearm rotation and clinical deformity may be corrected as soon as some strength and motion have been regained, but in children under 8 to 10 years remodeling can be quite significant. Deformities between 20 and 30 degrees may require early correction depending on the clinical appearance, the age of the child, and the location of the malunion. Even in busy centers, the need for corrective osteotomies for forearm malunions in children is uncommon (202). Distal deformity in children younger than 8 years is more likely to remodel (160). Results are better when deformity is corrected within 1 year of the initial injury (203). IM fixation is usually sufficient for younger children (204) (Fig. 33-98). Older children benefit from plate fixation to begin early motion after osteotomy to correct malunion (Fig. 33-99).

Other complications of forearm fractures include refracture, nonunion, compartment syndrome, nerve injuries, and synostosis. Refracture has been addressed as an indication for surgical stabilization when alignment cannot be maintained by closed means. Nonunion often requires surgical intervention, but long-term sequelae are uncommon (178). In the skeletally mature, IM rod fixation with a gap at time of fracture reduction may lead to a delayed or a nonunion.

Compartment syndrome of the forearm has been reported in association with floating elbow injuries (83). The risk of compartment syndrome may also be increased when closed IM fixation is difficult and tourniquet time is prolonged (188). Treatment of compartment syndrome is discussed elsewhere in this text.

Nerve injuries can occur in association with forearm fractures, but reports of this are uncommon. Nerve entrapment from forearm fracture is rare (205). Management of neurologic deficits following forearm fracture is similar to management for deficits following supracondylar fractures.

Posttraumatic radioulnar synostosis is also rare in children but may occur following closed or open management of forearm fracture. Results of resection are better in adults than in children. However, successful resections have been reported for nonarticular midshaft crossunion (206, 207).

Distal Metaphyseal Fractures of the Radius and the Ulna. Distal metaphyseal fractures of the radius and ulna are common. Increased risk of distal radius fracture has been noted in children with decreased bone mineral density and increased body mass (208, 209), but risk-taking behavior and morphology of the distal radius are also risk factors. Fractures of the distal radius and ulna are usually caused by a fall onto the hand with the wrist in a pronated, extended position.

Unicortical fractures (i.e., torus or buckle fractures) are stable injuries that are quite common. Treatment is directed toward patient comfort and protection of the forearm from further injury. Immobilization with a splint for 3 weeks without further follow-up is sufficient for managing these injuries (210, 211). However, torus or unicortical fractures should be differentiated from minimally displaced or angulated bicortical fractures because the latter have a propensity for secondary angulation (212, 213). A well-molded cast is recommended for complete fracture. Follow-up radiographs are recommended 1 week after complete bicortical fractures when there is any displacement or angulation >10 degrees (212, 213).

Fractures of the distal radial metaphysis have great potential for remodeling because of their proximity to the distal growth plate. Bayonet apposition with 15 degrees of angulation and 1-cm shortening may be accepted until early adolescence (214). Friberg observed that a dorsal tilt up to 20 degrees will remodel so long as there are 2 years of growth

Text continued on page 1764

Intramedullary Fixation of Forearm Fractures (Figs. 33-92 to 33-96)

FIGURE 33-92. **Intramedullary Fixation of Forearm Fractures.** It is easiest to position the patient supine, with a small translucent board extending from the operating table. This position facilitates the use of the image intensifier and allows the surgeon to flex the patient's arm across the chest for access to the proximal part of the ulna. A tourniquet should be placed in case the fracture site needs to be opened. If the ulna is approached first, there are three potential entry portals to the IM canal. The most commonly used is through the tip of the olecranon process, with the advantage of ease of entry, and the ability to leave the pin protruding for removal in the clinic in young patients in whom rapid healing is anticipated. The disadvantage is that if left in place for a few months, the end of the rod may become symptomatic as the elbow is often resting on hard surfaces (desks, armrests). The other proximal entry portal is distal and lateral on the proximal ulna beneath the anconeus, a few centimeters distal to the olecranon apophysis so that a centimeter of rod can be left outside the cortex, flat against the proximal lateral ulna. The third option is retrograde insertion dorsally in the distal metaphysis. Care must be taken to not injure the dorsal sensory branch of the ulnar nerve or the extensor tendon.

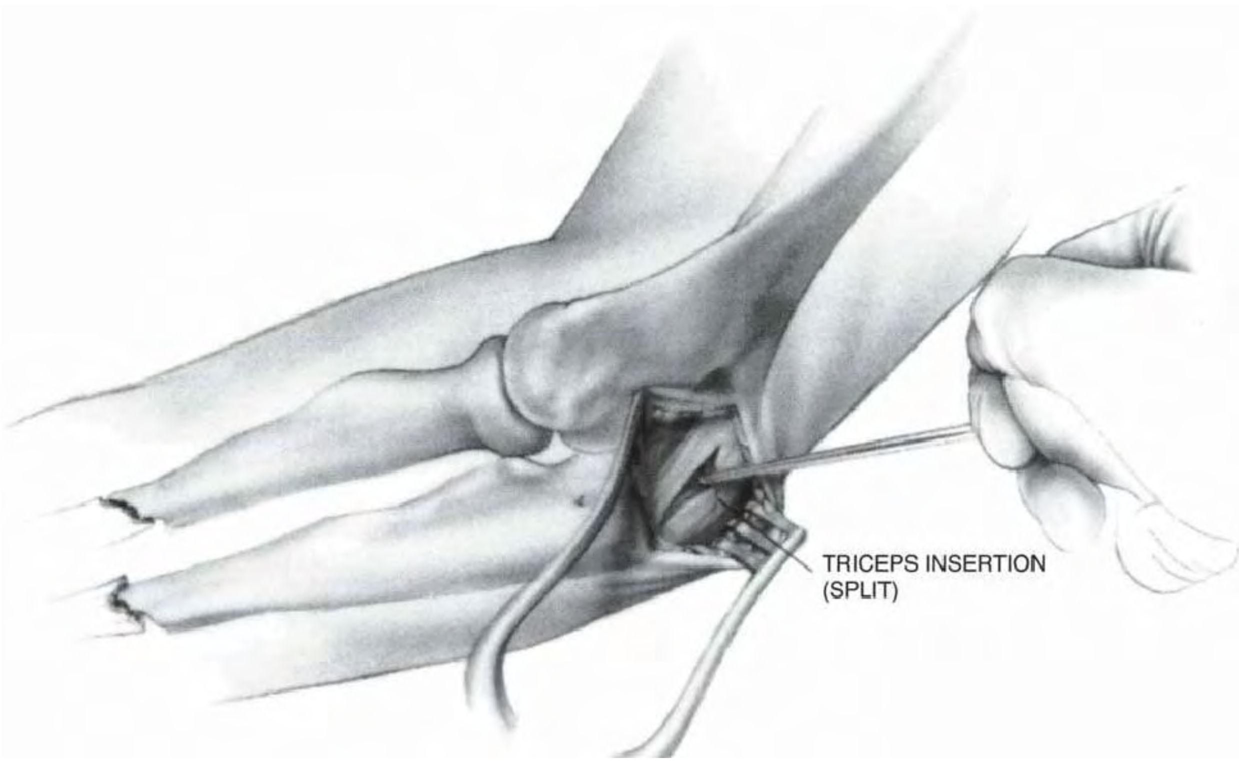


FIGURE 33-93. The ulna is exposed at its proximal tip by a small incision that is carried sharply down to the bone through the triceps insertion. (The incision is illustrated larger than necessary for the sake of clarity.) A drill or an awl is used to make a hole, opening into the medullary canal of the ulna.

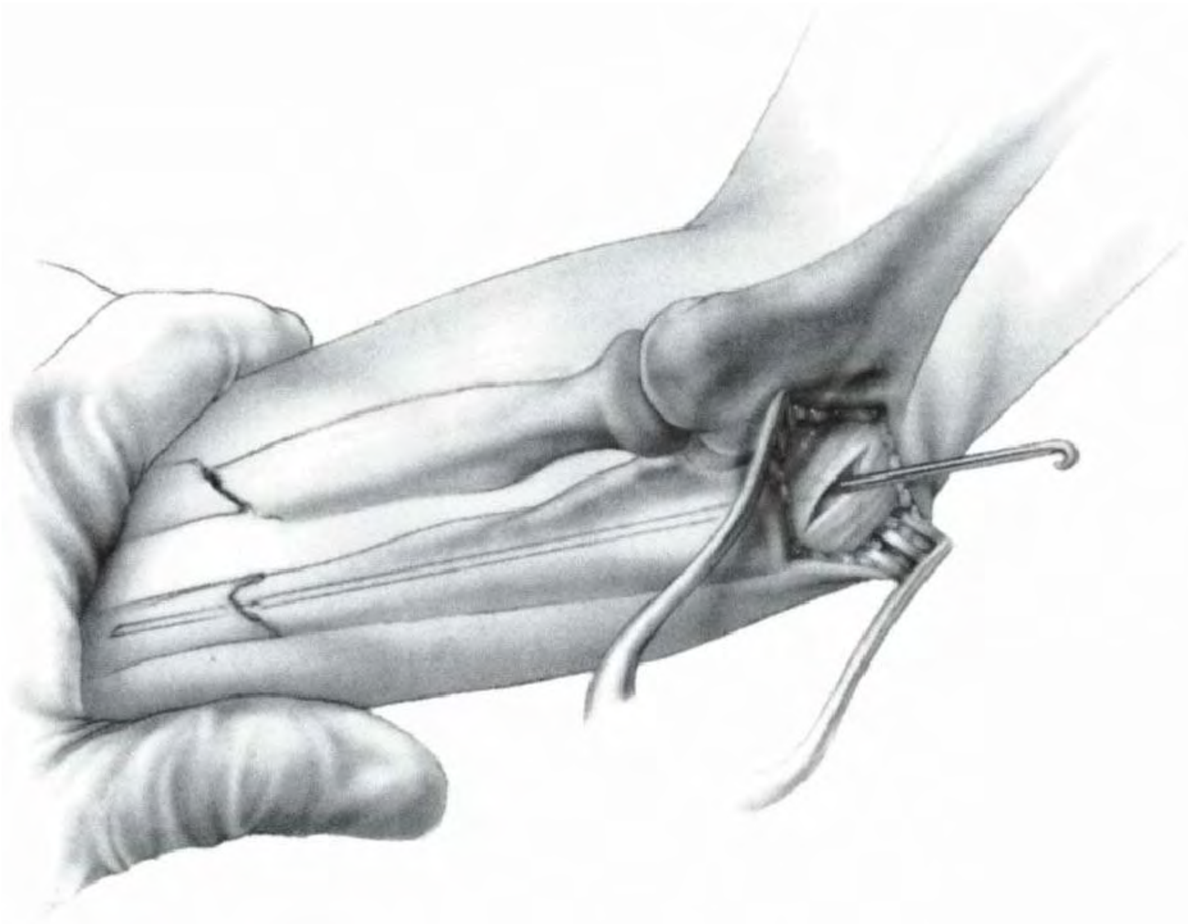


FIGURE 33-94. The proper length of rod is selected by placing it alongside the arm and checking the length with the image intensifier. Longer titanium nails or K-wires may be cut to length, and this step is not needed. Remember that the distal canal of the ulna is narrow and in most children a 1/8-in. rod will not pass to the distal end of the ulna. Attempting to pass a rod that is too wide into the distal canal may cause distraction at the fracture site and increase the risk of delayed or nonunion (189).

A rod is inserted up to the fracture site and just slightly beyond. This makes it easier to hook the distal fragment of the protruding tip of the rod during the reduction maneuver. The ulna is reduced, and the assistant advances the rod. If the ulna cannot be reduced closed, a small incision is made to facilitate reduction and passage of the rod.

The rod is usually prominent beneath the subcutaneous tissue and tends to be sensitive to repeated contusion. This problem can be minimized (but usually not eliminated) by impacting the rod beneath the triceps tendon and closing the tendon with a suture.

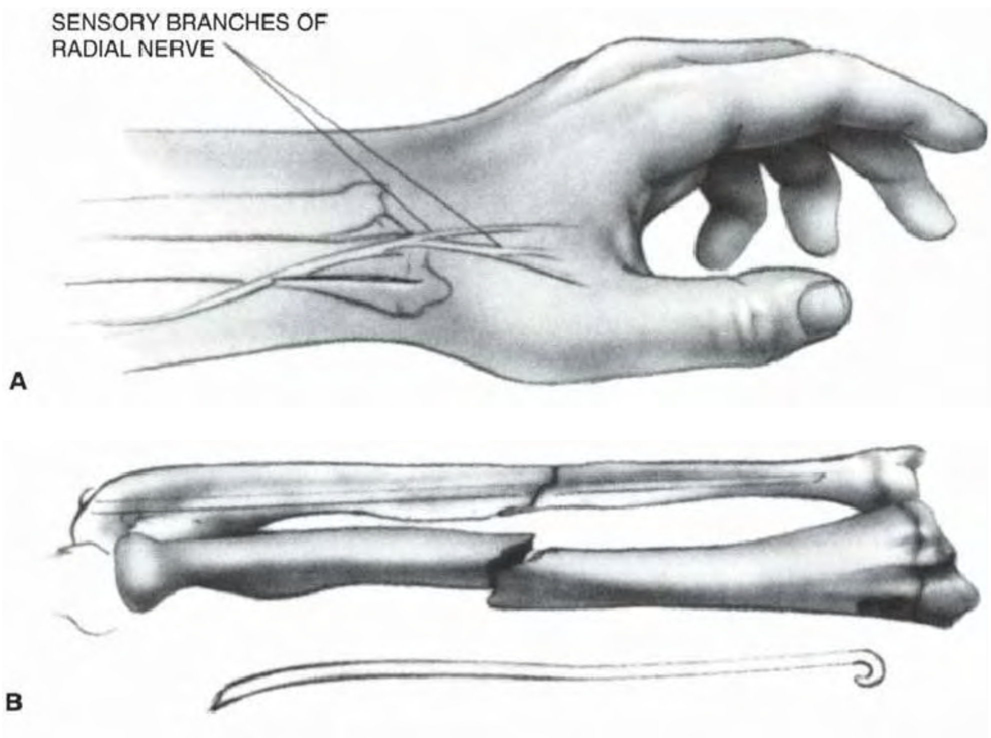


FIGURE 33-95. Two extraphyseal approaches to the distal radius for IM fixation are common. If using the lateral approach, care must be taken to avoid damage to one of the radial sensory branches **(A)**, although this does not appear to be a problem in children, as it is in adults. The disadvantage of this approach is the large amount of curve that the rod must accommodate and the problem of what to do with the end of the wire. It is difficult to place the end of the wire under the skin, and, if left out of the skin, there is the risk of infection. Usually, the K-wire has to be smaller and more flexible if inserted in this way. A small bend **(B)** within 0.5 cm of the tip of the rod helps it deflect off the medial cortex as it is being inserted, whereas a lateral bend is necessary to accommodate the lateral bow of the radius.

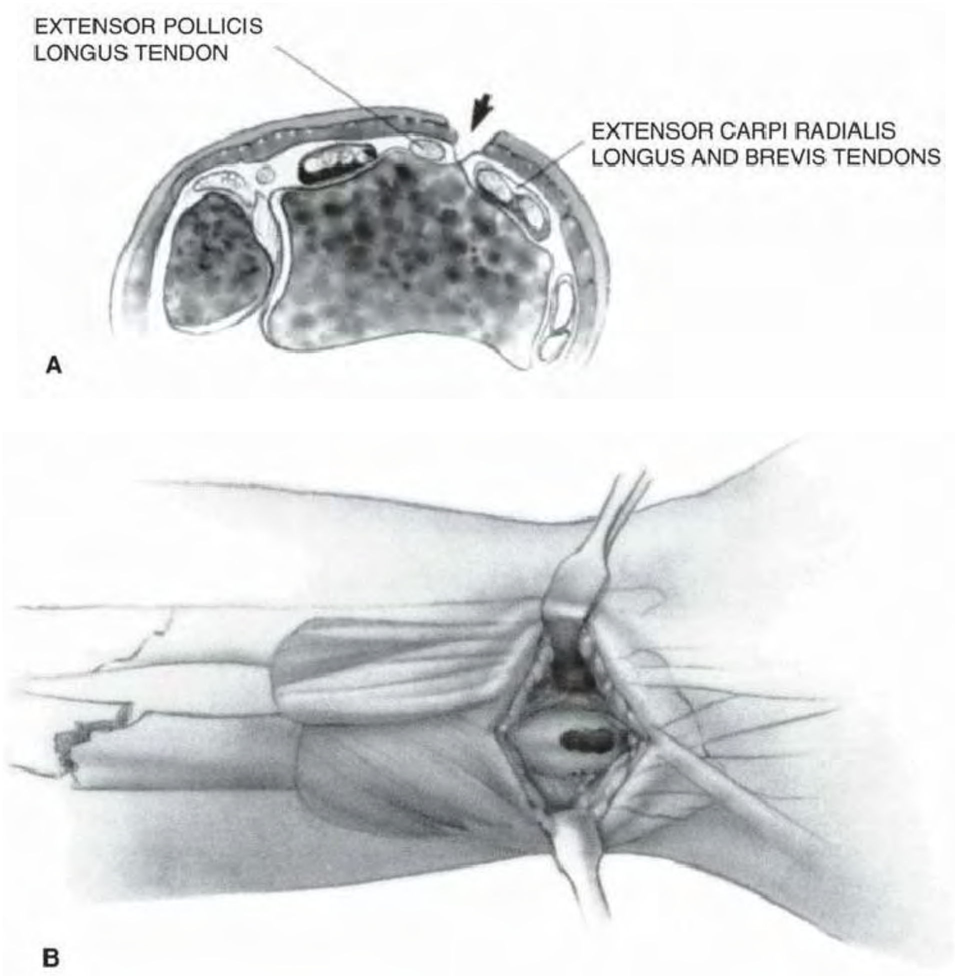


FIGURE 33-96. The other approach is the dorsal approach The radius can be reached, as recommended by Street (200), by splitting the extensor carpi radialis brevis and the longus tendons or by going between these tendons and the extensor pollicis longus tendon laterally to reach the Lister tubercle **(A)**. An oblique (30 degrees) unicortical drill hole is made into the medullary cavity just proximal to Lister tubercle **(B)** and is enlarged proximally. This approach offers more direct access to the medullary canal. A small bend should be placed in the tip of the rod, as described previously. If the rod has any rigidity, it should be bent to accommodate the lateral bow of the radius. A potential disadvantage to this technique is a rupture of the extensor pollicus longus.

The radius rod is advanced and the curve of the rod is used to deflect the rod away from the volar cortex, and then the rod is advanced by taps with the mallet to the fracture site. Rotation of the forearm will often align the distal and proximal medullary canals, and the rod is advanced across the fracture a few centimeters. Orthogonal fluoroscopy views should be taken to document IM position in the proximal fragment. If unsuccessful after two or three attempts, a small open approach to the fracture should be made. The rod is then advanced and rotated to attempt to restore the radial bow, and the tip is driven up to the metaphysis of the radial neck.

remaining (215–217). So long as the growth plate remains open, 50% of the remodeling occurs in the first 6 months, and the remaining 50% in the next 18 months (215–217). Deformity >20 degrees may also remodel, but is less predictable, especially in older children. Remodeling capacity is similar for dorsally angulated and palmarly angulated fractures (218). The guidelines for acceptable residual angulation are age dependent and serve only as a general indicator of expected results. Immobilization should be attempted to avoid angulation >20 degrees. When malunion occurs, dorsal tilt (apex-volar angulation) of up to 35 degrees can be accepted in children younger than 5 years. This decreases to 25 degrees for children between 5 and 12 years of age. In older children, the dorsal tilt should be controlled at <15 degrees to ensure a good outcome. Radial-ulnar (coronal plane) deviation remodels less than angulation in the plane of flexion and extension. Therefore, coronal plane deviation should be kept to <15 degrees in children younger than 12 years and to <10 degrees in older children (219–221).

Treatment of displaced or angulated fractures consists of closed reduction and immobilization in a cast. In complete

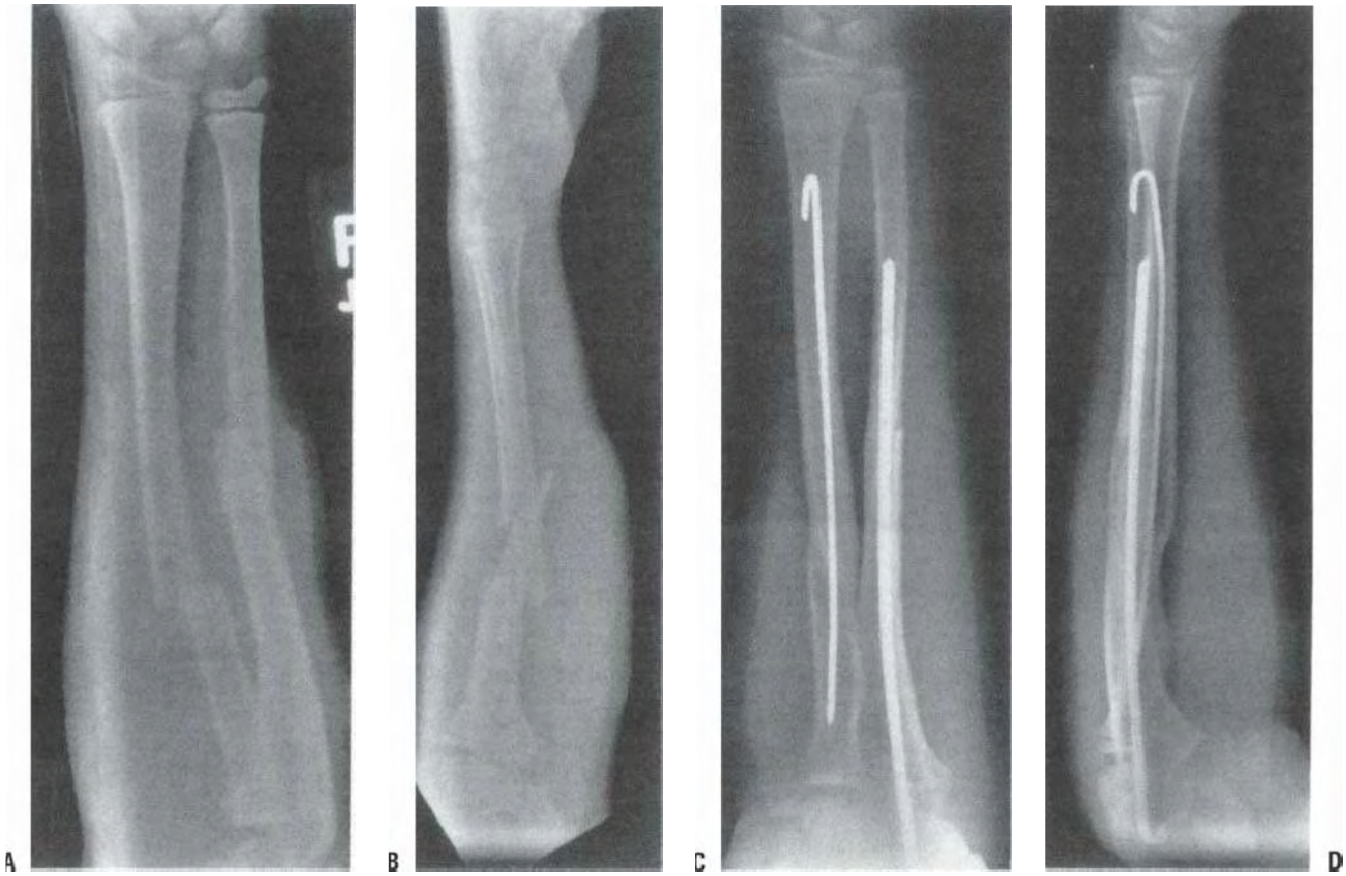


FIGURE 33-97. The AP **(A)** and lateral **(B)** radiographs of a 10-year-old boy who sustained a grade I open fracture of the radius and ulna. The proximal fragment of the radius had punctured the skin on the volar aspect of the forearm. After exploration, irrigation, and debridement, it was not possible to secure a stable reduction. The ulna and then the radius were treated with IM rodding. The radiographs 4 months after surgery **(C, D)** show the healing and the position of the rods. A more flexible Steinmann pin was used in the radius. This makes it easier to pass, is less likely to alter the radial bow, and provides adequate alignment.

fractures, the distal fragment is usually dorsally displaced, but the dorsal periosteum is intact. The deformity is increased to relax the intact periosteal hinge; longitudinal traction is then applied with digital pressure at the fracture site until length is restored. The angular deformity is then corrected. More reduction force is required if the ulna is intact, and pronating the distal segment during the reduction maneuver may assist in fragment realignment. After reduction, the wrist should be placed in slight palmar flexion and ulnar deviation. The cast is molded with three-point pressure dorsally over the distal fragment, centrally on the volar surface of the forearm, and proximally on the dorsal surface of the forearm. This cast-molding technique is designed to counter the tendency for later radial and dorsal fracture displacement. An above-elbow splint or a split cast has traditionally been recommended for immobilization, but it has been demonstrated that a well-molded, below-elbow cast can also effectively stabilize these fractures (222). The authors' practice is to use a short arm "waterproof" cast on forearm fractures in the distal half of the forearm, except in the youngest children who often require a long arm cast to prevent distal migration of the cast.

Anatomic reduction of a completely displaced, distal-third, metaphyseal fracture may be difficult to achieve by closed manipulation. Displacement and angulation may be accepted so long as alignment is within the described guidelines. However, redisplacement is more common when reduction is incomplete (223). Supination of the forearm has been recommended to reduce the pull of the brachioradialis and thereby reduce the incidence of delayed dorsal angulation (224). Fractures that do not maintain their positions can be remanipulated. Percutaneous pinning has been recommended to avoid repeated manipulation (223, 225). Randomized, controlled trials of above-elbow cast management versus the additional insertion of a K-wire determined no significant difference in clinical outcome. A higher percentage of patients in the groups managed only by cast required remanipulation, compared to none in the groups managed with pinning (226, 227). Regardless of method of immobilization, fracture alignment should be monitored closely for the first few weeks after injury. It is the authors' preference to use percutaneous pins only when completely displaced distal radius fractures cannot be satisfactorily

FIGURE 33-98. IM fixation is usually sufficient for younger children.

reduced (guidelines listed previously), or in the rare instance when an ipsilateral supracondylar fracture makes pinning of both injuries the safest treatment (Fig. 33-100). This can be performed by metaphyseal pinning, by transstyloid pinning through the growth plate, by transradioulnar K-wire (228) or by utilizing the intrafocal leverage technique of Kapandji (187, 229, 230). A modified Kapandji technique for pinning volarly displaced fractures in children utilizes a dorsal entry site with the tip of the pin as a buttress to prevent volar displacement (231).

Complications. Complications are rare. Significant residual deformity can remodel. Cases with a dorsal tilt of 35 degrees and radial tilt of 15 degrees should be given a chance to remodel before considering osteotomy. Galeazzi-type fracture may also be diagnosed. Galeazzi-type fracture dislocation should be suspected when an isolated radius fracture is associated with fracture of the ulnar styloid (155). Distal physeal separation of the ulna is uncommon but can lead to premature physeal closure (156). Rarely children with distal radius fractures also have ipsilateral scaphoid fractures. It is a good habit to carefully examine the carpal bones for fracture and malalignment in every wrist radiograph.

Distal Radius Physeal Fracture. Fracture of the growth plate of the distal radius is the second most common physeal injury, with phalangeal fractures being the most common (232).

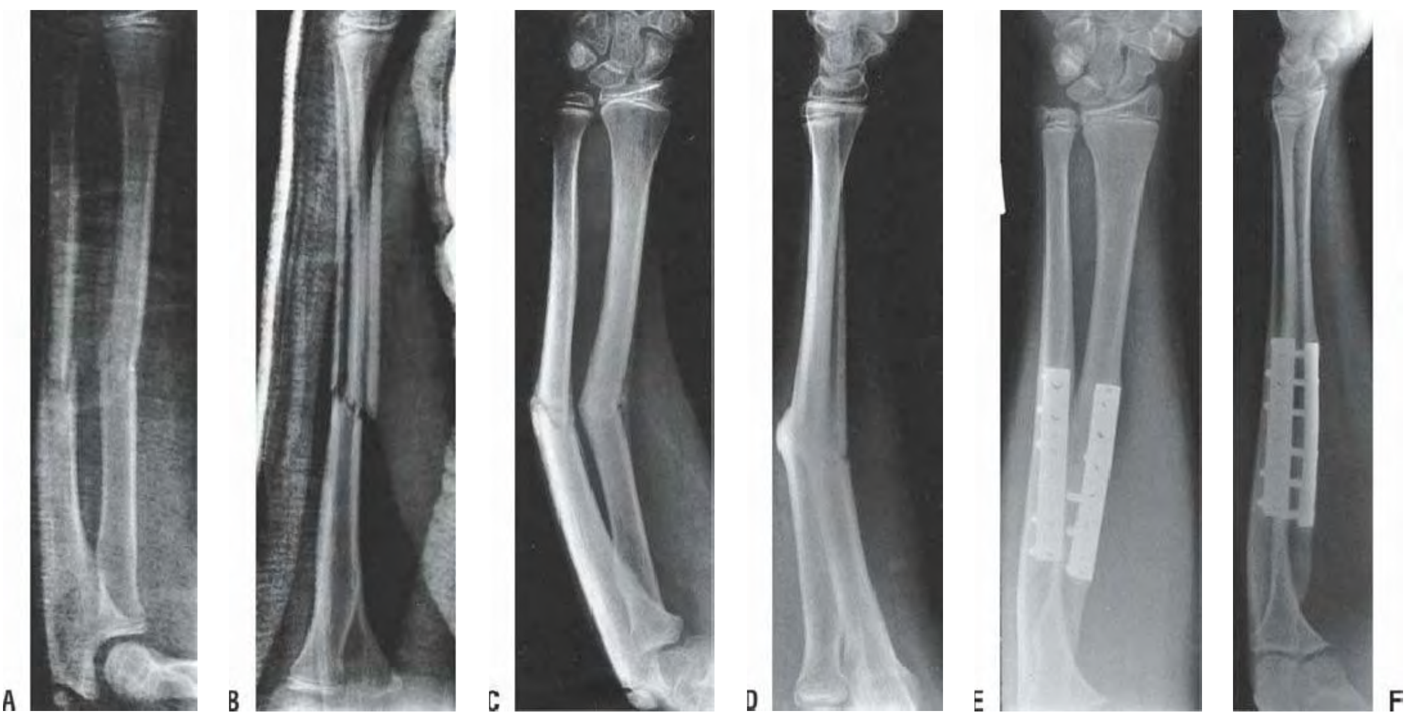
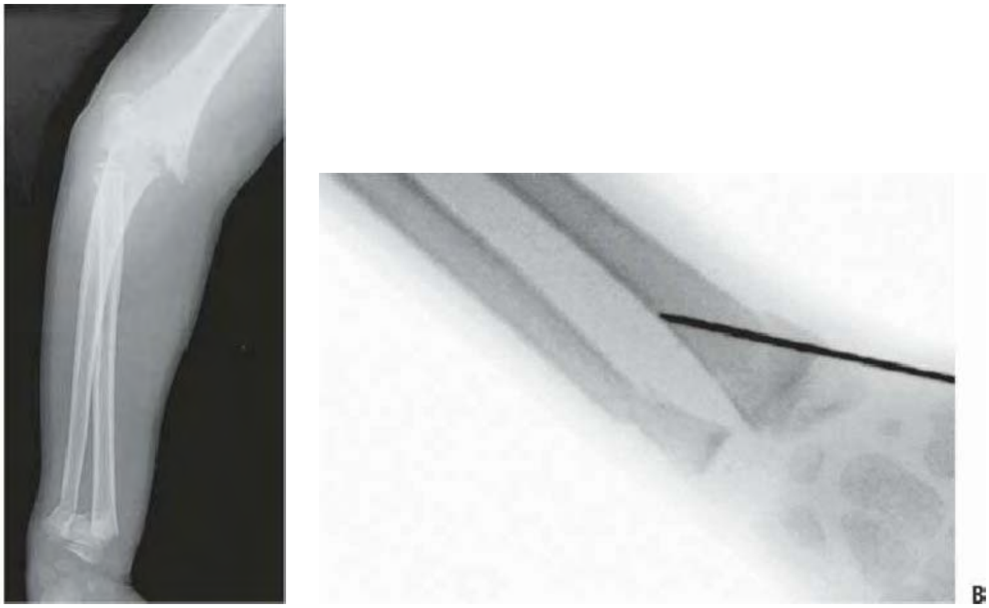


FIGURE 33-99. Malunion of the forearm in a 14-year-old child. **A:** AP view of the alignment after closed reduction and casting. **B:** The lateral projection shows acceptable alignment. **C:** The AP projection 12 weeks after treatment shows malunion of the radius and ulna. **D:** A lateral projection shows dorsal angulation. Clinical evaluation demonstrated only 15 degrees of rotation of the forearm. **E:** An AP projection after osteotomy and internal fixation with 0.35-mm compression plates. **F:** The lateral projection shows restoration of anatomic alignment. The range of motion was improved significantly, with full supination but a loss of the last 20 degrees of pronation.



A B

FIGURE 33-100. Fixation of a distal radius fracture with an ipsilateral supracondylar fracture. **A:** This AP radiograph of the forearm and elbow of a 6-year-old boy shows a completely displaced distal radius fracture and a type III supracondylar humerus fracture. The arm was swollen and the hand was perfused, but the radial pulse could not be palpated. Because of the risk of forearm compartment syndrome, the surgeon elected to do closed pinning of both the supracondylar fracture and the distal radius fracture. **B:** Intraoperative image after K-wire fixation was used for the distal radius fracture. After pinning, the arm and elbow were splinted with the elbow in 30 degrees of flexion.

Distal radius physeal fracture accounts for approximately 15% of all forearm fractures, with 70% of these injuries occurring in children older than 10 years (144, 233). Eighty percent are Salter-Harris type I or II injuries. More complex injuries are uncommon but have higher rates of premature growth arrest. Anatomic reduction may be required for complex physeal fractures, but anatomic reduction is unnecessary for type I or II physeal injuries of the distal radius because growth usually resumes and provides remodeling. Before 10 years of age, 20 degrees of angulation and 40% of displacement can be accepted without reduction for type II injuries (233).

Treatment guidelines for Salter-Harris fracture types I and II are similar to those previously described for distal radius metaphyseal fracture. Multiple reduction attempts may lead to growth-plate damage. Two or more attempts have produced growth arrest in slightly more than 25% of these patients (234). Repeat manipulation more than 7 to 10 days after injury may further damage the growth plate because physeal healing has already commenced. Cast immobilization can usually be discontinued 3 to 4 weeks after injury.

Complications. Growth arrest after a nondisplaced or a minimally displaced fracture is rare, and routine follow-up is not required. However, the authors recommend follow-up 4 to 6 months after complex distal radius and ulna physeal fracture to allow early detection of growth arrest prior to the development of a deformity. If growth arrest occurs, corrective lengthening osteotomy using iliac crest graft has been successful in restoring alignment and function (235, 236). Malunited distal radial physeal fractures have great capacity for remodeling, and thus observation for at least 6 to 12 months is recommended prior to osteotomy for malunion, or years in young children.

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