Forearm fractures in children are the most common long bone fractures, comprising about 40% of all pediatric fractures (19, 20, 32). The distal aspect of the radius and ulna is the most common site of fracture in the forearm (5, 18, 19, 26, 36). These fractures have been reported to be three times more common in boys; however, the increased participation in athletics by girls at a young age may be changing this ratio. Although these fractures occur at any age, they are most frequent during the adolescent growth spurt (2). A direct fall is the usual mechanism of injury. With the wrist and hand extended to protect the child, a fracture occurs if the mechanical force is sufficient. Regardless of the type, these fractures cause pain in the distal forearm, tenderness directly over the fracture site, and limited motion of the wrist and hand. Deformity depends on the degree of fracture displacement. Standard radiographs are diagnostic of fracture type and displacement. Metaphyseal fractures are most common, followed by physeal fractures (13, 23, 32); the distal fragment in either usually is extended. Associated fractures of the hand and elbow regions are rare. Occasionally a direct blow or a fall onto a flexed wrist and hand causes volar displacement or angulation of the distal fragment.

Repetitive loading of the wrist can lead to physeal stress injuries of the distal radius and, less commonly, the ulna. These injuries are rare, and occur most frequently in gymnasts (1, 4, 6, 9, 21, 27, 33). Any patient with chronic physeal region wrist pain who participates in an activity with repetitive axial loading of the wrist, such as gymnastics or break dancing (15), should be examined for a stress injury.

The pediatric Galeazzi injury usually involves a distal radial metaphyseal fracture and a distal ulnar physeal fracture. These injuries are rare, but need to be identified acutely for proper management. The specifics of injury mechanisms and fracture patterns for individual fracture types are discussed in separate sections of this chapter.

**CLASSIFICATION**

Distal radial and ulnar fractures are defined by their anatomic relationship to the physis. Transphyseal injuries are classified by the widely accepted Salter-Harris system (88). Metaphyseal injuries may be torus or buckle fractures, greenstick or incomplete fractures, or complete injuries. Pediatric equivalents of adult Galeazzi fracture–dislocations involve a distal radial fracture and either a soft tissue disruption of the distal radioulnar joint (DRUJ) or a transphyseal fracture of the ulna (Table 9-1). In contrast to adults, skeletally immature patients rarely sustain intraarticular fractures of the distal radius. On occasion, a Salter-Harris type III fracture, a triplane fracture (42), or an adolescent intraarticular Colles’ fracture occurs.

**TABLE 9-1. DISTAL FOREARM FRACTURES: GENERAL CLASSIFICATION**

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distal radius</td>
<td>Fracture in the distal part of the radius</td>
</tr>
<tr>
<td>Distal ulna</td>
<td>Fracture in the distal part of the ulna</td>
</tr>
<tr>
<td>Distal metaphyseal (radius or ulna)</td>
<td>Fracture involving the metaphyseal region of the radius or ulna</td>
</tr>
<tr>
<td>Torus</td>
<td>Fracture involving both the metaphyseal and diaphyseal regions</td>
</tr>
<tr>
<td>Greenstick</td>
<td>Fracture involving the metaphyseal region only</td>
</tr>
<tr>
<td>Complete fractures</td>
<td>Fractures with complete displacement of bone segments</td>
</tr>
<tr>
<td>Galeazzi fracture–dislocations</td>
<td>Fractures involving the distal radius and either a soft tissue disruption of the DRUJ or a transphyseal fracture of the ulna</td>
</tr>
<tr>
<td>Dorsal displaced</td>
<td>Displacement of bone fragment in the dorsal (anterior) direction</td>
</tr>
<tr>
<td>Volar displaced</td>
<td>Displacement of bone fragment in the volar (posterior) direction</td>
</tr>
</tbody>
</table>

Distal radial fracture stability has been more clearly defined in adults (35) than in children. At present, an unstable fracture in a child is often defined as one that cannot be reduced closed. Pediatric classification systems have yet to more precisely define fracture stability, but this issue is critical in determining proper treatment.
management.

Fractures also are defined by the degree of displacement and angulation. Static anteroposterior (AP) and lateral radiographs can be diagnostic of the fracture type and degree of deformity (Fig. 9-1). In adults, the distal radial articular alignment averages 22 degrees on the AP view and 11 degrees on the lateral view (17,22,24,28,34). Radial inclination is a goniometric measurement of the angle between the distal radial articular surface and a line perpendicular to the radial shaft on the AP radiograph. Palmar tilt is measured by a line across the distal articular surface and a line perpendicular to the radial shaft on the lateral view. Pediatric values for radial inclination tend to be less, depending on the degree of skeletal maturity of the patient. Palmar tilt tends to be more consistent regardless of the age of the patient.

![Figure 9-1](image)

**FIGURE 9-1.** Radiographic angulation of the distal radius. The correct position for a lateral view of the distal radius. The wrist is positioned as for the standard lateral radiograph, but the x-ray beam is directed 15 degrees cephalad. (Redrawn from Johnson PG, Szabo RM. Angle measurements of the distal radius: a cadaver study. *Skel Radiol* 1993;22:243; with permission.)

Rarely, tomographic views are necessary to assess intraarticular involvement or displacement (Fig. 9-2). This can be by AP and lateral tomograms, computerized tomographic (CT) scans, or magnetic resonance imaging (MRI). Dynamic motion studies with fluoroscopy can provide important information on fracture stability and the success of various treatment options (31). Dynamic fluoroscopy requires adequate pain relief and has been used more often in adult patients with distal radial fractures.

![Figure 9-2](image)

**FIGURE 9-2.** A: Computed tomography scan of displaced Salter-Harris type IV fracture. B: Surgical correction included external fixation distraction, arthroscopically assisted reduction, and smooth pin fixation.

ANATOMY

The distal radial epiphysis normally appears between 0.5 and 2.3 years in boys and 0.4 and 1.7 years in girls (12). Initially transverse in appearance, it rapidly becomes more adultlike with its triangular shape. The contour of the radial styloid progressively elongates with advancing skeletal maturity. The secondary center of ossification for the distal ulna appears at around age 7. Similar to the radius, the ulnar styloid appears with the adolescent growth spurt. It also becomes more elongated and adultlike until physeal closure. On average, the ulnar physis closes at age 16 in girls and age 17 in boys, whereas the radial physis closes on average 6 months later than the ulnar physis (16,30). The distal radial and ulnar physis contribute approximately 75% to 80% of the growth of the forearm and 40% of the growth of the upper extremity (75) (Fig. 9-3).

![Figure 9-3](image)

**FIGURE 9-3.** Ossification of the distal radius. A: Preossification distal radius with transverse ossification front in a 15-month-old boy. B: The triangular secondary ossification center of the distal radius in a 2-year-old girl. The initial ossification center of the styloid in this 7-year-old girl progresses radially (arrow). D: Extension of the ulnar ossification center into the styloid process of an 11-year-old. E: The styloid is fully ossified and the epiphyses have capped their relative metaphyses in this 13-year-old boy.

The distal radius articulates with the distal ulna at the DRUJ. Both the radius and ulna articulate with the carpus, serving as the support for the hand. The radial joint surface has three concavities for its articulations: the scaphoid and lunate fossa for the carpus and the sigmoid notch for the ulnar head. These joints are stabilized by a complex series of volar and dorsal radiocarpal, lunocarpal, and radioulnar ligaments. The volar ligaments are the major stabilizers. Starting radially at the radial styloid, the radial collateral, radioscaphocapitate, radiolunotriquetral, and radioscapholunate ligaments volarly stabilize the radiocarpal joint. The dorsal radioscaphoid and radial triquetral ligaments are less important stabilizers.

The triangular fibrocartilage complex (TFCC) is the primary stabilizer of the ulnocarpal and radio-ulnar articulations. It extends from the sigmoid notch of the radius across the DRUJ and inserts into the base of the ulnar styloid. It also extends distally as the ulnolunate, ulnotriquetral, and ulnar collateral ligaments and inserts into the ulnar carpus and base of the fifth metacarpal (19). The interosseous ligament helps stabilize the radius and ulna more proximally in the diaphysis of the forearm. The ulna remains relatively immobile as the radius rotates around it. The complex structure of ligaments stabilize the radius, ulna, and carpus through the normal wrist
motion of 120 degrees of flexion and extension, 50 degrees of radial and ulnar deviation, and 150 degrees of forearm rotation (19).

The length relationship between the distal radius and ulna is defined as ulnar variance. In adults, this is measured by the relationship of the radial corner of the distal ulnar articular surface to the ulnar corner of the radial articular surface (36). However, measurement of ulnar variance in children requires modifications of this technique. Hafner (53) described measuring from the ulnar metaphysis to the radial metaphysis to lessen the measurement inaccuracies related to epiphyseal size and shape (Fig. 9-4). If the ulna and radius are of equal lengths, there is a neutral variance. If the ulna is longer, there is a positive variance, and if the ulna is shorter, there is a negative variance.

![FIGURE 9-4. Hafner's technique to measure ulnar variance. A: The distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis. B: The distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis. (From Hafner R, Poznanski AK, Donovan JM. Ulnar variance in children. Standard measurements for evaluation of ulnar shortening in childhood. Skei Radiol 1989;18:514; with permission.)](image)

Variance is not dependent on the length of the ulnar styloid (3), but the measurement is dependent on forearm positioning and radiographic technique (8,11,29). Radiographs of the wrist to determine ulnar variance should be standardized with the hand and wrist pronated on the cassette, the elbow flexed 90 degrees, and the shoulder abducted 90 degrees. The importance of ulnar variance relates to the force transmission across the wrist with axial loading. Normally the radiocarpal joint bears approximately 80% of the axial load and the ulnocarpal joint bears 20%. Changes in the length relationship of the radius and ulna alter respective load bearing. Biomechanical and clinical studies have shown that this load distribution is important in fractures, TFCC tears, and Kienbock's disease (9,14,25).

PHYSEAL INJURIES

Distal radial physeal injuries were described more than 100 years ago (43,85), and these early descriptions raised concerns regarding permanent deformity from this injury. In the 1930s, however, Aitken (37,38) concluded from his observations at the Boston City Hospital outpatient clinic that permanent deformity was rare. Instead, he emphasized the remodeling potential of distal radial physeal fractures, even when not reduced. The observations of Aitken have been confirmed throughout the twentieth century (43,53). Most researchers agree that as long as there is sufficient growth remaining, a distal radial extension deformity from a malunited fracture has the potential to remodel. Permanent deformity can occur in malunited fractures near the end of growth or fractures that cause distal radial growth arrest.

![FIGURE 9-5. A: A 13-year-old boy presented 1 month after injury with a displaced and healed Salter-Harris type II distal radius fracture with obvious clinical deformity. B: Over the next 6 months the patient grew 4 inches and the deformity remodeled without intervention.](image)

Diagnosis

Distal radial physeal fractures are far more common than distal ulnar physeal fractures (61,71,79,84,91). The nondominant arm in boys is most commonly injured. The peak incidence is in the preadolescent growth spurt (36,61). More than 50% of distal radial physeal fractures have an associated ulnar fracture. This usually is an ulnar styloid fracture but can be a distal ulnar plastic deformation, greenstick, or complete fracture (40,65,67). The mechanism of injury generally is a fall on an outstretched hand and wrist. The distal fragment usually displaces dorsally, creating an extension deformity that is usually clinically apparent. Patients have pain and tenderness at the fracture site, and the range of motion at the wrist and hand usually is limited by pain. Neurovascular compromise is uncommon but can occur (95). When present, it usually consists of median nerve irritability or dysfunction caused by direct trauma to the nerve at the time of injury or ongoing ischemic compression from the displaced fracture. Thenar muscle function and discriminatory sensibility (two-point discrimination) should be tested before reduction in the emergency setting. Acute carpal tunnel syndrome or forearm compartment syndrome can occur, but more often is caused by marked volar forearm and wrist swelling that occurs after reduction and application of a well-molded, light cast (46,86,95). Open physeal fractures are rare, but the local skin should be examined closely for penetration.

Plain AP and lateral radiographs are diagnostic of the fracture type and deformity. Classification is by the Salter-Harris system for physeal fractures (89). Most are Salter-Harris type II fractures. The dorsal displacement of the distal fragment of the epiphysis and dorsal Thurstond-Holland metaphyseal fragment is evident on the lateral view (Fig. 9-6). Salter-Harris type I fractures also usually displace dorsally. Volar displacement of either a Salter-Harris type I or II fracture is less common (Fig. 9-7). Nondisplaced Salter-Harris type I fractures may be indi- cated only by a displaced pronator fat pad sign (Fig. 9-8) and Fig. 9-9) or tenderness over the involved physis (40,86). A scaphoid fat pad sign may indicate a scaphoid fracture (Fig. 9-10). If the acute fracture is unrecognized, a late-appearing periostial reaction may indicate the fracture.

![FIGURE 9-6. Dorsally displaced physeal fracture (type A). The distal epiphysis with a small metaphyseal fragment is displaced dorsally (curved arrow) in relation to](image)
the proximal metaphyseal fragment.

**FIGURE 9-7.** Volarly displaced physeal fracture (type B). Distal epiphysis with a large volar metaphyseal fragment is displaced in a volar direction (curved arrow). (Reprinted from Wilkins KE, ed. Operative management of upper extremity fractures in children. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1994:21; with permission.)

**FIGURE 9-8.** Subperiosteal hemorrhage from an occult fracture of the distal radius causes an anterior displacement of the normal pronator quadratus fat pad (arrows).

**FIGURE 9-9.** (A) A 13-year-old girl with tenderness over the distal radius after a fall. The only radiograph finding is an anterior displacement of the normal pronator quadratus fat pad (arrow). **B:** The opposite normal side (arrow indicates normal fat pad). **C:** Two weeks later, there is a small area of periosteal new bone formation (arrow) anteriorly, substantiating that bony injury has occurred.

**FIGURE 9-10.** Anatomic relationships of the navicular fat stripe (NFS). The NFS, shaded black, is located between the combined tendons of the abductor pollicis longus and extensor pollicis brevis, and the lateral surface of the carpal navicular. (Reprinted from Terry DW, Ramen JE. The navicular fat stripe. *J Roent Gen Med* 1975;124:25; with permission.)

Salter-Harris type III fractures are rare and may be caused by a compression injury or an avulsion of the radial origin of the volar radiocarpal ligaments (39,65) (Fig. 9-11). Triplane equivalent fractures (81–83), a combination of Salter-Harris type II and III fractures in different planes, are rare. CT scans may be necessary to define the fracture pattern and degree of intraarticular displacement (Fig. 9-2). Stress injuries to the physis occur most commonly in competitive gymnasts (Fig. 9-12).
FIGURE 9-11. Anteroposterior radiograph of Salter-Harris type III fracture of the distal radius.

FIGURE 9-12. Stress changes in a female gymnast with widening of the distal radial physis from long-standing high-level performance.

Treatment Options

As for most fractures, treatment options include no reduction, closed reduction and cast immobilization, closed reduction and pin fixation, and open reduction. Nondisplaced fractures are immobilized until appropriate healing and pain resolution have been achieved \(^{40,86}\). If there is a question of fracture stability, these fractures should be treated with a long arm cast and monitored closely during the first 3 weeks of healing to be certain that there is no loss of alignment. Most displaced Salter-Harris type I and II fractures can be treated successfully in the acute care setting with gentle closed reduction and cast immobilization. Closed reduction and percutaneous pin fixation are performed in patients with neurovascular compromise and displaced physeal fractures \(^{95}\) to lessen the risk of development of a compartment syndrome in the carpal tunnel or forearm. Open reduction is indicated for irreducible fractures, displaced Salter-Harris type III and IV fractures, and triplane equivalent fractures. Irreducible fractures are usually due to an entrapped periosteum or pronator quadratus \(^{70}\). Internal fixation usually is with smooth pins to lessen the risk of growth arrest. Plates and screws are rarely used unless the patient is near skeletal maturity because of concerns about further physeal injury. In the rare displaced intraarticular Salter-Harris type III or IV fracture, internal fixation can be intraepiphyseal without violating the physis. If it is necessary to cross the physis, then smooth pins should be used to lessen the risk of iatrogenic physeal injury. Extraarticular external fixation also can be used to stabilize and align the fracture.

Closed Reduction

Most displaced Salter-Harris I and II fractures are treated with closed reduction and cast stabilization. Closed manipulation of the displaced fracture is performed with appropriate sedation, analgesia, or anesthesia to achieve pain relief and an atraumatic reduction \(^{40,58,86}\). Most of these fractures involve dorsal and proximal displacement of the epiphysis with an apex–volar extension deformity. Manipulative reduction is by gentle distraction and flexion of the distal epiphysis, carpus, and hand over the proximal metaphysis (Fig. 9-13 and Fig. 9-14). The intact dorsal periosteum is used as a tension band to aid in reduction and stabilization of the fracture. Unlike similar fractures in adults, finger trap distraction with pulley weights is often counterproductive. However, finger traps can help stabilize the hand, wrist, and arm for manipulative reduction and casting by applying a few pounds of weight for balance. Otherwise an assistant is helpful to support the extremity in the proper position for casting.

If portable fluoroscopy is available, immediate radiographic assessment of the reduction is obtained. Otherwise, a long arm cast is applied and appropriate AP and lateral radiographs are obtained to assess the reduction. The cast should provide three-point molding over the distal radius to lessen the risk of fracture displacement (Fig. 9-13 and Fig. 9-14). The distal dorsal mold should not impair venous outflow from the hand, which can occur if the mold is placed too distal and too deep so as to obstruct the dorsal veins. Postcasting instructions for elevation and close monitoring of swelling and the neurovascular status of the extremity are critical.
The fracture also should be monitored closely with serial radiographs for the first 3 weeks to be certain that there is no loss of anatomic alignment (Fig. 9-15). Generally these fractures are stable after closed reduction and cast immobilization. If there is loss of reduction after 7 days, the surgeon should be wary of repeat reduction because of the risk of physeal arrest (40,88). Fortunately, remodeling of an extension deformity with growth is common if the patient has greater than 2 years of growth remaining and the deformity is less than 20 degrees (Fig. 9-5).

**FIGURE 9-15.** A: Anteroposterior and lateral radiographs of severely displaced Salter-Harris type II fracture of the distal radius. B: Closed reduction shows marked improvement but not anatomic reduction. The cast had to be bivalved due to excessive swelling. C: Unfortunately, the patient lost reduction after a new fiberglass cast was applied. D: Out of cast radiographs show a healed malunion in a similar position to the prereduction radiographs.

**Closed Reduction and Percutaneous Pinning**

The indications for percutaneous pinning of distal radial physeal fractures are controversial. The best indication is a displaced radial physeal fracture with median neuropathy and significant volar soft tissue swelling (95) (Fig. 9-16). These patients are at risk for development of an acute carpal tunnel syndrome or forearm compartment syndrome with closed reduction and cast immobilization (46,54,89,95). The torn periosteum volarly allows the fracture bleeding to dissect into the volar forearm compartments and carpal tunnel. If a tight cast is applied with a volar mold over that area, compartment pressures can increase dangerously. Percutaneous pin fixation allows the application of a loose dressing, splint, or cast without the risk of loss of fracture reduction (Fig. 9-16).

**FIGURE 9-16.** A: Clinical photograph of patient with a displaced Salter-Harris type II fracture of the distal radius. The patient has marked swelling volarly with hematoma and fracture displacement. The patient had a median neuropathy upon presentation. B: Lateral radiograph of the displaced fracture. C: Lateral radiograph in postoperative splint after percutaneous pinning to lessen the risk of neurovascular compromise in a cast.

Pin fixation can either be single or double (Fig. 9-17). Fluoroscopy is used to guide proper fracture reduction and pin placement. Anesthesia is used for adequate pain relief and to lessen the risk of further physeal injury. The fracture is manipulated into anatomic alignment and the initial, and often only, pin is placed from the distal epiphysis of the radial styloid obliquely across the physis into the more proximal ulnar aspect of the radial metaphysis (Fig. 9-17). A sufficient skin incision should be made with pin placement to be certain there is no iatrogenic injury to the radial sensory nerve or extensor tendons. Stability of the fracture should be evaluated with flexion/extension and rotatory stress under fluoroscopy. Often in children and adolescents a single pin and the reduced periosteum provide sufficient stability to prevent redisplacement of the fracture. If fracture stability is questionable with a single pin, a second pin should be placed. The second pin can either parallel the first pin or, to create cross-pin stability, can be placed distally from the ulnar corner of the radial epiphysis between the fourth and fifth dorsal compartments and passed obliquely to the proximal radial portion of the metaphysis (10,66,69). Again, the skin incisions for pin placement should be sufficient to avoid iatrogenic injury to the extensor tendons.

**FIGURE 9-17.** A: Anteroposterior and lateral radiographs of displaced Salter-Harris type II fracture pinned with a single pin. B: After reduction and pinning with parallel pins.

The pins are bent, left out of the skin, and covered with a sterile dressing. Splint or cast immobilization is used but does not need to be tight because fracture stability is provided by the pins. The pins are left in until there is adequate fracture healing, usually 4 weeks. The pins can be removed in the office without sedation or anesthesia.

One of the arguments against pin fixation is the risk of additional injury to the physis by a pin (42), but this has not been documented. The risk of physeal arrest is more from the displaced fracture than from a short-term, smooth pin. As a precaution, smooth, small-diameter pins should be used, insertion should be as atraumatic as possible, and removal should be executed as soon as there is sufficient fracture healing for fracture stability in a cast or splint alone.

**Open Reduction**

The main indication for open reduction of a displaced distal radial Salter-Harris type II physeal fracture is irreducibility (Fig. 9-18). Most often this is caused by
interposed periosteeum or, less likely, pronator quadratus (57,70,89). Open reduction is performed via a volar approach to the distal radial physy. The interval between the radial artery and the flexor carpi radialis is used. This dissection also can proceed directly through the flexor carpi radialis sheath to protect the artery. The pronator quadratus is isolated and elevated from radial to ulnar. Although this muscle can be interposed in the fracture site, the volar periosteeum is more commonly interposed. This is evident with elevation of the pronator quadratus. The periosteeum is extracted from the physy with care to minimize further injury to the physy. The fracture can then be easily reduced. Cast immobilization is possible, but usually a percutaneous smooth pin is used for stabilization of the reduction. The method of pin insertion is the same as after closed reduction.

FIGURE 9-18. Irreducible fracture. This 13-year-old sustained severe trauma producing widely displaced fracture fragments (arrows). Closed reduction could not be performed because of interposed median nerve and deep flexor tendons: open reduction was required. (Courtesy of Earl A. Stanley, M.D.)

Open physeal fractures are rare but do require open reduction. The open wound and fracture site require irrigation and debridement. Care should be taken with mechanical debridement of the physeal cartilage to avoid further risk of growth arrest. Cultures should be taken at the time of operative debridement, and appropriate antibiotics are used to lessen the risk of deep space infection.

The rare Salter-Harris type III or IV fracture or triplane fracture (53) may require open reduction if the joint or physy cannot be anatomically reduced closed. The articular and physeal alignment can be evaluated by radiographic tomograms (trispiral or CT), MRI scans, or wrist arthroscopy (Fig. 9-2). If anatomic alignment of the physeal and articular surface is not present, the risk of growth arrest, long-term deformity, or limited function is great (Fig. 9-15). Even minimal displacement (>1 mm) should not be accepted in this situation. Arthroscopically assisted reduction is helpful to align and stabilize these rare physeal fractures (47,50).

AUTHOR'S PREFERRED METHOD OF TREATMENT

Most Salter-Harris type I and II fractures are reduced closed under conscious sedation with the assistance of portable fluoroscopy. A long arm cast with appropriate three-point molding is applied. This is changed to a short arm cast when there is sufficient healing for fracture stability, usually after 3 to 4 weeks. Cast immobilization is discontinued when there is clinical and radiographic evidence of fracture healing, generally 4 and 6 weeks after fracture. Range-of-motion and strengthening exercises are begun with a home program. When the child achieves full motion and strength, he or she can return to full activity, including competitive sports. Follow-up radiographs are obtained at 6 to 12 months after fracture to be certain there is no growth arrest.

A patient with a displaced Salter-Harris type I or II physeal fracture, significant soft tissue swelling volarly, and median neuropathy (Fig. 9-19) with ipsilateral elbow and radial fractures (Fig. 9-19) is treated with closed reduction and percutaneous pinning. This avoids the increased risk of compartment syndrome in the carpal canal or volar forearm that is present if a well-molded, light cast is applied. In addition, acute percutaneous pinning of a waist of the fracture prevents increased swelling, cast splitting, loss of reduction, and concerns about malunion or growth arrest with repeat reduction (Fig. 9-17). Acute pinning of the fracture with one or two smooth pins through the radial epiphysis provides fracture stability without a compressive cast. The risk of growth arrest from a narrow-diameter, smooth pin left in place for 3 to 4 weeks is exceedingly small.

FIGURE 9-19. A: Ipsilateral distal radial physeal and supracondylar fractures. This 6-year-old sustained both a dorsally displaced distal radial physeal fracture (closed arrow) and a type II displaced supracondylar fracture of the humerus (open arrows). B: Similar case treated with percutaneous pinning of radial physeal fracture and supracondylar humeral fracture.

Open reduction is reserved for irreducible Salter-Harris type I and II fractures, open fractures, fractures with associated acute carpal tunnel or forearm compartment syndrome, displaced (>1 mm) Salter-Harris type III or IV fractures, or triplane equivalent fractures. For an irreducible Salter-Harris type I or II fracture, exposure is from the side of the torn periosteeum. Because these fractures usually are displaced dorsally, a volar exposure is used. Smooth pins are used for stabilization and are left in for 3 to 4 weeks. Open reductions are exposed through the open wound with proximal and distal extension for adequate debridement. All open debridements are performed in the operating room under general anesthesia. Acute compartment syndromes are treated with immediate appropriate release of the transverse carpal ligament or forearm fascia. The transverse carpal ligament is released in a Z-plasty fashion to lengthen the ligament and prevent volar bow-stringing and scarring of the median nerve against the palmar skin. Displaced intraarticular fractures are best treated with arthroscopically assisted reduction and fixation, but this is an equipment-intensive option requiring arthroscopic instruments, camera, and monitor, along with fluoroscopy. Distraction across the joint can be achieved with application of an external fixator or finger traps. Standard dorsal portals (3/4 and 4/5) are used for viewing the intraarticular aspect of the fracture and alignment of the reduction (Geising). In addition, direct observation through the arthroscope can aid in safe placement of the intraarticular pins. Fluoroscopy is used to evaluate the extraarticular aspects of the fracture (triplane equivalent and type IV fractures), the reduction, and placement of fixation pins (Fig. 9-2).

Complications

Malunion

Complications from physeal fractures are relatively rare. The most frequent problem is malunion. Fortunately, these fractures often occur in children with significant growth remaining. The deformity from a Salter-Harris type I or II fracture is within the plane of motion of the wrist joint and, therefore, will remodel with ensuing growth (40,58,88). Repeat reduction should not be performed more than 7 days after fracture because of the risk of growth arrest. The malunited fracture should be monitored over the next 6 to 12 months for remodeling. If the fracture does not remodel, persistent extension deformity of the distal radial articular surface puts the patient at risk for developing mid-carpal instability (96) or degenerative arthritis of the wrist. Corrective osteotomy with bone grafting and internal fixation is required (49) (Fig. 9-20). An opening-wedge dorsal osteotomy is made, iliac crest bone of appropriate trapezoidal shape to correct the deformity is inserted, and either plate or
external fixator is used to maintain correction until healing.

**FIGURE 9-20.** A: Radial metaphyseal fracture that did not remodel in a now 16-year-old skeletally mature boy. B: Corrective osteotomy with iliac crest bone graft and internal fixation was performed.

Intraarticular malunion is more worrisome (Fig. 9-21 and Fig. 9-22) because of the risk of development of degenerative arthritis if the articular step-off is more than 2 mm (59). MRI or CT scans can be useful in preoperative evaluations. Arthroscopy allows direct examination of the deformity and areas of impingement or potential degeneration. Intraarticular osteotomy with bone grafting in the metaphysis to support the reconstructed articular surface is controversial and risky. However, it has the potential of restoring anatomic alignment to the joint and preventing serious long-term complications. This problem fortunately is uncommon in children because of the rarity of the injury and this type of malunion.

**FIGURE 9-21.** A: Anteroposterior and lateral radiographs of a 15-year-old skeletally mature boy with a displaced intraarticular fracture. B: This fracture needs to be treated like an adult’s, with open reduction and internal fixation with a volar buttress plate.

**FIGURE 9-22.** A: Anteroposterior and lateral radiographs of a 14-year-old girl who fell from a height. There is extensive intraarticular comminution. B: Open reduction, internal fixation, and external fixation was performed. C: One year follow-up radiographs reveal early arthrosis. The patient has mild pain and near full range of motion.

**Physeal Arrest**

Distal radial physeal arrest can occur from either the trauma of the original injury (Fig. 9-23) (55,65,94) or late (>7 days) reduction of a displaced fracture. The exact incidence of radial growth arrest is unknown, but has been estimated to be 7% of all displaced radial physeal fractures. (65). The trauma to the physeal cartilage from displacement and compression is a significant risk factor for growth arrest. However, a correlation between the risk of growth arrest and the degree of displacement, type of fracture, or type of reduction has yet to be defined. Similarly, the risk of further compromising the physis with late reduction at various time intervals is still unclear. The current recommendation is for an atraumatic reduction of a displaced physeal fracture less than 7 days after injury.

**FIGURE 9-23.** Physeal arrest in a Peterson type I fracture. A: Injury film showing what appears to be a benign metaphyseal fracture. Fracture line extends into the physis (arrows). B: Two years postinjury, a central arrest (open arrow) has developed, with resultant shortening of the radius. (Reprinted from Wilkins KE, ed. Operative management of upper extremity fractures in children. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1994:21; with permission.)

When a growth arrest develops, the consequences depend on the severity of the arrest and the amount of growth remaining. A complete arrest of the distal radial physis in a skeletally immature patient can be a serious problem. The continued growth of the ulna with cessation of radial growth can lead to incongruity of the DRUJ ulnocarpal impaction, and development of a TFCC tear (Fig. 9-24). The radial deviation deformity at the wrist can be severe enough to cause limitation of wrist and
forearm motion (Fig. 9-25). Pain and clicking can develop at the ulnocarpal or radioulnar joints, indicative of ulnocarpal impaction or a TFCC tear. The deformity will progress until the end of growth. Pain and limited motion and function will be present until forearm length is rebalanced; until the radiocarpal, ulnocarpal, and radioulnar joints are restored; and until the TFCC tear and areas of chondromalacia are repaired or debrided (72,77,93).


Ideally, physeal arrest of the distal radius will be discovered early before the consequences of unbalanced growth develop. Radiographic screening 6 to 12 months after injury can identify the early arrest. A small area of growth arrest in a patient near skeletal maturity may be clinically inconsequential. However, a large area of arrest in a patient with marked growth remaining can lead to ulnocarpal impaction and forearm deformity if intervention is not performed early. An MRI scan can map the area of arrest (80) (Fig. 9-26). If it is less than 45% of the physis, a bar resection can be attempted (63,64). This may restore radial growth and prevent future problems (Fig. 9-27). If the bar is larger than 45% of the physis, an ulnar epiphysiodesis will prevent growth imbalance of the forearm (72). The growth discrepancy between forearms in most patients with fractures is minor and does not require treatment.

FIGURE 9-26. A: Anteroposterior radiograph of growth arrest with open ulnar physis. B: Magnetic resonance imaging scan of large area of growth arrest that was not deemed resectable by mapping.

FIGURE 9-27. Osseous bridge resection. A: This 10-year-old had sustained a distal radial physeal injury 3 years previously and now complained of prominence of the distal ulna with decreased supination and pronation. B: Polytomes revealed a well-defined central osseous bridge involving about 25% of the total diameter of the physis. C: The bridge was resected, and autogenous fat was inserted into the defect. Growth resumed with resumption of the normal ulnar variance. Epiphysiodesis of the distal ulna was postponed for 6 months. D: Unfortunately, the radius slowed its growth, and a symptomatic positive ulnar variance developed. E: This was treated with an epiphysiodesis (open arrow) and surgical shortening of the ulna. The clinical appearance and range of motion of the forearm returned to essentially normal.

**Ulnocarpal Impaction Syndrome**

The growth discrepancy between the radius and ulna can lead to relative radial shortening and ulnar overgrowth (Fig. 9-28). The distal ulna can impinge on the lunate and triquetrum and cause pain with ulnar deviation, extension, and compression activities (41). Loading the ulnocarpal joint in ulnar deviation and compression will recreate the pain. Radiographs show the radial arrest, ulnar overgrowth, and distal ulnocarpal impingement. The ulnocarpal impaction may be caused by a hypertrophic ulnar styloid fracture union (Fig. 9-28) or an ulnar styloid nonunion (44,68) (Fig. 9-30). An MRI scan may reveal chondromalacia of the lunate or...
triquetrum, a tear of the TFCC, and the extent of the distal radial physeal arrest.

**FIGURE 9-28.** A: A markedly displaced Salter-Harris type IV fracture of the distal radius in an 11-year-old boy who fell from a horse. B: Film taken 3 weeks after closed reduction demonstrates displacement of the comminuted fragments. C: Eighteen months postinjury, there was 15 mm of radial shortening, and the patient had a pronounced radial deviation deformity of the wrist.

**FIGURE 9-29.** Anteroposterior radiograph revealing hypertrophic ulnar styloid healing as the source of the ulnar carpal impaction pain in this patient.


Treatment should correct all components of the problem. The ulnar overgrowth is corrected by either an ulnar shortening osteotomy or radial lengthening. Most often a marked degree of positive ulnar variance requires ulnar shortening to neutral or negative variance. If the ulnar physis is still open, a simultaneous arrest should be performed to prevent recurrent deformity. If the degree of radial deformity is marked, this should be corrected by a realignment or lengthening osteotomy. Criteria for radial correction is debatable, but I have used radial inclination of less than 11 degrees on the AP radiograph (Fig. 9-31) (72). In the rare case of complete arrest in a very young patient, radial lengthening is preferable to ulnar shortening.

**FIGURE 9-31.** A: More severe ulnar overgrowth with dislocation of the distal radioulnar joint and flattening of the radial articular surface. B: Intraoperative fluoroscopic view of ulnar shortening and radial osteotomy to corrective deformities.

**Triangular Fibrocartilage Complex Tears**

Triangular fibrocartilage complex tears should be repaired. The presence of an ulnar styloid nonunion is often indicative of an associated peripheral tear of the TFCC (72,73). The symptomatic ulnar styloid nonunion is excised (44,68,76) and any TFCC repaired. If physical examination or preoperative MRI scan indicates a TFCC tear in the absence of an ulnar styloid nonunion, an initial arthroscopic examination can define the lesion and appropriate treatment. Peripheral tears (Palmer type B) are the most common TFCC tears in children and adolescents and can be repaired arthroscopically by an outside-in suture technique. Central tears (Palmer type A) are rare in children and can be debrided arthroscopically. Tears off the sigmoid notch (Palmer type D) can be repaired open or arthroscopically. Distal volar tears (Palmer type C) are repaired open, at times with ligament reconstruction.

**Neuropathy**

Median neuropathy can occur from direct trauma from the initial displacement of the fracture, traction ischemia from a persistently displaced fracture, or the development of a compartment syndrome in the carpal canal or volar forearm (Fig. 9-32) (65). All patients with displaced distal radial fractures should undergo a
careful motor-sensory examination upon presentation to an acute care facility. The flexor pollicis longus, index flexor digitorum profundus, and abductor pollicis brevis muscles should be tested. Light touch and two-point discrimination sensibility of the thumb and index finger should be tested in any child over 5 years of age with a displaced Salter-Harris type I or II fracture. The presence of median neuropathy and marked volar soft tissue swelling are indications for percutaneous pin stabilization of the fracture to lessen the risk of compartment syndrome in a cast.

FIGURE 9-32. Volar forearm anatomy outlining the potential compression of the median nerve between the metaphysis of the radius and dorsally displaced physeal fracture. The lank volar transcarpal ligament and fracture hematoma are also contributing factors. (Redrawn from Waters PM, Koletis GJ, Schwend R. Acute median neuropathy following physeal fractures of the distal radius. J Pediatr Orthop 1994;14:173–177; with permission.)

Median neuropathy caused by direct trauma or traction ischemia generally resolves after fracture reduction. The degree of neural injury will determine the length of time to recovery. Recovery can be monitored with an advancing Tinel's sign along the median nerve. Motor-sensory testing can define progressive return of neural function.

Carpal Tunnel Syndrome

Median neuropathy caused by a carpal tunnel syndrome will not recover until the carpal tunnel is decompressed. After anatomic fracture reduction and pin stabilization, volar forearm and carpal tunnel pressures are measured. Gelberman (51) recommended waiting 20 minutes or more to allow for pressure-volume equilibration before measuring pressures. If the pressures are elevated beyond 40 mm Hg or the difference between the diastolic pressure and the compartment pressure is less than 30 mm Hg (50), an immediate release of the affected compartments should be performed. The carpal tunnel is released through a palmar incision in line with the fourth ray, with care to avoid injuring the palmar vascular arch and the ulnar nerves exiting Guyon's canal. The transverse carpal ligament is released with a Z-plasty to prevent late bow-stringing of the nerve against the palmar skin. The volar forearm fascia is released in the standard fashion.

RADIAL PHYSEAL STRESS FRACTURES

Repetitive axial loading of the wrist in dorsiflexion can lead to physeal stress injuries (Fig. 9-12), almost always involving the radius. Competitive gymnastics is by far the most common cause (6,7,21,33,45,69,87). Other activities reported to cause radial physeal stress fractures include break dancing (15). Factors that predispose to this injury include excessive training, poor techniques, and attempts to advance too quickly in competitive level. Proper coaching is important in preventing these injuries.

A child with a radial physeal stress fracture has recurring, activity-related wrist pain, usually aching and diffuse, in the region of the distal radial metaphysis and physis. Extremes of dorsiflexion and palmar flexion reproduce the pain. There is local tenderness over the dorsal, distal radial physis. Resistive contracture strength testing of the wrist dorsiflexors often reproduces the pain. There may be fusiform swelling about the wrist if there is reactive bone formation. The differential diagnosis includes physeal stress injury, ganglion, ligamentous or TFCC injury, tendonitis or muscle–tendon tear, fracture such as a scaphoid fracture, and avascular necrosis of the scaphoid (Preiser's disease) or lunate (Kienbock's disease). Radiographs may be diagnostic. Physeal widening and reactive bone formation are indicative of chronic physeal stress fracture. Premature physeal closure indicates long-standing stress (27,88). In this situation, continued ulnar growth leads to an ulnar positive variance and pain from ulnocarpal impaction or a TFCC tear (133). Normal radiographs may not show an early physeal stress fracture. If the diagnosis is suggested clinically, a bone scan or MRI scan is indicated. Bone scans are sensitive but nonspecific. MRI scans usually are diagnostic.

Treatment first and foremost involves rest. This may be difficult depending on the skill level of the athlete and the desires of the child, coach, and parents. Short arm cast immobilization for several weeks may be the only way to restrict stress to the radial physis in some patients. Splint protection is appropriate in cooperative patients. Protection should continue until there is resolution of pain with examination and activity. The athlete can maintain cardiovascular fitness, strength, and flexibility while protecting the injured wrist. Once the acute physeal injury has healed, return to weight-bearing activities should be gradual. This requires the cooperation of the coach and parents. Adjustment of techniques and training methods often is necessary to prevent recurrence. The major concern is development of a radial growth arrest in a skeletally immature patient. This is an avoidable complication with well-trained coaches and athletes.

If a radial growth arrest has already occurred upon presentation, treatment depends on the degree of deformity and the patient's symptoms. Physeal bar resection usually is not possible because the arrest is usually too diffuse in stress injuries. If there is no significant ulnar overgrowth, a distal ulnar epiphysiodesis will prevent the development of an ulnocarpal impaction syndrome. For ulnar overgrowth and ulnocarpal pain, an ulnar shortening osteotomy is indicated. Techniques include transverse, oblique, and Z-shortening osteotomies. Transverse ostectomy has a higher risk of nonunion than either oblique or Z-shortening and should be avoided. The status of the TFCC also should be evaluated by MRI scan or wrist arthroscopy. If there is an associated TFCC tear, it should be debrided or repaired as appropriate.

ULNAR PHYSEAL FRACTURES

Isolated ulnar physeal fractures are rare injuries. Most ulnar physeal fractures occur in association with radial metaphyseal or physeal fractures. Physeal separations are classified by the standard Salter-Harris criteria. These injuries include types I, II, III, and rarely IV fractures. The rare pediatric Galeazzi injury usually involves an ulnar physeal fracture rather than a soft tissue disruption of the distal radioulnar joint. Another ulnar physeal fracture is an avulsion fracture off the distal aspect of the ulnar styloid (91). Although an ulnar styloid injury is an epiphyseal avulsion, it usually is associated with soft tissue injuries of the TFCC and ulnocarpal joint and does not cause growth-related complications.

Physeal growth arrest is frequent with distal ulnar physeal fractures. The incidence has been cited from 21% (73) to 55% (52). It is unclear why the distal ulna has a higher incidence of growth arrest after fracture than does the radius.

Treatment

Treatment options are similar to those for radial physeal fractures: immobilization alone, closed reduction and cast immobilization, closed reduction and percutaneous pinning, and open reduction. Often these fractures are minimally displaced or nondisplaced. Immobilization until fracture healing at 3 to 6 weeks is standard treatment. Closed reduction is indicated for displaced fractures with more than 50% translation or 20 degrees angulation. Most ulnar physeal fractures reduce to a near anatomic alignment with reduction of the radial fracture. Failure to obtain a reduction of the ulnar fracture may indicate that there is soft tissue interposed in the fracture site. This is an indication for open reduction. Exposure should be from the side of the torn periosteum. The interposed soft tissue (periosteum, extensor tendons, and flexor tendons (48,80,74)) must be extracted from the fracture site. If reduction is not stable, a small-diameter smooth pin can be used to maintain alignment until healing at 3 to 4 weeks. Further injury to the physis should be avoided during operative exposure and reduction because of the high risk of growth arrest (Figs. 9-33, Fig. 9-34, and Fig. 9-35).
FIGURE 9-33. A and B: A 10-year-old boy sustained a closed Salter-Harris type I separation of the distal ulnar physis (arrows), combined with a fracture of the distal radial metaphysis. C: An excellent closed reduction was achieved atraumatically. D: Long-term growth arrest of the distal ulna occurred.

FIGURE 9-34. A: The appearance of the distal ulna in the patient seen in Fig. 9-21 3 years after injury, demonstrating premature fusion of the distal ulnar physis with 3.2 cm of shortening. The distal radius is secondarily deformed, with tilting and translocation toward the ulna. B: In the patient in Fig. 9-21 with distal ulnar physeal arrest, a lengthening of the distal ulna was performed using a small unipolar distracting device. The ulna was slightly overlengthened to compensate for some subsequent growth of the distal radius. C: Six months after the lengthening osteotomy, there is some deformity of the distal ulna, but good restoration of length has been achieved. The distal radial epiphyseal tilt has corrected somewhat, and the patient has asymptomatic supination and pronation to 75 degrees.

FIGURE 9-35. Similar case to Fig. 9-34, but with more progressive distal radial deformity treated with corrective osteotomy and epiphysiodesis of the distal radius.

ULNAR STYLOID FRACTURES

Ulnar styloid avulsion fractures are common in association with radial fractures (91) and represent a soft tissue avulsion of the attachment of the TFCC or ulnocarpal ligaments. Treatment consists of immobilization and monitoring of long-term outcome, and most heal without sequelae (62). However, an acute displaced fracture of the base of the styloid represents a disruption of the TFCC. Most of these injuries occur in adolescents with high-velocity trauma at or near skeletal maturity. Treatment should be by tension band reinsertion of the styloid to the metaphysis and repair of the TFCC (Fig. 9-36). The tension band wire is removed at 3 to 6 weeks.

FIGURE 9-36. A: An adolescent with an open, comminuted fracture of the distal radius metaphysis and a base of ulnar styloid fracture with disruption of the triangular fibrocartilage complex (TFCC). B: After thorough irrigation and debridement of the radius, internal fixation of the radius was performed with care taken to not violate the physis with hardware. The ulna styloid base fracture and TFCC was repaired with an open tension band technique with a suture and smooth wire.

Some ulnar styloid fractures result in nonunion (Fig. 9-30) or hypertrophic union (Fig. 9-29) (44,68,76,93). Nonunion may be associated with TFCC tears or ulnocarpal impaction. The hypertrophic healing represents an ulnar positive variance and ulnocarpal impaction. Both cause ulnar-sided wrist pain. Compression of the lunate or triquetrum on the distal ulna reproduces the pain. Clicking with ulnocarpal compression or forearm rotation represents either a TFCC tear or chondromalacia of the lunate or triquetrum. Surgical excision of the nonunion or hypertrophic union with repair of the TFCC to the base of the styloid is the treatment of choice. Postoperative immobilization for 4 weeks in a long arm cast followed by 2 weeks in a short arm cast protects the TFCC repair.

Complications

Growth Arrest

The most common complication of distal ulnar physeal fractures is growth arrest. Golz (52) described 18 such fractures, with growth arrest in 10%. If the patient is
young enough, continued growth of the radius will lead to deformity and dysfunction. The distal ulnar aspect of the radial physis and epiphysis appears to be tethered by the foreshortened ulna (Fig. 9-34 and Fig. 9-35). The radial articular surface develops increased inclination toward the foreshortened ulna (Fig. 9-34 and Fig. 9-35). The radial articular surface develops increased inclination toward the foreshortened ulna. This is similar to the deformity Peinado (78) created experimentally with arrest of the distal ulna in rabbits' forelimbs. The distal ulna loses its normal articulation in the sigmoid notch of the distal radius. The metaphyseal-diaphyseal region of the radius often becomes notched from its articulation with the distal ulna during forearm rotation. Frequently, these patients have pain and limitation of motion with pronation and supination (41).

Ideally, this problem is identified before the development of marked ulnar foreshortening and subsequent radial deformity. Because it is well known that distal ulnar physeal fractures have a high incidence of growth arrest, these patients should have serial radiographs to identify growth arrest early. Unfortunately, in the distal ulnar physeal, physeal bar resection generally is unsuccessful. Surgical arrest of the radial physis can prevent radial deformity. Usually this occurs late enough in growth that the forearm length discrepancy is not a problem.

Most often these patients present late with established deformity. Treatment then involves rebalancing the length of the radius and ulna. The options include hemiphyseal arrest of the radius, corrective closing wedge osteotomy of the radius, ulnar lengthening (41,52,73), or a combination of these procedures (Fig. 9-34 and Fig. 9-35). The painful impingement of the radius and ulna with forearm rotation can be corrected with reconstitution of the DRUJ. If the radial physeal has significant growth remaining, a radial physeal arrest should be performed at the same time as the surgical rebalancing of the radius and ulna. Treatment is individualized depending on the age of the patient, degree of deformity, and level of pain and dysfunction.

METAPHYSEAL FRACTURES

The metaphysis of the distal radius is the most common site of forearm fracture in children and adolescents (19,32,154). They occur most commonly in boys in the nondominant arm (168). These fractures have a peak incidence during the adolescent growth spurt, which in girls is age 11 to 12 years and in boys is 12 to 13 years (2). During this time of extensive bone remodeling, there is relative osteoporosis of the distal radial metaphysis, which makes this area more susceptible to fracture with a fall.

Diagnosis

The mechanism of injury is generally a fall on an outstretched hand. The usual dorsiflexion position of the wrist leads to tension failure on the volar side. Fracture type and degree of displacement depend on the height and velocity of the fall (154). These fractures can be nondisplaced torus or buckle injuries (common in younger children with a minimal fall) or dorsally displaced fractures with apex volar angulation (more common in older children with higher velocity injuries) (Fig. 9-37). Displacement may be severe enough to cause foreshortening and bayonet apposition (Fig. 9-38). Rarely, a mechanism such as a fall from a height can cause a distal radial fracture associated with a more proximal fracture of the forearm or elbow (97,143,155) (Fig. 9-39). A fall with a palmar flexed wrist can produce a volarly displaced fracture with apex dorsal angulation (Fig. 9-38, Table 9-2).

FIGURE 9-37. Metaphyseal biomechanical patterns. A: Torus fracture. Simple bulging of the thin cortex (arrow). B: Compression greenstick fracture. Angulation of the dorsal cortex (large curved arrow). The volar cortex is intact but slightly plastically deformed (small white arrows). C: Tension failure greenstick fracture. The dorsal cortex is plastically deformed (white arrow) and the volar cortex is complete and separated (black arrows). D: Complete length maintained. Both cortices are completely fractured, but the length of the radius has been maintained. (Reprinted from Wilkins KE, ed. Operative management of upper extremity fractures in children. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1994:24; with permission.)


Children with distal radial fractures present with pain, swelling, and deformity of the distal forearm (Fig. 9-40 and Fig. 9-41). The clinical signs depend on the degree of fracture displacement. With a nondisplaced torus fracture in a young child, medical attention may not be sought until several days after injury, because the intact periosteum is protective in this situation, lessening pain and the child's restriction of activities. Most distal radius fractures, however, will present acutely after the fall with an obvious deformity. Physical examination is limited by the patient's pain and anxiety. It is imperative to obtain an accurate examination of the motor and sensory components of the radial, median, and ulnar nerves before treatment. Median nerve motor function is evaluated by testing the abductor pollicis brevis (intrinsic) and flexor pollicis longus (extrinsic) muscles. Ulnar nerve motor evaluation includes testing the first dorsal interosseous (intrinsic), abductor digit quinti (intrinsic), and flexor digitorum profundus to the small finger (extrinsic) muscles. Radial nerve evaluation involves testing the common digital extensors for metacarpophalangeal joint extension. Sensibility to light touch and two-point discrimination should be tested. Normal two-point discrimination is less than 5 mm but is not present until age 5 to 7 years. Pin-prick sensibility testing will only hurt and scare the already anxious child and should be avoided. A recent prospective study indicated an 8% incidence of nerve injury in children with distal radial fractures (168).

The ipsilateral extremity should be carefully examined for fractures of the carpus, forearm, or elbow (107, 128, 129, 133, 147, 155, 160–162) because 3% to 13% of distal radial fractures have associated ipsilateral extremity fractures (Fig. 9-42) (120, 155), increasing the risk of neurovascular compromise and compartment syndrome (Papavasilious, Staninski, ring).

Radiographs are diagnostic of the fracture type and degree of displacement. Standard AP and lateral radiographs usually are sufficient. Complete wrist, forearm, and elbow views are necessary for high-velocity injuries or when there is clinical tenderness. More extensive radiographic studies (CT scan, tomograms) usually are not necessary unless there is intrarticular extension of the metaphyseal fracture in a skeletally mature adolescent.
Treatment of incomplete distal radial and ulnar fractures depends on the age of the patient, the degree and direction of fracture displacement and angulation, the surgeon’s biases regarding remodeling, and the surgeon’s and community’s biases regarding deformity. In younger patients, the remodeling potential of an acute distal radial malunion is extremely high. Acceptable sagittal plane angulation of an acute distal radial metaphyseal fracture has been reported to be from 10 to 35 degrees in patients under 5 years of age (74,103,108,141,145,153,168). Similarly, in patients under 10 years of age, the degree of acceptable angulation has ranged from 10 to 25 degrees (74,103,108,141,153,168). In patients over 10 years of age, acceptable malunion has ranged from 5 to 20 degrees depending on the skeletal maturity of the patient (74,103,108,112,141,153,167,168). These factors define in general terms unstable fractures.

The ulnar fracture often associated with radial metaphyseal fracture can be metaphyseal or physeal, or an ulnar styloid avulsion. Similar to radial metaphyseal fractures, the ulnar fracture can be complete or incomplete.

Distal radial fractures also can occur in conjunction with more proximal forearm fractures (101). Monteggia fracture–dislocations (102), supracondylar distal humeral fractures (Reis, ring, Stanisrski), or carpal fractures (192,128,129,133,161,163). The combination of a displaced supracondylar distal humeral fracture and a displaced distal radial metaphyseal fracture has been called the pediatric floating elbow. This injury combination is unstable and has an increased risk for malunion and neurovascular compromise.

Classification

These fractures are classified by fracture pattern, type of associated ulnar fracture, and direction of displacement. Fracture displacement is broadly classified as dorsal or volar. Most distal radial metaphyseal fractures are displaced dorsally with apex volar angulation (32). Volar displacement with apex dorsal angulation can occur with palmar flexion injuries.

Metaphyseal fracture patterns are either torus, incomplete or greenstick, or complete fractures. Torus fractures are axial compression injuries. The site of cortical failure is the transition from metaphysis to diaphysis (138). These injuries are stable because of the intact periosteum. On rare occasion, they may extend into the physes, putting them at risk for growth impairment (80,81). Incomplete or greenstick fractures occur with a combination of compressive and rotatory forces, generally a dorsiflexion force and supination deforming force. This leads to a volar tension side failure and a dorsal compression injury. The degree of force determines the amount of plastic deformation, dorsal comminution, and fracture angulation and rotation. If the force is sufficient, a complete fracture occurs with displacement of both the volar and dorsal cortices. Length may be maintained with apposition of the proximal and distal fragments. Frequently, the distal fragment lies proximal and dorsal to the proximal fragment in bayonet apposition (Table 9-2).

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Pedicastic distal radial metaphyseal fractures are not classified by degree of instability. Unstable fractures have been predominately identified retrospectively by the failure to maintain a successful closed reduction (Fig. 9-43). This occurs in approximately 30% of complete distal radial metaphyseal fractures (139,145,167). This high percentage of loss of alignment has been tolerated because of the remodeling potential of the distal radius. Anatomic remodeling is possible because the extension deformity is in the plane of motion of the wrist joint, the metaphyseal fracture is juxtaphysseal, and most of these fractures occur while there is still significant growth remaining. However, concern has increased about the high failure rate of closed reduction to maintain anatomic alignment of these fractures. Factors that have been identified as increasing the risk of loss of reduction with closed manipulation and casting include poor casting, bayonet apposition, translation greater than 50% the diameter of the radius, apex volar angulation greater than 30 degrees, isolated radial fractures, and radial and ulnar metaphyseal fractures at the same level (139,145,167). These factors define in general terms unstable fractures.

![Figure 9-43](image.png)

**Figure 9-43.** Results of angulation. A: Significant apex volar angulation of the distal fragment. B: The appearance was not as apparent cosmetically as in another patient with less angulation that was directed apex dorsally. (Reprinted from Wilkins KE, ed. Operative management of upper extremity fractures in children. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1994:27; with permission.)

Treatment

Treatment options are similar to those for radial physeal fractures: immobilization alone, closed reduction and cast immobilization, closed reduction and percutaneous pinning, and open reduction. The fracture type, degree of fracture instability, associated soft tissue or skeletal trauma, and the age of the patient all influence choice of treatment.

**Torus Fractures**

Torus fractures are compression injuries with minimal cortical disruption. If only one cortex is violated, the injury is stable. Treatment should consist of protected immobilization to prevent further injury and relieve pain. Once the patient is comfortable, range-of-motion exercises and nontraumatic activities can begin. Fracture healing usually occurs in 2 to 4 weeks (20,40,68,74). Simple torus fractures usually heal without long-term sequelae.

Bicortical disruption on both the AP and lateral views indicates a more severe injury than a stable torus fracture. Splint or limited immobilization in this situation puts the child at risk for displacement. More prolonged immobilization, long arm cast protection in a young patient, and closer follow-up are generally recommended to lessen the risk of malunion. These fractures generally heal in 3 to 6 weeks.

**Incomplete/Greenstick Fractures**

**Immobilization Alone**

Treatment of incomplete distal radial and ulnar fractures depends on the age of the patient, the degree and direction of fracture displacement and angulation, high percentage of loss of reduction with closed manipulation and casting include poor casting, bayonet apposition, translation greater than 50% the diameter of the radius, apex volar angulation greater than 30 degrees, isolated radial fractures, and radial and ulnar metaphyseal fractures at the same level (139,145,167). These factors define in general terms unstable fractures.

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Acceptable residual angulation is that which will result in total metaphysseal and partial physeal union.

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1. Acceptable residual angulation is that which will result in total metaphysseal and partial physeal union.
2. Classification of distal radial metaphyseal fractures is based on injury pattern, type of associated ulnar fracture, and direction of displacement. Fracture displacement is broadly classified as dorsal or volar. Most distal radial metaphyseal fractures are displaced dorsally with apex volar angulation. Volar displacement with apex dorsal angulation can occur with palmar flexion injuries.
The high potential for remodeling of a distal radial metaphyseal malunion has led some researchers to recommend immobilization alone. As mentioned, the range of accepted malalignment has been broad as well as age and researcher dependent (Fig. 9-44 and Fig. 9-45).

![Extensive remodeling. A: Injury film of a 7-year-old with a tension failure greenstick fracture. B and C: Lateral and anteroposterior views of the same patient taken 1 month later showing development of 45 degrees angulation in the sagittal plane and 40 degrees in the coronal plane. D and E: True appearance taken 4 years later shows only residual angulation of 10 degrees in the sagittal plane and full correction of radial angulation in the coronal plane. The patient had a range of forearm motion equal to that of the opposite extremity and was asymptomatic.](image)

![Bayonet remodeling. A: After numerous attempts at closed reduction, the best alignment that could be obtained was dorsal bayonet apposition in this 8-year-old. B: Three months postfracture, there is good healing and early remodeling. C and D: Five years after the injury (age 13), remodeling was complete and the patient had normal appearance and forearm motion. Acceptable frontal plane deformity has been more uniform. The fracture tends to displace radially with an apex ulnar angulation. This does have the potential to remodel (144), but less so than sagittal plane deformity. Most researchers agree that only 10 degrees or less of acute malalignment in the frontal plane should be accepted. More malalignment than this may not remodel and may result in loss of forearm rotation because of the loss of interosseous space between the radius and ulna (169) (Table 9-3).

Closed Reduction

Most researchers agree that displaced and malaligned incomplete fractures should be reduced closed. The areas of controversy are the degree of acceptable deformity, whether the intact cortex should be fractured, and the position of immobilization.

Controversies about acceptable angulation of the fracture after closed reduction involve the same differences discussed in the immobilization section. As mentioned, more malalignment can be accepted in younger patients, in those with sagittal plane deformity, and in those without marked cosmetic deformity. Malaligned apex volar incomplete fractures are less obvious than the less common apex dorsal fractures.

As Evans (115) and Rang (86) emphasized, incomplete forearm fractures have a rotatory component to their malalignment. The more common apex volar fractures represent a supination deformity, whereas the less common apex dorsal fractures are malrotated in pronation. Correction of the malrotation is necessary to achieve anatomic alignment. Controversy exists regarding completion of greenstick fractures (15,65,111,115,151). Most researchers advocate completion of the fracture to reduce the risk of subsequent loss of reduction from the intact periosteum and concave deformity acting as a tension band (157,168) to redisplace the fracture. Completing the fracture increases the risk of instability and malunion.

The position and type of immobilization also have been controversial. Recommendations for the position of postreduction immobilization include supination, neutral, and pronation. The rationale for immobilization in pronation is that reduction of the more common apex volar fractures requires correction of the supination deformity (115). Following this rationale, apex dorsal fractures should be reduced and immobilized in supination. Pollen (145) believed that the brachioradialis was a deforming force in pronation and was relaxed in supination (Fig. 9-48) and advocated immobilization in supination for all displaced distal radial fractures. Kasser (59) recommended immobilization in slight supination to allow better molding of the volar distal radius. Some researchers advocate immobilization in a neutral position, believing this is best at maintaining the interosseous space and has the least risk of disabling loss of forearm rotation in the long term (113,141,155). Davis and Green (111) and Ogden (74) advocate that each fracture seek its own preferred position of stability. Gupta and Danielsson (130) randomized immobilization of distal radial metaphyseal greenstick fractures in neutral, supination, or pronation to try to determine the best position of immobilization. Their study showed a statistical improvement in final healing with immobilization in supination.

![The brachioradialis is relaxed in supination but may become a deforming force in pronation. (Reprinted from Pollen AG. Fractures and dislocations in](image)
Another area of controversy is whether long arm or short arm cast immobilization is better. Most publications on pediatric distal radial fracture treatment advocate long arm cast treatment for the first 3 to 4 weeks of healing (20,40,58,74,103,158). The rationale is that elbow flexion reduces the muscle forces acting to displace the fracture. In addition, a long-arm cast may further restrict the child's activity and therefore decrease the risk of displacement. However, Chess (104,105) published reported redisplacement and reduction rates with well-molded short arm casts similar to those with long arm casts. They used a cast index (sagittal diameter divided by coronal diameter at the fracture site) of 0.7 or less to indicate a well-molded cast. Wilkins achieved similar results with short-arm cast treatment (168). However, in most centers, the standard is still long arm cast immobilization (20,40,58,103,158).

COMPLETE FRACTURES

Complete fractures of the distal radius, with or without an associated displaced ulnar fracture, are unstable fractures. Generally these fractures are displaced dorsally, tearing the volar periosteum and soft tissues. The distal fragment of epiphysis and metaphysis often is in bayonet apposition with the proximal fragment (Fig. 9-38). Concomitant radial and ulnar fractures at the same level may be more unstable than isolated fractures (167) (Fig. 9-47). However, Gibbons reported loss of reduction in 91% of isolated radial fractures after closed reduction. Although a rare fracture with bayonet apposition in a very young patient may remodel (168), the standard treatment for completely displaced fractures is reduction and stabilization. The current controversy is whether cast immobilization alone is adequate stabilization or whether percutaneous pin fixation is more appropriate for displaced, complete, distal radial metaphyseal fractures.

FIGURE 9-47. Radial deviation constricts the interosseous space, which may decrease forearm rotation. (Reprinted from Wilkins KE, ed. Operative management of upper extremity fractures in children. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1994:28; with permission.)

Reduction Techniques

Techniques of reduction have included initial distraction with finger traps (111,157) followed by manipulation and direct manipulation of the fracture by accentuating the deformity (Fig. 9-48 and Fig. 9-49). Both Rang (86) and Fernandez (118) expressed concern about the success of finger trap distraction because the intact dorsal periosteum will not stretch adequately to allow reduction. They advocated sequential reduction maneuvers: initial manipulation of the distal fragment dorsally to accentuate the deformity (Fig. 9-48), thumb pressure on the relaxed dorsal edge of the distal fragment to correct the overriding, and reduction of the fracture by forceable application of distal and volar pressure (Fig. 9-49). Anatomic reduction may require repetitive “toggling” of the distal fragment volarly.

FIGURE 9-48. A and B: Use of the thumb to push the distal fragment hyperdorsiflexed 90 degrees (solid arrow) until length is reestablished. Countertraction is applied in the opposite direction (open arrows).

FIGURE 9-49. A and B: Once length has been reestablished, the distal fragment is flexed into the correct position. Alignment is checked by determining the position of the fragments with the thumb and forefingers of each hand.

There is considerable controversy about what constitutes an acceptable reduction (76,110,111,121,123,131,137,148,149,163). This is clearly age dependent, because the younger the patient, the greater the potential for remodeling (Fig. 9-50). Volar-dorsal malalignment has the greatest potential for remodeling because this is in the plane of predominant motion of the joint. Marked radioulnar malalignment is less likely to remodel. Malrotation will not remodel (Fig. 9-51). The ranges for acceptable reduction according to age are given in the immobilization section on incomplete fractures and apply to complete fractures as well.
FIGURE 9-50. A: Appearance 6 weeks after closed reduction of a distal forearm fracture in an 8½-year-old boy. The radius was reduced, and the ulnar fracture remained overriding. B: Eighteen months after injury the ulnar fracture had remodeled completely with symmetric distal radioulnar joints.

FIGURE 9-51. A: This 7-year-old with bayonet apposition was immobilized in a long arm cast in full pronation. B: One year later, there was still considerable angulation with significant loss of forearm rotation and an unacceptable cosmetic appearance.

Cast Immobilization

As discussed earlier there is some disagreement regarding short arm or long arm cast immobilization (104,105,168). However, regardless of the length of the cast, it is imperative to have a well-molded cast over the fracture site (Fig. 9-52). After reduction of a dorsally displaced fracture, three-point fixation is used with dorsal pressure proximal and distal to the fracture site and volar pressure over the reduced fracture. Excessive swelling should be monitored. If there is any concern regarding impending compartment syndrome, the cast and webri should be immediately bivalved and the patient's clinical status monitored closely.

FIGURE 9-52. Three-point molding. Top: Three-point molding for dorsally angulated (apex volar) fractures, with the proximal and distal points on the dorsal aspect of the cast and the middle point on the volar aspect just proximal to the fracture site. Bottom: For volar angulated fractures, where the periosteum is intact volarly and disrupted on the dorsal surface, three-point molding is performed with the proximal and distal points on the volar surface of the cast and the middle point just proximal to the fracture site on the dorsal aspect of the cast.

The primary problem with closed reduction and cast immobilization is loss of reduction (Fig. 9-53). Mani et al. (139) and Proctor et al. (146) described remanipulation rates of 21.3% and 23.5%, respectively. Mani et al. (139) concluded that initial displacement of the radial shaft of over 50% was the single most reliable predictor of failure of reduction. Proctor et al. (146) found that complete initial displacement resulted in a 52% incidence of redisplacement of distal radial fractures in children. Gibbons et al. (126) noted that completely displaced distal radius fractures with intact ulnas had a remanipulation rate of 91% after closed reduction and cast immobilization alone versus a 0% rate of remanipulation when the same fractures were treated with closed reduction, Kirschner wire fixation, and cast immobilization. All three researchers strongly advocated percutaneous pinning of distal radial fractures at risk of redisplacement (Fig. 9-54). Widmann and Waters (167) prospectively studied all distal radial metaphyseal fractures, 31% lost reduction and required further intervention with repeat reduction, casting, or pinning. In patients over 10 years of age with angulation of more than 30 degrees, the remanipulation rate was 75%. These findings led to a more recent prospective, randomized study by Waters et al. (168) of distal radial metaphyseal fractures treated by either closed reduction and cast immobilization or closed reduction and percutaneous pinning. Selection criteria were a closed metaphyseal fracture angulated more than 30 degrees in a skeletally immature patient over 10 years of age. To maximize the outcome of the cast immobilization group, these patients were treated by a member of the Pediatric Orthopedic Society of North America with expertise in trauma care. General anesthesia, fluoroscopic control, and a long arm cast were used. Despite these optimal conditions, 7 of 18 patients in the cast immobilization group lost reduction and required remanipulation.

FIGURE 9-53. Serial radiographs at 3 days (A) and 10 days (B) revealing slow loss of reduction that is commonplace after distal radial metaphyseal fracture closed reduction.
Additional stability to pin fixation (indications for the use of external fixation. Supplemental external fixation also may be necessary for severely comminuted frac-


The results of all of these studies indicate that distal radial metaphyseal fractures with initial displacement of more than 30 degrees are inherently unstable. Loss of
reduction is common, with the risk in the 30% to 40% range. Incomplete reduction (139,146) and poor casting techniques (194,105,168) increase the risk of loss of
reduction. In addition, the risk of loss of reduction increases with the age of the patient and the degree of initial displacement.

Loss of reduction requires repeat manipulation or it will result in a malunion. Although the rate of malunion is frequent after these fractures
(40,46,54,58,67,69,134,105,109,111,165), because of the potential for remodeling in skeletally immature patients, it has not been considered a serious problem
(17,37,38,103,121–124). Distal radial fractures are juxtaphyseal, the malunion often is in the plane of motion of the wrist joint (dorsal displacement with apex volar
angulation), and the distal radius accounts for 60% to 80% of the growth of the radius. All these factors favor remodeling of a malunion. However, deCourville et al.
(112) reported that of 602 distal radial fractures, 14% had an initial malunion of more than 5 degrees. Of these, 78% corrected the frontal plane deformity and only
53% remodeled completely in the sagittal plane. In addition, 37% had loss of forearm rotation.

Closed Reduction and Percutaneous Pinning

In the past 10 years, closed reduction and percutaneous pinning have become more common as the primary treatment of distal radial metaphyseal fractures in
children and adolescents (125,139,146,166,167). The indications cited include fracture instability and high risk of loss of reduction (125,139,146), excessive local
swelling that increases the risk of neurovascular compromise (95,166,168), ipsilateral fractures of the distal radius and elbow region (floating elbow) that increase the
risk of compartment syndrome (Fig. 9-43) (155,169), and any remanipulation (Fig. 9-55) (167,168).

Pinning usually is done from distal to proximal under fluoroscopic guidance. When possible, the physis is avoided. Adequate exposure should be obtained to avoid
radial sensory nerve or extensor tendon injury. Smooth Kirschner or C-wires are used. In younger patients, a single pin with supplemental cast immobilization may be
adequate fixation. Crossed pins are more stable (Fig. 9-56). The first pin, or single pin, enters from the radial side distal to the fracture and passes obliquely to the
ulnar aspect of the radius proximal to the fracture. The second pin enters the radius distal to the fracture between the fourth and fifth compartments and passes
obliquely across the fracture to the proximal radial side of the radius. The pins are left out through the skin to allow easy removal in the ambulatory setting. A
supplemental, loose-fitting cast is applied. The advantage of pin fixation is that a tight, well-molded cast is not necessary to maintain reduction. This lessens the risk of
neurovascular compromise with associated excessive swelling or ipsilateral fractures. Obviously, pin fixation avoids the risk of loss of reduction in an unstable
fracture. Pinning does have the risk of infection and concerns regarding growth injury.

External Fixation

Unlike distal radial fractures in adults, external fixation rarely is indicated in skeletally immature patients. Although it can be used successfully (152,165), the success
rates of both closed reduction and percutaneous pinning techniques make it unnecessary for uncomplicated distal radial fractures in children. The best indication is
severe associated soft tissue injuries. A severe crush injury, open fracture, or replantation after amputation that requires extensive soft tissue care and surgery are all
indications for the use of external fixation. Supplemental external fixation also may be necessary for severely comminuted fractures to maintain length and provide
additional stability to pin fixation (Fig. 9-22). Standard application of the specific fixator chosen is performed with care to avoid injury to the adjacent sensory nerves.

The results of all of these studies indicate that distal radial metaphyseal fractures with initial displacement of more than 30 degrees are inherently unstable. Loss of
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additional stability to pin fixation (Fig. 9-22). Standard application of the specific fixator chosen is performed with care to avoid injury to the adjacent sensory nerves.
Open Reduction

Open reduction is indicated for open or irreducible fractures (Fig. 9-57, Fig. 9-58, and Fig. 9-59). Open fractures constitute approximately 1% of all distal radial metaphyseal fractures. All open fractures, regardless of grade of soft tissue injury, should be irrigated and debrided in the operating room. The open wound should be enlarged adequately to debride the contaminated and nonviable tissues and protect the adjacent neurovascular structures. After thorough irrigation and debridement, the fracture should be anatomically reduced and stabilized, usually with two smooth pins. If the soft tissue injury is severe, supplemental external fixation allows for observation and treatment of the wound without jeopardizing the fracture reduction. The original open wound should not be closed primarily. Appropriate prophylactic antibiotics should be used depending on the severity of the open fracture.

Irreducible fractures are rare (Fig. 9-58) and generally are secondary to interposed soft tissues. With dorsally displaced fractures, the interposed structure usually is the volar periosteum or pronator quadratus (Fig. 9-58) and rarely the flexor tendons or neurovascular structures. In volarly displaced fractures, the periosteum or extensor tendons may be interposed. The fracture should be approached in a standard fashion opposite the side of displacement (i.e., volar approach for an irreducible dorsal fracture). The adjacent neurovascular and tendinous structures are protected and the offending soft tissue is extracted from the fracture site. Pin stabilization is recommended to prevent problems with postoperative swelling or loss of reduction in cast.

Closed reduction rarely fails if there is no interposed soft tissue. However, occasionally multiple attempts at reduction of a bayonet apposition fracture can lead to significant swelling that makes closed reduction impossible. If the patient is too old to remodel bayonet apposition, open reduction is appropriate. Pin fixation without violating the physis is recommended.

AUTHOR’S PREFERRED METHOD OF TREATMENT

Nondisplaced Fractures

Nondisplaced metaphyseal compression fractures, including torus and unicortical compression greenstick fractures, are inherently stable. These include torus and unicortical compression greenstick fractures. Immobilization is used until resolution of pain and radiographic evidence of healing, generally about 3 weeks. Depending on the activity level of the patient, a volar wrist splint or a short arm cast can be used. Immobilization provides comfort from pain during healing and protects against displacement with secondary injury. It is important that an unstable bicondylar fracture not be unrecognized on radiograph. Bicondylar fractures need more protection, longer restriction of activity, and closer follow-up to avoid displacement and malunion. A well-molded long arm cast is applied and radiographs obtained every 7 to 10 days until evidence of early radiographic healing. A short-arm cast is then worn until clinical and radiographic healing is complete. Any loss of reduction is treated with repeat reduction. Return to contact sports is restricted until the patient regains full motion and strength.

Minimally Displaced Fractures

Displaced greenstick fractures that are reduced are at risk for redisplacement. If left unreduced or poorly immobilized, a mild deformity can become severe during the course of healing. Therefore, closed anatomic reduction is performed in all bicondylar fractures with more than 10 degrees of malalignment. Generally these fractures have apex volar angulation and dorsal displacement. Conscious sedation is used with portable fluoroscopy in the emergency care setting. The distal fragment and hand are distracted and then reduced volarily. With isolated distal radial fractures, it is imperative to reduce the DRUJ with appropriate forearm rotation. For apex volar fractures, this usually is with pronation. If the fracture is apex dorsal with volar displacement, the reduction forces are the opposite. A long arm cast with three-point molding is used for 3 to 4 weeks. Radiographs are obtained every 7 to 10 days until there is sufficient callus formation. A short-arm cast or volar wrist splint is used until full healing, generally at 4 to 6 weeks after fracture reduction. The patient is then restricted from contact sports until full motion and strength are regained, which may take up to 3 weeks after cast removal. Formal therapy rarely is required. The patient and parents should be warned at the start of treatment of the risk of redisplacement of the fracture.

Bayonet Apposition

Marked displacement of distal radial metaphyseal fractures usually results in foreshortening and dorsal overlap of the distal fragment on the proximal fragment. This often is associated with a same-level volar metaphyseal fracture, similarly in bayonet apposition. Rarely, the distal fragment is in volar bayonet apposition. Both of these situations require more skill of reduction and complete analgesia at the fracture site. At our institution, we reduce this fracture in the operating room with general anesthesia or in the emergency room with conscious sedation and supplemental local hematoma block. In either situation, portable fluoroscopy is used. The fracture usually is reduced in the emergency room in young patients with minimal swelling and no neurovascular compromise, and in whom cast treatment will be sufficient. Reduction with general anesthesia is preferred for older patients and for those with marked displacement, swelling, or associated neurovascular compromise in whom
percutaneous pin treatment is chosen.

**AUTHOR’S PREFERRED METHOD OF TREATMENT**

The reduction maneuver is the same regardless of anesthesia type or stabilization method. As opposed to a Colles’ fracture in an adult, traction alone will not reduce the fracture because the dorsal periosteum acts as a tension band that does not respond to increasing linear traction with weights. Finger traps with minimal weight (less than 10 pounds) can be used to balance the hand and help with rotational alignment (the “steel resident”) (Fig. 9-59). However, applying progressive weight will only distract the carpus and will not alter the fracture alignment.

FILE 9-59. Once reduced, the fracture is maintained with finger trap traction and countertraction on the arm. The quality of reduction is assessed quickly with the image intensifier.

After applying preliminary traction with either light-weight finger traps or hand traction, a hyperdorsiflexion maneuver is performed (Fig. 9-48). The initial deformity is accentuated and the distal fragment is brought into marked dorsiflexion. The dorsum of the hand should be brought more than 90 degrees, and at times parallel to the dorsum of the forearm to lessen the tension on the dorsal forearm. Thumb pressure is used on the distal fragment while still in this deformed position (Fig. 9-48) to restore length by bringing the distal fragment beyond the proximal fragment. Reduction is then obtained by flexing the distal fragment while maintaining length (Fig. 9-49). Often this initial reduction maneuver restores length and alignment, but translational reduction is incomplete. The fracture should be completely reduced by toggling the distal fragment all the way volarly by repetitive slight dorsiflexion positioning of the distal fragment followed by volar pressure with the thumbs. It is important to anatomically reduce the fracture. Loss of reduction with cast immobilization is more likely if the fracture remains translated or malaligned.

If the patient presents late with marked swelling and the reduction is difficult, it is useful to try to lever the proximal fragment distally with a percutaneous smooth wire (Fig. 9-60). This may prevent an unnecessary open reduction. Percutaneous pin fixation is used after reduction.

FILE 9-60. Pin leverage. A: If a bayonet is irreducible, after sterile preparation, a chisel-point Steinmann pin can be inserted between the fracture fragments from a dorsal approach. Care must be taken not to penetrate too deeply past the dorsal cortex of the proximal fragment. B: Once the chisel is across the fracture site, it is levered into position and supplementary pressure is placed on the dorsum of the distal fragment (arrow) to slide it down the skid into place. This procedure is usually performed with an image intensifier.

**Cast Treatment**

If the patient is under 10 years of age, has no prereduction signs or symptoms of neurovascular impairment, or has minimal swelling, then cast immobilization is used (Fig. 9-61 and Fig. 9-62). I use a long arm cast. The cast is applied with the aid either of an assistant or finger traps and balancing counter weights on the upper arm (Fig. 9-62). The advantage of the finger trap steel resident is that there is no risk of muscle fatigue, mental distraction, or failure to maintain elbow flexion at 90 degrees that can occur with a human assistant. The cast is applied with the elbow flexed 90 degrees, the wrist in slight palmar flexion, and the forearm in the desired rotation for stability and alignment. This varies with each fracture and each surgeon. My preference is slight supination (20–30 degrees) unless the fracture dictates differently. This allows excellent molding against the volar aspect of the distal radius at the fracture site.

Distal radial metaphyseal fractures have complications similar to physeal fractures but with different frequencies. Loss of reduction often is used with Gustilo grade 1 or 2 open fractures. More severe soft tissue injuries usually require external fixation with a unilateral frame, with care taken to avoid soft tissue impingement during pin placement. If flap coverage is necessary for the soft tissue wounds, the fixator pins should be placed in consultation with the microvascular surgeon planning the soft tissue coverage.

Irreducible fractures are usually secondary to soft tissue entrapment. With dorsal displacement, this is most often either the volar periosteum or pronator quadratus, and open reduction through a volar approach is necessary to extract the interposed soft tissues and reduce the fracture (Fig. 9-63). Percutaneous pin fixation usually is used to stabilize the fracture in patients with open physis. If plate fixation is used, it should avoid violation of the physis (Fig. 9-36). Displaced intraarticular injuries in skeletally immature patients are adultlike and require standard treatment such as open reduction and internal fixation (Fig. 9-21) or combination treatment with internal and external fixation (Fig. 9-55).

Complications

Distal radial metaphyseal fractures have complications similar to physeal fractures but with different frequencies. Loss of reduction and malunion are the most
common problems, and growth-related complications are infrequent. Neurovascular compromise does occur and should be considered in the acute management of this fracture.

**Malunion**

Loss of reduction is a common complication of distal radial metaphyseal fractures treated with cast immobilization. Because this complication occurs in at least 30% of bayonet apposition fractures (126,139,146,166,167), many surgeons treat this fracture primarily with pin fixation to avoid the problems that can occur with malunion (Fig. 9-91). Otherwise it is clear that patients treated with cast immobilization need to be monitored closely (172).

Fortunately, many angular malunions of the distal radius will remodel (13,74,76,103,111,121,122 and 123,137,144,149), probably because of asymmetric physeal growth (136,137). The younger the patient, the less the deformity, and the closer the fracture is to the physis, the greater the potential for remodeling. It is unclear whether there is any capacity for rotational malunion remodeling (124,150). Angular and rotational malunion that does not remodel can lead to loss of motion. The degree and plane of loss of motion, as well as the individual affected, determine if this is functionally significant (172). Cadaveric studies indicate that residual malangulation of more than 20 degrees of the radius or ulna will lead to loss of forearm rotation (140,158,159). Less than 10 degrees of malangulation did not alter forearm rotation significantly in either study. Distal third malunion affected rotation less than middle or proximal third malunion. Radioulnar malunion affected forearm rotation more than volar-dorsal malunion. Malangulation may lead to a loss of rotation at a 1 : 2 degree ratio, whereas malrotation may lead to rotational loss at only a 1 : 1 degree loss (86). The functional loss associated with rotational motion loss is difficult to predict. This has led some clinicians to recommend no treatment (110,111), arguing that most of these fractures will remodel, and those that do not remodel will not cause a functional problem (134). However, a significant functional problem is present if shoulder motion cannot compensate for loss of supination.

I prefer to reduce these fractures as anatomically as possible and lessen the risk of malunion. No element of malrotation is accepted in the reduction. As indicated in the treatment sections, fractures at high risk of loss of reduction and malunion are treated with anatomic reduction and pin fixation. Fractures treated in a cast are followed closely and re-reduced for any loss of alignment of more than 10 degrees. Although loss of rotation can occur with anatomic reduction (32,148,168), it is less likely than with malunions.

**Nonunion**

Nonunion of a closed radial or ulnar fracture is rare. In children, nonunion has been universally related to a pathologic condition of the bone or vascularity (168). Congenital pseudarthrosis or neurofibromatosis (135) (Fig. 9-64) should be suspected in a patient with a nonunion after a benign fracture. This occurs most often in an isolated ulnar fracture. The distal bone is often narrowed, sclerotic, and plastically deformed. These fractures rarely heal with immobilization. Vascularized fibular bone grafting usually is necessary for healing of a nonunion associated with neurofibromatosis or congenital pseudarthrosis. If the patient is very young, this may include a vascularized epiphyseal transfer to restore distal growth.

**Cross-Union**

Cross-union is a rare complication of pediatric distal radial and ulnar fractures. It has been described after high-energy trauma and internal fixation (164). A single pin crossing both bones increases the risk of cross-union (184). Synostosis take-down can be performed, but the results usually are less than full restoration of motion. It is important to determine if there is an element of rotational malunion with the cross-union because this will affect the surgical outcome.

Soft tissue contraction across both bones also has been described (116). Contracture release resulted in restoration of forearm motion.

**Refracture**

Fortunately, refractures after metaphyseal radial fractures are rare and much less common than after diaphyseal level radial and ulnar fractures. Most commonly, refracture occurs with premature discontinuation of immobilization or early return to potentially traumatic activities. It is advisable to protectively immobilize the wrist until full radiographic and clinical healing (usually 6 weeks) and to restrict activities until full motion and strength are regained (usually an additional 1–3 weeks). Individuals involved in high-risk activities, such as downhill ski racing, snowboarding, or skateboarding, should be protected with a splint during those activities for much longer.

**Growth Disturbance**

Growth arrest of the distal radius after metaphyseal fracture is rare. Abram and Connolly each reported one patient with physeal arrest after nondisplaced torus fractures. Two additional patients were reported in a series of 150 distal radial metaphyseal fractures (119). Wilkins and O’Brien (168) proposed that these arrests may be in fractures that extend from the metaphysis to the physis. This coincides with a Peterson type I fracture (81,49) (Fig. 9-65) and in essence is a physeal fracture. These fractures should be monitored for growth arrest.
Both undergrowth and overgrowth of the distal radius after fracture has been described by DePablos (114). The average difference in growth was 3 mm, a range of −5 to +10 mm of growth disturbance compared with the contralateral radius. Maximal overgrowth occurred in the 9- to 12-year-old age group. As long as the patient is asymptomatic, under- or overgrowth is not a problem. If ulnocarpal impaction or DRUJ disruption occurs, then surgical rebalancing of the radius and ulna may be necessary.

**Neurovascular Injuries**

Both the median and ulnar (106,163) nerves are less commonly injured in metaphyseal fractures than in physeal fractures. The mechanisms of neural injury in a metaphyseal fracture include direct contusion from the displaced fragment, traction ischemia from tenting of the nerve over the proximal fragment (144), entrapment of the nerve in the fracture site (40,170), rare laceration of the nerve (Fig. 9-66), and the development of an acute compartment syndrome. If there is concern about compartment syndrome, the forearm and carpal canal pressures should be measured immediately. If pressures are markedly elevated, appropriate fasciotomies and compartment releases should be performed immediately. Finally, if the nerve was intact before reduction and is out after reduction, neural entrapment should be considered, and surgical exploration and decompression may be required. Fortunately, most median and ulnar nerve injuries recover after anatomic reduction of the fracture.

**Infection**

Infection after distal radial fractures is rare and is associated with open fractures or surgical intervention. Fee et al. (117) described the development of gas gangrene in four children after minor puncture wounds or lacerations associated with distal radial fractures. Treatment involved only local cleansing of the wound in all four and wound closure in one. All four developed life-threatening clostridial infections. Three of the four required upper limb amputations, and the fourth underwent multiple soft tissue and bony procedures for coverage and treatment of osteomyelitis.

Infections related to surgical intervention also are rare. Superficial pin site infections can occur and should be treated with pin removal and antibiotics. Deep-space infections from percutaneous pinning of the radius has not been described, but it is only reasonable to think that it will occur at some point. All deep-space infections should be treated with appropriate surgical debridement, antibiotics, and wound management.

**PEDIATRIC GALEAZZI FRACTURES**

Fractures of the distal radius associated with DRUJ disruption have been called Galeazzi fracture–dislocations. Although Sir Ashley Cooper is credited with the first description of this injury in 1824, Riccardo Galeazzi (177,186) (Fig. 9-67) gave this fracture–dislocation its name with his 1934 report of 18 such injuries. In children, this injury may involve either disruption of the DRUJ ligaments or, more commonly, a distal ulnar physeal fracture. The former is called a true Galeazzi lesion and the latter is a Galeazzi equivalent lesion (Fig. 9-68) (60,181,182,187,188).

**FIGURE 9-65.** Peterson type I physeal injury. A: A comminuted distal metaphyseal fracture that extends to the physis (open arrow). B: Six weeks after the fracture, the callus also extends up to the physis (open arrow).

**FIGURE 9-66.** A grade III open fracture of the radius resulted in complete disruption of the ulnar nerve. Intraoperative photographs of the nerve deficit between the operative jeweler’s forceps (A) and sural nerve grafting (B) after the wound was clean enough to allow for nerve reconstruction.


Anatomy

The radius normally rotates around the relatively stationary ulna. The two bones of the forearm articulate at the proximal and distal radioulnar joints. In addition, proximally the radius and ulna articulate with the distal humerus and distally with the carpus. These articulations are responsible for forearm pronation and supination, as well as elbow and wrist flexion and extension. At the DRUJ, the concave sigmoid notch of the radius incompletely matches the convex, asymmetric, semicylindrical shape of the distal ulnar head (Fig. 9-69) (3). This allows some translation at the DRUJ with rotatory movements. The ligamentous structures are critical in stabilizing the radius as it rotates about the ulna.

The DRUJ includes multiple soft tissue attachments, the most important of which is the TFCC. The TFCC includes the volar and dorsal ligamentous attachments of the distal ulna to the radial sigmoid notch, as well as the distal extension to the ulnar styloid, carpus, and base of the fifth metacarpal. The volar ulnocarpal ligaments (V ligament) from the ulna to the lunate and triquetrum are important ulnocarpal stabilizers (3,190,196). The central portion of the TFCC is the articular disk (Fig. 9-70). The interaction between the bony articulation and the soft tissue attachments accounts for stability of the DRUJ during pronation and supination. At the extremes of rotation, the joint is most stable. The compression loads between the radius and ulna are aided by the tensile loads of the TFCC to maintain stability throughout rotation (Fig. 9-71).

Throughout the mid-forearm, the interosseous ligament (Fig. 9-72) connects the radius to the ulna. It passes obliquely from the proximal radius to the distal ulna. However, the interosseous ligament is not present in the distal radius. Moore et al. found that injuries to the TFCC and interosseous ligament were responsible for progressive shortening of the radius with fracture in a cadaveric study. The soft tissue component to the injury is a major factor in the deformity and instability in a Galeazzi fracture–dislocation.
volar-to-dorsal force should reduce the incomplete fracture of the radius and the DRUJ dislocation (incomplete radial fracture is an apex dorsal volar displaced fracture, the rotatory deformity is pronation (deformity is supination. Pronating the radius and applying dorsal-to-volar reduction force should align the fracture and reduce the DRUJ dislocation.

The method of reduction for greenstick radial fractures depends on the type of displacement. With apex volar dorsally displaced fractures, the distal ulnar fracture often is a greenstick type that is stable after reduction and cast immobilization is sufficient (Fig. 9-73). This is evident both on clinical and radiographic examinations. In addition, the radius is foreshortened in a complete fracture, causing more radial deviation of the hand and wrist (Fig. 9-76). A child with a Galeazzi injury has pain and limitation of forearm rotation and wrist flexion and extension. Neurovascular impairment is rare.

The radial fracture is evident on radiographs, and concurrent injuries to the ulna or DRUJ should be identified. A true lateral view is necessary to identify the direction of displacement, which is imperative to determine the method of reduction. Rarely are special radiographs, such as a CT scan, necessary.

Classification

Galeazzi fracture–dislocations are most commonly described by direction of displacement of either the distal ulnar dislocation or the radial fracture. Letts (181,182) preferred to describe the direction of the ulna: volar or dorsal. Walsh and McLaren (194) classified pediatric Galeazzi injuries by the direction of displacement of the distal radial fracture. Dorsal displacement (apex volar) fractures were more common than volar displacement (apex dorsal) fractures in their series (Fig. 9-73). Wilkins and O'Brien (168) modified the Walsh and McLaren method by classifying radial fractures as incomplete and complete fractures and ulnar injuries as true dislocations and physeal fractures (Table 9-4). DRUJ dislocations are called true Galeazzi lesions and distal ulnar physeal fractures are called Galeazzi equivalent lesions (60,178,181,182).

TABLE 9-4. CLASSIFICATION: GALEAZZI FRACTURES IN CHILDREN

<table>
<thead>
<tr>
<th>Type</th>
<th>Volar Displacement of Distal Radius</th>
<th>Ulnar Displacement Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Comminuted volar</td>
<td>DRUJ dislocation</td>
</tr>
<tr>
<td>B</td>
<td>Partially comminuted volar</td>
<td>DRUJ dislocation</td>
</tr>
<tr>
<td>C</td>
<td>Complete volar</td>
<td>DRUJ dislocation</td>
</tr>
</tbody>
</table>

Type of fracture: (A) Comminuted volar displacement of the distal radius; (B) Partially comminuted volar displacement of the distal radius; (C) Complete volar displacement of the distal radius. DRUJ dislocation: (A) Comminuted volar DRUJ dislocation; (B) Partially comminuted volar DRUJ dislocation; (C) Complete volar DRUJ dislocation.

Pediatric Galeazzi fractures have a higher success rate with nonoperative treatment than similar injuries in adults (183,187). In adults, it is imperative to anatomically reduce and internally fix the distal radial fracture (190,183,184,185,187). Generally the DRUJ is reduced with reduction and fixation of the radius. In pediatric patients, the distal radial fracture often is a greenstick type that is stable after reduction and cast immobilization is sufficient (183,194). However, adolescents with complete fractures should be treated with internal fixation similar to adults.

Closed Reduction

The method of reduction for greenstick radial fractures depends on the type of displacement. With apex volar dorsally displaced fractures of the radius, the rotatory deformity is supination. Pronating the radius and applying dorsal-to-volar reduction force should align the fracture and reduce the DRUJ (Fig. 9-74). Similarly, if the incomplete radial fracture is an apex dorsal volar displaced fracture, the rotatory deformity is pronation (Fig. 9-75). Supinating the forearm and applying volar-to-dorsal force should reduce the incomplete fracture of the radius and the DRUJ dislocation (168,181,182,193). In both these situations, portable fluoroscopy...
can be used to evaluate the fracture–dislocation reduction and to test the stability of the distal ulna. If anatomically reduced and stable, a long arm cast is applied with appropriate rotation and three-point molds. The cast is left in place for 6 weeks to allow the soft tissue injuries to heal.

**FIGURE 9-74.** Supination-type Galeazzi fracture. A: View of the entire forearm of an 11-year-old boy with a Galeazzi fracture–dislocation. B: Close-up of the distal forearm shows that there has been disruption of the distal radioulnar joint (arrows). The distal radial fragment is dorsally displaced (apex volar), making this a supination type of mechanism. Note that the distal ulna is volar to the distal radius. C and D: The fracture was reduced by pronating the distal fragment. Because the distal radius was partially intact by its greenstick nature, the length was easily maintained, reestablishing the congruity of the distal radioulnar joint. The patient was immobilized in supination for 6 weeks, after which full forearm rotation and function returned.

In a Galeazzi equivalent injury with a radial fracture and an ulnar physeal fracture, both bones should be reduced. Usually this can be accomplished with the same methods of reduction if the radial fracture is incomplete. The distal ulnar physeas can remodel a nonanatomic reduction if there is sufficient growth remaining and the ulnar physeas continues to grow normally. Unfortunately, the risk of ulnar growth arrest after a Galeazzi equivalent has been reported to be as high as 55% (52).

Complete fractures of the distal radius have a higher rate of loss of reduction after closed treatment (168). If not monitored closely and re-reduced if necessary, loss of reduction can lead to malunion with loss of motion and function. These injuries may be best treated with open reduction as in adults.

**Open Reduction**

The indication for open reduction of the radial fracture is failure to obtain or maintain fracture reduction. This most often occurs with unstable complete fractures (Fig. 9-76). Open reduction and internal fixation of the radius are performed via an anterior approach (Fig. 9-77). Standard compression plating is preferred to intramedullary or cross-pinning techniques. Stable, anatomic reduction of the radius almost always leads to stable reduction of the DRUJ dislocation. A long arm cast is used for 6 weeks to allow fracture and soft tissue healing.

**FIGURE 9-76.** Fractures of the distal radius are angulated toward the ulna due to the pull of the long forearm muscles and the pronator quadratus. (Redrawn from Cruess RL. The management of forearm injuries. *Orthop Clin North Am* 1973;4:969–982; with permission.)

**FIGURE 9-77.** A: The patient with the pronation injury shown in Fig. 9-69 had a closed reduction and attempted fixation with pins placed percutaneously across the fracture site. However, this was inadequate in maintaining the alignment and length of the fracture of the distal radius. B: The length of the radius and the distal radioulnar relationship were best reestablished after internal fixation of the distal radius with a plate placed on the volar surface. The true amount of shortening present on the original injury film (see Fig. 9-69A) is not really appreciated until the fracture of the distal radius is fully reduced. (Reprinted from Wilkins KE, ed. Operative management of upper extremity fractures in children. Rosemont, IL: American Academy of Orthopaedic Surgeons, 1994:34; with permission.)
Occasionally, the DRUJ dislocation cannot be reduced (Fig. 9-78) because of interposed soft tissues, most commonly the periosteum, extensor tendons (extensor carpi ulnaris, extensor digiti quinti), TFCC, or other ligamentous structures. The easiest approach for open reduction of the DRUJ is an extended ulnar approach. Care should be taken to avoid injury to the ulnar sensory nerve. This approach allows for exposure both volarly and dorsally to extract the interposed soft tissues and repair the torn structures. Smooth pin fixation of the DRUJ can be used to maintain reduction and allow application of a loose-fitting cast. The pin is removed in the office at four weeks with continuation of the cast for 6 weeks.

![Figure 9-78](image)

**FIGURE 9-78.** An adolescent girl presented 4 weeks postinjury with a painful, stiff wrist. A: By examination, she was noted to have a volar distal radioulnar dislocation that was irreducible even under general anesthesia. B: At the time of surgery the distal ulna was noted to have buttonholed out of the capsule, and there was entrapped triangular fibrocartilage and periosteum in the joint.

Similarly, the ulnar physeal fracture can be irreducible in a Galeazzi equivalent injury. This also has been reported to be secondary to interposed periosteum, extensor tendons (48,52,103), or joint capsule (176). Open reduction must be executed with care to avoid further violating the physis.

**AUTHOR’S PREFERRED METHOD OF TREATMENT**

**Incomplete Fractures**

Incomplete fractures of the distal radius with either a true dislocation of the DRUJ or an ulnar physeal fracture are treated with closed reduction and long arm cast immobilization. This can be performed in the emergency setting with conscious sedation or in the operating room with general anesthesia. Portable fluoroscopy is used. If the fracture is apex volar with dorsal displacement of the radius and volar dislocation of the DRUJ, then pronation and volar-to-dorsal force on the radial fracture is used for reduction. If the fracture is apex dorsal with volar displacement of the radius and dorsal dislocation of the DRUJ, then supination and dorsal-to-volar force is applied to the distal radius for reduction. The reduction and stability of the fracture and DRUJ dislocation are checked on dynamic fluoroscopy before long arm cast immobilization. If both are anatomically reduced and stable, the cast is used for 6 weeks to allow soft tissue and fracture healing. In a Galeazzi equivalent injury, there is potential for remodeling of the physeal fracture if sufficient growth remains. As long as the DRUJ is reduced, malalignment of less than 10 degrees can remodel in a young child. The risk of physeal growth arrest is high with this physeal injury, and operative exposure may increase the growth impairment. If the fracture is severely malaligned, the DRUJ cannot be reduced, or the patient is older and remodeling is unlikely, open reduction and smooth pin fixation are indicated (186).

**Complete Fractures**

Open reduction and internal fixation with an anterior plate and screws are used for complete Galeazzi fractures of the radius. The DRUJ usually reduces anatomically and is stable with reduction and fixation of the radius. The patient is immobilized in a long arm cast for 4 weeks and a short arm cast for 2 more weeks. Return to unrestricted activities and sports depends on restoration of full motion and strength.

**Irreducible Dislocations**

Irreducible dislocations are treated with open reduction. Extensile exposure is necessary to define the pathologic anatomy and carefully reduce the DRUJ. The interposed soft tissues are extracted and repaired. Depending on the stability of the reduction and repair, a supplemental smooth pin may be used across the DRUJ for 4 weeks to maintain the joint reduction. This is particularly true if the patient presents late.

**Complications**

**Malunion and DRUJ Subluxation**

Malunion of the radius can lead to subluxation of the DRUJ, limited forearm rotation, and pain, usually secondary to persistent shortening and malrotation of the radial fracture. Most often this occurs when complete fractures are treated with closed reduction and there is failure to either obtain or maintain reduction of the radial fracture. The ulna remains subluxed and heals with an incongruent joint. Treatment for this requires proper recognition and corrective osteotomy. If physical examination is not definitive for diagnosis, then a CT scan in pronation, neutral rotation, or supination may be helpful. An MRI scan or wrist arthroscopy will aid in the diagnosis and management of associated ligamentous, chondral, or TFCC injuries that will benefit from debridement or repair. It is important to understand that if the DRUJ subluxation is caused by a radial malunion, a soft tissue reconstruction of the DRUJ alone will fail (3).

**Ulnar Physeal Arrest**

Golz and Ogden (52) cited a 55% incidence of ulnar physeal arrest with Galeazzi equivalent fractures. If the patient is young enough, this ulnar growth arrest in the presence of ongoing radial growth will lead to deformity. Initially there will be ulnar shortening. Over time, the foreshortened ulna can act as a tether, causing asymmetric growth of the radius. There will be increased radial articular inclination on the AP radiograph and subluxation of the DRUJ. Operative choices include ulnar lengthening, radial closing wedge osteotomy, radial epiphysodesis, and a combination of the above procedures that is appropriate for the individual patient’s age, deformity, and disability.

**Nerve Injury**

Injuries to the ulnar nerve (183) and anterior interosseous nerve (192,195) have been described with Galeazzi fracture–dislocations. These injuries have had spontaneous recovery. Moore et al. (186) described an 8% incidence of injury to the radial nerve with operative exposure of the radius for internal fixation in their series. Careful surgical exposure, dissection, and retraction can decrease this risk.

**ACKNOWLEDGMENT**

I thank the previous authors of this section, Drs. Kaye E. Wilkins and Eugene O’Brien, for their outstanding contributions and previous work. It is a pleasure to continue their fine chapter in this edition.