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Pediatric Forearm and Distal Radius Fractures

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Forearm fractures in children are common and are managed differently than similar injuries in adults. Historically, the results of nonoperative treatment of adult forearm fractures have been poor, with reports of nonunion, malalignment, and stiffness due to the lengthy immobilization required for union. Currently, most adults with both-bone forearm fractures are treated by open reduction and internal fixation. In pediatric patients, treatment is primarily nonoperative because of uniformly rapid healing and the potential for remodeling of residual deformity.

Although the outcomes in children are usually good, treatment of individual patients and education of families can be challenging. Beyond the sometimes-difficult mechanics of fracture reduction and maintenance, the clinician is faced with controversies regarding techniques of reduction, position of immobilization, and definition of an acceptable reduction.

The purpose of this article is to critically summarize available information and present treatment recommendations based on a literature review and the previous experience of the senior author (C.T.P.). The scope of this discussion will be limited to the more common entities, such as pediatric forearm and distal radius fractures, and will not include articular fractures, plastic deformation, and fracture-dislocations, such as Monteggia lesions.

Functional Anatomy

The ulna is a relatively straight bone around which the curved radius rotates during pronation and supination. The axis of rotation passes obliquely from the distal ulnar head to the proximal radial head. The two bones are stabilized distally and proximally by the triangular fibrocartilage complex and the annular ligament, respectively. Further stabilization is provided by the interosseous membrane, with oblique fibers passing distally from the radius to the ulna; these fibers are somewhat relaxed in supination and tighter in pronation.

The pronator quadratus (distally) and pronator teres (inserting on the middle portion of the radius) actively pronate the forearm, while the biceps and supinator (proximal insertions) provide supination. The insertions of these four muscles can partially account for fragment position in complete fractures. In distal-third fractures, the proximal fragment will be in neutral to slight supination, and the weight of the hand combined with the pronator quadratus tends to pronate the distal fragment. In proximal-third fractures, the distal fragment is pronated, and the proximal fragment is supinated. Mid-shaft fractures tend to leave both fragments in a neutral position with the distal fragment slightly pronated and the proximal fragment slightly supinated.

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Several anatomic differences distinguish pediatric forearms from those of adults. The pediatric radial and ulnar shafts are proportionately smaller, with narrow medullary canals, and the metaphysis contains more trabecular bone. In addition, the periosteum in children is much thicker than that in adults; this feature can both hinder and help in the management of pediatric fractures.

Normal Growth and Implications for Remodeling

The proximal and distal physes provide longitudinal growth, which contributes to remodeling after fracture healing. The distal radial and ulnar growth plates are responsible for 75% and 81% of the longitudinal growth of each bone, respectively. 1 This is consistent with the oft-made observation that distal forearm fractures have greater potential for remodeling than do more proximal fractures. 2-4 Additional remodeling can also be attributed to elevation of the thick osteogenic periosteum after fracture (Fig. 1). Intramembranous ossification by the periosteum will assist in rapid healing and subsequent remodeling of residual diaphyseal deformity. Normal Function and Treatment Objectives. The goal of treatment of forearm and distal radius injuries is to facilitate union of the fracture in a position that restores functional range of motion to the elbow and forearm. The predominant motions affected by malunion are pronation and supination, which are a function of skeletal length and axial and rotational alignment. Normal supination from neutral is 80 to 120 degrees; normal pronation from neutral is 50 to 80 degrees. 5 It is important to realize that “normal" motion may not be what is needed for normal function Biomechanical testing has revealed that common activities of daily living require 100 degrees of forearm rotation, equally split between pronation and supination. 6 Limited pronation is more easily compensated for by shoulder abduction. Secondary concerns include cosmetic alignment; however, acceptable reduction usually precludes gross malalignment. Ulnar alignment is the most important cosmetic determinant.

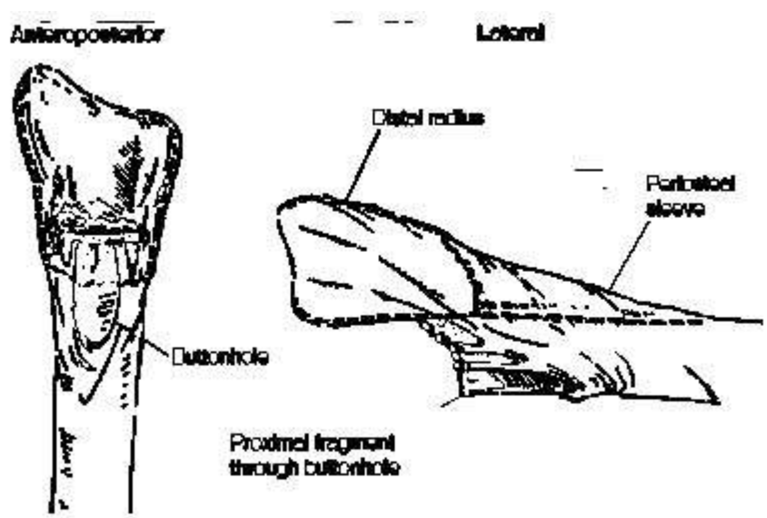

Fig. I In completely displaced pediatric forearm fractures; the periosteum is tom and elevated. In cases of reversed fracture obliquity, it becomes difficult to reduce the bone end to end with longitudinal traction, as the periosteum tightens around the buttonholed proximal end. However, the elevated periosteum does provide a framework for rapid cortical remodeling as bone and cous form along the elevated margin.

Classification

Specific classification schemes have not been developed, but fractures are generally categorized according to location, amount of cortical disruption, displacement, angulation, and malrotation. As mentioned previously, we will not address articular fractures, physeal fractures, or fracture-dislocations in this article. Three main types of forearm fractures will be discussed: greenstick fractures, complete fractures, and distal radial metaphyseal fractures. Greenstick fractures are incomplete fractures with an intact cortex and periosteum on the concave surface. These are usually the result of excessive rotational force. Complete fractures of both bones of the forearm are classified by location as being in the proximal, middle, or distal third. Proper treatment depends on differentiating greenstick and complete fractures. Completely displaced distal metaphyseal fractures of the radius will be discussed separately because of the differences in reduction and outcome.

Mechanism of Injury

It is important to have a basic understanding of the forces leading to forearm fracture, as reductions are often performed in the direction opposite to that of the initial injury. Pediatric forearm fractures typically follow indirect trauma, such as a fall on an outstretched hand. Direct trauma may additionally account for open fractures, severely displaced fractures, and those in the proximal forearm.9 Evans described an indirect mechanism of axial compression force in varying directions and degrees of rotation, the latter accounting for different patterns of fragment angulation. The final degree of fragment displacement due to indirect trauma varies between greenstick and complete fractures, but the initial mechanism of injury is usually the same. In some cases, the force is not sufficient to completely displace the fracture, and therefore a greenstick fracture results. A greenstick fracture in one forearm bone may coexist with a complete fracture in the other.

Radiographically, greenstick fractures demonstrate angulation due to rotational deformity. 7,10 Fractures with apex-volar angulation are the result of an axial force applied with the forearm in supination; fractures with the less common apex-dorsal angulation are the result of an axial force applied in pronation. 10 Reducing a greenstick fracture usually involves rotation in the direction opposite to the deforming force. When indirect or direct trauma exceeds the resistance of the forearm, complete fractures of both bones will follow. In severe falls, the bones may initially angulate according to the rotation of the wrist.

However, when completely broken by either indirect or direct forces, the bones shorten, angulate, and rotate within the confines of the surrounding periosteum, interosseous membrane, and muscle attachments. Because the final positioning in complete fractures depends to some degree on the relationship of fracture location and the insertions of the pronating and supinating muscles, reduction is more complex than for simple greensick fractures.

Distal radius fractures usually follow a fall on an outstretched hand. The resultant angulation may also be accompanied by rotational deformity. Apex-volar angulation (the most common deformity) is accompanied by supination and apex-dorsal angulation with pronation. In our experience, solely ulnar fractures are less common, and probably result from direct trauma.

Patient Assessment and Radiographic Evaluation

The diagnosis of forearm fractures is usually self-evident from the history and the obvious deformity. Child abuse must always be considered in patients less than 3 years of age. Inspection and palpation should be carefully performed; occasionally, soft tissue swelling will obscure gross malalignment. The wrist and elbow should be examined for swelling, tenderness, and unusual prominences that may signify a Monteggia or Galeazzi fracture. Cursory examination of the humerus and clavicle may detect fractures that have also resulted from a fall on an outstretched hand. Detailed neurovascular examination is necessary before and after reduction; median, ulnar, and posterior interosseous neurapraxias have been documented. Such deficits usually resolve with observation in 2 to 3 weeks.

Radiographic evaluation should include anteroposterior (AP) and lateral views of the forearm. If the elbow and wrist are not adequately visualized, corresponding views should be obtained to eliminate radial head dislocation, supracondylar fracture, and distal radioulnar joint injury. Forearm radiographs are examined to determine fracture pattern (complete or greenstick), location (proximal, middle, or distal third), displacement, angulation, and rotation.

Displacement and angulation are fairly easy to document on AP and lateral views. Although deformities can often be quantified and described on these standard views, it is important to remember that fracture angulation and displacement are always in a single plane, between those obtained on orthogonal radiographs. The magnitude of the deformity is at least as great as or greater than that seen on each view. Malrotation in complete fractures can be difficult to detect and assess, but can be suspected when the cortical, medullary, or bone diameters of both fragments are not equal. Malrotation can be gauged from deviations of normal orientation of proximal and distal bony prominences.

On a standard AP view, the radial tuberosity is seen in profile on the medial side, while the radial styloid and thumb are seen 180 degrees opposite on the lateral side. On this same view, ulnar styloid and coronoid process are not seen. Lateral views reveal the ulnar styloid pointing posterior and the coronoid process pointing directly anterior; the aforementioned radial prominences will not be seen. Another useful method for determining rotation of the proximal fragment utilizes the tuberosity view described by Evans. This technique allows a quantitative assessment of proximal fragment rotation. The distal fragment can then be manipulated and rotated into a corresponding position.

Anesthesia (edited)

In many centers, a large proportion of forearm and distal radius fractures are treated outside the surgical suite, requiring the treating surgeon to consider and administer appropriate anesthesia. Strict guidelines for conscious sedation have been established by the American Academy of Pediatries.14 A survey of orthopaedic surgeons completed in 1993 indicated that as many as one third of orthopaedic surgeons were not in compliance with these guidelines during fracture reduction. 15

The chosen method should be as safe as possible, induce the least trauma, including fracture reduction. As no one method completely meets these criteria, several different choices exist, each with its own advantages and disadvantages.

Options include quick reduction without anesthesia, hematoma block which involves an injection of the anesthetic in the area of the fracture or going to the hospital for either a block type or a general anesthetic. Intravenous sedation entails the potential for overdosage and cardiopulmonary depression.

Regional intravenous blocks have the advantages of rapid onset of effect, simple administration, and good muscle relaxation. Disadvantages include pain when the injured limb is exsanguinated by wrapping or elevation. Premature cuff deflation may lead to major neurologic and cardiac complications when high doses are used.

Use of general anesthesia relieves the surgeon of the burden of providing safe and effective anesthesia. This allows the surgeon to concentrate on reduction and stabilization unencumbered by the proximity of anxious parents. In addition, if several reduction attempts are required, general anesthesia provides total relaxation with minimal constraints. Furthermore, if reduction is inadequate or unstable, it easy to convert to operative stabilization.

Adequacy of Reduction and Results of Closed Treatment

Anatomic reduction is usually not required for pediatric forearm fractures due to the potential for growth and remodeling. However, the treating physician must be able to define reasonable residual malalignment by answering several important questions: What are the acceptable limits of displacement at healing, and to what degree do the deformities remodel over time? How is remodeling potential affected by variables such as age and location of the fracture? Does malalignment at healing and follow-up correlate with loss of motion? What degree of documented motion loss is associated with poor function and patient dissatisfaction?

It is uniformly agreed that post-traumatic angular deformities in children have variable remodeling potential; however, it has not been consistently proved that deformities characterized by rotational malalignment will also remodel. Many studies have documented better radiographic remodeling of distal fracture and fractures in patients less than 9 or 10 years of age. It is important to realize that fracture location and age may not be independent variables. Creasman et al 22 documented better results in distal fractures; however, their patients were on average 3 years younger than patients with proximal fractures. Whether anatomic alignment correlates with final range of motion is controversial. Fuller and McCullough4 demonstrated a positive relationship with residual angulation and eventual range of motion. However, there are certainly examples of excessive malunion with good motion.

Conversely, cases of "anatomic" healing with documented motion loss have been reported. Carey et al 24 reported the follow-up data on 33 patients with both bone forearm fractures and demonstrated average angulation of 12 degrees in patients aged 6 to 10 years and 9 degrees in patients aged 11 to 15 years. While almost all patients in the former group had full motion, those in the latter group had a small loss of rotation averaging 20 to 30 degrees. This disparity suggests that factors other than alignment may affect range of motion. Perhaps motion loss in such cases is due to contracture of the interosseous membrane from the injury and/or immobilization.

However, it is clear from in vitro studies that fracture malrotation proportionally decreases forearm rotation.27 Published discrepancies between residual angular deformity and final forearm rotation may be due to inability to accurately document and record radiographic malrotation. Finally, what is the subjective outcome in pediatric patients with fractures of both forearm bones, and does residual deformity or motion loss correlate with decreased function? Although several authors have demonstrated decreased remodeling potential in proximal fractures, Holdsworth and Sloan found that only 3 of 51 proximal forearm malunions showed marked loss of function, with a mean attendant loss of 65 degrees of forearm rotation. Studies of documented malunions demonstrate that good function can be obtained in all patients with motion loss up to 50 degrees, and that more symptomatic losses of 90 degrees can be partially compensated for with shoulder abduction. Other authors have demonstrated little functional loss with decreases in forearm rotation of 35 to 40 degrees. Higgstrom et al 3 found that some patients with a limitation of 60 degrees or less in the range of pronation and supination appeared to be unaware of their incapacity. In addition, it is conceivable that patients with initially unsatisfactory motion may have improvement with time. Although differing definitions of acceptable alignment have been delineated in the literature, many patients with residual deformity have good functional results.

Our recommendations are based on previous studies of malunion in children with relatively good function. In fractures at any level in children less than 9 years of age, we accept complete displacement, 15 degrees of angulation, and 45 degrees of malrotation. In children 9 years of age and older, we continue to accept bayonet apposition but only 30 degrees of malrotation; acceptable angulation is 10 degrees in proximal fractures and 15 degrees in more distal fractures. In distal radial metaphyseal fractures, we accept complete displacement and up to 20 degrees of angulation. In cases of completely displaced and slightly angulated distal radius fractures, it is important to inform the family that cosmetic deformity may be noted initially after fracture healing; however, remodeling can be expected to improve the appearance as long as 2 years of growth remains.

Reduction and Casting Greenstick Fractures

Historically, incomplete fractures were treated by completing the fracture and then manipulating the bones into an acceptable position. This approach has the theoretical advantage of increasing the size of the fracture callus and decreasing the risk of refracture. Currently, it is recognized that residual angulation is a result of malrotation and that the fracture should be reduced by rotating in the direction opposite to the deforming force. Traction and manipulation of the apex while rotating will often assist in the reduction. Most greenstick fractures are supination injuries with apex-volar angulation, which can be reduced with varying degrees of pronation. It can be difficult to remember whether to pronate or supinate the hand. Most fractures can be reduced by rotating the palm toward the deformity. Fractures with apex-volar angulation are a result of axial load in supination; there- fore, the palm should be rotated volarly (pronation). Fractures with apexdorsal angulation are a result of pronation force; therefore, the palm should be rotated dorsally (supination). It is not uncommon to see a greenstick fracture of one bone and a complete fracture of the other. in these cases, we use the same principles of reduction by rotation.

After reduction, the forearm should be immobilized in the same position that reduced the fracture. Studies have documented 10% to 16% rates of redisplacement when greenstick fractures were not adequately rotated in the cast. Complete Fractures Complete both-bone forearm fractures are reduced with a combination of sustained traction and manipulation. The fingers are taped to prevent sores and placed in finger traps with the elbow at 90 degrees of flexion. Countertraction is provided by 10 to 15 lb. of weight suspended from a sling over the distal humerus. The fracture and soft tissues are slowly brought out to length for 10 to 15 minutes, and the arm is allowed to find its own rotation.12 end-to-end apposition is then attempted with deformity exaggeration and direct manipulation. If attempts to achieve bone apposition are unsuccessful, complete overriding of fracture fragments is accepted as long as rotation and angulation are reduced (Fig. 2). Fracture alignment in traction is assessed with fluoroscopy or plain radiography. If alignment is adequate, the distal part of the long arm cast is applied and molded while the arm is still in traction. Residual malrotation is addressed before cast application by rotating the forearm. It was traditionally taught that the hand should be casted in a position dictated by the relationship of fracture location with the insertions of the pronators and supinators. This principle is used to direct distal forearm positioning when residual malrotation is present. Because most displaced both-bone fractures are in the middle region, the hand is placed in a neutral or slightly supinated position, which usually accommodates rotation and angulation. Pronation is rarely employed for complete fractures and may result in a functional loss of supination due to soft-tissue contracture.

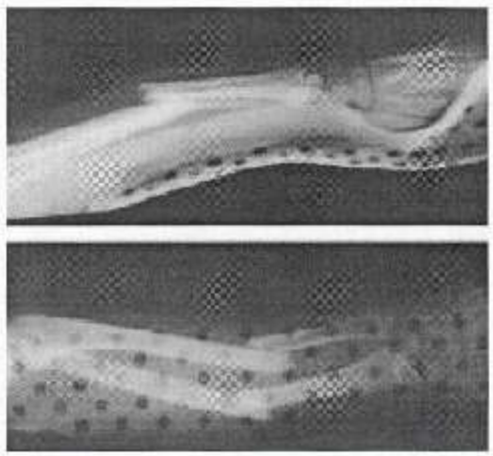

Figure 2A

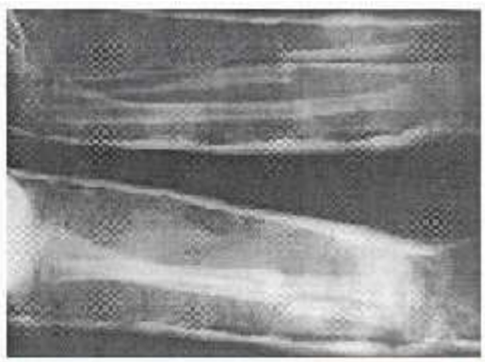

Figure 2B

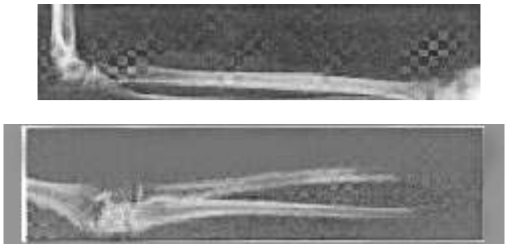

Figure 2C

Fig. 2A, Displaced midshaft fracture of the radius and ulna in a girl aged 9 years I month. 2B, The fracture was reduced in neutral position. Bayonet apposition with minimal angulation and no rotational malalignment was accepted. The fracture united in this position. 2C, Radiographs obtained 6 years later demonstrate complete remodeling. Clinical examination demonstrated full range of motion in pronation and supination.

Distal Radius Fractures

Distal radius fractures are reduced with a combination of traction, angulation, and rotation of the palm in the direction of the angulation. In the case of completely displaced and bayoneted fractures, sustained longitudinal traction is used with finger traps, as previously described. After the fracture has been brought out to length, deformity exaggeration and rotation may produce end-to-end contact. It may be difficult to obtain apposition, as torn periosteum tightens around the buttonholed proximal fragments (Fig. 1). In these cases, it is acceptable to leave the fragments overlapped as long as rotation and angulation are reduced (Fig. 3). Typically, these fractures are immobilized in casts. Sugar-tong splinting is another form of immobilization commonly used immediately after reduction. If this method is selected, it is important to tighten the splint or convert to a cast when the initial swelling resolves in 2 or 3 days; high rates of reangulation in distal radius fractures have been reported. Distal radius fractures without ulnar fracture are immobilized in a lesser degree of pronation or supination depending on the apex direction. As these fractures are the result of an angulatory force as well as rotation, the position of the wrist is less critical. There is some suggestion that distal radius fractures are more stable in supination because of the action of the brachioradialis.

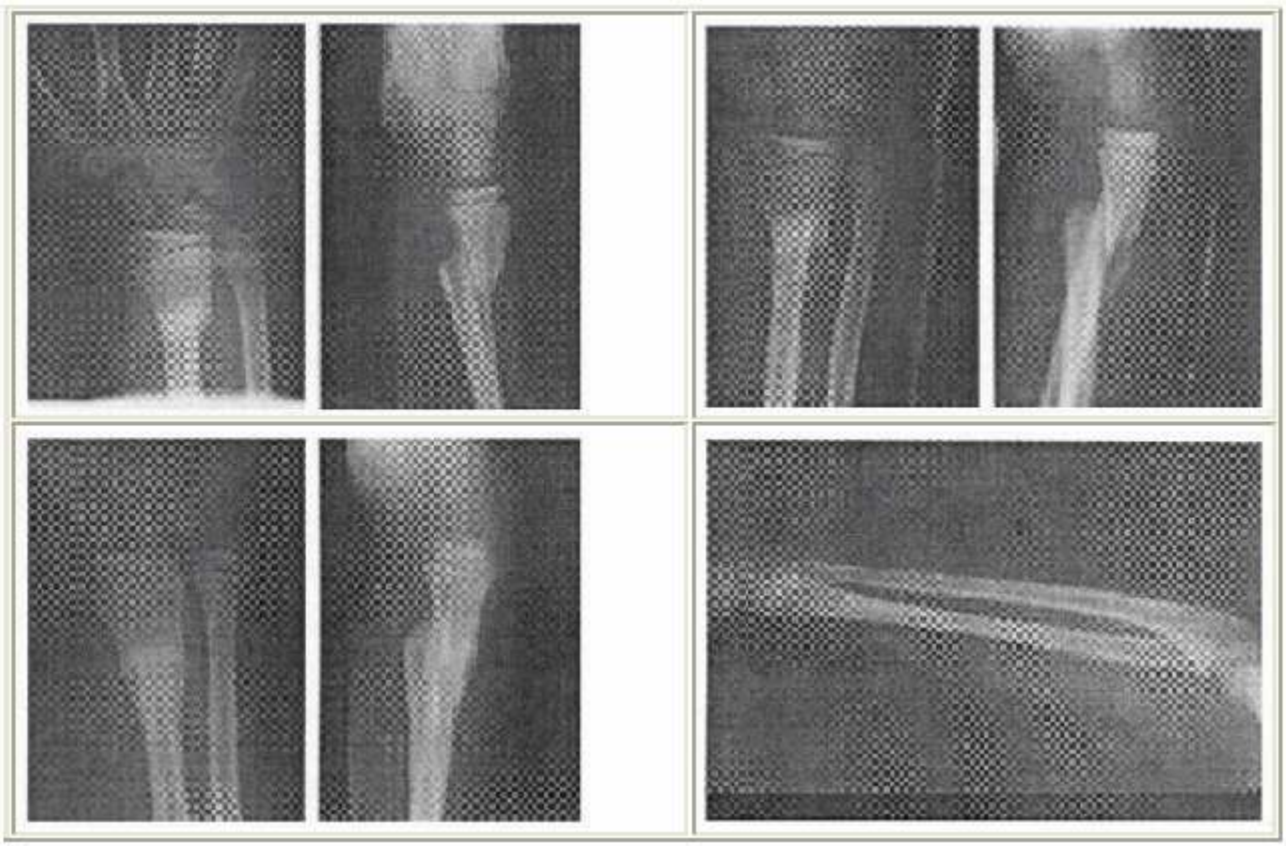

Fig. 3A, Distal radius fracture and intact ulna in an 8-year-old girl. Preliminary reduction failed to reduce bayonet apposition. B, After initial immobilization in a sugar-tong splint, a change was made to a long arm fiberglass cast. Early callus formation is noted along the dorsally elevated periosteum. C, Continued remodeling was noted 3 months after fracture. D, The fracture was almost completely remodeled 2 years after injury.

All fractures are eventually placed in either fiberglass or plaster long arm casts with the elbow at 90 degrees. Plaster may be easier to mold, but fiberglass permits better radiographic visualization. Casts are molded with anterior and posterior pressure applied over the interosseous membrane (Fig. 4, A). This tends to separate the bones and increase stability in the cast, and a straight ulnar border is produced. Medial and lateral molding above the humeral condyles will prevent the cast from sliding distally and angulating the fracture after swelling resolves (Fig. 4, B). Meticulous casting is critical as several studies have documented reangulation in approximately 8% to 14% of cases. 11,12,28,29 Some have blamed poor casting technique,11,28 while others have attributed the reangulation to residual rotational malalignment.7,12,30 Forearm AP and lateral radiographs are taken after reduction and immobilization, and improvements of residual angulation can then be corrected by wedging the cast. 23

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After adequate reduction and immobilization, patients typically return for a follow-up radiograph 1 to 2 weeks after injury. Several studies have documented reangulation during the first 2 weeks. If reangulation is documented, cast removal and re-reduction under general anesthesia are recommended. Good results of re-reduction have been documented if performed within a few weeks of the initial fracture. If no reangulation is appreciated, the cast is continued for 6 to 8 weeks or until there is radiographic evidence of healing. Patients cannot participate in contact sports for 4 to 6 months, but all other activities are permitted. Refractures are uncommon; when they do occur, it is usually within several months of cast removal.