

Forearm and Distal Radius Fractures in Children

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Abstract

Pediatric forearm and distal radius fractures are common injuries. Resultant deformities are usually a product of indirect trauma involving angular loading combined with rotational displacement. Fractures are classified by location, completeness, angular and rotational deformity, and fragment displacement. Successful outcomes are based on restoration of adequate pronation and supination and, to a lesser degree, acceptable cosmesis. When several important concepts are kept in mind, these goals are usually met with conservative treatment by reduction and immobilization. Greenstick fractures are reduced by rotating the forearm such that the palm is directed toward the fracture apex. Complete fractures are manipulated and reduced with traction and rotation; extremities are then immobilized in well-molded plaster casts until healing, which usually takes about 6 weeks. Radiographs should be obtained between 1 and 2 weeks after initial reduction to detect early angulation. In fractures at any level in children less than 9 years of age, complete displacement, 15 degrees of angulation, and 45 degrees of malrotation are acceptable. In children 9 years of age and older, 30 degrees of malrotation is acceptable, with 10 degrees of angulation for proximal fractures and 15 degrees for more distal fractures. Complete bayonet apposition is acceptable, especially for distal radius fractures, as long as angulation does not exceed 20 degrees and 2 years of growth remains. Operative intervention is used when the fracture is open and when acceptable alignment cannot be achieved or maintained. Single-bone intramedullary fixation has proved useful.

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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.

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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.

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.

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

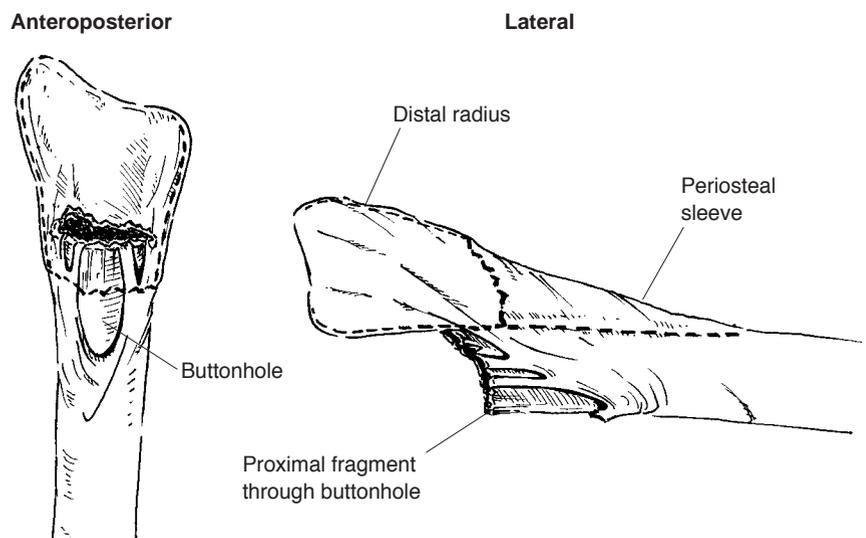


Fig. 1 In completely displaced pediatric forearm fractures, the periosteum is torn and elevated. In cases of reversed fracture obliquity, it becomes difficult to reduce the bone end to end with longitudinal traction, as the periosteum tightens around the buttonholed proximal end. However, the elevated periosteum does provide a framework for rapid cortical remodeling as bone and callus form along the elevated margin.

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,^{7,8} 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 Evans⁷ 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 angula-

tion 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 greenstick 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.¹¹ 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 under 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.¹² 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.¹³ This technique allows a quantitative assessment of proximal fragment rotation. The distal fragment can then be manipulated and rotated into a corresponding position.

Anesthesia

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 Pediatrics.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 anesthetic should be relatively safe and painless at all steps, including fracture reduction. Postreduction amnesia is also desirable. Quick and complete relaxation of the patient and the forearm muscles greatly facilitates 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 (a practice that we do not endorse), hematoma or intravenous regional block,¹⁶ axil-

lary block,¹⁷ intravenous sedation,¹⁸ self-administered nitrous oxide (50:50 ratio of nitrous oxide and oxygen),^{19,21} and general anesthesia. Intravenous sedation and regional block have traditionally been the most widely used. Intravenous sedation entails the potential for overdose¹⁸ and cardiopulmonary depression. Varela et al¹⁸ reported on the use of meperidine and midazolam for this purpose. The target doses were 2 mg/kg of body weight and 0.1 mg/kg, respectively. Half of the recommended dose was infused over a period of 1 to 3 minutes. After an additional 3 to 5 minutes of observation, the remainder was titrated to achieve adequate sedation.

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. Juliano et al¹⁶ reported safe, successful pain relief with the use of a 0.125% solution of lidocaine administered to a total dose of 1 mg/kg (this is lower than the usually recommended dose of 3 to 5 mg/kg).

Self-administered nitrous oxide anesthesia is relatively safe²¹ and has the advantage of having more rapid onset and effect with greater patient satisfaction.^{19,20} Nitrous oxide is contraindicated for patients with middle ear infections or effusions.¹⁹ Although this technique is attractive, potential side effects, such as nausea and diffusion hypoxia (which requires 100% oxygen after reduction), may be seen.^{20,21}

Concerns about incomplete analgesia have been addressed with supplementary local anesthesia. Henn-

rikus et al²¹ demonstrated 97% successful analgesia with self-administered nitrous oxide and oxygen followed by hematoma block. No side effects were encountered.

Recently, randomized studies have examined the effectiveness of intramuscular sedation¹⁹ and regional anesthesia²⁰ compared with self-administered nitrous oxide anesthesia alone. These studies demonstrate similar pain relief with visual analog scales and standardized surveys.

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 is 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.^{4,5,22} Many studies have documented better radiographic remodeling of distal fractures^{2,4,5,22,23} and fractures in patients less than 9 or 10 years of age.^{3-5,9,23,24} It is important to realize that fracture location and age may not be independent variables. Creasman et al²² 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.⁵ Conversely, cases of "anatomic" healing with documented motion loss have been reported.^{2,3,5,25,26} Carey et al²⁴ 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.^{2-5,8,22,25,26,28,29}

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 Sloan⁸ 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.^{2,4} Other authors have demonstrated little functional loss with decreases in forearm rotation of 35 to 40 degrees.^{5,24} Högström et al³ 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.³⁰

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.^{2,4,8,24} 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.^{9,23} This approach has the theoretical advantage of increasing the size of the fracture callus and decreasing the risk of refracture.¹¹ 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; therefore, the palm should be rotated volarly (pronation). Fractures with apex-dorsal 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.^{7,12}

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 fingertraps 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.⁹ 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.^{5,7,12,24} Pronation is rarely employed for complete fractures and may result in a functional loss of supination due to soft-tissue contracture.

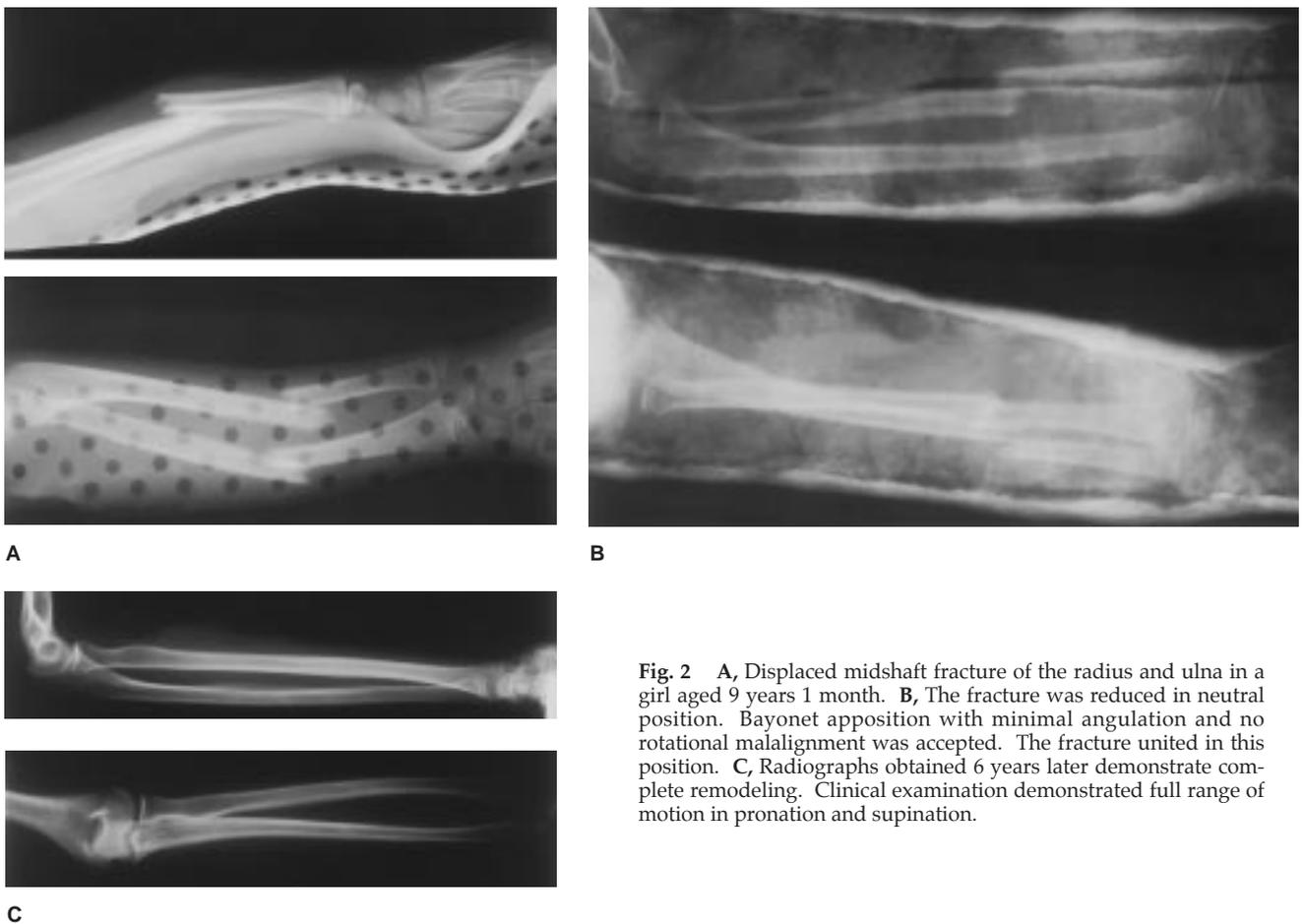


Fig. 2 A, Displaced midshaft fracture of the radius and ulna in a girl aged 9 years 1 month. B, The fracture was reduced in neutral position. Bayonet apposition with minimal angulation and no rotational malalignment was accepted. The fracture united in this position. C, Radiographs obtained 6 years later 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 fingertraps, 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 apposi-

tion, as torn periosteum tightens around the buttonholed proximal fragment³¹ (Fig. 1). In these cases, it is acceptable to leave the fragments overlapped as long as rotation and angulation are reduced³¹ (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.³¹ 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.³²

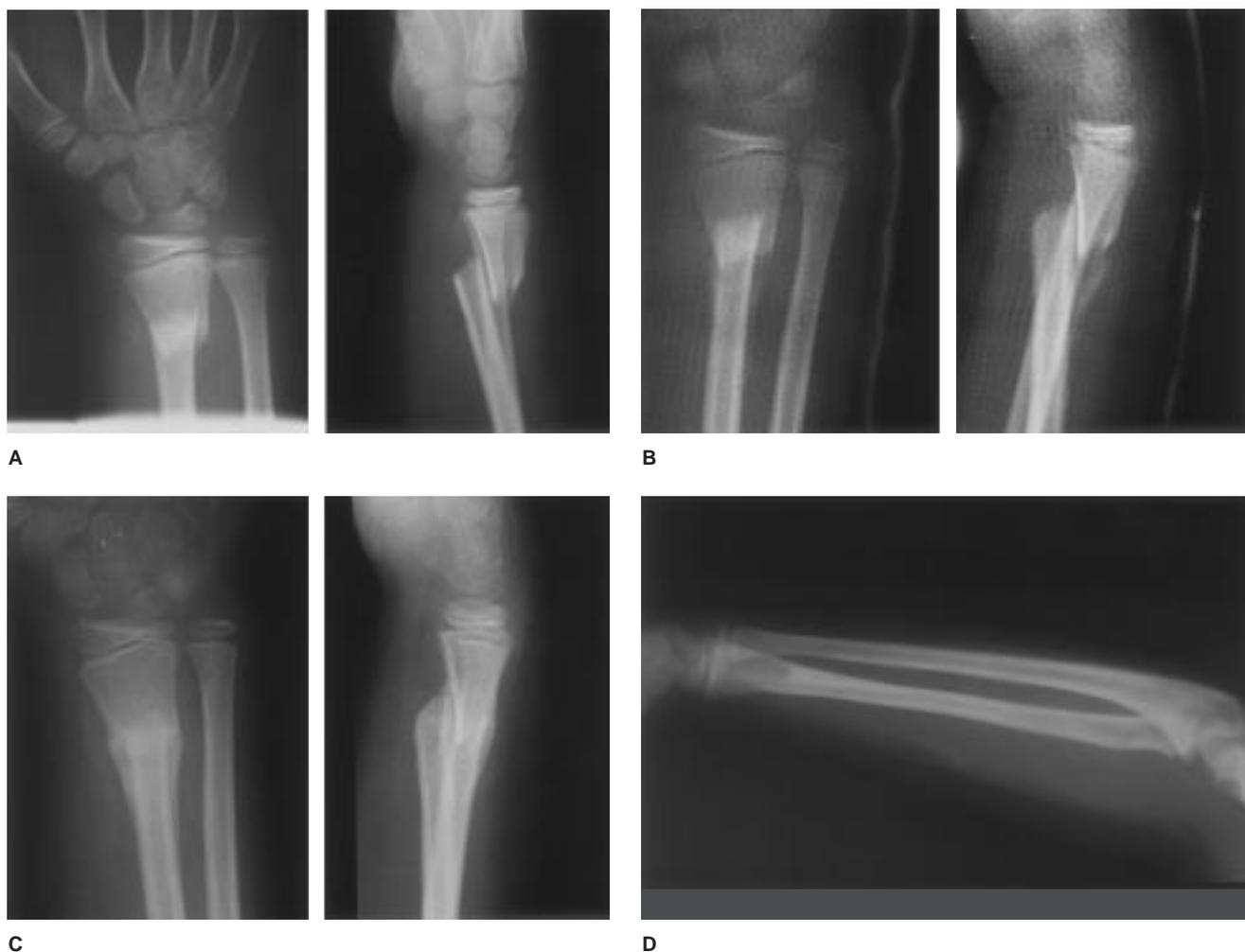


Fig. 3 A, Distal radius fracture and intact ulna in an 8-year-old girl. Preliminary reduction failed to reduce bayonet apposition. B, After initial immobilization in a sugar-tong splint, a change was made to a long arm fiberglass cast. Early callus formation is noted along the dorsally elevated periosteum. 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

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.^{23,28,29} 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.^{2,28} 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.^{9,33}

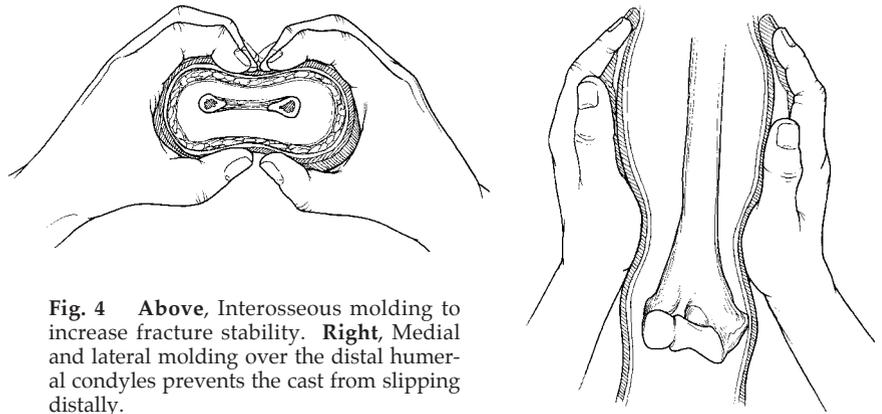


Fig. 4 Above, Interosseous molding to increase fracture stability. Right, Medial and lateral molding over the distal humeral condyles prevents the cast from slipping distally.

Operative Indications and Technique

Because most pediatric forearm fractures are treated by closed reduction with good results, operative reduction and stabilization are rarely necessary. The indications for surgical intervention in pediatric forearm fractures include (1) open fractures; (2) fractures shortly before skeletal maturity; (3) irreducible fractures, with or without soft-tissue interposition; (4) unstable fractures after reduction; and (5) Monteggia fractures with an unstable radial head and residual ulnar angulation.

Several different techniques are available, including pins and plaster,³⁴ open reduction and internal fixation with plates,^{35,36} and closed intramedullary nailing of one or both bones.³⁷⁻³⁹ Percutaneous pinning for unstable but reducible distal radius fractures has also been described; most authors report excellent results in these severe cases.

As anatomic reduction is usually not needed, we prefer closed intramedullary fixation of one or both bones. Immobilization in a supplemental plaster or fiberglass long arm cast is generally used; however, in cases of severe soft-tissue

injury, it is possible to avoid casting altogether if both bones are rodded with snug-fitting nails.³⁹ The advantages of nailing include the need for only one operation (prominent rods can be removed in the office with local anesthesia), lower infection risk, small scars with minimal dissection, and possibly better postoperative motion.

Intramedullary rodding is performed with the patient under general anesthesia. The arm is prepared and draped, and preliminary reduction is assessed under fluoroscopy. The bone that is easiest to reduce is approached first; if both bones appear to be equally reducible, the normally straight ulna is approached first. A small incision is made over the tip of the ulnar apophysis, and a straight awl is used to gain access to the proximal ulna. A 1.5- or 2.5-mm-diameter rod (with the distal 5 mm bent approximately 30 degrees to facilitate reduction) is placed under fluoroscopy through the proximal fragment, passed across the fracture site, and advanced to within 2 cm of the distal growth plate. The rod is cut proximally and bent 90 degrees to prevent migration. If the radial fracture can be reduced closed and appears to be stable, the wound is closed over a slightly

prominent ulnar pin. A long arm cast is used for 6 to 8 weeks (Fig. 5).

If the reduction or stability of the radius is in question, it should be fixed with a 15- to 25-degree prebent rod. Contouring the center of the rod in this manner will allow reconstitution of the normal radial bow. Access to the radius is gained through a small distally based incision just proximal to the distal physis. A proximally directed drill hole is placed, and the prebent rod is passed retrograde across the fracture under fluoroscopic control; the rod tip is bent and cut off, and the skin is closed over the prominent end. In general, if both fractures were rodded, the arm should be immobilized for 3 to 4 weeks in a long arm cast. The rod is usually removed 3 or more months after surgery.

Complications

Malunion

Forearm fractures treated conservatively will rarely present with malreduction that precludes activities of daily living. In those rare cases in which motion loss is

greater than 60 degrees, surgical correction can be obtained with drill osteoclasis and casting⁴⁰ or with open osteotomy and plating.⁴¹ Both techniques will increase motion; however, better results are obtained when surgical correction is performed within 1 year of the original fracture.⁴¹

Occasionally, cosmetic concerns will predominate over functional limitations. If that is the case, malunion osteotomy can be performed to improve appearance; however, the patient should be warned of potential motion loss.⁴¹

Refracture

Although uncommon, refracture can occur as long as 6 months after the original injury.⁹ Some have documented less optimal clinical outcome in cases of refracture^{2,33}; in such instances, operative intervention may be indicated to ensure an adequate reduction. Increased rates of refracture have also been documented after immobilization of greenstick fractures, possibly because of weaker union at the fractured cortex due to inadequate callus formation.⁴² Fractures have also

followed hardware removal after treatment with primary open reduction and internal fixation.^{26,36,39} For this reason, removable wrist splints may be recommended during physical activity for several months for patients who have greenstick fractures or have undergone routine hardware removal.

Crossunion

Synostosis between the radius and ulna occurs rarely. The risk of this complication is increased by high-energy trauma or associated head injury. A few cases of successful resection have been reported, but restoration of motion is usually poor in children and adolescents.⁴³ When the forearm is in a functional position, resection is rarely indicated.

Other Complications

Vascular complications and compartment syndrome have been reported only rarely in conjunction with pediatric forearm fractures. Admission of the patient for a short period of observation should be considered if the fracture is a result of high-energy injury, if there is significant initial displacement, or

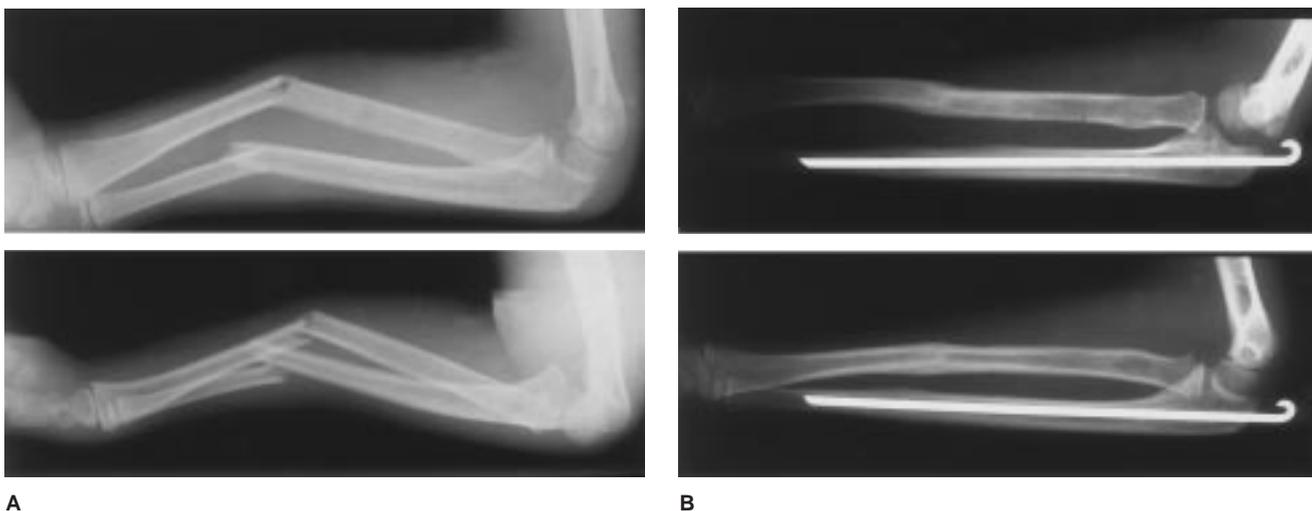


Fig. 5 A, Open both-bone forearm fracture. B, Five months after ulnar rodding, the fracture was clinically healed.

if the patient's social surroundings prevent good care.

Summary

Pediatric forearm fractures are common injuries faced by most orthopaedists. Fractures may be complete or incomplete (greenstick). Associated joint injuries must be ruled out. Most of these injuries are treated with closed reduction and immobilization. Treatment is usually performed with the patient sedated or with the use of regional block or general anesthesia.

Reduction maneuvers depend on fracture type. Greenstick frac-

tures are reduced by rotating the forearm and palm toward the apex of the deformity. It is not necessary to complete the fracture, although such a maneuver may have the theoretical advantage of a lower refracture rate. Isolated and overlapped distal radius fractures may be hard to reduce end to end; however, those treated with bayonet apposition and angulation less than 20 degrees will usually remodel. Complete fractures are reduced with fingertrap traction and manipulation. In children aged 9 years and older, bayonet apposition is accepted if malrotation does not exceed 30 degrees and angulation does not exceed 10 degrees for proximal fractures and

15 degrees for more distal fractures. Complete fractures are usually immobilized for 6 to 8 weeks in neutral or slight supination. Closed intramedullary nailing is performed in cases of open fracture and when satisfactory alignment cannot be obtained or maintained.

Radiographic malunion may occur; however, it correlates poorly with forearm rotation. In cases of motion loss greater than 60 degrees, corrective osteotomy may be useful if performed within 1 year of the injury. Serious neurovascular injuries are rare; nevertheless, they should not be overlooked in the treatment of pediatric forearm fractures.

References

- Digby KH: The measurement of diaphyseal growth in proximal and distal directions. *J Anat Physiol* 1915;50:187-188.
- Price CT, Scott DS, Kurzner ME, Flynn JC: Malunited forearm fractures in children. *J Pediatr Orthop* 1990;10:705-712.
- Högström H, Nilsson BE, Willner S: Correction with growth following diaphyseal forearm fracture. *Acta Orthop Scand* 1976;47:299-303.
- Fuller DJ, McCullough CJ: Malunited fractures of the forearm in children. *J Bone Joint Surg Br* 1982;64:364-367.
- Daruwalla JS: A study of radioulnar movements following fractures of the forearm in children. *Clin Orthop* 1979;139:114-120.
- Morrey BF, Askew LJ, An KN, Chao EY: A biomechanical study of normal functional elbow motion. *J Bone Joint Surg Am* 1981;63:872-877.
- Evans EM: Fractures of the radius and ulna. *J Bone Joint Surg Br* 1951;33:548-561.
- Holdsworth BJ, Sloan JP: Proximal forearm fractures in children: Residual disability. *Injury* 1982;14:174-179.
- Blount WP, Schaefer AA, Johnson JH: Fractures of the forearm in children. *JAMA* 1942;120:111-116.
- Rang MC: *Children's Fractures*, 2nd ed. Philadelphia: JB Lippincott, 1983, pp 197-220.
- Chess DG, Hyndman JC, Leahey JL, Brown DCS, Sinclair AM: Short arm plaster cast for distal pediatric forearm fractures. *J Pediatr Orthop* 1994;14:211-213.
- Davis DR, Green DP: Forearm fractures in children: Pitfalls and complications. *Clin Orthop* 1976;120:172-184.
- Evans EM: Rotational deformity in the treatment of fractures of both bones of the forearm. *J Bone Joint Surg* 1945;27:373-379.
- American Academy of Pediatrics Committee on Drugs: Guidelines for monitoring and management of pediatric patients during and after sedation for diagnostic and therapeutic procedures. *Pediatrics* 1992;89(6 pt 1):1110-1115.
- Price CT, Choy JY: Current practice of sedation and pain management in the reduction of pediatric forearm fractures: A survey. *Orthop Trans* 1995;19:42.
- Juliano PJ, Mazur JM, Cummings RJ, McCluskey WP: Low-dose lidocaine intravenous regional anesthesia for forearm fractures in children. *J Pediatr Orthop* 1992;12:633-635.
- Wedel DJ, Krohn JS, Hall JA: Brachial plexus anesthesia in pediatric patients. *Mayo Clin Proc* 1991;66:583-588.
- Varela CD, Lorfing KC, Schmidt TL: Intravenous sedation for the closed reduction of fractures in children. *J Bone Joint Surg Am* 1995;77:340-345.
- Evans JK, Buckley SL, Alexander AH, Gilpin AT: Analgesia for the reduction of fractures in children: A comparison of nitrous oxide with intramuscular sedation. *J Pediatr Orthop* 1995;15:73-77.
- Gregory PR, Sullivan JA: Nitrous oxide compared with intravenous regional anesthesia in pediatric forearm fracture manipulation. *J Pediatr Orthop* 1996;16:187-191.
- Hennrikus WL, Shin AY, Klingelberger CE: Self-administered nitrous oxide and a hematoma block for analgesia in the outpatient reduction of fractures in children. *J Bone Joint Surg Am* 1995;77:335-339.
- Creasman C, Zaleske DJ, Ehrlich MG: Analyzing forearm fractures in children: The more subtle signs of impending problems. *Clin Orthop* 1984;188:40-53.
- Hughston JC: Fractures of the forearm in children. *J Bone Joint Surg Am* 1962;44:1678-1693.
- Carey PJ, Alburger PD, Betz RR, Clancy M, Steel HH: Both-bone forearm fractures in children. *Orthopedics* 1992;15:1015-1019.

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25. Nilsson BE, Obrant K: The range of motion following fracture of the shaft of the forearm in children. *Acta Orthop Scand* 1977;48:600-602.
26. Kay S, Smith C, Oppenheim WL: Both-bone midshaft forearm fractures in children. *J Pediatr Orthop* 1986;6:306-310.
27. Tarr RR, Garfinkel AI, Sarmiento A: The effects of angular and rotational deformities of both bones of the forearm: An in vitro study. *J Bone Joint Surg Am* 1984;66:65-70.
28. Voto SJ, Weiner DS, Leighley B: Redispacement after closed reduction of forearm fractures in children. *J Pediatr Orthop* 1990;10:79-84.
29. Kramhøft M, Sølgaard S: Displaced diaphyseal forearm fractures in children: Classification and evaluation of the early radiographic prognosis. *J Pediatr Orthop* 1989;9:586-589.
30. Thomas EM, Tuson KWR, Browne PSH: Fractures of the radius and ulna in children. *Injury* 1975;7:120-124.
31. Roy DR: Completely displaced distal radius fractures with intact ulnas in children. *Orthopedics* 1989;12:1089-1092.
32. Gupta RP, Danielsson LG: Dorsally angulated solitary metaphyseal greenstick fractures in the distal radius: Results after immobilization in pronated, neutral, and supinated position. *J Pediatr Orthop* 1990;10:90-92.
33. Arunachalam VSP, Griffiths JC: Fracture recurrence in children. *Injury* 1975;7:37-40.
34. Voto SJ, Weiner DS, Leighley B: Use of pins and plaster in the treatment of unstable pediatric forearm fractures. *J Pediatr Orthop* 1990;10:85-89.
35. Vainionpää S, Böstman O, Pätäälä H, Rokkanen P: Internal fixation of forearm fractures in children. *Acta Orthop Scand* 1987;58:121-123.
36. Nielsen AB, Simonsen O: Displaced forearm fractures in children treated with AO plates. *Injury* 1984;15:393-396.
37. Flynn JM, Waters PM: Single-bone fixation of both-bone forearm fractures. *J Pediatr Orthop* 1996;16:655-659.
38. Amit Y, Salai M, Chechik A, Blankstein A, Horoszowski H: Closing intramedullary nailing for the treatment of diaphyseal forearm fractures in adolescence: A preliminary report. *J Pediatr Orthop* 1985;5:143-146.
39. Verstreken L, Delronge G, Lamoureux J: Shaft forearm fractures in children: Intramedullary nailing with immediate motion—A preliminary report. *J Pediatr Orthop* 1988;8:450-453.
40. Blackburn N, Ziv I, Rang M: Correction of the malunited forearm fracture. *Clin Orthop* 1984;188:54-57.
41. Trousdale RT, Linscheid RL: Operative treatment of malunited fractures of the forearm. *J Bone Joint Surg Am* 1995;77:894-902.
42. Gruber R: The problem of the relapse fracture of the forearm in children, in Chapchal G (ed): *Fractures in Children*. New York: Georg Thieme Verlag, 1981 pp 154-158.
43. Vince KG, Miller JE: Cross-union complicating fracture of the forearm: Part II. Children. *J Bone Joint Surg Am* 1987;69:654-661.