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Nonoperative Management of Pediatric Upper Extremity Fractures or 'Don't Throw Away the Cast'

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Summary: With the exception of fractures involving the distal humerus, almost all fractures of the upper extremity can be successfully treated by noninvasive methods. The surgeon treating upper extremity fractures in children in areas of developing nations where the medical and surgical resources are limited should have a good knowledge of the nonoperative techniques available. He or she should also be skilled in administering local and regional anesthesia. Fortunately, in the pediatric age group, there is a considerable remodeling potential. This fact determines the adequacy of the best reduction that can be obtained by nonoperative methods. Knowledge of the limits of satisfactory remodeling for the various fracture patterns is also essential. Anyone treating fractures in these areas needs to be flexible with their approach and innovative in their methods. Although these fractures often present challenges for the treating physician, they can provide a great deal of satisfaction when they are conquered and the patient's fracture treatment has a successful outcome. The specific techniques for the nonoperative management of upper extremity fractures in the pediatric patient are discussed in detail. It must be emphasized, however, that the treating surgeon should both teach and perform procedures to achieve as satisfactory a reduction as possible within the resources of the local area. **Key Words:** Fractures—Nonoperative—Conservative—Casts.

Emphasis on Surgery

In the United States, there has been an increasing emphasis on managing difficult pediatric fractures surgically.[34] The most important factor stimulating this has been the universal availability of image intensifiers. These have enhanced the surgeon's ability to treat pediatric fractures operatively with percutaneous or other minimally invasive techniques. Other factors such as the need to decrease hospitalization times and allow rapid return to a functional recovery have also driven this desire to use methods of surgical stabilization.

Limited Resources

Unfortunately, the resources for performing these minimally invasive techniques are often not available to the surgeon treating pediatric fractures in many developing nations. Likewise, the implants are expensive and thus are rarely available. As a result, there is a need to use nonoperative measures in treating fractures in these countries.

With the emphasis on the use of surgical techniques, many of the recent graduates of orthopaedic training programs have not mastered the skills to effectively manage pediatric fractures nonoperatively. It is hoped that this article will provide a resource to the modern orthopaedic surgeon as to the effective methods of treating pediatric fractures nonoperatively.

Treatment of fractures in an environment where there are limited resources requires a great deal of flexibility and innovation. In the past, surgeons were able to treat most fractures with noninvasive methods. Anyone planning on treating fractures in a developing nation should review some of the techniques described in older textbooks.[6,9,27,33]

BASIC PRINCIPLES

Obtain Reduction

The basic principle in treating all fractures, whether they are pediatric or adult, is that the individual treating the fracture must *first obtain a satisfactory reduction.*

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Remodeling Potential

Fortunately, in children, there is a tremendous capacity to remodel the residual postfracture deformity into a nearly anatomic position. The treating physician needs to have a general knowledge as to how and where the postreduction deformities will remodel. As a result of the limited space of this article, these specific limits are not discussed. They can be found in the two major textbooks dealing with pediatric fractures.[18,28] In addition, two articles have been published in recent orthopaedic journals, which fully discuss the limits of remodeling of specific children's fractures.[16,36]

Maintenance of the Reduction

Once a reduction has been obtained, it must then be *maintained*. This is where the emphasis on this article is placed, that is, maintaining the fracture reduction effectively using noninvasive techniques.

MATERIALS AVAILABLE

In the treatment centers of most developing nations, there is a wide variety of materials available for immobilizing fractures after the reduction. Plaster of Paris is the most universal material available. In many areas, the patient's family has to purchase the materials from outside sources. In the more developed countries, plaster is being either replaced or supplemented with the newer fiberglass products.

Plaster of Paris

Advantages

The main advantage of plaster is its universal availability. It is also very inexpensive. In some developing nations, the plaster rolls are fabricated by hand using basic gauze rolls and rolling raw powdered plaster of Paris into them. The rolls are initially produced in 12- to 18-inch lengths. Before being used, the rolls are then cut to the desired shorter lengths ranging from 2 to 6 inches.

These plaster rolls can then be stored in a dry place without much deterioration. Plaster is easy to roll and mold to the desired shape. Plaster casts, although heavy, are relatively comfortable for the patient.

Disadvantages

Plaster, if kept dry, is able to maintain adequate strength and is very useful in immobilizing upper extremity fractures. Unfortunately, if it gets wet or damp, it loses its strength and tends to break. This is a problem in weightbearing lower extremity casts. Often, excessive amounts of plaster need to be applied to obtain adequate strength.

Fiberglass

Advantages

The standard rigid fiberglass is very strong and can retain its strength even if wet. It is reasonably easy to mold.

Disadvantages

There are many disadvantages, however. First, it is very expensive and often beyond the budgets of many facilities in the developing nations. Second, it becomes hard when it is exposed to the atmosphere. It must be stored in an airtight aluminum foil package. Any puncture of these packages can allow air to enter, which prematurely hardens the fiberglass roll. In addition, as it ages, the rolls tend to harden spontaneously.

Because it is very rigid, the edges tend to be very sharp and irritating to the patient. Because of the rigidity, removal of fiberglass casts with regular cast saws may also be difficult. Theoretically, special cast saws with hardened steel blades should be used. Technically, casts made of fiberglass are waterproof. The lining is the problem. If they get wet, they must be thoroughly dried with artificial means or require special (and very expensive) quick-drying liners. If the lining remains wet, skin maceration can occur. Finally, the fiberglass does not easily absorb liquids such as blood and sweat. The materials tend to harden in the cast padding or dressings.

Composite Cast

One method of combining the advantages of both plaster and fiberglass is to apply composite casts. The first layers consist of a routine plaster cast application. Often, in the acute stage, the plaster cast is applied, which is subsequently split to allow for postreduction swelling. This initial layer can absorb any fluids that are produced. In approximately 1 week, when the initial swelling has subsided, the plaster can then be closed and covered with an outer layer of fiberglass. This single outer layer of fiberglass adds strength to the cast and makes it water-resistant (not waterproof). In areas where there are adequate resources, this combines the moldability of plaster with the strength of fiberglass at a somewhat lower cost.

"Soft Cast"

One of the newest innovations in external immobilization is the use of "Soft Cast" (3M Medical Markets Laboratory, Borken, Germany), which has become popular in Europe. It is a semirigid fiberglass, which can be easily applied and has some flexibility. According to recent reports,[31] this flexibility allows a small amount of motion, which theoretically hastens the decrease of the acute edema associated with the fracture. Small splints of regular fiberglass are placed at strategic areas to provide the necessary strength. Most of these casts can be applied acutely with only a couple of layers of fiberglass and then split only with *scissors* to allow for acute postreduction swelling. After 1 week, a second layer of "Soft Cast" is overwrapped. The ability to remove these casts with scissors is a definite advantage in the pediatric age group.

Advantages

The ease of application, ability to allow some motion, and ease of removal with scissors are definite advantages for this material.

Disadvantages

Cost and availability in countries with limited resources is still a problem. Because only a small amount may be used, the number of rolls needed is less, making it closer to the use of plaster, which may require multiple rolls.

There is not enough experience yet with the use of this material in developing nations to see where it fits into the scheme of nonoperative management of pediatric fractures.

PAIN RELIEF

General Relaxation Agents

General anesthesia and sedation

The use of general anesthesia and conscious sedation may be somewhat limited in areas with limited medical resources. Many facilities either do not have the ability to purchase or store securely the various narcotics and other conscious sedation agents. Often, availability of personnel to administer general anesthesia is also very limited and can be time-consuming. Thus, these measures are usually not universally available.

Ketamine

Ketamine has become an agent that is widely used in many areas where general anesthesia or conscious sedation is not available.[17,21] Although not without risks, it is reasonably safe to use. The drug is not overly costly. Before using this drug, the treating surgeon needs to be fully aware of the side effects and the possible risks associated with its use. There are many recent reference sources delineating its use and need to be read before the administration of this drug.[13]

Monitoring essential

If at all possible, when a drug like this or even a conscious sedation medication is used, a separate medically trained individual should be monitoring the patient's vital signs and level of consciousness. This individual also needs to be sure that an adequate airway is being maintained. Fortunately, in some remote areas, pulse oximeters or other circulatory monitoring are usually available and should always be used.

Injectable Local and Regional Procedures

Hematoma block

If the fracture is fresh or less than 3 to 4 days old, injecting the fracture hematoma in many cases can provide good pain relief. There are some important factors to remember when using a hematoma block. First, it is essentially an intravenous injection and only the minimal amount needed should be used. Second, to prevent increasing the volume of fluid at the fracture site, the "Barbotage" technique should be used (Fig. 1). Third, because one is injecting directly into the fracture site, aseptic techniques should always be followed. Finally, the anesthetic agent should be free of both preservatives and epinephrine.

Regional nerve blocks

Regional injection of a local anesthetic into the axilla, if performed properly, can provide very good anesthesia to the upper extremity. Use of ring blocks in the wrist can also be useful. Unfortunately, because of the requirement of multiple injections, these regional nerve blocks are not universally well tolerated by the pediatric patient.

Regional intravenous nerve blocks

There has been a lot of experience with using the "Bier" intravenous block. When used appropriately, it is a safe and effective method of achieving good local anesthesia in the forearm.[14] Once the initial anesthesia is obtained, it can be supplemented with a local hematoma block as described in the previous section. Again, local anesthesia without epinephrine or preservatives should be used. The specific technique for administering regional intravenous anesthesia can be found in other sources.[13,14]

Advantages

It requires only two injections: one for intravenously access in a noninvolved extremity and one to inject the extremity for the block.

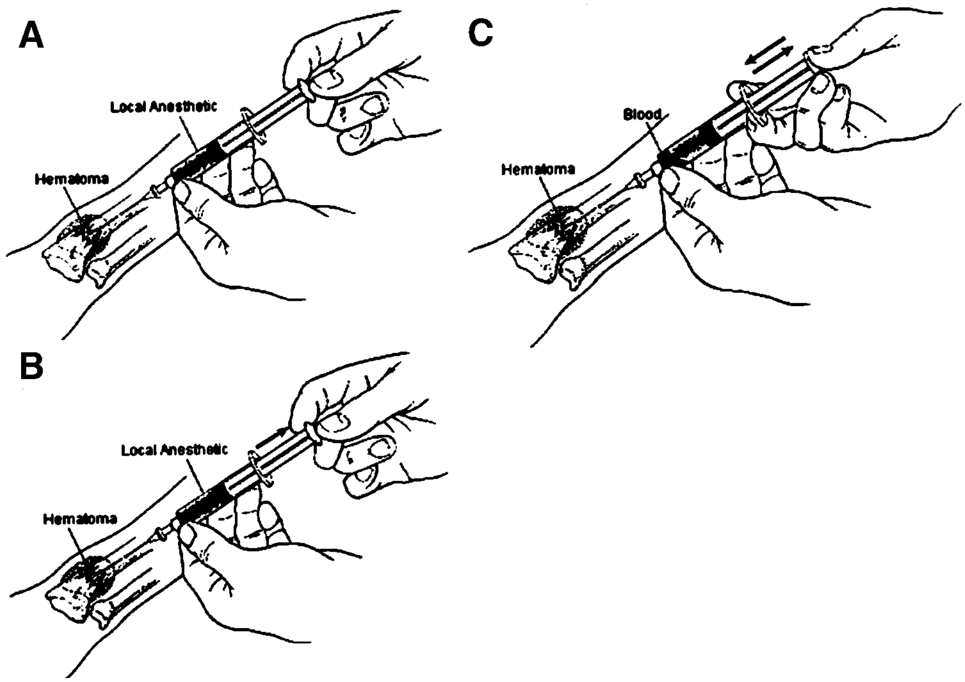


FIG. 1. Barbotage technique. The local anesthetic is mixed with the hematoma by the process called Barbotage. (**A**) Half the anesthetic is injected into the hematoma. (**B**) The blood from the hematoma is then withdrawn to equal the original volume. (**C**) This material is then repeatedly injected and reaspirated until the anesthetic is completely mixed within the hematoma. It is important that the final aspirate equal that of the original volume so that the amount of fluid in the hematoma has not been increased. (Reproduced with permission from: Sedation and analgesia in the child with a fracture. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children*, 4th ed. Philadelphia: Lippincott-Raven; 1996:72–73.)

Disadvantages

Because the anesthetic medication is administered intravenously, using a dependable tourniquet is vital. Ideally, these patients need to be monitored as well to look for signs of systemic toxicity.

SPECIFIC FRACTURE PROCEDURES

In this section, the specific manipulative and immobilization techniques are discussed. The techniques described are those that have been developed over the past 30 years by the author and are now used. It needs to be mentioned that some areas such as type III supracondylar fractures cannot be adequately managed by nonoperative techniques.

It must also be emphasized that open fractures need to undergo the appropriate operative management before they are reduced and immobilized.

Distal Radial Physis Fractures

Fractures of the distal radial physis occur more commonly in the older age groups.[22] Fortunately, as was demonstrated over 70 years ago, these fractures have a tremendous potential to remodel[1] (Fig. 2). In fact, up to 50% displacement can be accepted with at least 1½ years of growth remaining.[1] The major reason for even reducing these fractures is to relieve the pressure on the structures in the carpal tunnel. The distal location of the fracture surface of a severely displaced distal fragment can increase the risk of producing acute carpal tunnel syndrome in the unreduced situation. This rarely occurs with the distal radial metaphysis fractures (Fig. 3). Minimally to moderately displaced fractures of the distal radial physis should be simply immobilized with a cast and usually can be expected to remodel fully within a year (see Fig. 2).

Manipulative procedures

The most serious complication associated with this fracture is growth arrest. Often this is beyond the control of the treating surgeon because the growth arrest results from the forces applied during the initial injury. To prevent further injury, it is important that any manipulative procedure minimize the amount of shear forces that occur in the reduction process. After achieving adequate anesthesia, traction can be applied with either finger traps or having an assistant suspend the hand against countertraction applied to the distal arm above the elbow. If the fracture is fresh, simple traction often results in an adequate reduction (Fig. 4A, B). If this is not sufficient, a simple horizontal force can then be applied to the distal fragment (Fig. 4C). Keeping traction applied during the manipulative process theoretically should decrease the shear forces applied to the fracture fragments.

Immobilization techniques

Traditionally, in the past, it has been recommended that these fractures have required a long arm cast for

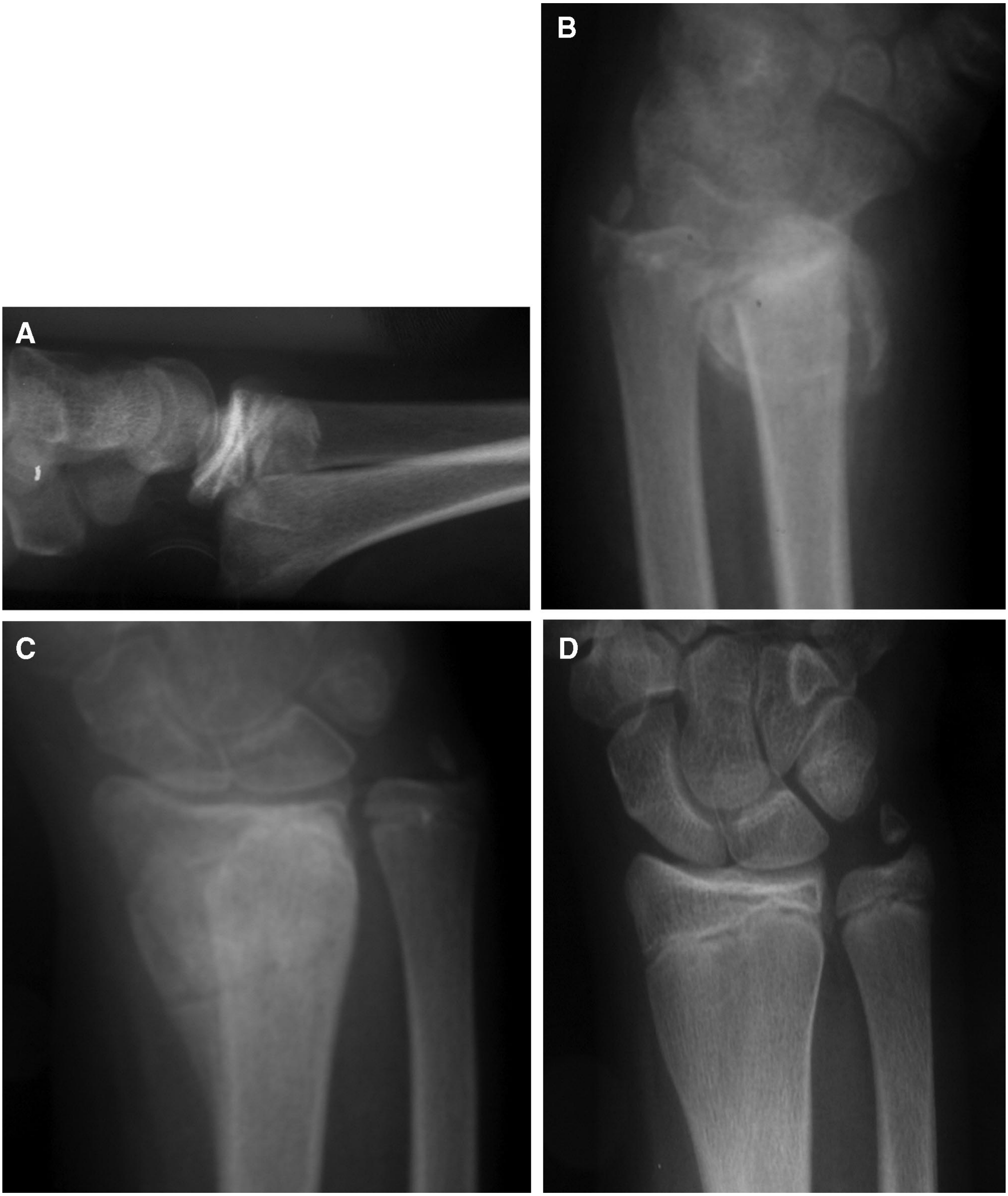


FIG. 2. Remodeling. (**A**) Injury film of a 10-year-old boy demonstrating a type A distal radial physeal fracture with complete displacement. (**B**) When the cast was removed at 1 month, there was marked displacement of the distal fragment with callus formation. (**C**) By 3 months, there had been considerable remodeling and realignment of the distal fragment. (**D**) At 1 year, there is essentially complete remodeling and realignment of the distal fragment.

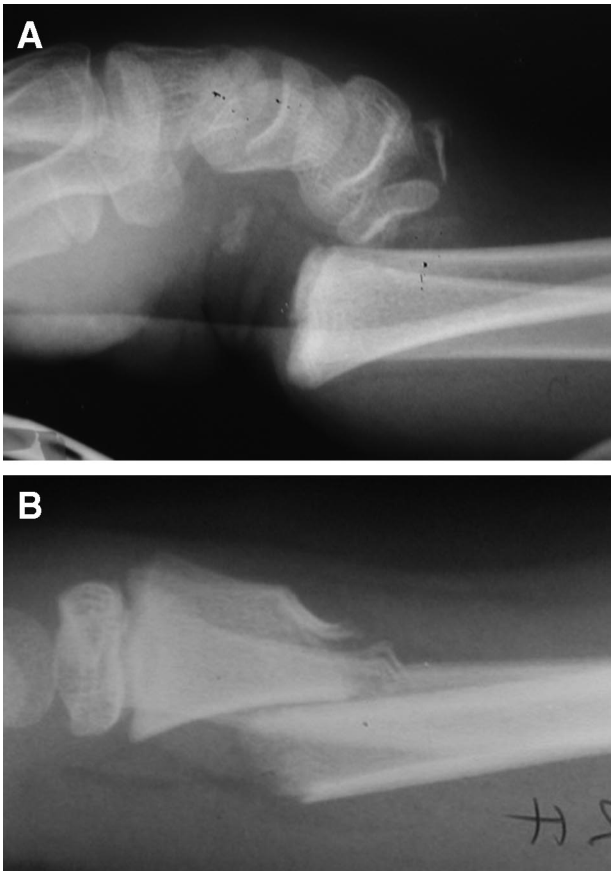


FIG. 3. Carpal tunnel syndrome. (**A**) Position of fracture fragments with a distal radial physeal injury. The distal fragment is markedly displaced and there is considerable pressure by the volar aspect of the proximal fragment against the contents of the carpal tunnel. (**B**) With metaphyseal fractures, the fracture is a little more proximal and away from the carpal tunnel, producing only minimal pressure on the neurovascular structures.

immobilization ([2,19]). The rationale for this was that the joints above and below should be immobilized to prevent displacement. More recently, Chess and coworkers[8] have demonstrated that these fractures can be very adequately immobilized with a short leg cast. The key is to make the cast elliptic. Chess and his workers found that if the anterior–posterior diameter exceeded the transverse diameter by a factor of more than 0.7, there was a greater incidence of late displacement. They termed this ratio as the "cast index" (Fig. 5). The exact technique of properly applying a short arm cast and molding it properly is discussed in the following section dealing with immobilization of distal radial metaphyseal fractures.

Distal Radial Metaphyseal Fractures

Fracture patterns

The metaphysis of the distal radius is one of the most common areas fractured in children.[22] The fracture pat-

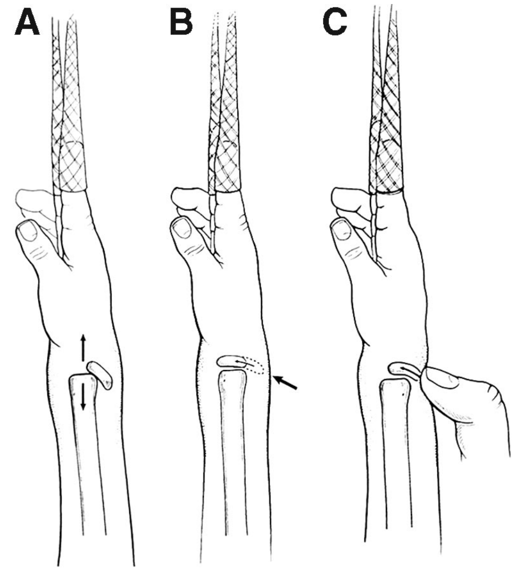


FIG. 4. Traction reduction. (**A**) Applying finger traps tends to distract the fracture fragments. (**B**) Often the traction alone allows spontaneous reduction. (**C**) If there is still an inadequate reduction, applying direct pressure over the distal fragment with the thumb often will complete the reduction. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:464.)

terns range from a simple torus fracture to a complete fracture with bayonet apposition (Fig. 6).

Remodeling potential

Fortunately, there is a considerable amount of remodeling of fracture deformities in this area. This fact stimulated Do and associates[10] to develop a policy of not

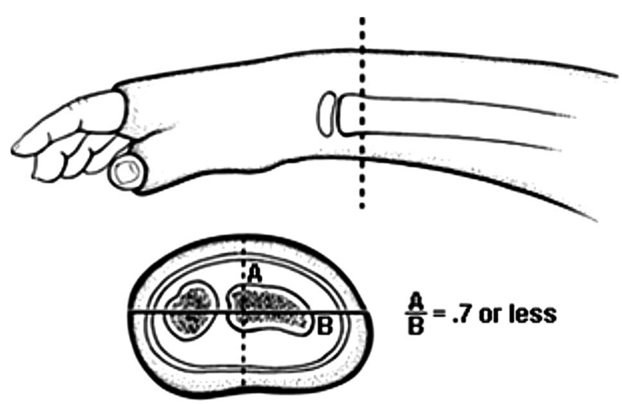


FIG. 5. Cast index. This index is obtained by dividing the sagittal diameter (**A**) by its coronal diameter (**B**) at the fracture site. This ratio or index should be .7 or less. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children*, vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:486.)

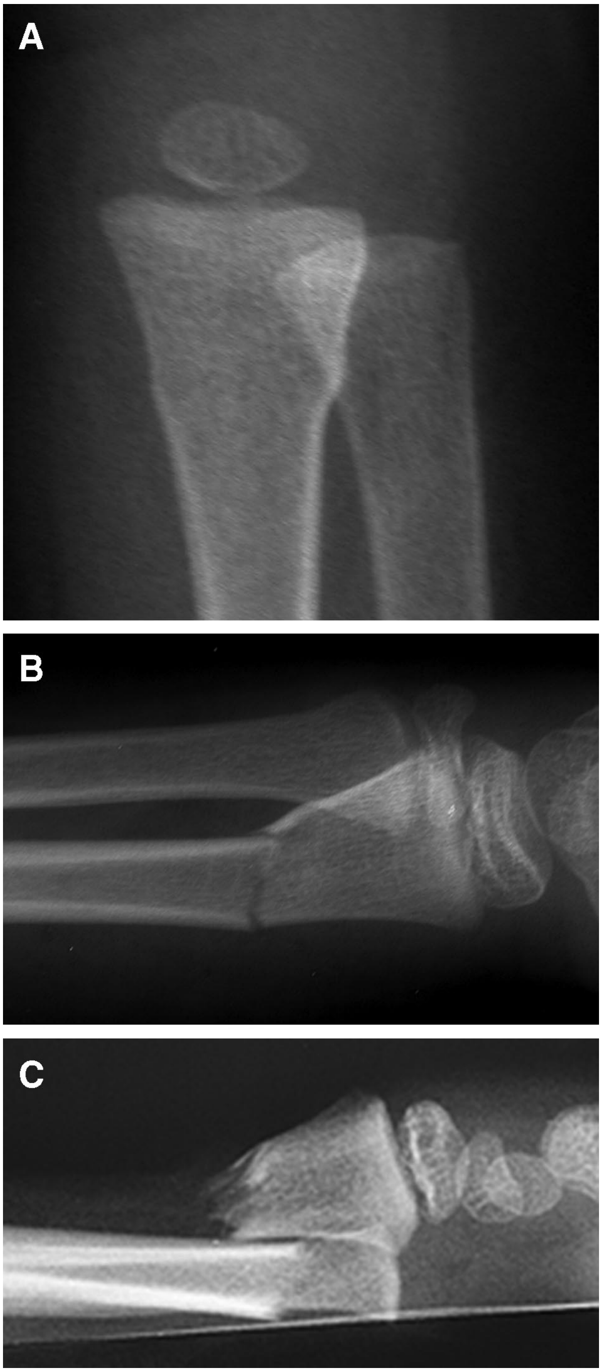


FIG. 6. Metaphyseal patterns. The distal radius can present in one of three types of fracture patterns: (**A**) torus fracture, (**B**) greenstick fracture (tension), (**C**) complete with dorsal bayonet apposition.

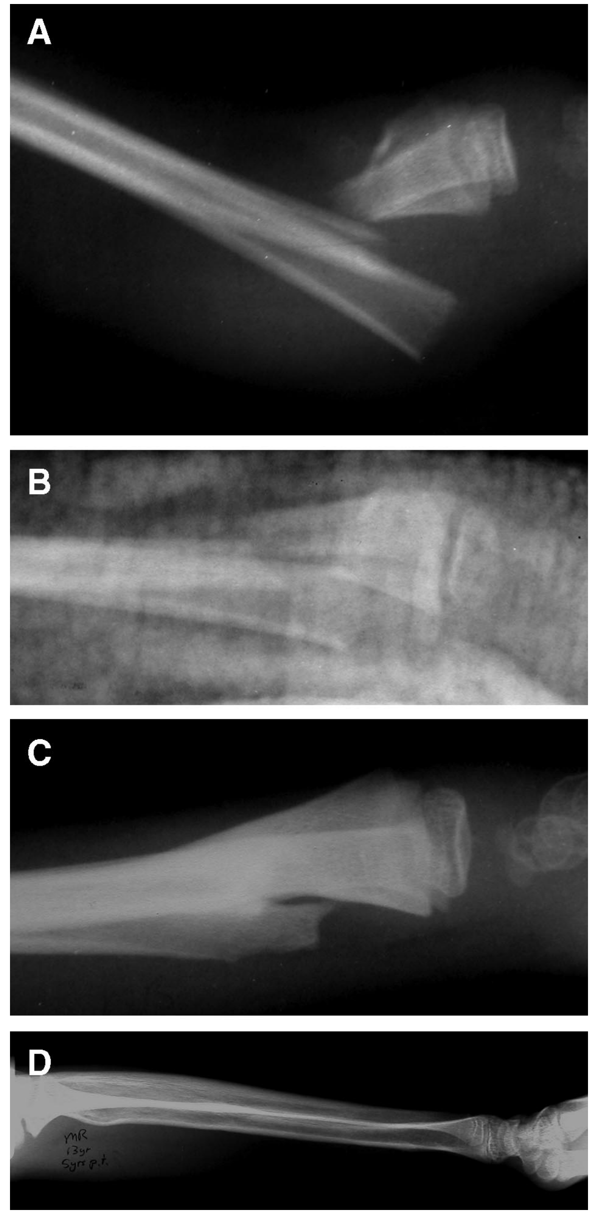


FIG. 7. Bayonet remodeling. (**A**) Injury film of an 8 year old who sustained a complete fracture of the distal radius and ulna. (**B**) The best reduction that was obtained was dorsal bayonet. (**C**) The appearance at 4 months postfracture shows early remodeling. (**D**) By 5 years postinjury (age 13), remodeling was complete and the patient had a normal appearance and forearm motion. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children*, vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:489.)

even reducing their distal radial and metaphyseal fractures in the emergency room in young children. They accepted up to 15° of primary angulation and 1 cm of shortening in boys up to 14 years of age and girls up to 12 years. It was their opinion that it was both a waste of time and an unnecessary utilization of financial resources to manipulate these fractures in the emergency room. They observed that the fractures that

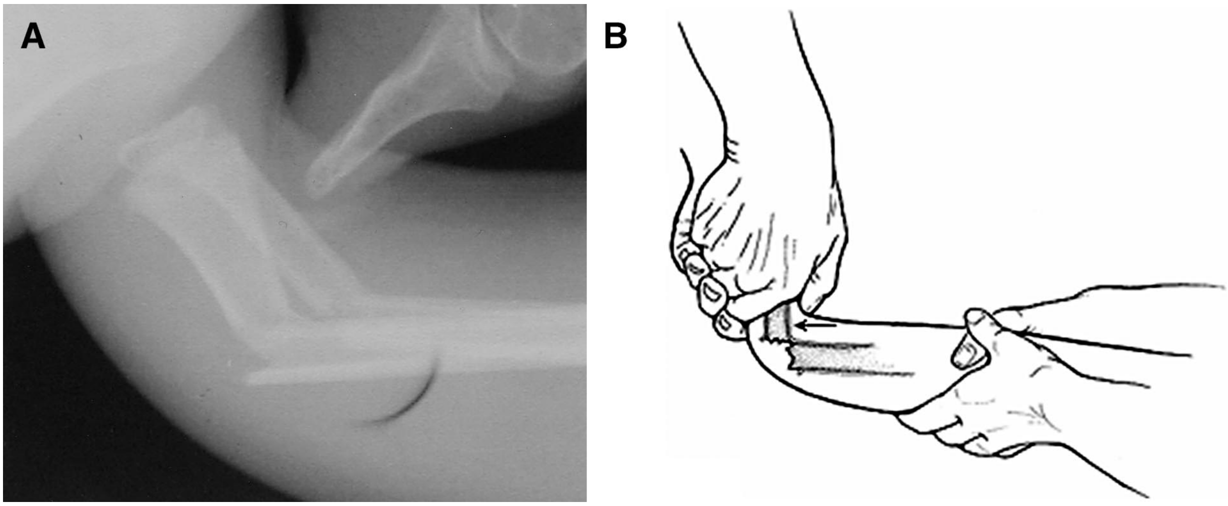


FIG. 8. Reestablishing length. (**A**) X-ray demonstrating the position of the surgeon's thumb pressed against the dorsal surface of the hyperextended distal fragments. To reestablish length, one must first hyperextend the distal fragment by (**B**) walking the distal fragment until it is just at the edge of the distal surface of the proximal fragment. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children*, vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:496.)

were completely unreduced had essentially complete remodeling at the termination of growth (Fig. 7).

Manipulative procedures

Each of the separate fracture patterns requires its own specific manipulative techniques.

Torus fractures. Torus fractures do not require any manipulation. They need nothing more than simple splintage to provide comfort and protect from further injury.

Greenstick fractures. With 5 years of growth remaining, 30° to 35° angulation in the sagittal of the fracture

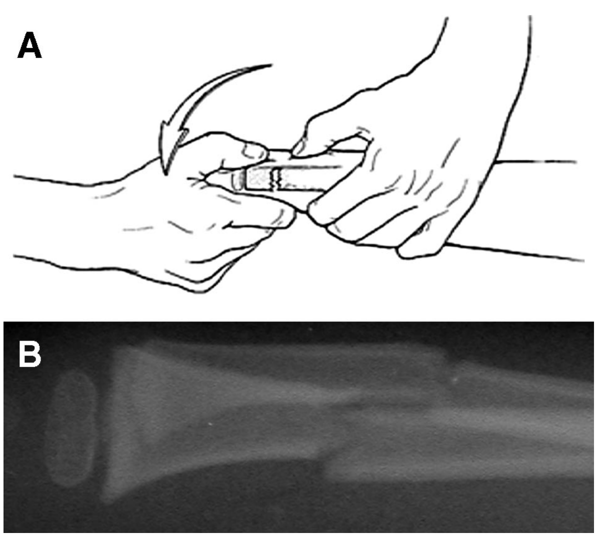


FIG. 9. Angulation correction. (**A**) X-rays demonstrating the reduction of the fracture in **B**. (**B**) The length has been reestablished and the angulation is corrected by rotating it into alignment with the proximal fragment. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:497.)

FIG. 10. Plaster application. Plaster is applied with the fingers in some type of traction, this case being finger traps. This allows the surgeon's hand to be completely unobstructed around the forearm. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:498.)

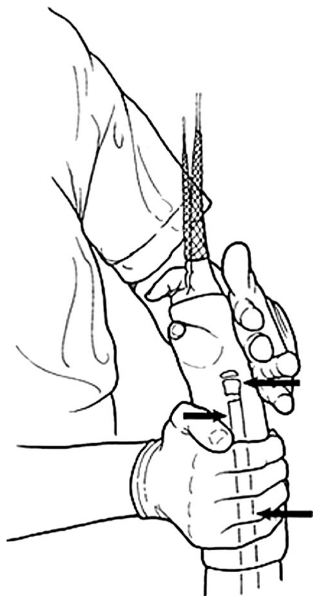


FIG. 11. Three-point molding. As the cast is setting up, three pressure points are molded into the cast (arrows) to apply pressure on the distal fragment and proximal fragment and use the intact dorsal periosteum to further maintain the reduction. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children*, vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:499.)

FIG. 13. Cast cutting. While it is still suspended, the cast is split and spread in its distal three fourths. Splitting should include the padding down to the skin. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children*, vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:499.)

fragments and 10° in the coronal plane can be expected to remodel to a satisfactory clinical alignment and acceptable function at the termination of growth.[15,34,35]

So, which metaphyseal fractures need to be manipulated? In North America and probably most European countries, there is an expectation on the part of the parents that these fractures should return to as near normal alignment as possible. Thus, in most instances, in these regions, an attempt is made to achieve an anatomic reduction. Certainly, in children 12 years of age and older, if resources are available to reduce and immobilize these fractures under adequate anesthesia, a manipulative reduction should be performed.

Complete dorsal bayonet fractures. It is the author's experience and that of others[7,29] that bayonet apposition can be expected to remodel to a satisfactory degree in children 12 years and younger (see Fig. 7). Thus, dorsal bayonet fractures in the younger age group can simply be immobilized. It is important to immobilize them in neu-

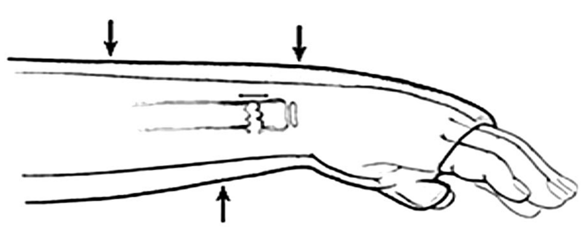


FIG. 12. Pressure points. The wrist is placed in slight flexion to allow pressure over the pressure points (arrows) to be applied dorsally over the distal fragment on the volar aspect of the distal end of the proximal fragment and in the third position of the dorsum of the proximal forearm. This uses the intact periosteum to stabilize the fracture fragments. (Reproduced with permission from: Fractures of the distal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:496.)

FIG. 14. Postreduction swelling. Appearance of a postreduction of a distal metaphyseal fracture showing the swelling that has migrated into the thenar eminence. This can cause considerable pressure against the skin at the edge of the cast. This is easily eliminated by incorporating the thumb into the plaster cast.

tral rotation. Also, it needs to be explained that there will be more swelling in the immediate postcast period. Care should also be taken to maintain alignment in the coronal and sagittal planes. If there is any sign of compromise of the neurovascular structures, the fracture should be reduced.

To reduce the complete dorsal bayonet fractures, one has to perform two manipulative procedures: 1) reestablish length and 2) correct the angulation.

Because of the aggressive nature of the manipulative process, adequate local anesthesia needs to be obtained. This author prefers the combination of a regional Bier block supplemented with a hematoma block.

To *reestablish length*, preliminary traction in the axis of the forearm will help but will not of itself fully reestablish the length. The distal fragment must be hyperextended and walked off distally to reach the distal dorsal edge of the proximal fragment (Fig. 8). Once the length has been established, proximal fragment is then bent forward to line up the proximal and distal fragments to *correct the angulation* (Fig. 9).

Immobilization techniques

This is achieved in the same manner as for fractures of the distal radial physis, that is, applying a short arm cast. The cast should have an index of 0.7 or less. A short arm cast can easily be applied while the extremity is held in traction (Fig. 10). If finger traps are available, they can be used to eliminate the need for an assistant. Suspending the upper extremity with the elbow at 90° allows the surgeon free access to all sides of the forearm. This also enables the surgeon to apply the proper molding to achieve a cast index of .7 or less (Fig. 11). In addition to generally molding the cast elliptically to achieve the proper cast index, three specific point molding points should be applied to the various portions of the cast to use the intact periosteum as a stabilizing force (Fig. 12).

Postoperative swelling. Immediately after applying and molding the cast appropriately, the cast is split along the ulnar border to within 2 inches of the proximal edge. This cast is then spread to allow for postreduction swelling (Fig. 13). The cast is then covered with a soft bandage. In addition, with distal metaphyseal and physeal radial fractures, considerable swelling occurs in the hand. This swelling can often migrate into the thenar eminence, causing the edge of the cast to press on the skin at the base of the thumb (Fig. 14). This irritating pressure point can be eliminated by incorporating the thumb into the cast during the first week.

Postreduction follow up. If possible, the patient should then return for a postreduction check at 1 week to make sure there are no problems. The swelling should be decreased sufficiently at this point to permit the cast to be closed and the thumb freed up. If available, this is the ideal time to cover the cast with a single layer of fiberglass material. For the non- or minimally displaced fracture, immobilization for a month is usually sufficient. For severely displaced fractures, the cast should remain for at least 6 weeks. Because the refracture rate is low, no further support is usually needed after the cast is removed.

FIG. 15. Shaft fracture patterns. (**A**) Plastic deformation demonstrating bending of the bone but no apparent fracture. (**B**) Greenstick fracture with the compression side still remaining intact. (**C**) Complete fractures of both shafts with bayonet apposition.

Fractures of the Radial and Ulnar Shafts

Fractures of the shafts of the radius and ulna are not as forgiving as those in the distal metaphysis. Less angulation can be accepted because there is less remodeling capacity of diaphyseal bone. Because the tissue in this area is primarily mature cortical bone, the healing process is much slower. For this reason, the immobilization time is longer. To adequately stabilize the reduction achieved, the forearm needs to be immobilized in a long

TABLE 1. *Acceptable Malalignment for Radial Shaft Fractures*[26]

Age (yr)	Angulation	Malrotation	Displacement	Loss of Radial Bow
9	15°	45°	Complete	Yes
9	10°	30°	Complete	Partial

FIG. 16. Gradual reduction. Plastic deformation is gradually reduced by applying three-point pressures over a fulcrum placed under the apex of the fracture. Both hands need to be used in applying gradual pressure for 1 to 2 minutes until the deformity is corrected. (Reproduced with permission from: Injuries to the shafts of the radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:550.)

arm cast until there is some intrinsic stability, which is usually approximately 4 weeks.

The fracture patterns

The patterns of fracture are dependent on the degree of completeness of failure of the shaft (Fig. 15).

Plastic deformation. There is the rare occurrence of plastic deformation in which the failure is totally internal. On the x-rays, there is demonstrated only a bending of the shaft. No gross cortical failure is seen. It is important to realize that this angular deformity can become permanent if not corrected.

Greenstick fracture. The greenstick fracture represents an incomplete fracture in which the compressive side of the cortex is still intact but plastically deformed. The tension cortex has failed completely.

FIG. 17. Greenstick fracture patterns. (**A**) Apex anterior with supination of the distal fragment. (**B**) Apex dorsal with pronation of the distal fragment.

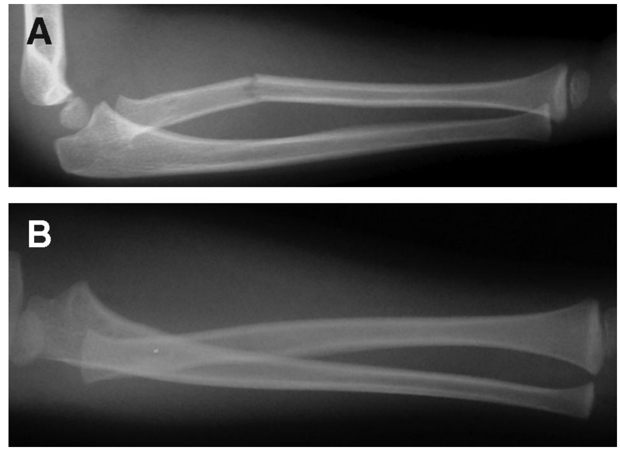


FIG. 18. Reduction into pronation. (**A**) Injury film of a 7 year old with a greenstick fracture of the apex anterior of the radius and supination of the distal fragment. (**B**) By pronating the distal fragment, the angulation and rotation of the radius has been corrected.

Complete fracture. The final degree of failure occurs when both cortices are completely separated. Because there is not intrinsic stability, there is often shortening at the fracture site with overriding of the fracture fragments.

Remodeling potential

Based on their wide experience and extensive review of these fractures, Price and Mencino have set some guidelines to consider the various factors in evaluating their remodeling potential.[26] These can be found in Table 1.

FIG. 19. Reduction into supination. (**A**) Injury film of an 8 year old with an apex dorsal greenstick fracture pattern. (**B**) By rotating the distal fragment into supination, the *angulation and rotation have been corrected.* (Reproduced with permission from: Injuries to the shafts of the radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:524.)

Manipulative procedure

Each of the three types of fracture patterns requires its own separate manipulative procedure. That is why it is important to first determine the pattern of failure.

Plastic deformation, manipulative procedures. Sanders and Heckman in their study of these fractures determined that to correct the deformity associated with these fractures, a gradual force needed to be applied across the apex of the deformity (Fig. 16).[30] Because the plastic deformation is slowly corrected, this force needs to be applied continuously for at least 1 to 2 minutes. The end point is when full supination and pronation have been reestablished and the curvature deformity appears to have been corrected clinically.

Immobilization techniques. Immobilization accomplished in a simple long arm cast for 4 to 6 weeks with the forearm placed in either supination or pronation in opposition to the original deformity is usually all that is needed to immobilize these fractures.

Greenstick fractures, patterns. It is important to recognize that greenstick fractures can occur in one or two major fracture patterns. Greenstick fractures have both an angular and rotational component. In the most common pattern, the distal fragments are supinated with the apex of the fracture being anterior (Fig. 17A). An opposite pattern occurs less commonly in which the apex of the fracture is dorsal and the distal fragment is pronated (Fig. 17B).

Manipulative procedures. The key to correcting the deformities with greenstick fractures lies in applying both rotational and angular correction in the manipulative process. With the apex anterior–supination patterns, the distal fragment needs to be pronated during the manipulative maneuver. Usually correcting the rotational alignment corrects most of the angular deformity (Fig. 18). The final angular correction is achieved by direct three-point pressure with the apex being at the middle pressure point.

In the apex dorsal fracture patterns, the distal fragment needs to be manipulated into supination (Fig. 19). Again, the final angular correction is achieved by three-point molding.

In addition to three-point molding in both types of fracture patterns, there needs to be longitudinal interosseous molding, which will help keep the shafts of the radius and ulna separated in the cast.

Immobilization techniques. Apex volar fractures need to be immobilized in a long arm cast with the elbow flexed at 90° and the forearm pronated (Fig. 18B). The apex dorsal fractures need to be immobilized with the elbow in the same degree as elbow flexion but the forearm needs to be placed in a supination position (Fig. 19B). Usually, the long arm cast is maintained until some intrinsic stability has developed at the fracture site. This usually occurs at approximately 4 weeks postfracture when early callus has developed. Immobilization with a short arm cast for another 4 weeks is usually sufficient. If there are limited resources, immobilization with the elbow at 90° for the full 8 weeks usually does not appear to produce much elbow stiffness in the pediatric age group. It must be remembered that greenstick fractures have a higher rate of refracture and thus should be immobilized for the full 8 weeks.

FIG. 20. Proximal migration. (**A**) X-rays of a greenstick fracture of the shafts of the radius and ulna in a 6 year old with an apex anterior–supination deformity. This patient was placed in a long arm cast with neutral forearm rotation and the elbow placed at 90°. (**B**) X-rays taken in the cast 2 weeks later demonstrate the forearm has slipped up into the cast, in a posterior angulation of both the ulna and radius. (**C**) Clinical appearance showing the unsightly prominence of the ulnar bow after cast removal. This fracture was remanipulated and placed in a long arm extension cast.

In very small individuals, who have either fat or short forearms, there is a tendency for the forearm to migrate proximally in the cast, creating a very unsightly apex dorsal deformity (Fig. 20). This migration can be prevented by applying a long arm cast with the elbow in extension. Some modifications need to be made when applying the elbow extension casts. These casts tend to

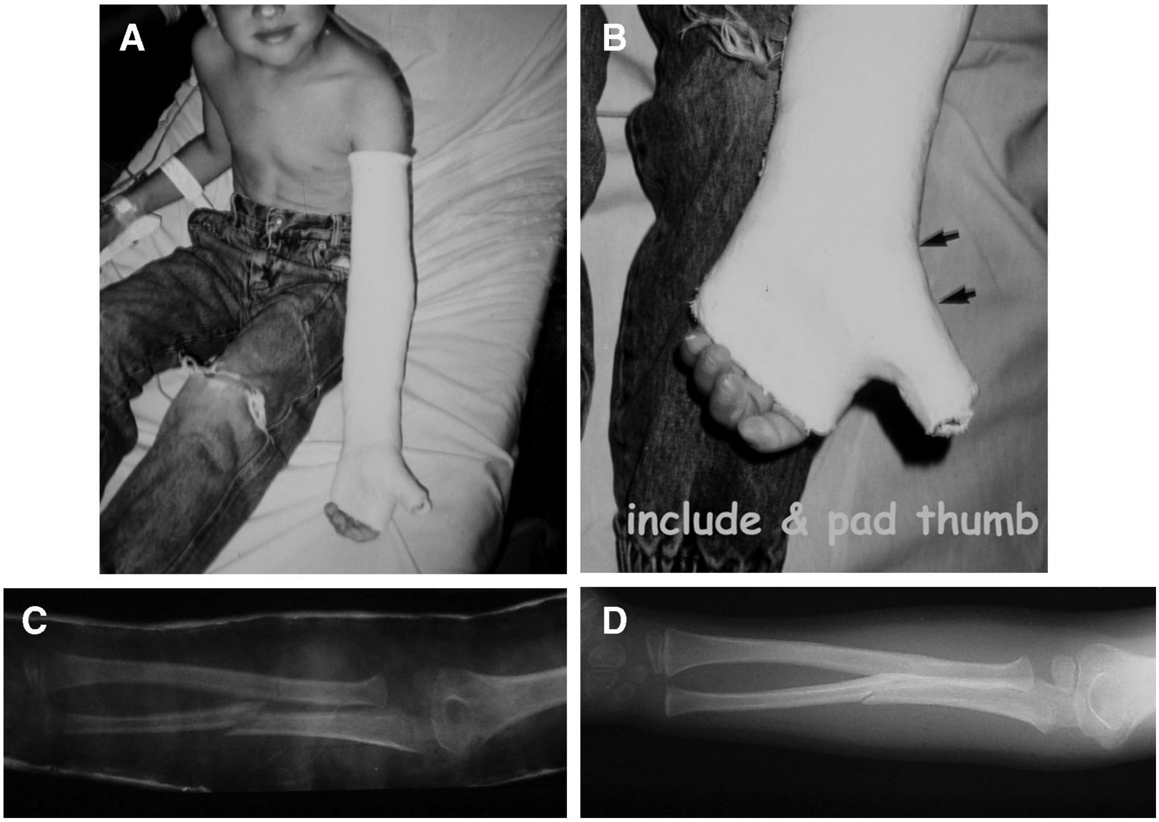


FIG. 21. Long arm extension cast. (**A**) Full view of the typical long arm extension cast demonstrating molding in the supracondylar area and incorporation of the thumb. (**B**) In addition to including the thumb, it is important that extra padding be placed at the base of the thenar eminence. Occasionally, local pressure develops in this area from minor distal slippage of the cast. (**C**) Postsecond reduction x-ray of the patient presenting in Figure 20 demonstrating satisfactory alignment of both the shafts of the radius and ulna. (**D**) Appearance at 8 weeks on cast removal showing slight radial angulation of the ulna, which poses no cosmetic or functional difficulties.

migrate distally to some degree. This requires applying a good mold in the supracondylar area. In addition, the thumb needs to be included in the cast with extra padding over the base of the thenar eminence (Fig. 21). It would be unwise to immobilize the elbow for longer than 4 weeks in extension because of the possibility of developing stiffness in the elbow.

Complete fractures. These fractures have primarily shortening and some angulation. There can also be independent rotation of the proximal fracture fragments. Thus, the injury films need to be evaluated carefully to see if the proximal fragment is rotated into supination (Fig. 22).

Manipulative procedures. Usually hanging these fractures in traction with the elbow at 90° allows the fragments to seek their own degree of rotation. Much of the angulation also corrects. If the proximal fragment is supinated on the injury film, care must be taken to be sure that the distal fragment is placed in the same degree of rotation. In these fractures, bayonet apposition can be accepted because this will remodel quite adequately (Fig. 23). Shortening is usually not a problem either cosmetically or functionally.

Immobilization techniques. These fractures need to be immobilized in a long arm cast with either the elbow at 90° of flexion or full extension, much the same as with the greenstick fractures. The position of the forearm is determined by the rotation of the proximal fragment. Most of these fractures are immobilized with the forearm in mid rotation. It is imperative that a good interosseous mold be applied to the forearm portion of the cast to maintain the normal spreading of the separate forearm shafts. Depending on the type of cast, age, and fracture pattern, the cast can be cut down or changed to a short arm cast after 4 weeks. This short arm cast is usually retained for a second 4 weeks (8 weeks total).

Monteggia Lesions

Although originally described by Giovanni Monteggia in 1814,[23] it was Jose Luis Bado[4] who provided the most

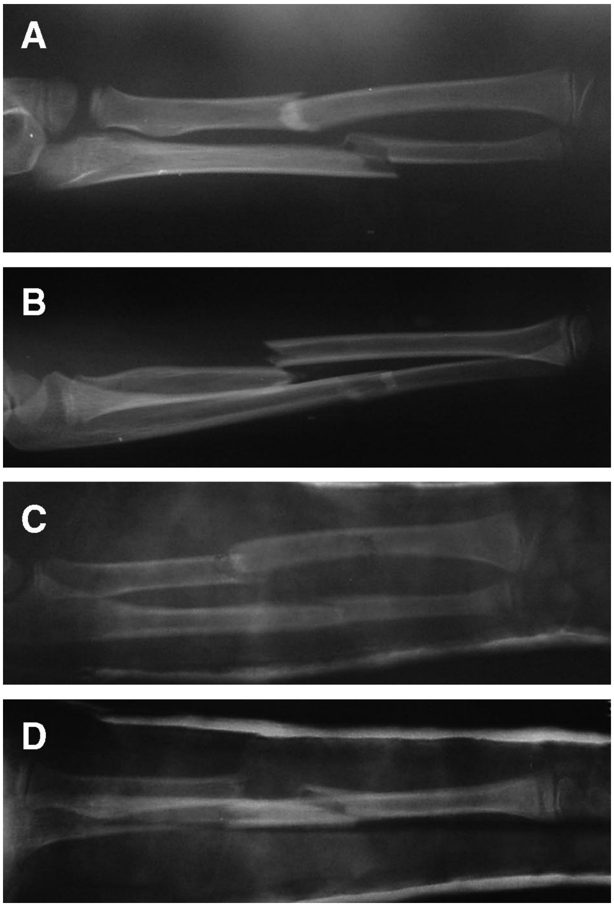


FIG. 22. Independent rotation. (**A**) Injury films of complete fractures of the midshafts of the radius and ulna, anterior–posterior view. (**B**) Lateral view. (**C**) X-rays after reduction of the fracture in placing in a long arm cast with the elbow at 90° and the forearm rotated only to neutral. Notice that the bicipital tuberosity is very prominent indicating full supination, whereas the radial styloid is only in lateral view indicating that the rotation relationship is only 90° instead of the usual 180°. (**D**) Lateral view demonstrating again 90° rotation of the distal fragments in relation to the proximal fragment is manifest also by the difference in the diameters of the radius and ulna at the fracture site. This fracture required a second manipulation.

insight as to the management of these fracture patterns. He described the four classic types with some equivalents. Each of these fracture patterns has a unique mechanism and its own specific manipulative procedure to achieve an adequate reduction. The treating surgeon needs to have a thorough knowledge of the fracture patterns and their mechanism to be able to treat them appropriately.

Type I Monteggia lesion

The typical type I Monteggia lesion consists of an oblique fracture of the midshaft of the ulna and an anterior dislocation of the radial head. In the pediatric

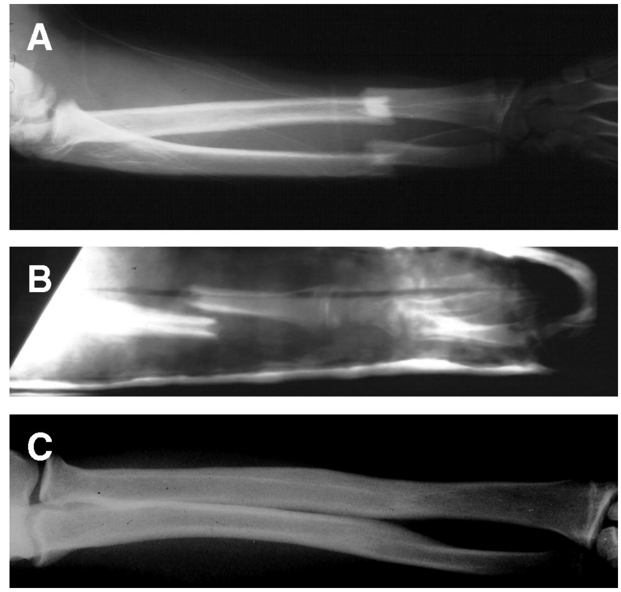


FIG. 23. Bayonet remodeling. (**A**) Injury film of a complete fracture of the distal radial and ulnar shafts. (**B**) X-rays demonstrating the best reduction achieved which was that of bayonet apposition. (**C**) X-rays 2 years later show that there has been almost complete remodeling of the bayonet apposition. The rotational alignment is anatomic. This patient had full range of forearm motion and was cosmetically acceptable. (Reproduced with permission from: Injuries to the shafts of the radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:523.)

age group, the ulnar fracture has a tendency to be a greenstick pattern, although it may be completely displaced.

Mechanism. In general, the mechanism of injury is one of extension. The most widely accepted mechanism is that proposed by Tompkins.[32] He theorized that when the child tries to break his or her fall with the outstretched upper extremity, the failure occurs in three stages. In the first stage, there is a reflex contracture of the biceps to resist the extension of the elbow (Fig. 24A). In the second stage, the biceps tendon pulls the radial head out of its proximal articulation to produce a complete dislocation (Fig. 24B). In the third stage, all of the body weight passing through the extremity is transferred to the shaft of the ulna. Because the ulna is a thin nonweightbearing bone, it fails in an oblique tension pattern (Fig. 24C). Thus all the forces and deformities are directed anteriorly or in extension (Fig. 25).

Manipulative procedures. Because this is basically an *extension* injury, all of the manipulative procedures need to be directed toward *flexion*. The manipulative procedure occurs in two stages. The ulnar length must first be reestablished. This usually is achieved by simply correcting the angular deformity. Three-point pressure is

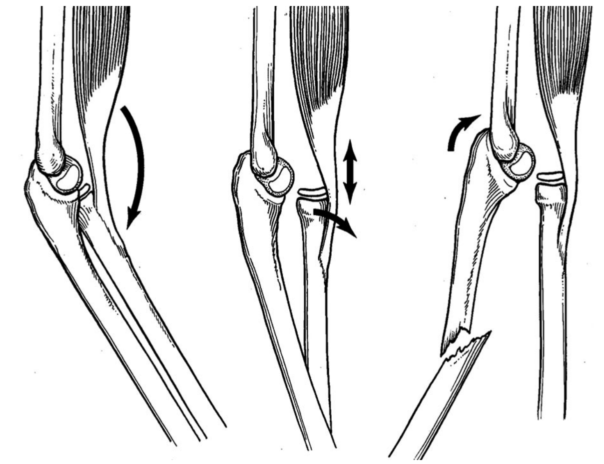


FIG. 24. Hyperextension mechanism. (**A**) A fall on the outstretched hand tends to force the elbow into extension. This stimulates a reflex contracture of the biceps. (**B**) The biceps' pull has a tendency to forcibly dislocate the radial head anteriorly. (**C**) Now that all the weight is transferred to the ulna, it fails in tension producing an oblique fracture. (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:563.)

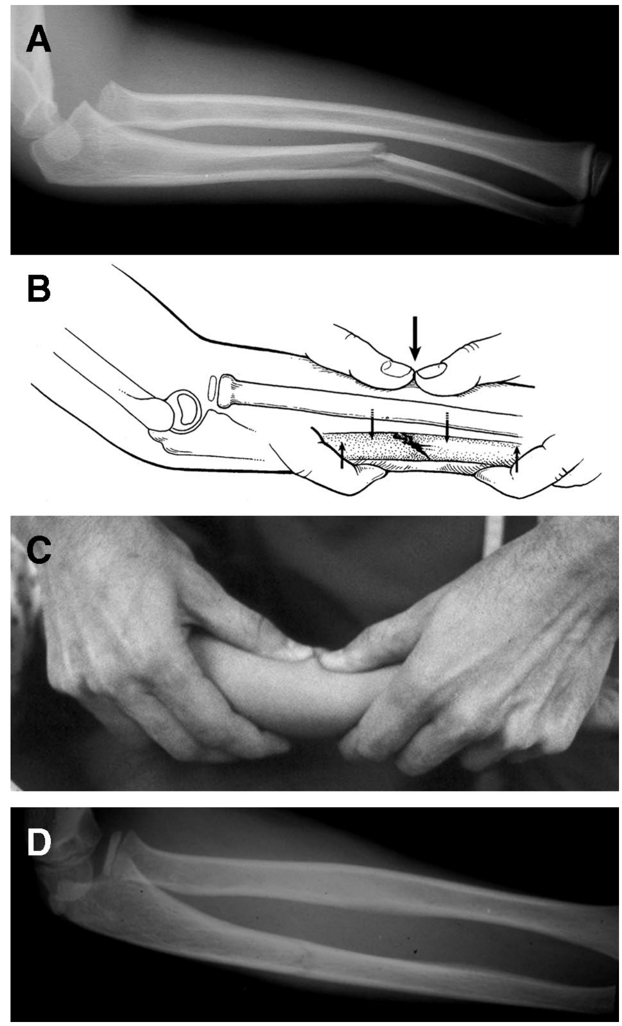


FIG. 26. Ulnar reduction. (**A**) Injury film of a 7 year old sustaining a type I Monteggia lesion with apex anterior greenstick fracture of the ulna. (**B**) Three-point pressure is applied over the apex of the ulna to correct the angulation (arrows). (**C**) Clinical picture demonstrating location of the pressure points to correct the angulation. (**D**) X-ray taken demonstrating reduction of the ulna. Notice that there is still dislocation of the radial head. (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:564.)

required to reverse the anterior angulation deformity (Fig. 26).

The second part of the procedure is the reduction of the radial head. Once the ulnar length and alignment have been reestablished, it is now possible to reduce the radial head. Usually, simply flexing the elbow achieves this (Fig. 27). A posteriorly directed force applied directly to the anterior surface of the radial head may be necessary to achieve the final reduction.

Immobilization techniques. Once achieved, the reduction needs to be maintained by preventing the secondary deformities. First, the forearm flexor muscles tend to bow the shaft of the ulna toward the radial shaft (Fig. 28A). This can be decreased by immobilizing the forearm with a Munster cast or sugar tong splint and applying a three-point mold over the shaft of the ulna. To best achieve the three-point molding, the forearm should be placed in neutral rotation (Fig. 28B).

Second, redislocation of the radial head can be minimized by placing the elbow in hyperflexion. This is best achieved by applying a "figure-of-eight" elbow flexion cast (Fig. 29). This "figure-of-eight" cast is removed in 3 weeks to allow the patient to resume elbow flexion and extension. The ulnar fracture needs to be further protected with a short arm cast for another 2 to 3 weeks.

The third deformity that often is seen in type I Mon-

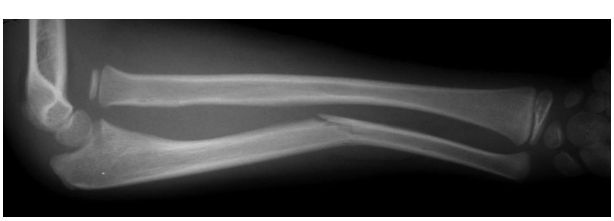
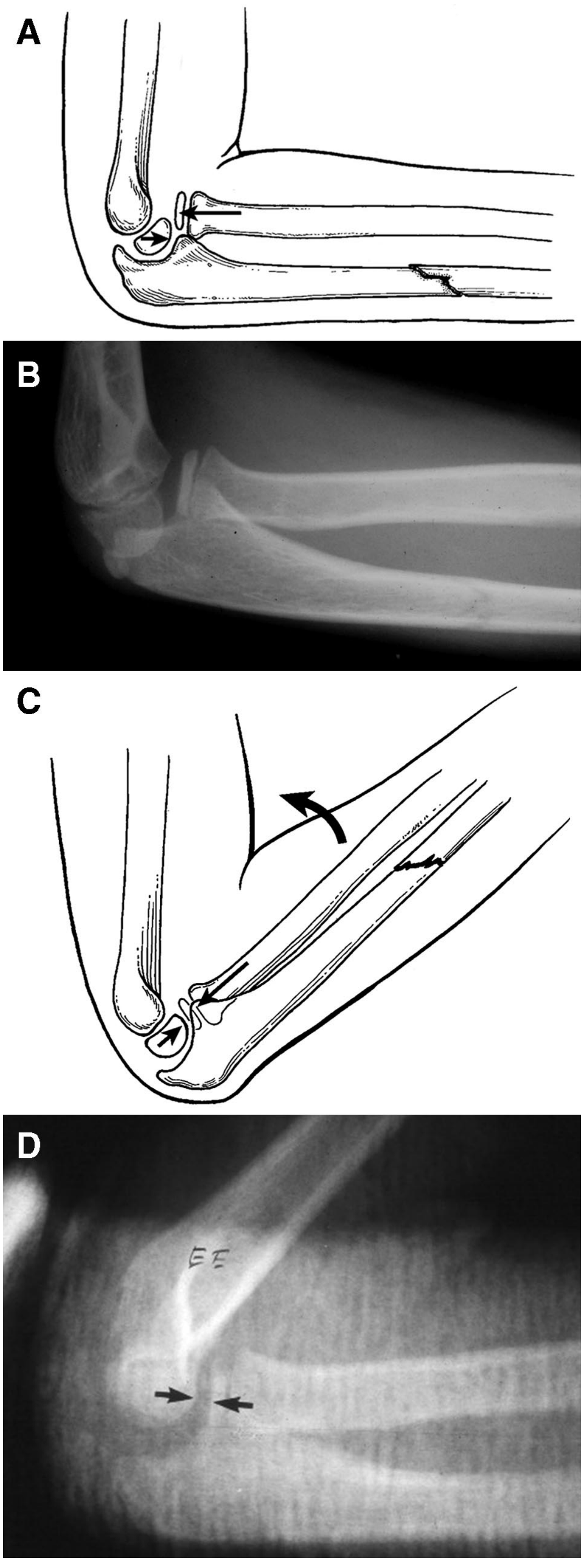


FIG. 25. Pathology of type I lesions. A characteristic lateral x-ray of a type I lesion demonstrating an oblique greenstick fracture of the midshaft of the ulna with apex anterior. This is also combined with an anterior dislocation of the radial head.



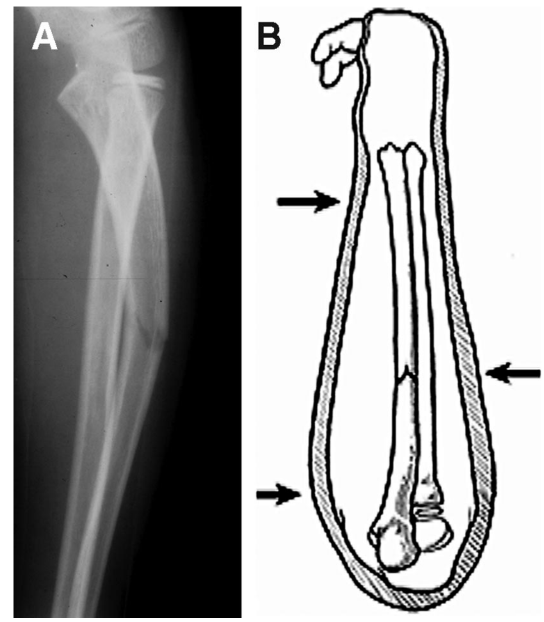


FIG. 28. Radial bow of the ulna. (**A**) X-ray demonstrating bowing of the ulna in a radial direction. This is felt to be the result of contracture of the forearm flexure muscles. (**B**) Splint applied demonstrating three-point molding to prevent this radial bowing of the ulna. Three-point pressure is applied proximally, distally, and then at the apex of the fracture site. (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:567.)

teggia fractures treated nonoperatively is a posterior angulation of the ulna. This cannot be well controlled with noninvasive methods. Although it may cause an unappealing posterior prominence of the proximal ulna, the deformity usually remodels enough to not affect the cosmetic appearance or function of the patient's forearm or elbow (Fig. 30).

Type II Monteggia lesion

The patterns of deformity in type II lesions consist of a posterior angulation of the proximal ulna or olecranon combined with a posterior dislocation of the radial head (Fig. 31A, B). In many patients in the pediatric age group, the fracture pattern may be a posterior angulated fracture of the radial neck instead of the dislocation of the radial head (Fig. 31C). Thus, the pediatric counterpart is actually a type II equivalent.

FIG. 27. Reduction of radial head. (**A**) Following the ulna, there is still lack of alignment of the proximal radius with the capitellum (arrows). (**B**) X-ray of a reduced ulna with persistent radial head dislocation. (**C**) Simply flexing the elbow to hyperflexion realigns the proximal radius with the capitellum (arrows). (**D**) X-ray demonstrating that the radial head is now reduced with hyperflexion of the elbow (arrows). (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:566.)

FIG. 29. Figure-of-eight cast. After reduction to maintain hyperextension, a figure-of-eight cast is applied. Notice that the cast is left open to expose the antecubital space. Also, the sling must be incorporated in the cast.

Mechanism. Because of the rarity of this lesion, there is very little data regarding the mechanism. Penrose, in his description of this lesion in older adults, felt that the injury occurred when the individual tried to break their fall with the elbow semiflexed.[25] In most children, this causes a posterior lateral dislocation of the elbow. On occasion, however, the olecranon will fail in flexion, producing the characteristic type II fracture dislocation lesion (Fig. 32).

Manipulative procedures. Again, with this fracture, the mechanism will need to be reversed. Because the mechanism is one of failure in *flexion* of the elbow, it must be *extended* to achieve a reduction. Like with type I injuries, the ulna must be reduced first. This is usually accomplished by bringing the elbow into full extension. When the elbow extends, the radial head usually reduces spontaneously (Fig. 33). If it is an equivalent lesion, the neck fracture usually reduces as well. Sometimes direct digital pressure on the proximal radius may be necessary to effect the final reduction.

Immobilization techniques. Because the elbow needs to be extended to effect the reduction, it must also be immobilized in extension to maintain the reduction (Fig. 34). There does not seem to be any effect of forearm rotation on the maintenance of the reduction. The fracture in the proximal metaphysis is in a rapid healing area. As a result, there is usually sufficient callus by 3 weeks

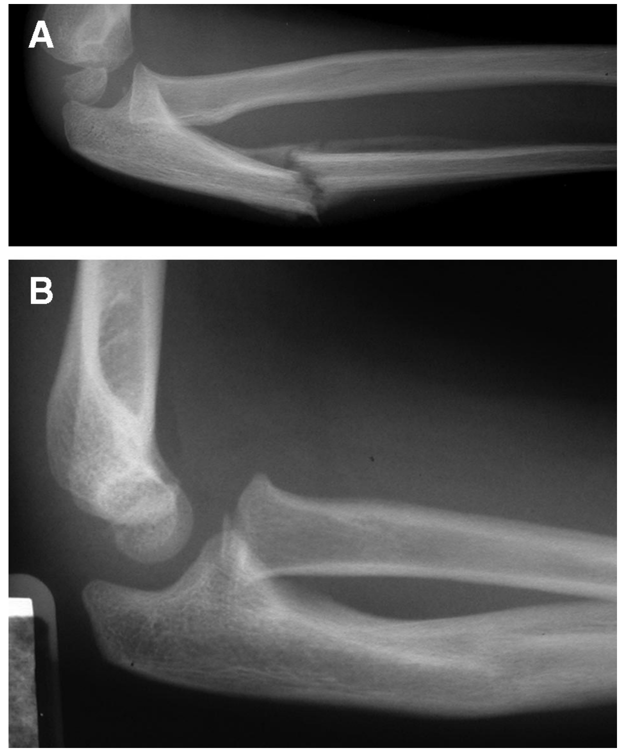


FIG. 30. Posterior ulnar bowing. (**A**) X-rays taken at 3 weeks postinjury demonstrate some angulation of the ulna caused by the pull of the triceps. (**B**) Remodeling at 6 months, the posterior prominence is almost completely remodeled. (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:565.)

to remove the cast to allow the patient to resume active motion.

Type III Monteggia lesion

Type III Monteggia lesions consist of a greenstick fracture of the olecranon or proximal ulna in which the apex of the deformity is directed laterally. The associated radial head is also dislocated laterally or anterolaterally (Fig. 35).

Mechanism. Wright[37] proposed that this fracture is produced when the supinated forearm becomes fixed on the ground. The weight of the body against the extended elbow forces it into varus. This causes the proximal ulna, which is locked in the olecranon fossa in the extended position, to fail as a greenstick fracture into varus. This same varus force also causes the radial head to dislocate laterally or anterolaterally.

Manipulative procedures. Because the forces producing this injury are directed in a *varus* direction, the deformity is corrected by forcing the extended elbow into *valgus*. The olecranon is reduced by locking it in its

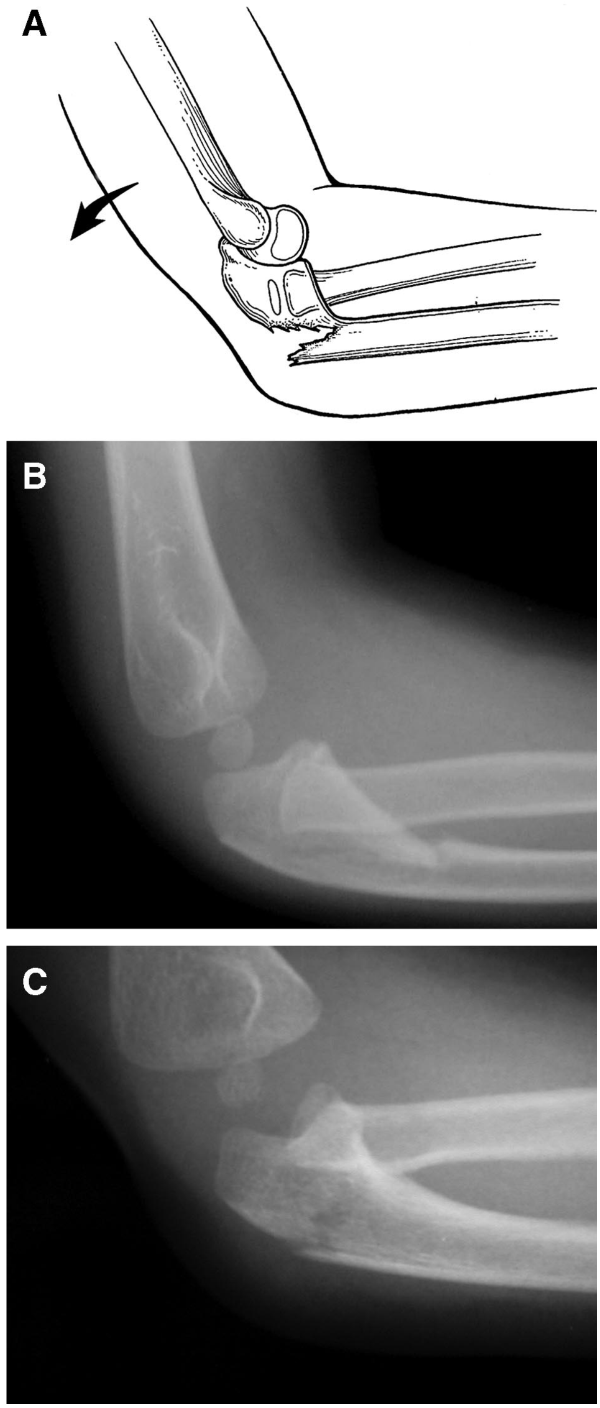


FIG. 31. Type II Monteggia lesion. (**A**) The posterior angulation of the fracture of the proximal ulna combined with the posterior dislocation of the radial head is typical of the type II lesion. (**B**) X-ray of a typical type II lesion seen in a 6 year old. The radius is dislocated posteriorly. (**C**) Type II equivalent demonstrating a posterior angulated fracture of the radial neck and a posterior greenstick fracture of the radial neck. (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:570.)

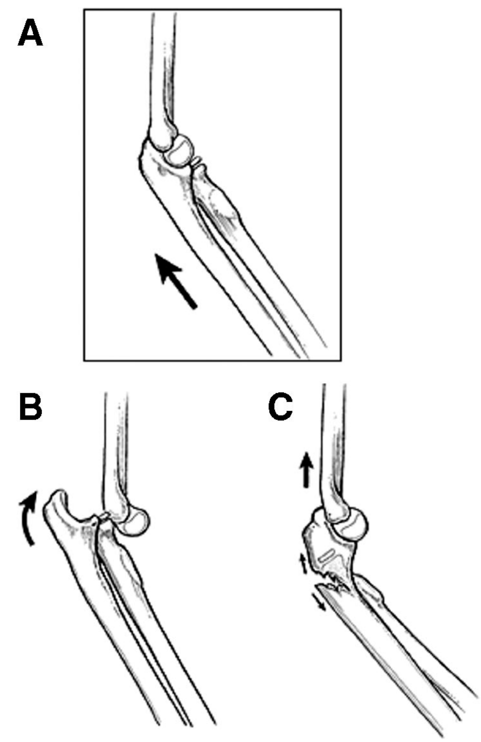


FIG. 32. Type II mechanism. (**A**) With the elbow flexed at approximately 60°, a force is applied longitudinally parallel to the shafts of the radius and ulna. (**B**) Most commonly, a posterior elbow dislocation results. (**C**) Occasionally, the integrity of the posterior cortex of the ulna is compromised producing a typical type II fracture dislocation. (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:570.)

respective fossa of the distal humerus by forcing the elbow first into full extension. When this is achieved, the forearm is forced into valgus to realign the proximal ulna. This maneuver usually reduces the radial head spontaneously. If not, direct digital pressure is applied to the lateral aspect of the proximal radius to effect the final reduction (Fig. 36).

Immobilization techniques. If a stable reduction is achieved, these fractures can be immobilized in a long arm cast with the elbow flexed at 90°. If the greenstick fracture of the ulna tends to redeform, it is often best to place the extremity in a long arm elbow extension cast with the forearm supinated. The molding of the cast in the supracondylar area and the incorporation of the thumb with the thenar eminence padding likewise needs to be incorporated in this elbow extension cast. There is usually sufficient callus and soft tissue healing after 3 weeks to permit the cast to be removed and allow the resumption of elbow and forearm motion.

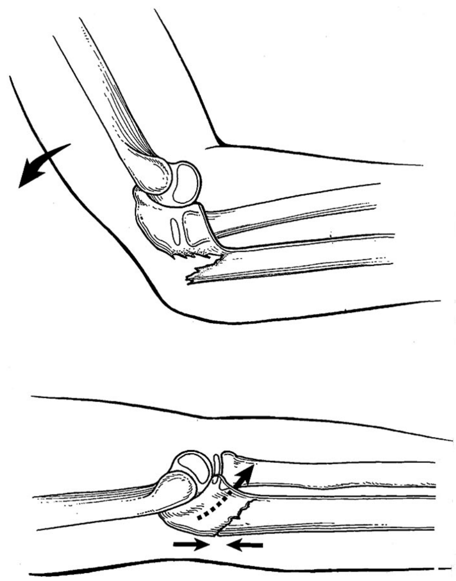


FIG. 33. Reduction of type II lesion. (**Top**) Characteristic of prereduction deformity. (**Bottom**) With extension of the elbow, the posterior gap of the ulna is closed (facing arrows). This also usually resolves in a spontaneous anterior displacement of the radial head to return it to its reduced position (curved arrow). (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:570.)

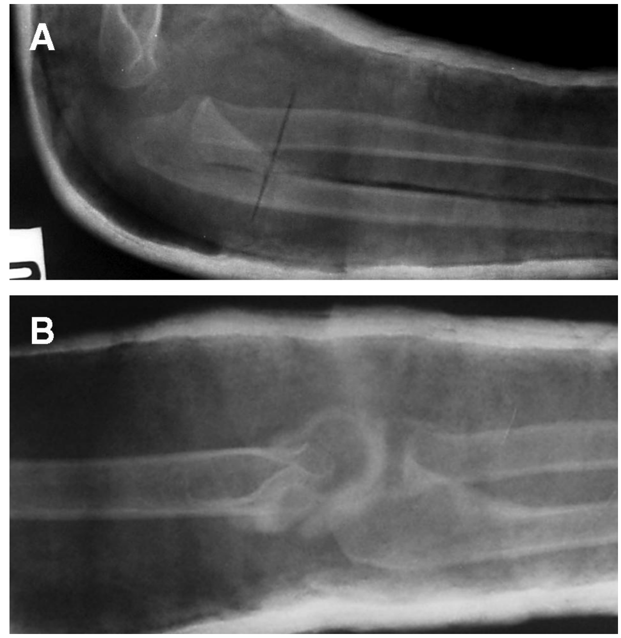


FIG. 34. (**A**) Typical true type II lesion placed in a long arm cast with the elbow at 90°. The radial head is still posteriorly displaced and still unreduced as is the posterior angulation of the ulna. (**B**) Realignment of the radial head and capitellum along with the proximal ulna was achieved by extending the elbow and placing it in a long arm elbow extension cast.

Type IV Monteggia lesions

Because a type IV lesion consists of fractures of both the radial and ulnar shafts along with a dislocation of the radial head, a floating elbow situation is produced. Often, it is very difficult both to obtain and maintain a reduction of both shafts and the radial head simultaneously. There is no intact lever arm for the radius to manipulate the head into position. This fracture pattern often requires repeated manipulations to achieve a satisfactory reduction. Closed reduction of both the radial head dislocation and shaft fractures may not be possible by closed methods.

It may be best to focus on getting the shaft fractures aligned and healed. The radial head dislocation often is not a significant disabling factor for normal activities. If there are good surgical facilities available in the local area and the radial head dislocation is significantly disabling, then late replacement of the radial head by surgical techniques consisting of either annular ligament reconstruction or ulnar osteotomy may be performed.

Fractures of the Olecranon

Flexion fractures of the olecranon present little opportunity to be treated nonoperatively because of the tension forces applied by the triceps. This tension usually causes considerable separation of the fracture fragments. Only the nondisplaced or minimally displaced flexion failure patterns can be adequately treated with a long arm extension cast. Those fractures that fail in extension or are the result of flexion shear forces can be treated in a long arm elbow hyperflexion cast. In these types, failure occurs anteriorly and the posterior periosteum remains intact. This intact posterior periosteum can serve as a natural tension band to secure the fragments that reduce in flexion.

Fractures of the Proximal Radius

The most common area involved in the proximal radius is the radial neck. These are usually metaphyseal fractures. The fracture pattern and displacement is usually dictated by the mechanism of injury. If it is the result of a valgus force applied to the extended elbow, the radial head usually angulates with some degree of translocation. If the fracture occurs during either dislocation or during the reduction of the elbow, the radial is usually completely displaced. Up to 30° of angulation does not require any manipulation. The key to what is acceptable is the degree of passive rotation of the forearm. At least 45° of supination and pronation will provide an acceptable functional result.

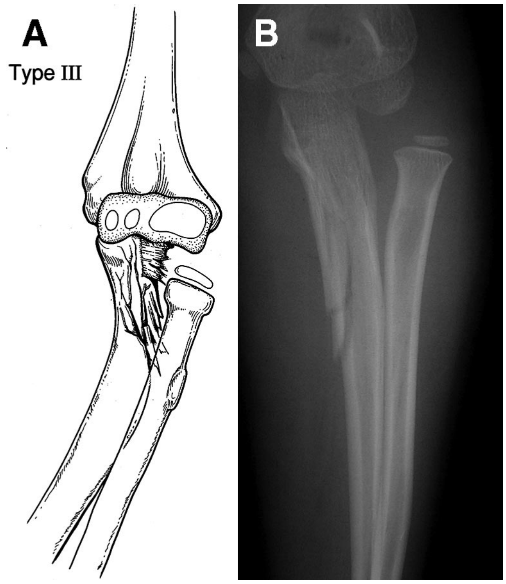


FIG. 35. Type III pathology. (**A**) Type III lesions characteristically have a greenstick fracture of the ulna and olecranon with apex radial bow. In addition, there is a lateral dislocation of the radial head. (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:553.) (**B**) Anterior–posterior x-ray demonstrating greenstick fracture of the proximal ulna and lateral dislocation of the radial head.

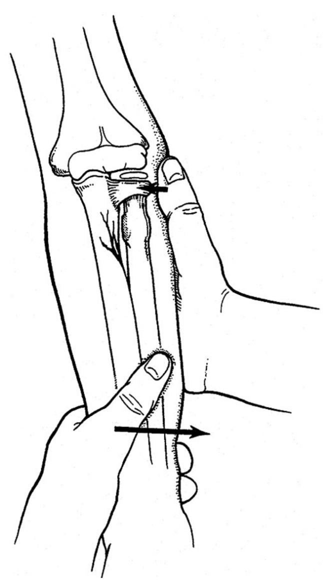


FIG. 36. Reduction of type III lesions. The fracture is reduced by applying a valgus force (long arrow) to the forearm with the elbow fixed in extension. In addition, medially directed pressure is placed over the radial head to complete its reduction (small arrow). (Reproduced with permission from: Monteggia fracture–dislocation in children. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:571.)

Manipulative procedures

Various manipulative techniques have been proposed. The standard has been the Patterson technique in which direct pressure is applied to the radial head.[24] In this author's experience, this has been only marginally successful. There is usually so much swelling over the proximal radius that it is very difficult to accurately palpate the radial head. Kaufman has proposed an alternative method to manipulate the forearm to obtain a reduction.[20] It involves forcing the forearm into full pronation with the elbow flexed. He also describes placing the thumb of the opposite hand directly over the radial head as the forearm is pronated (Fig. 37). There is some question as to whether this effects the reduction. It is the author's opinion that the forced pronation is the most effective part of this manipulative process. This author has also been able to effect a satisfactory reduction using this Israeli method with some completely displaced fractures (Fig. 38). This technique is not effective unless the forearm is fixed in supination, which usually is the case. No matter what the pattern or how severely displaced the fracture, manipulation of the forearm into pronation with the elbow flexed is a useful procedure. The surgeon may be surprised with the results.

If a reduction in which an anticipated satisfactory functional result cannot be achieved, then the feasibility of performing an open reduction will need to be explored.

Immobilization techniques

Once reduced, the fractures are usually stable. Because there is a tendency to lose pronation, a long arm cast with the elbow flexed to 90° and the forearm fully pronated is applied for 2 or, at most, 3 weeks.

Fractures of the Distal Humerus

Fractures of the distal humerus can be divided into intraarticular and extraarticular fractures.

Extraarticular fractures

The most common extraarticular fracture of the distal humerus is the supracondylar fracture. The medial epicondyle is also classified as an extraarticular fracture.

Supracondylar. Supracondylar fractures can occur in one of three types based on the stages of displacement.

Stage I: no displacement. These are fractures in which the displacement is in a satisfactory enough position so as not to require any manipulation. They are simply protected with a posterior splint or long arm cast for 2 or 3 weeks.

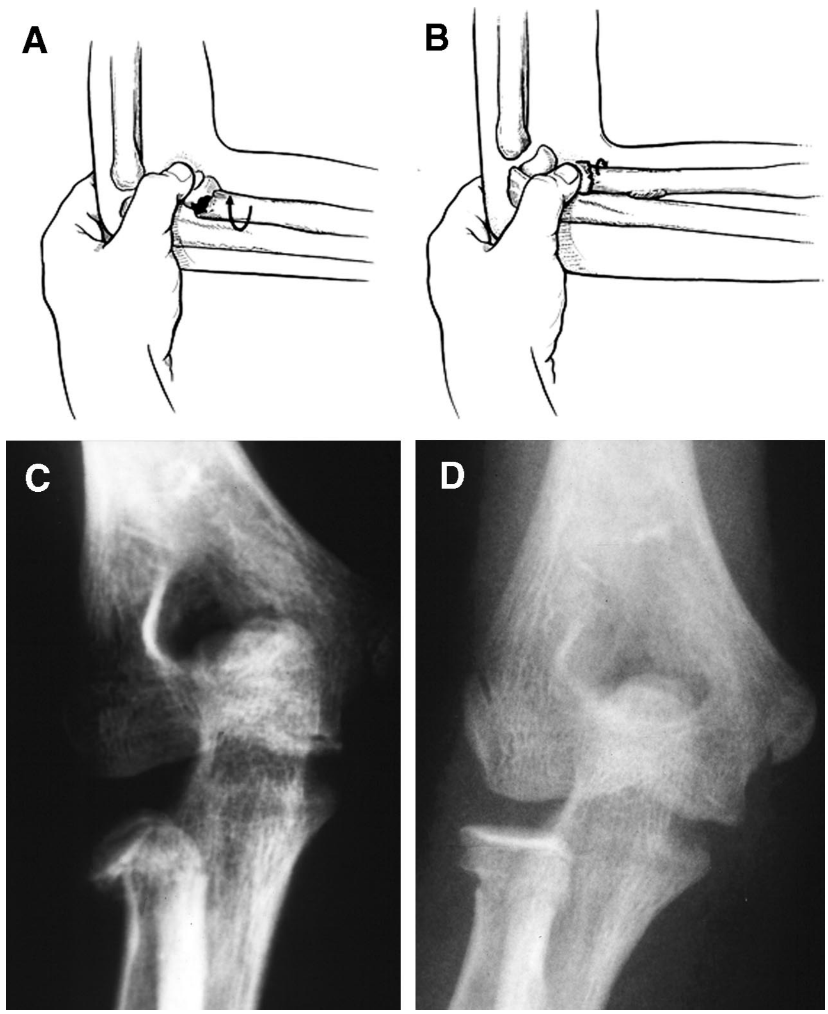


FIG. 37. Israeli flexion–pronation technique. (**A**) With the elbow at 90° of flexion, the thumb stabilizes the radial head. The forearm that has been fixed in a position of supination is then pronated to swing the proximal shaft up into alignment with the neck (arrow). (**B**) The final alignment is achieved by continuing to force the forearm into full pronation (arrows). (**C**) Injury film of a displaced radial neck fracture. The forearm is fixed in supination. (**D**) X-ray after the reduction with the Israeli flexion–pronation technique showing anatomic realignment of the radial head. (Reproduced with permission from: Fractures of the proximal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:606.)

Stage II: partial displacement**.** These are greenstick type fractures with only partial displacement. Fractures in this stage still have enough posterior cortical integrity so that there is some intrinsic stability to resist rotation when they are reduced. They do require manipulation to be aligned adequately.

Manipulative Procedures

Obtaining adequate anesthesia with other than peripheral techniques may present something of a problem. A Bier block combined with a hematoma block usually provides adequate local anesthesia. An axillary block may be better because it removes the obstruction to full flexion created by the tourniquet.

The key element in reducing type II fractures is to reestablish full flexion. Before flexing the elbow, any malalignment in the coronal plane needs to be corrected. Once full flexion is achieved, the elbow is the reextended to 90° to 110° of elbow flexion.

Immobilization Techniques

In treating supracondylar fractures in which there is an inability to stabilize them by surgical percutaneous pin fixation, the priority should be on safety rather than on securing an adequate reduction. The elbow should never be flexed up past 120°. If there is any concern about vascular compromise, then the elbow should be immobilized at 90° of flexion or less. Although it may be

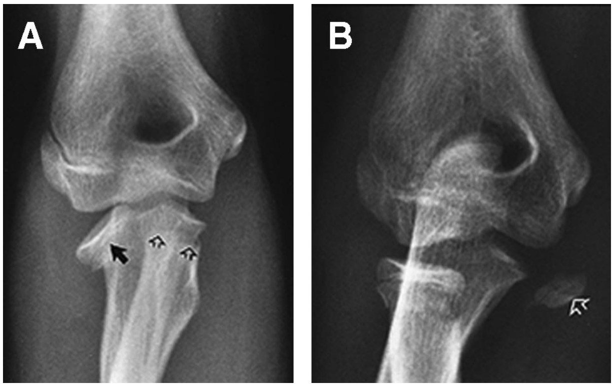


FIG. 38. Widely displaced fracture. (**A**) A 9-year-old girl sustained a widely displaced fracture of the neck with complete loss of reduction (black arrow). The fracture surface of the proximal radial has been displaced medially (open arrows). (**B**) Using the Israeli technique with this widely displaced fracture, a satisfactory reduction was achieved. There was a small fragment medially (arrow) from the neck of the metaphysis. This patient went on to recover with full forearm rotation. (Reproduced with permission from: Fractures of the proximal radius and ulna. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:607.)

cosmetically unappealing, for practical purposes, a cubitus varus deformity produces very little functional disability. The same is true for the inability to achieve full flexion.

Unfortunately, in areas with limited medical resources, the patients do not present acutely. They present with swollen elbows often covered with blisters. Because these fractures heal very rapidly, it may be difficult to even perform a manipulation of the fracture after approximately 1 a week. Even with completely displaced fractures, the outcome may be surprising after the fracture has fully healed[3,5] (Fig. 39). If surgery is to be performed with limited resources, it may be wiser to wait until the fracture has healed completely and perform a corrective osteotomy when the soft tissues have recovered from the initial trauma.

In areas where there are language barriers and lack of adequate follow up, it may be unwise to try to get a completely anatomic reduction. Safety and retention of forearm function is probably the initial priority in treating these fractures.

Stage III: completely displaced. Unfortunately, there are no totally satisfactory nonoperative methods of achieving a reduction of type III supracondylar fractures that are totally safe and effective. If hospital facilities are available, management with either Dunlops[11] or overhead olecranon pin traction may be the best method to treat this type of fracture. Because of the lack of imaging equipment in most areas of developing nations, the only

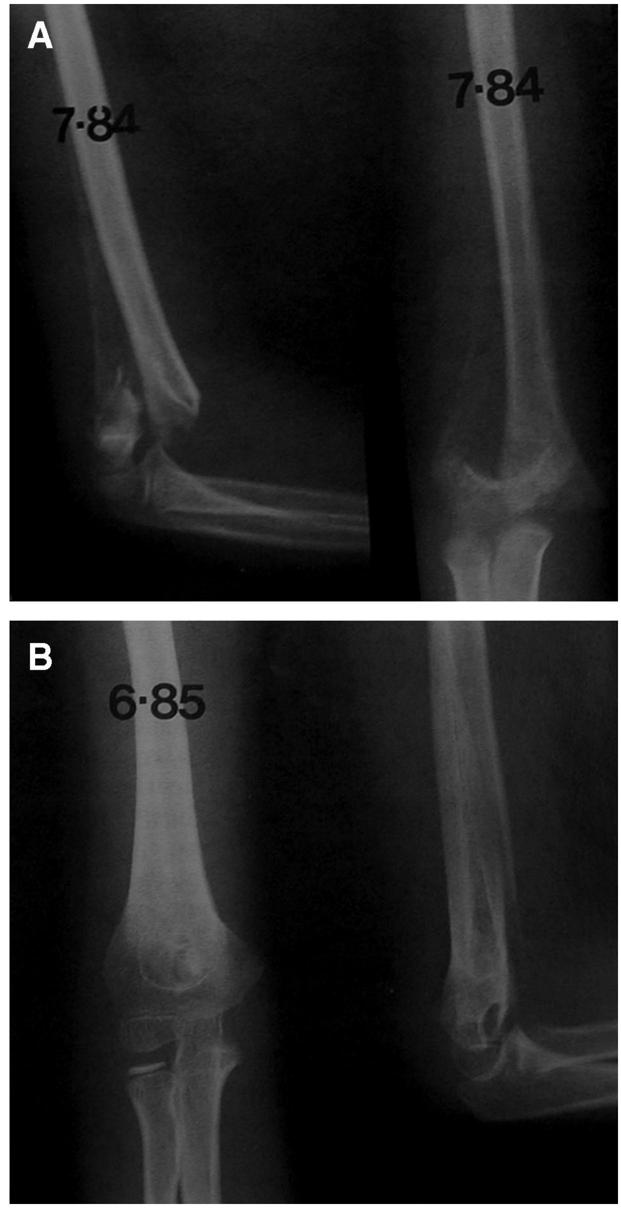


FIG. 39. Translocation remodeling. (**A**) Position at 3 weeks postfracture with 100% posterior translocation. The distal fragment is also 60% translocated laterally. (**B**) Eleven months later, the translocation has remodeled. There is still some loss of shaft, angle which clinically resulted in some loss of elbow flexion. (Reproduced with permission from: Supracondylar fractures of the distal humerus. In: Rockwood CA Jr, Wilkins KE, Beaty JH, eds. *Fractures in Children,* vol III, 4th ed. Philadelphia: Lippincott-Raven; 1996:721.)

way to achieve an adequate alignment is with an open reduction.

Immobilization Techniques

With an acutely swollen elbow, it may be best to try to achieve as good a clinical alignment as possible and

FIG. 40. Figure-of-eight cast. This old illustration taken from Blount's classic textbook on children's fractures demonstrates the typical collar and cuff technique of immobilization.

then immobilize it with the old collar and cuff technique (Fig. 40).

Medial epicondyle. The other less common extraarticular fracture is that of the medial epicondyle. Unless the fragment is incarcerated within the joint, these fractures can almost always be treated with nonoperative means. The major complication with this fracture is stiffness. Thus, active elbow motion needs to be initiated as soon as the pain and swelling permit.

Intraarticular fractures. Because these fractures involve the articular surface, less than an anatomic reduction may produce some joint incongruity and restriction of motion.

Lateral and medial condylar fractures. There is no satisfactory method of reducing and maintaining completely displaced intraarticular fractures. Patients with nonunion of these types of fractures may have an undesirable cosmetic result. There also may be the loss of stability and strength. Although there is also loss of stability of strength, the patient can perform most of the functions of activities of daily living (Fig. 41).

Manipulative procedures

It has been shown that placing the elbow in 120° of flexion and full pronation will enable the aponeurosis of the triceps to secure a reduction. This technique can be used to keep stage II lateral condyle fractures from displacing further.

Immobilization techniques

Here again, the simple collar and cuff technique can be used as a method of immobilization for the minimally displaced lateral condyle fractures. If stiffness is a problem, early motion should probably be encouraged.

T-condylar fractures. Often, these fracture fragments are displaced in many directions. An old technique popularized by Eastwood in England during the 1930s was called the "bag of bones" technique.[12] It involved simply placing the arm in a collar and cuff initially and with as much flexion as possible. With this technique, it is important that the elbow is left hanging free so as to enable the fracture fragments to settle into a more natural alignment. Some attempt at an initial reduction can be made. The effectiveness of this is questionable. Active motion should be started at approximately 7 to 10 days as the swelling subsides. Although this technique may result in some loss of motion, hopefully, a functional range would be achieved.

Fractures of the Humeral Shaft

Humeral shaft fractures can usually be treated adequately with nonoperative methods. Even moderate angulation may not produce any significant cosmetic deformity unless it is very distal.

Manipulative procedures

Most shaft fractures are allowed to hang at the side to facilitate simple gravity aligning the fragments into a satisfactory position. The one exception is in the very small child in whom the arm is short and is bowed into varus when strapped to the side of the chest. With the application of the immobilization device, some manipulation and molding can be achieved to correct most angular deformities.

Immobilization techniques

Various methods of immobilization of humeral shaft fractures have been used. The use of a hanging arm cast is probably not practical in countries where living conditions are primitive. A hanging arm cast usually requires the patient to sleep in a reclining chair for the first 10 to 14 days until there is some intrinsic stability. Very few houses in these countries have chairs suited to this activity. The coaptation splint a very simple and effective method of maintaining alignment of the humeral shaft fractures (Fig. 42). With this splint, the arm needs to hang with the force of gravity. Thus, the forearm needs to be supported with a simple collar and cuff, not a standard sling (Fig. 42C). These fractures usually heal quite rapidly, and depending on the age of the patient, the splint can be removed in 3 to 4 weeks. After this time, a simple sling will suffice.

FIG. 41. Lateral condyle nonunion. (**A**) Anterior–posterior and (**B**) lateral views of x-rays of a 10 year old who had had an injury to his elbow 3 years previously. This demonstrates a complete nonunion of the lateral condyle with some valgus angulation. Clinically, however, he had only minimal cubitus valgus on the (**C**) coronal plane. Functionally, he exhibited full flexion (**D**) and (**E**) extension. He was able to engage in all types of physical activity suitable for a child of his age.

Fractures of the Proximal Humerus

The remodeling potential in the proximal humerus is very great. There are two major types of fracture patterns: 1) those in which the fracture line traverses the metaphysis and 2) those in which the fracture line traverses the epiphysis.

Proximal metaphyseal fractures

The metaphyseal fractures do not angulate because the pectoralis major is attached to the proximal fragment. Thus, where these fractures are complete, they tend to lie in bayonet apposition (Fig. 43). Fortunately, these fractures will remodel sufficiently to allow resumption of a functional range of motion even in some young teenagers.

Manipulation and immobilization. Simple gravity is usually enough to allow these to drift into satisfactory bayonet apposition. The minimal shortening does not appear to be of any functional or cosmetic significance. Adequate immobilization can usually be accomplished with the simple collar and cuff technique.

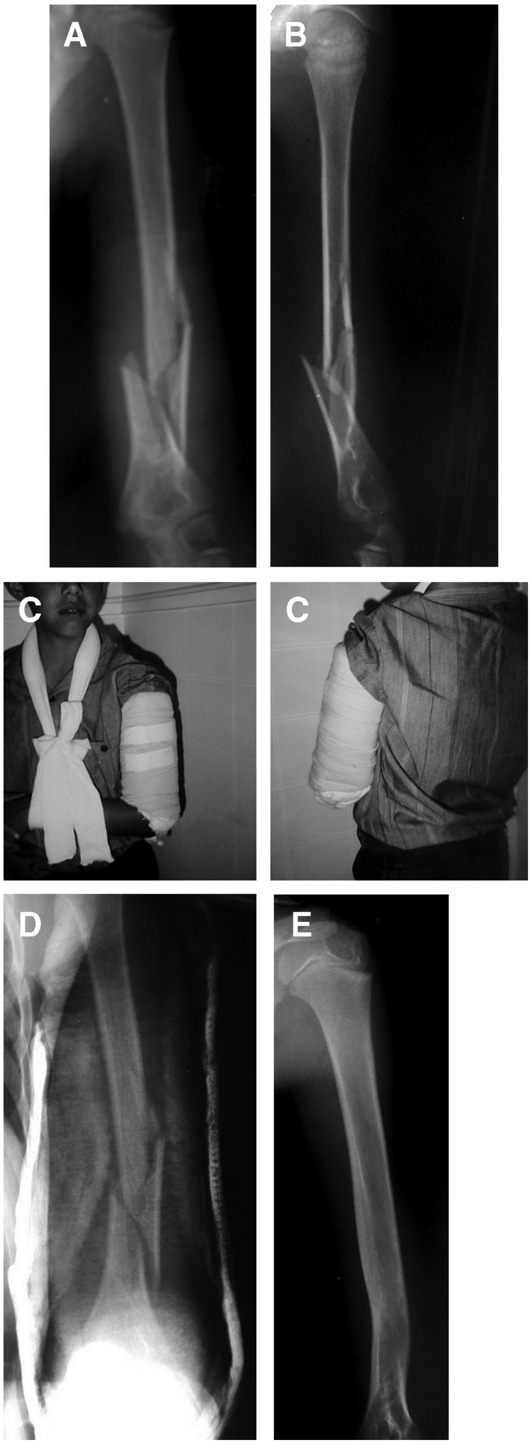


FIG. 42. Humeral shaft fracture. (**A** and **B**) Injury film showing comminution and slight valgus angulation of a distal humeral shaft fracture. (**C**) Lateral and (**D**) posterior–anterior views of a typical coaptation plaster splint supplemented with an elastic bandage. Notice that the forearm is suspended by a collar and cuff mechanism. (**E**) X-ray of the fracture in the coaptation splint demonstrating only slight varus angulation. (**F**) This patient demonstrated essentially full remodeling on the x-ray and also clinical recovery.

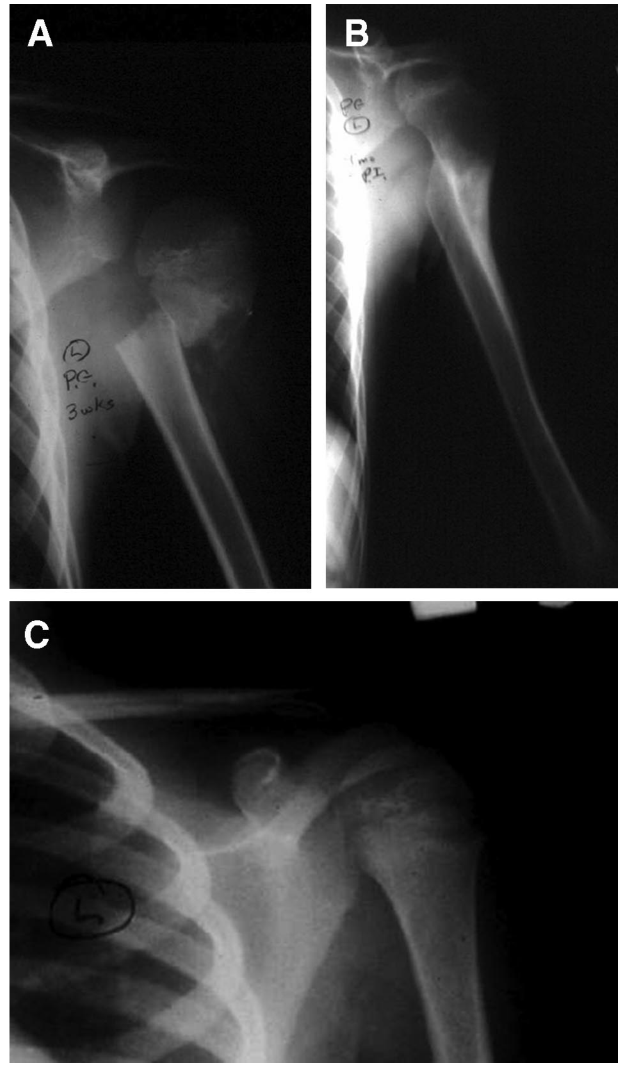


FIG. 43. Proximal humeral metaphyseal remodeling. (**A**) Injury film of an 8 year old demonstrating bayonet positioning of a proximal metaphyseal fracture. (**B**) Two months postinjury, remodeling has already begun. The patient had only very limited abduction at this time. (**C**) Two years postinjury, there has been complete remodeling of the proximal humerus with resumption of full shoulder motion.

Proximal physeal injuries

Because there are no opposing adduction forces (pectoralis major muscles) on the proximal fragment, the muscles of the rotator cuff tend to rotate the proximal fragment into external abduction and external rotation. Thus, in the initial injury films, the proximal fragment will be externally rotated and abducted.

Manipulative procedures. These fractures can usually be well reduced by abducting and externally rotating the distal fragment. Unless there is some internal fixation, this manipulation process can be futile because the

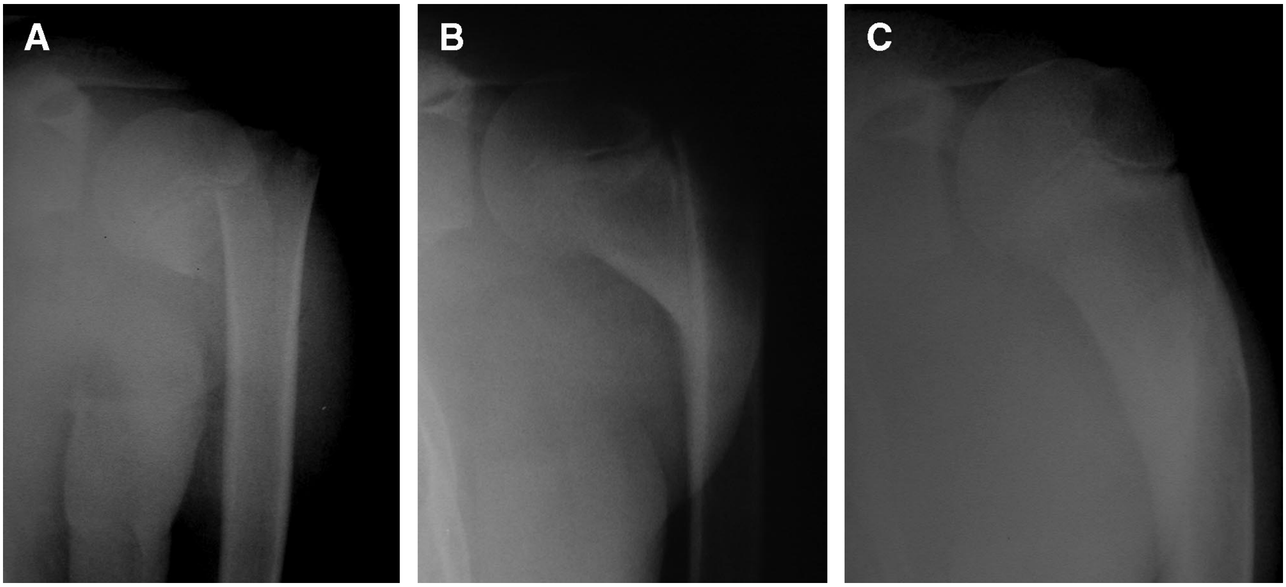


FIG. 44. Proximal humeral physeal remodeling. (**A**) Injury film showing the typical angulation of the epiphysis with the proximal humeral physeal injury in a 9 year old. (**B**) Three months later, the fracture has already begun extensive remodeling. (**C**) One year postinjury, the proximal humerus is almost fully remodeled with minimal angulation. Again, this patient had a full function range of motion of his shoulder joint.

fragments often tend to return to their original postfracture position. In some cases, the degree of deformity can be lessened by a simple manipulation.

Immobilization techniques. Again, the remodeling capacity in this area is quite good except for the patient who is very near to skeletal maturity (Fig. 44). These patients usually can be satisfactorily immobilized with a simple collar and cuff. The caretakers of the patient should be warned that it may take up to a year before a satisfactory range of shoulder motion has been reestablished.

SUMMARY

With the exception of fractures involving the distal humerus, almost all fractures of the upper extremity can be successfully treated by noninvasive methods. It must be emphasized, however, that the surgeon should try to achieve as adequate reduction as possible based on the resources of the local area or country. The surgeon treating upper extremity fractures in children in areas of developing nations where the medical and surgical resources are limited should have a good knowledge of the nonoperative techniques available. He or she should also be skilled in administering local and regional anesthesia. Fortunately, in the pediatric age group, there is a considerable remodeling potential. This fact helps when an anatomic reduction cannot be achieved or maintained. Knowledge of the limits of satisfactory remodeling for the various fracture patterns is also essential.

It must be emphasized, however, that the treating surgeon should both teach and perform procedures to achieve as satisfactory a reduction as possible within the resources of the local area. Every effort should be made to get as good a result as possible.

Many of the newer fracture textbooks focus on treatment of fractures by high technology methods. A surgeon who anticipates treating fractures in an area with limited resources should review the treatment methods described in some of the older textbooks.[6,9,27,33] Anyone treating fractures in these areas needs to be flexible with their approach and innovative in their methods. Although these fractures often present challenges for the treating physician, they can provide a great deal of satisfaction when they are conquered and the patient's fracture treatment has a successful outcome.

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