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Walter W. Huurman, MD* and Glen M. Ginsburg, MD†

IMPORTANT POINTS

1. **Compartment syndromes result from decreased vascular perfusion due to increased pressure in a closed osteofascial compartment.**
2. **Placement of ice packs is an important immediate therapy for soft-tissue injuries, but packs must be applied for at least 20 minutes.**
3. **More severe sprains require protection against another injury during healing.**
4. **Nursemaid's elbow is a common injury and can be treated safely by the pediatrician.**
5. **Supracondylar fractures commonly are associated with neurologic and vascular injury.**

Introduction

Over the past 2 decades, the number of musculoskeletal injuries sustained by children and adolescents has increased markedly. This may reflect an increasing use of motorized and high-speed wheeled vehicles among this population. Orthopedic injuries incurred while using all-terrain vehicles, inline skates, and skateboards that rarely were seen 20 years ago now are common. It is important to recognize the basic skeletal differences between children and adults; the common signs and symptoms of fractures, sprains, strains, and dislocations; and the initial treatment and stabilization of these injuries in children.

A reasonable understanding of the basic physiology involved in bone growth and development is required to identify and recognize appropriate treatment for fractures in the skeletally immature individual. The patient and parents should anticipate return to as normal function as could be expected given the circumstances of a particular injury.

Immature Skeletons

Bone is a dynamic organ that is ever-changing and, especially in the growing child, possesses tremendous healing characteristics. The skeleton is involved in up to 20% of childhood injuries, with 18% to 30% of these occurring directly to the growth mechanism. The unique features of this organ in the pediatric population distinguish it and the treatment of its problems due to trauma from those in the skeletally mature.

ANATOMY

The outer layer of young bone, periosteum, which is thick and flexible but strong (Fig. 1), often remains partially or entirely intact, despite disruption (fracture) of the remainder of the bone's structure. Encircling the underlying layer (cortex), the periosteum is richly vascularized and possesses bone-forming capabilities, which explains its major role in fracture healing. After skeletal maturity, both the thickness of the periosteal layer and its role in fracture healing decrease.

Under the periosteum, the hard lamellar shell or cortex defines the shape and strength of the bone. It increases in thickness during growth and becomes less plastic (bendable without breaking) and more resistant to stress. Normal adolescent bone is hard and strong. Although the concentration of bone formative cells (osteocytes) is lower within the substance of the cortical bone, they are present in lacunae (longitudinal bone-lined microcanals within the cortex), which are clustered in groups around small vascular passages running the length of the bone (a Haversian system). Concentration of both Haversian systems and cellular elements (osteoblasts and osteoclasts) is greater during growth and progressively decreases as part of the normal aging process.

The inner lining of the bone, the endosteum, plays a role in the formation of new bone during fracture healing. The innermost structural component, the medullary canal, is loosely honeycombed with thin-walled bony chambers, richly vascularized, and filled with marrow cellular elements. The honeycombed structure (cancellous bone) is structurally weak, but because of the abundance of cellular elements and vascular richness, its contribution to the fracture healing cascade occurs first and progresses most rapidly. The increased activity of the marrow in the pediatric age group is another factor in the healing potential of youth.

Regardless of the bone shape (long — the arm, forearm, thigh, or leg; cuboidal — the wrist, vertebrae, and hindfoot; or flat — the skull, pelvic bones, and scapula), the same basic structure is present, although the percent contribution of each element to the entire bone's composition varies.

Long bones in the immature skeleton are divided into four basic regions. The *diaphysis* is the elongated shaft composed of rather thick, variably mature lamellar bone covered with thick periosteum. Toward the end of the long bone, the shape begins to expand into the *metaphysis,* which has a spongy, honeycombed inner substance covered by thin laminar cortical bone. The *epiphyses* are the chondro-osseous ends of the bone, each containing a center that ossifies during growth and an outer articular portion covered with special cartilage. The *physis,* or growth plate, separates the epiphysis from the metaphysis. This is the anatomic area where chondrocytes, in response to the influence of growth hormone, account for the majority of longitudinal bone growth. Because of the relatively large ratio of cells to matrix in the physis, it is particularly vulnerable to fracture under tension or shear stress. The importance of physeal integrity to future

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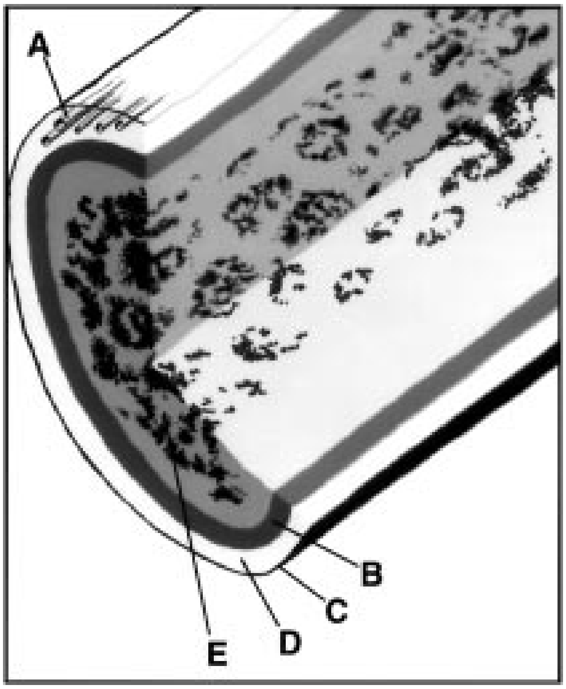

FIGURE 1. Cross-section of diaphyseal bone: A) Haversian canals, B) endosteal bone, C) periosteum, D) cortical bone, E) cancellous bone and marrow elements.

growth makes timely anatomic reduction imperative when dealing with fractures crossing this area.

FRACTURE PATTERNS

Children exhibit different fracture patterns from adults because of the varying amounts of cartilaginous anlage present in immature bone and the thick periosteum, which can aid or impede fracture reduction. Plastic deformation of bone is a common finding in pediatric trauma. The bone is bent beyond its elastic recoil potential, causing persistent bony deformity. This is seen commonly in the ulna and fibula (Fig. 2), with fracture of their paired bone (radius or tibia). Plastically deformed bone frequently must be straightened or broken to effect reduction. Torus or buckle fractures occur in metaphyseal bone of children when the bone fails circumferentially in compression without periosteal rupture. These fractures are most common in the distal radius, are stable, and require only 4 to 6 weeks of immobilization. Greenstick fractures are incomplete fractures of diaphyseal or metaphyseal bone in which an intact bridge of cortex and periosteum on the compression (concave) side of the deformity remains. The residual intact bone frequently deforms plastically, requiring completion of the fracture to achieve reduction.

FRACTURE HEALING

The severity of anatomic disruption at the time of initial trauma depends on the type and magnitude of energy (force) delivered to the bone, the strength of the bone, and the mass of its soft-tissue envelope (the "cushioning" effect of the surrounding muscles). Because of its flexibility, the periosteum remains intact while the cortical bone sustains a disruption of continuity (fracture). The cancellous bone of the marrow canal fractures easily if the surrounding cortex is broken. Vessels of the marrow canal and the cortex as well as a variable number of periosteal vessels are torn and pour blood into the surrounding soft-tissue spaces, forming a hematoma. The injured bony elements may separate (displacement), angulate (deformity), overlap (overriding, shortening), or puncture soft tissue, including skin (open fracture). Associated soft-tissue injury may involve muscle, ligament, tendon, nerve, or vessel with extremity trauma; the spinal cord may be compromised with injury to the head/neck or trunk/pelvis.

Healing begins as soon as bleeding stops from pressure confinement or natural clotting. The environment in the pediatric population (blood supply, abundant cellularity) is extremely conducive to prompt healing, and treatment should enhance this natural process. Factors that disrupt the natural healing cascade, such as loss of hematoma and its cellular elements in an open fracture, involvement of the fracture in an infectious process, loss of blood supply to the bone due to massive soft-tissue injury, and unfavorable metabolic factors accompanying massive trauma or chronic disease states, may affect the treatment and end result negatively.

SOFT TISSUE (MUSCLE, TENDON, LIGAMENT) AND JOINT INJURY

Strains are muscular injuries caused by excessive stretching that result in pain and swelling of that muscle. Sprains are caused by overstretch and partial tearing of a ligament. Subluxation is an incomplete separation of a joint in which there still is partial contact between each bone's articular cartilage. Dislocation is a complete separation in which all contact is lost between articular surfaces.

TREATMENT OF SOFT-TISSUE INJURY

The majority of sprains and strains in children heal promptly with minimal-to-moderate immobilization. These injuries usually are incomplete and generally heal with rest, ice, compression, and elevation (RICE). Return to function may progress as tolerated, but rigorous physical activity should be avoided for 3 weeks. Adults suffer more soft-tissue injuries and traumatic joint dislocations than do children, who suffer more contusions (bruises). Structural failure occurs more frequently near the osteoligamentous junction, usually through the adjacent physis because of the decreased tensile strength of the growth plate.

GROWTH PLATE INJURY

Physeal injuries are the domain of the skeletally immature because they involve the open (functioning) growth plate. In 1963, Salter and Harris devised the most widely used classification scheme (numbered I through V) for physeal injuries. Salter-Harris (SH) type I fractures (Fig. 3) pass completely and only through the physis; the epiphysis and metaphysis are not involved. Because this fracture is entirely through the cartilaginous plate, it may be invisible on radiographs unless the fragments are displaced. Pain over the region of the physis

FIGURE 2. Fracture of proximal tibia and plastic deformity of fibula in a 6-year-old girl. A) Anteroposterier radiograph, B) Lateral radiograph. C) The tibial fracture was irreducible until the plastic deformity was corrected by using significant force under general anesthesia.

and swelling may be the only clues to its presence. Fortunately, an adverse effect on growth is unlikely.

The SH II fracture line (Fig. 4) includes the growth plate and a corner of the adjacent metaphysis, but not the epiphysis. These are the most common physeal fractures and, like SH I, possess a substantial potential for remodeling.

SH III fractures (Fig. 5) involve a portion of the epiphysis and physis, but not the metaphysis. By definition, this is an intra-articular fracture (extends into the joint) and requires anatomic reduction (often surgical) to restore joint anatomy and to decrease the potential for partial growth interruption.

SH IV fractures (Fig. 6) involve both the epiphysis and metaphysis, crossing the physis. If anatomic reduction is not achieved, the fracture will result in joint incongruity and/or partial growth arrest with progressive angular deformity.

SH V fractures (Fig. 7) are crush injuries to the growth plate. Often these are not diagnosed at presentation; they are mistaken for a sprain or undisplaced SH I fracture. The incidence of growth arrest associ-ated with SH V fractures is high. Although strictly speaking not a fracture, direct damage to the outer perichondrial ring of the growth plate as, for example, in a lawnmower injury, can disturb growth and occasionally

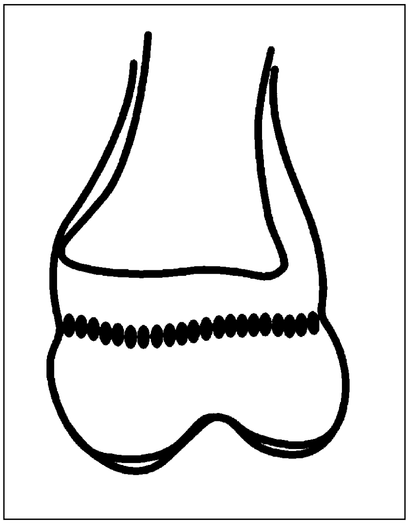

FIGURE 3. Salter-Harris type I fracture along the growth plate.

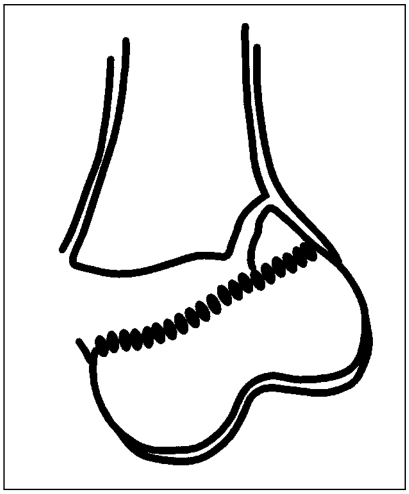

FIGURE 4. Salter-Harris type II fracture along the growth plate and into the metaphysis.

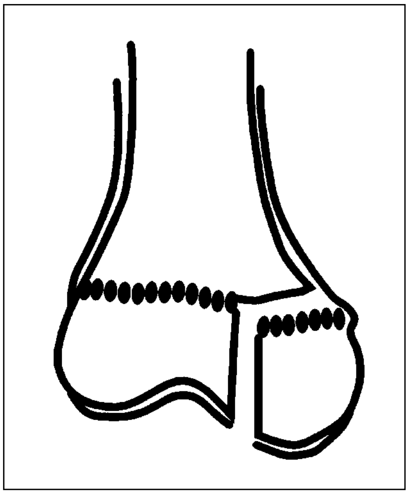

FIGURE 5. Salter-Harris type III fracture crossing the growth plate and epiphysis.

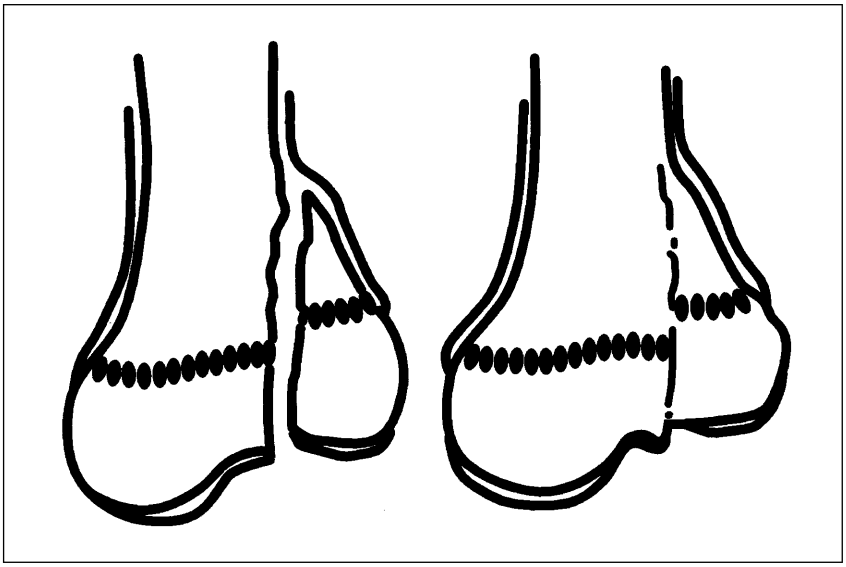

FIGURE 6. Salter-Harris type IV fracture crossing through metaphysis, physis, and epiphysis (left). Malunion with growth arrest and irregularity of articular surface (right).

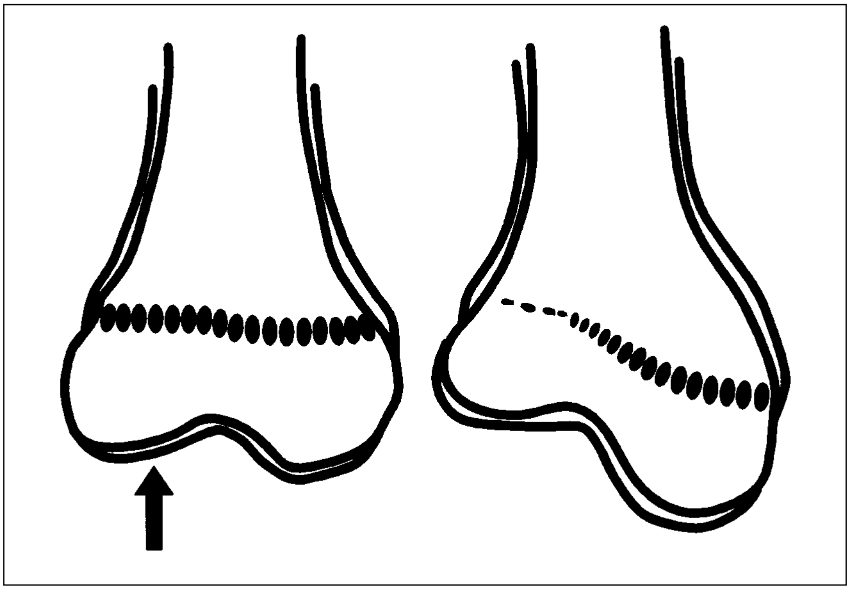

FIGURE 7. Salter-Harris type V fracture with crush of physis (left). Resulting growth arrest and progressive angular deformity (right).

is included in the growth plate classification systems.

Fractures of the Upper Extremities

CLAVICLE

The clavicle functions as a strut to keep the shoulder a constant distance from the sternum. It grows from physes on either end and is divided medial to lateral into proximal, mid-shaft, and distal regions. Complete mid-shaft fractures are rare, but because injuries in this region are caused by compression (falling on the tip of the shoulder), clavicular diaphyses are susceptible to plastic or greenstick deformity. Clavicular fractures occur in 3% of live births during obstetric delivery, although the majority are occult, of no consequence, and require no treatment. However, 5% of obstetric clavicular fractures are accompanied by brachial plexus injury.

The signs and symptoms of a mid-clavicular fracture include pain, deformity, and regional swelling; the medial fragment usually is elevated by the sternocleidomastoid muscle. Displaced mid-shaft fractures are seen easily on radiography, but plastic deformation may require a radiograph of the contralateral side for confirmation. Mid-one third congenital pseudoarthrosis of the clavicle may mimic a fracture, although the ends of a pseudoarthrosis usually are rounded and the condition is painless. Treatment of mid-shaft clavicular fractures by partial immobilization in a figure eight or Velpeau splint is adequate for small children, and older children are relatively comfortable in a sling. The toddler should be immobilized for 7 to 10 days, the young child for 2 to 3 weeks, and the older child for 3 to 4 weeks. The usual mechanism of outer one third clavicle diaphyseal fracture is a direct blow to the lateral aspect of the shoulder. Careful radiographic review usually shows the distal epiphysis and metaphyses to be in their anatomic positions, with the shaft of the clavicle elevated abnormally. Treatment with a sling for 2 to 3 weeks allows full remodeling because of the intact periosteal tube. Nonunion of clavicular fractures is extraordinarily rare.

Childhood distal clavicle fractures are common. Injuries that cause an acromioclavicular (shoulder) separation in adults usually result in distal clavicular physeal injury in a child. The distal epiphysis of a child's clavicle is attached firmly to the acromion by the strong acromioclavicular ligaments, and the distal clavicular metaphysis is anchored to the coracoid process by the coracoclavicular ligament. A blow to the acromion will cause the clavicular periosteum to tear longitudinally. Laterally the acromioclavicular ligament remains attached to the epiphysis, and a bit more medially the coracoclavicular ligament is attached to the distal metaphyseal periosteum. The bony metaphysis separates from the cartilageous epiphysis through the growth plate and rides upward through the periosteal tear. This injury must be differentiated from a true acromioclavicular separation to avoid inappropriate overtreatment and iatrogenic injury. A true acromioclavicular separation may occur in older teenagers; the mechanism does not differ from that of a distal clavicle fracture. Following a downward blow on the lateral shoulder, the joint separation can range from partial to a full traumatic dislocation. Treatment of mild injuries in which the ligaments are intact includes a sling or figure eight bandage for 2 to 3 weeks. Complete separations may require closed or open reduction to free an entrapped distal clavicle from the trapezius muscle.

SHOULDER DISLOCATION

True shoulder (glenohumeral) dislocations, like acromioclavicular separations, are very infrequent in children and adolescents. The glenohumeral joint is stabilized by its strong capsule and the glenohumeral ligaments. Although trauma accounts for a majority of shoulder dislocations, congenital or volitional dislocation due to inherent ligamentous laxity does occur. Trauma is the usual cause of an anterior dislocation, while posterior dislocations are more likely due to anatomic instability or epileptic seizure.

The patient who has an acute traumatic dislocation will exhibit significant shoulder pain and pseudoparalysis (unwillingness to move the extremity). With anterior dislocation, the arm is held externally rotated and slightly abducted. Posterior dislocation is more difficult to diagnose; the arm is held in internal rotation and adduction and the coracoid process is prominent.

A thorough neurovascular examination is essential because brachial plexus and vascular injuries have been documented with shoulder dislocation. Three radiographic projections of the shoulder are helpful in documenting a glenohumeral dislocation: anteroposterior, lateral, and axillary or scapular lateral views.

Manipulative reduction can be performed in an appropriate setting with sedation, narcotic analgesia, and muscle relaxants, usually by an orthopedist. After reduction, the neurovascular status should be rechecked. For an anterior dislocation, the arm is placed in a sling for 3 to 4 weeks, followed by pendulum exercises for an additional 3 weeks. Motion in abduction and forward flexion may be allowed after 6 weeks. Following reduction of a posterior dislocation, the shoulder should be maintained in slight external rotation by a shoulder spica cast. Unfortunately, the recurrence rate of this rare injury in children 1 to 10 years of age may be as high as 100%; for those 11 to 20 years of age, the recurrence rate may be 0%.

HUMERAL FRACTURES

The proximal humeral physis provides 80% of the longitudinal growth of this long bone. Fractures in this area account for fewer than 1% of all pediatric fractures. In children younger than 5 years of age, these are usually physeal injuries and SH I fractures. Metaphyseal involvement is more common between the ages of 5 and 11 years, usually resulting in SH II fractures. In each case, the mechanism is a fall on the outstretched arm with the shoulder extended and the arm externally rotated.

The proximal arm is commonly swollen and tender. Findings on radiography of a SH I fracture may be inconclusive, especially in infants. The proximal humerus is a common location for benign tumors such as simple bone cysts, fibrous cortical deficits, and eosinophilic granuloma, and a fracture through these may mask the underlying pathology.

Because of their tremendous remodeling potential, treatment for most proximal humeral fractures in children and adolescents is nonoperative, using a sling that keeps the arm comfortably at the side. In children younger than 5 years of age, some degree of fragment apposition and up to 70 degrees of angulation is considered acceptable. In older children, less angular deformity and translation are tolerated. The best possible readily attainable reduction should be acquired initially, although loss of reduction does not mandate surgical intervention or remanipulation.

Humeral shaft injuries represent approximately 2% of all pediatric fractures. Twisting injuries to the humerus produce spiral-type fractures, and child abuse is a common cause of such injuries in infants and toddlers. In older children, direct trauma is the most common mechanism, and the fracture is more commonly transverse than spiral.

In neonates, the shaft fracture only needs to be immobilized against the side of the body for 10 to 14 days with a soft bandage or stockinette "T shirt" (Fig. 8). In infants younger than 3 years of age, the same type of immobilization for 3 weeks allows satisfactory healing. Children 3 to 12 years of age can be treated with a more formal Velpeau sling and/or coaptation splint. If the fracture is displaced significantly, a light hanging cast will control shortening and angulation, although the child must sleep in a semi-upright position for the first 2 to 3 weeks after injury. Fractures normally heal within 4 to 6 weeks, and angular or rotational deformity is rarely a functional problem because of the tremendous range of normal glenohumeral motion. Radial nerve and brachial artery injuries that involve tethering of these structures by soft tissue and stretching at the time of injury on rare occasion accompany distal humeral shaft fractures. Therefore, the neurovascular status must be assessed both initially and after reduction.

Fractures of the distal humerus are much more common in children than in adults, with the majority occurring in the first decade of life. Diagnosis often is difficult because this area ossifies slowly. The distal humerus is entirely cartilaginous until the appearance of the capitellar ossification center late in the first year of life. The medial epicondylar ossification center appears next, but not until 5 to 9 years of age, depending on gender (females earlier). The lateral trochlear ossification center becomes evident between 7 and 13 years of age, often as multiple centers that ultimately coalesce. These can be mistaken for ostechondrotic lesions or fracture, requiring a comparison view of the uninjured elbow to clarify findings. Last to appear radiographically is the lateral epicondylar ossification center between 8 and 13 years of age.

Transphyseal (transcondylar) fractures are SH I or II fractures (Fig. 9) of the distal humeral physis. These occur in the infant or young child and often are misdiagnosed as elbow dislocations. If the distal

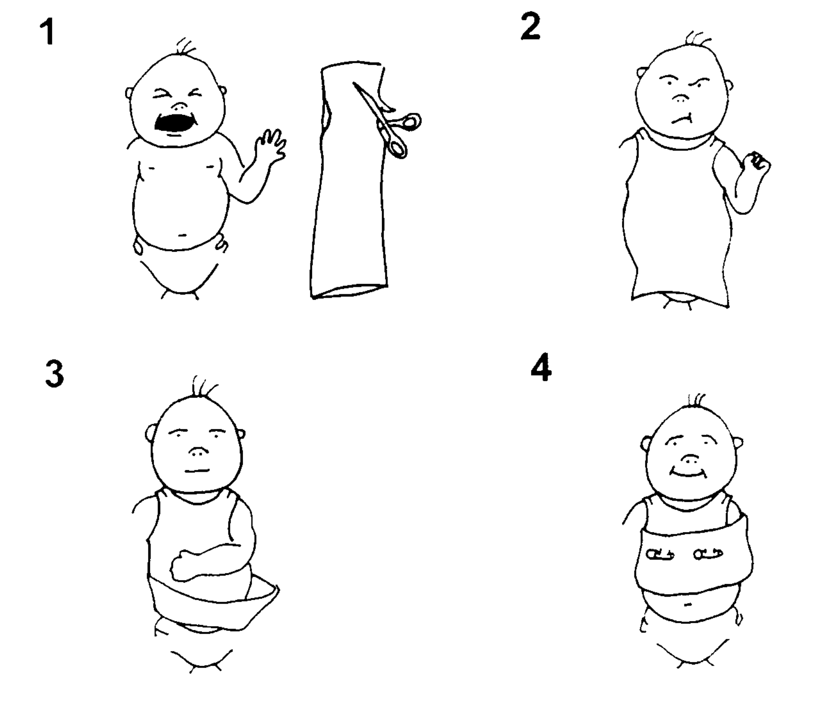

FIGURE 8. "Stockinette T shirt" method of immobilizing upper extremity in an infant and toddler. An appropriate length of 4-in stockinette has arm holes cut (1) and is placed on the patient as a T shirt (2). The injured extremity is placed across the abdomen, and the lower edge of the stockinette is turned up (3) and pinned front and back (4).

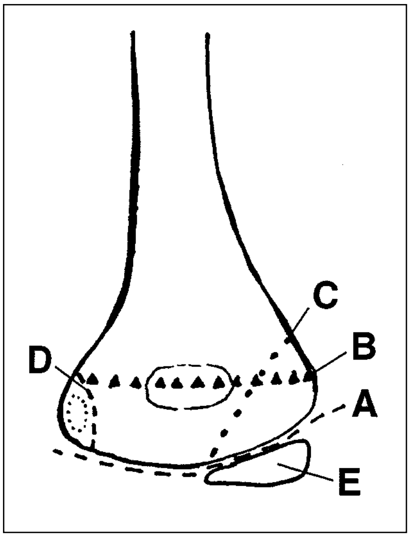

FIGURE 9. Distal humerus fracture patterns. A) Transphyseal fracture, B) supracondylar fracture, C) lateral condyle fracture, D) medial epicondyle fracture, and E) capitellar ossification center.

humerus is entirely cartilaginous, arthrography may be required to clarify the nature of injury. Usually these fractures can be reduced by manipulation and splinted in flexion and pronation for 3 to 4 weeks. For the infrequent case of instability, percutaneous pinning may be necessary.

Supracondylar humeral fractures (Fig. 9) comprise 60% of elbow fractures in children. Accurate diagnosis and initial immobilization is imperative because there is a high incidence of associated neurovascular injury. Initial triage should include a documented, thorough assessment of the neurovascular status and search for open wounds. Anteroposterior, lateral, and oblique radiographs of the elbow are sufficient to make the diagnosis. Immobilization for transport in a long medial and lateral splint without any attempt at reduction is essential after initial triage. The neurologic and vascular status of the arm should be reassessed after applying the splint; neurologic injury occurs in up to 8% of supracondylar humeral fractures, with the radial, median, and ulnar nerves affected almost equally. Vascular injuries are less common, but their sequelae can be disastrous. The vascular status of the hand must be assessed accurately at each stage of treatment. If the circulation is compromised and the limb threatened, urgent reduction and stabilization of the fracture by a trained orthopedist is required.

Lateral condyle fractures (Fig. 9) comprise about 20% of distal humeral injuries. Because of a high potential for nonunion, early recognition is essential. They are classified as SH IV fractures involving the lateral metaphysis, capitellum, and varying amounts of the trochlea. This fracture is caused either by compression of the lateral joint in valgus or varus distraction with avulsion of the lateral condylar fragment. Undisplaced lateral condyle fractures can be treated in a medial/lateral long arm splint that extends onto the hand with the elbow at 90 degrees of flexion and either neutral forearm rotation or supination. If displacement of the articular surfaces is greater than 2 mm, anatomic reduction (often surgical) is required.

Fracture of the medial epicondyle (Fig. 9) accounts for 5% to 10% of injuries in this region. A valgus stress to the elbow avulses the epicondyle by pulling on the ulnar collateral ligament and flexor muscle origin. The injury frequently is associated with elbow dislocation; the medial epicondylar fragment may be displaced entirely into the joint, which is an indication for closed manipulation and/or open reduction.

Elbow dislocations are relatively common in children younger than age 10 years and are accompanied by injury to the medial epicondyle, the coronoid process of the ulna, or the radial head. Neurologic injury, especially ulnar nerve palsies, may be associated, so thorough neurologic assessment before and after reduction is required. If reduction is delayed, general anesthesia may be necessary. Early protected motion is encouraged to prevent elbow stiffness. As in the vast majority of elbow injuries, physical therapy should not be employed to regain lost motion. Passive stretching and therapeutic modalities will cause more stiffness. The motion will return with normal childhood activity.

Radial head subluxation, better known as "nursemaid's elbow," usually occurs in children younger than 6 years of age. A history of vigorous pull on the arm by a caretaker is common. Longitudinal traction on the arm with the elbow extended and the forearm pronated pulls the radial head away from the capitellum (Fig. 9), and subsequent relaxation of the deforming force leaves the proximal portion of the annular ligament (which surrounds the radial neck) trapped between the radial head and the capitellum. The child usually holds the arm pronated and partially flexed, refusing to move it voluntarily. Radiographs appear normal.

Reduction may be accomplished by flexion of the elbow to 90 degrees followed by full passive pronation and then supination, with the examiner's free thumb placed over the radial head (Fig. 10). A click usually can be felt as the annular ligament slides over the radial head to its normal position around the neck. Although the maneuver is initially painful, discomfort resolves quickly and the child will begin using the arm voluntarily; immobilization generally is not necessary. If the maneuver does not resolve symptoms promptly, radiographs of the entire extremity should be obtained before any attempt at remanipulation. It is terribly embarrassing to discover an occult fracture of the

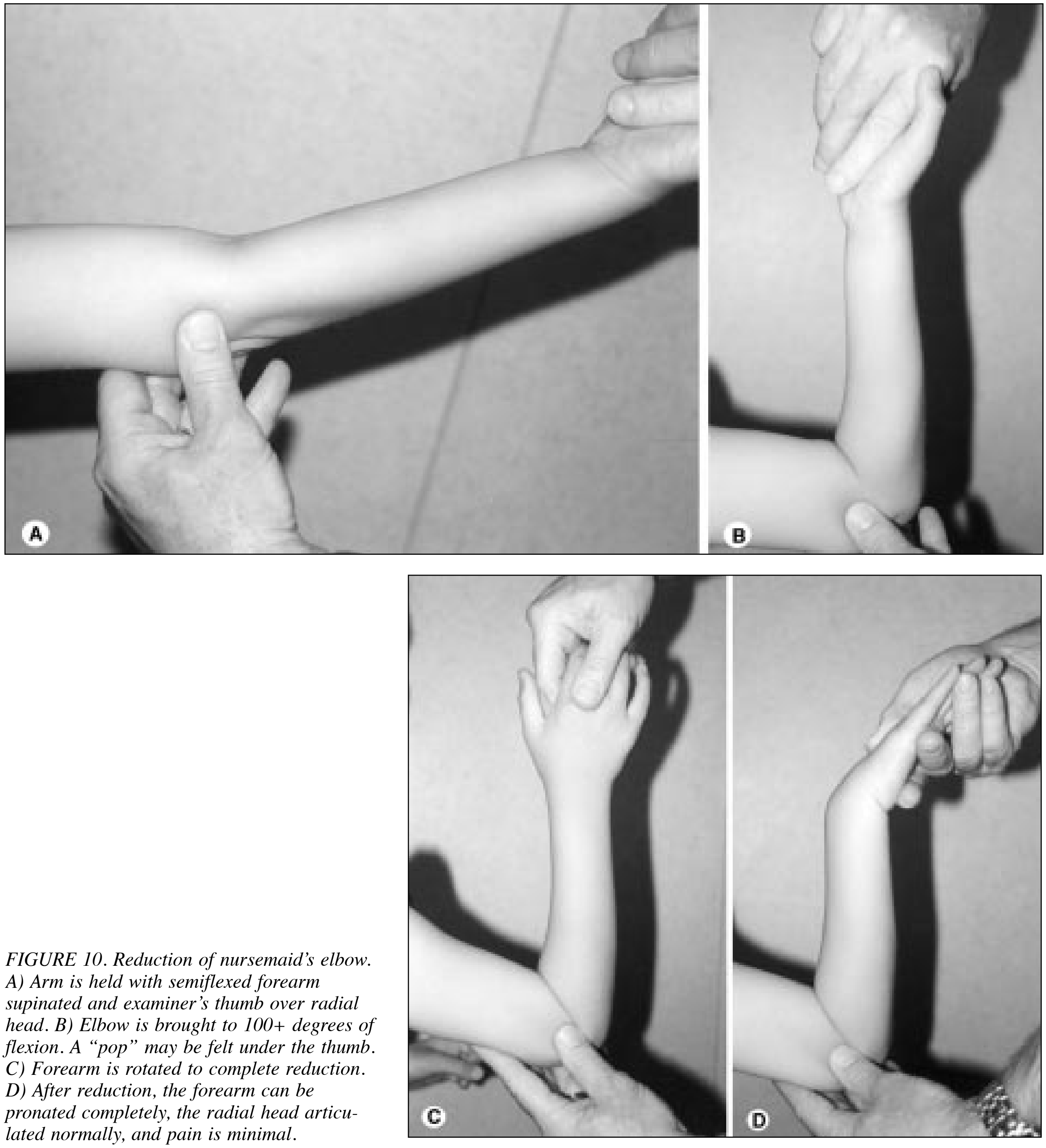

FIGURE 10. Reduction of nursemaid's elbow. A) Arm is held with semiflexed forearm supinated and examiner's thumb over radial head. B) Elbow is brought to 100+ degrees of flexion. A "pop" may be felt under the thumb. C) Forearm is rotated to complete reduction. D) After reduction, the forearm can be pronated completely, the radial head articulated normally, and pain is minimal.

distal humerus or forearm bones after several manipulations to reduce a presumed "nursemaid's elbow."

FOREARM FRACTURES

The forearm is the most common site of fracture in children. Comprised of the radius, ulna, and proximal and distal radial-ulnar joints, the forearm complex behaves as a rectangle. Isolated injuries of one limb of the rectangle are rare. Associated injuries to the distal radial-ulnar joint or proximally to the annular ligament must be ruled out when either the radius or ulna alone are fractured. As with any fractures, radiographs of the forearm should include the joints both above and below the involved bone because there is a significant association of supracondylar humeral fractures with diaphyseal forearm fractures.

Radial head fractures are difficult to diagnose in the child younger than 4 years of age because the proximal radial epiphysis is unossified; ultrasonography can help to visualize the radial head. Angulation of less than 30 degrees and translation less than 2 mm is acceptable and does not require reduction. Greater deformity requires closed reduction, and if significant (>45 degrees), reduction under general anesthesia may be necessary. Three or four weeks of cast immobilization followed by active motion should return the elbow to normal function.

Monteggia fracture-dislocations are a complex of injuries involving dislocation of the proximal radius and concomitant proximal ulnar fracture or plastic deformation that require orthopedic care.

Diaphyseal (shaft) fractures usually involve both the radius and ulna. Either one or both bones may exhibit greenstick or plastic deformity. The primary concerns are inherent instability and/or potential malalignment. Adequate relaxation with sedation or general anesthesia is required for reduction, although open reduction and internal fixation rarely are required. It is important to remember that remodeling of an angular deformity in the radial shaft can occur at about 1 degree per month, but a rotational deformity does not remodel. Once reduced, immobilization in a long arm cast or a splint placed medially and laterally and crossing both elbow and wrist may be safest because it allows for swelling of the limb. Once the time of potential swelling has passed, a long arm cast can be applied. Compartment syndromes following diaphyseal forearm fractures can occur, and parents should be instructed to elevate the arm above the level of the heart for at least 48 hours after reduction and immobilization.

The distal one third of the radius and/or ulna is involved in 55% of all childhood fractures; 75% occur in the distal one third of the radius, making it the single most common fracture. The bony disruption runs the gamut from torus or greenstick to full displacement and overriding. Torus fractures are stable injuries that require only cast immobilization for 4 to 6 weeks. Children younger than 5 years should be treated with a long arm cast, and older children need only a short arm cast. Greenstick fractures commonly involve both the distal radius and ulna, and because intact metaphyseal bone on the compression side of the injury is relatively thin, completion of the fracture is relatively nontraumatic and allows for an anatomic reduction of both bones.

Caution should be exercised when examining a fracture of the distal one third of the radius that is not accompanied by an ulnar fracture because there may be an associated injury to the distal radioulnar joint (the Galeazzi fracture). In such an instance, restoration of radial length is imperative in addition to immobilization in supination to allow healing of the distal radioulnar joint.

Treatment of totally displaced distal one third fractures may require significant sedation or general anesthesia because acceptable reduction occasionally is impeded by the thick periosteum and/or soft-tissue impingement. Immobilization in a long arm cast for 6 to 8 weeks is necessary. An initial postreduction angulation of greater than 30 degrees in a distal radial fracture is unacceptable and an indication for repeat closed manipulation. Residual angulation less than 30 degrees will remodel.

SH I or II physeal fractures of the distal radius are more commonly adolescent injuries. The distal radial epiphysis usually is displaced dorsal to the radial metaphyses and is relatively easy to reduce in the emergency department if the appropriate regional or local anesthetic is administered. Rarely are general anesthetics required for reduction. Repeated attempts at reduction should be avoided because possible iatrogenic damage to the growth plate may lead to future growth arrest. Further, closed reduction after 7 to 10 days of displacement is extremely difficult and similarly increases the risk of growth arrest. These injuries usually are stable once reduced and should be immobilized for 5 weeks in a long arm cast in neutral rotation.

The signs and symptoms of a mid-clavicular fracture include pain, deformity, and regional swelling.

INJURIES TO THE HAND AND WRIST

Wrist fractures and dislocations are extraordinarily rare in children. The most frequently injured carpal bone is the scaphoid, although these represent fewer than 0.5% of all childhood fractures. Most scaphoid fractures in the early years are of the distal pole, and displacement is uncommon. Unlike in adults, scaphoid fractures in the child heal well, with immobilization in a short arm thumb spica cast for 3 to 4 weeks being adequate. More proximal fractures or fractures in which the diagnosis is delayed may require 6 to 8 weeks of casting.

Fractures in the hand are far more frequent than dislocations. In the young child, crush injuries, especially to the distal phalanx, are common; in the adolescent, injuries such as fractures of the border digits sustained from sports activities occur more often. These injuries to the proximal phalanx of the little finger and the metacarpal of the thumb tend to be SH II and can be treated with gentle closed reduction followed by splinting or casting. Fractures of the central digits usually are undisplaced and will heal well with simple protective immobilization. Although most fractures are nondisplaced and heal readily, "buddy taping" of metacarpal or phalangeal fractures should be used cautiously because of the ease with which the child may remove the tape. Children who have such injuries should be immobilized in splints or casts with the hand in the position of function: the wrist in 30 degrees of dorsiflexion and the metacarpophalangeal joints in 50 to 70 degrees of flexion.

The rare indication for operative treatment of children's hand fractures include displaced intra-articular SH III and IV injuries associated with growth arrest, displaced phalangeal neck fractures, and open fractures. Treatment of metacarpal neck fractures, especially the fifth metacarpal ("boxer") fracture, involves gentle reduction and immobilization of the involved and adjacent digits in the position of function. Buddy taping can be used beneath a splint to control rotation of the fingers. Aggressive reduction rarely is required; successful remodeling of boxer's fractures angulated by as much as 60 to 70 degrees has been described. It is important to check the rotational alignment before and after reduction in all children's metacarpal and phalangeal fractures. Rotational deformities do not remodel; a malrotated finger will cause problems with grip and overall hand function throughout life.

FRACTURES OF THE SPINE

Because of the potential for devastating neurologic compromise, attention to the possibility of spine injury is paramount whenever the mechanism suggests that the central skeleton is at risk. The child who has fallen from a significant height, has been involved in a motor vehicle accident as a restrained or unrestrained passenger, has been struck by a vehicle, or otherwise has been the victim of violent trauma must have the spine evaluated carefully.

Supine placement on a firm surface for initial examination without moving the head, neck, or trunk should be routine. Depending on the probability of neck injury, an appropriately sized and fitted cervical immobilization device should be used. Because the anterior-posterior diameter of the child's head is proportionately larger than the chest and shoulder girdle, lying supine on a flat surface forces the neck into flexion, which is not an optimal position in the case of cervical injury. Adaptation of the surface should allow the head to drop back slightly, permitting the cervical spine to be neither passively flexed nor extended. Screening radiographs should be obtained in this position and the bony elements evaluated for fracture, malalignment, or suspicious soft-tissue swelling.

The unique nature of children's bone results in different spinal injury/fracture patterns than seen in the adult. Instead of a vertebral body fracture or dislocation, growth plates can separate, which results in disruption of spinal canal alignment that appears radiographically to be dislocation without fracture. Displaced and radiologically lucent cartilaginous end plates may protrude into the canal, compressing neural elements. Spinal cord injury without radiologic abnormality (SCIWORA) is a rare injury to the spinal cord that cannot be identified on any currently available imaging study but results in neurologic compromise.

Before proceeding with treatment of less emergent injuries, status of the spine must be ascertained. A complete physical examination should evaluate sensory function, including in the perineal area, and motor power in all muscle groups. Plain radiographs of the neck and, if indicated, the spine should be obtained. Depending on the circumstances, magnetic resonance imaging (MRI) or computed tomography (CT) of a suspicious area may be appropriate.

Many spine injuries in children are stable, do not involve neurologic compromise, and do not lead to progressive deformity. Once identified, the vertebral injury should be treated by a clinician who appreciates the vagaries of the pediatric spine and its neural elements. Over- or undertreatment can be equally problematic.

True shoulder (glenohumeral) dislocations, like acromioclavicular separations, are very infrequent in children and adolescents.

Fractures of the Lower Extremities

PELVIC FRACTURES

Pelvic fractures generally are the result of a crush-type injury, an avulsion of muscle (hamstring, rectus femoris, sartorius) origin, or, in the case of the pubis or iliac crest, a direct blow. Local tenderness is present, and the fracture line is evident on anteroposterior radiographs of the pelvis. As in any trauma to the hip region, an initial radiograph that does not include the entire pelvis and both hips is inadequate. The importance of comparing the injured with the uninjured side on the same film cannot be overstated.

Most pelvic fractures in children do not require operative management, although those that result in instability or include disruption of the sacro-iliac joint demand more than observation or an assisted walking program. Associated injury to the urethra, bladder, bowel, or sacral nerve plexus should be ruled out in every case by reviewing the urine microscopically or possibly by CT or MRI.

If one fracture of the pelvic ring is identified, a second should be sought. If a second fracture is not seen, the sacro-iliac joint may be disrupted to some degree. Compressing the iliac crests together or placing the leg in a figure 4 position will provoke pain in the sacro-iliac region when nearby bony or physeal injury has occurred. Once identified, bed rest, skin/skeletal traction, casting, or surgical repair, depending on the specific injury, may be required.

HIP FRACTURE

Fracture of the intracapsular femur (femoral head or neck) in a child requires significant force and, therefore, frequently is seen in combination with other bony, head, or abdominal injuries. The blood supply to the upper femur is precarious in children, and intracapsular hip fractures are associated with a relatively high incidence of complications that can include nonunion, growth disturbance, and avascular necrosis. Surgical intervention consisting of reduction and fixation requires use of pediatric-specific devices, minimal soft-tissue dissection, and postoperative casting. Despite attention to these details, complications still may occur, and parents must be made aware of the magnitude of the injury.

FEMORAL FRACTURE

Treatment of femoral fracture has evolved over the past decade. Interest in reducing cost and quickly returning the individual to semi-independence has resulted in movement toward "immediate" casting and/or operative intervention using either external or internal fixation. Like most fractures in children, those of the femur heal quite readily, and any form of treatment must be compared with the time-proven standard–a period in traction that allows healing to begin followed by twice as many weeks in a spica cast to complete the process.

Because an upper shaft (intertochanteric) fracture treated with early casting tends to heal with deformity, initial treatment usually consists of traction (up to 3 weeks) with the hip and knee flexed 90 degrees. After stability is obtained in traction, subsequent spica casting for a period that is based on the child's age follows. Surgical intervention rarely is warranted.

Femoral mid-shaft fractures also may be treated with initial traction followed by casting or by fixation, using externalized pins inserted into the bone above and below the fracture and attached to a frame. Use of the percutaneous external fixator allows the patient to move knee and hip, be free of cast encumbrance, and be ambulatory (even going to school) and results in a shorter (by up to 2 weeks) hospital stay. The cost of this treatment is no less than that of traction/casting; complications include infection, permanent pin-site scars, and potential nonunion. Because a certain degree of patient cooperation and insight is required for the use of these devices, they should be employed with caution in children younger than 8 years of age.

Immediate casting has been popular for femoral fracture in the child younger than 3 years of age. Typically, a spica cast is applied under either general anesthesia or significant sedation within the first few days of injury. The cast may be applied after any other coexisting injury has been ruled out and the clinician is satisfied that the fracture, which results from considerable force, occurred accidentally and not as the result of child abuse. Six to eight weeks of casting typically are required in this age group; hospital stay is minimal and complications are few.

Immediate casting has been popular for femoral fracture in the child younger than 3 years of age.

Hospital stays and extent of casting also can be decreased by using percutaneous intramedullary fixation with semirigid rods. This approach stabilizes the fracture to a degree that immediate postoperative long leg instead of spica casting is sufficient and eliminates the need for traction until the fracture becomes stable. Although this approach is just as costly as traction/spica casting, it is particularly applicable in the child who has multiple injuries, in whom an extended period of bed confinement would be detrimental, or whose femoral fracture cannot be aligned adequately in traction.

Operative intervention in the form of standard intramedullary rodding should be used cautiously. Osteomyelitis and avascular necrosis of the femoral head are complications (up to 2% incidence) that can be avoided with other forms of treatment.

Femoral shaft fracture in children 2 to 10 years of age typically stimulates accelerated growth of the involved femur for 2 years, making anatomic reduction of these fractures undesirable. Because approximately 1.5 cm of overgrowth routinely occurs, the fracture fragments should be allowed to override by that amount to avoid a leg length discrepancy at the end of growth. This overgrowth phenomenon should be considered when deciding whether to employ flexible intramedullary nailing.

Injury to the distal femoral physis is common in preadolescents and young teenagers. Partial or near-complete growth arrest is more common (up to 50%) than in any other similarly injured physis. Anatomic reduction, frequently operative, is required, and subsequent growth function must be monitored for at least 2 years to identify a growth problem as it emerges and to plan in advance an appropriate treatment program.

TIBIAL FRACTURE

Tibial shaft fractures usually are amenable to cast treatment following closed reduction. Children tend to destroy ambulatory casts and are not excessively inhibited by long leg, nonweight-bearing immobilization. Torus fracture of the distal tibia and stable undisplaced fractures, which require 5 to 6 weeks of immobilization, may be treated in a short leg walking cast, but the destroyed walking cast probably will have to be replaced at least once during the immobilization.

Displaced tibial shaft fractures require long leg nonambulatory casting after reduction for 5 to 6 weeks followed by several additional weeks in a short leg walking cast. Older children and teenagers require a total of 10 to 12 weeks of casting followed by physical therapy to regain full function; younger children usually require less time. Individuals who have multiple injuries or those in whom satisfactory alignment cannot be attained or maintained with a cast alone require stabilization with flexible intramedullary rods combined with cast treatment or an external fixator.

Following a tibial physeal fracture, the need to align fractured joint surfaces anatomically, especially in this weight-bearing bone, most often requires open reduction. In the proximal tibia, an injury that in an older individual would tear one of the cruciate ligaments often avulses the tibial spine. At the ankle, medial malleolar fracture involves the growth plate with an attendant risk of growth arrest and subsequent deformity. Fracture through the lateral distal tibial physis is unique to the adolescent, often requiring CT for assessment and treatment planning. Surgical intervention usually is necessary and requires different fixation methods from those employed in the adult. Implanted devices should not cross the growth plate in children.

Despite adequate treatment, distal tibial growth arrest may occur. To prevent joint malformation, surgical completion of partial tibial arrest or distal fibular epiphysiodesis may be necessary. Excision of bony bars that are causing partial growth arrest, with interposition of autogenous fat or bone cement, may restore normal physeal function in the child in whom significant growth remains.

FOOT FRACTURES

Fractures involving the hindfoot, midfoot, and metatarsals in the immature individual normally only need to be immobilized in a below-knee cast for 3 to 6 weeks. Fractured toes can be treated symptomatically by buddy taping and/or a stiff shoe. Young children often destroy walking casts (regardless of casting material) after 2 weeks; they probably will need to be replaced at least once during the course of that treatment. Crushing injuries of the foot can create a compartment syndrome. If a compartment syndrome is suspected, prompt, appropriate treatment is required.

Compartment Syndromes

A compartment syndrome is a symptom complex resulting from decreased vascular perfusion due to increased tissue pressures in a closed osteofascial compartment. It may follow fractures, crush injuries, insect or snake bites, injection injury, or an overly tight cast or bandage. Although it can occur in any limb, the forearm and leg are most susceptible. Diagnosis is difficult in the child, but pain out of proportion to the magnitude of injury in an otherwise healthy individual is the hallmark of this condition. Pain on passive stretch of involved compartment muscles is the most reliable clinical sign, and sensory deficit involving the nerves of that compartment is an early indicator of increased pressure. The absence of pulse or capillary refill is not reliable for ruling out compartment syndrome.

When this condition is suspected, the limb must be elevated, all circumferential dressings released, and orthopedic or vascular surgical consultation sought to ascertain the compartment pressure and approach the limb surgically if necessary. A compartment pressure reading within 10 to 30 Hg of the diastolic pressure indicates a positive diagnosis.

Pearls for Treatment of Musculoskeletal Injury in Children

- Splint immobilization placed on the posterior aspect of the arm, leg, or ankle is ineffective; it can break and become a "hinge" within 24 to 48 hours. Splints applied to the medial and lateral aspects of the extremity have greater longevity.
- Casts and splints that end a few inches above the elbow, ankle, wrist, or knee and/or do not extend to the distal palm or toes immobilize a fracture incompletely and create excessive pressure on the soft tissues where the cast ends. Apply immobilization devices well up the arm, forearm, thigh, or leg and to the full length of the hand or foot.
- Ace bandages compress tissues and can be dangerous. Apply in a manner that does not create excessive compression or choose another material (Kling or flannel bandage) to wrap a splint in place.
- With the exception of the elbow and interphalangeal finger joints, children rarely lose function after a reasonable period of immobilization. Applying or changing to a shorter device in the middle of treatment to allow motion and prevent stiffness rarely is indicated.
- Young people will not wear a sling as a supportive or protective device; rarely should they be prescribed.
- Commercial "off-the-shelf" knee, ankle, and forearm braces do not fit children; a "custom-fit" plaster or fiberglass splint is less expensive and more satisfactory.
- Walking casts do not stand up to the wear and tear inflicted by youth; nonambulatory long leg casts/splints are effective, efficient, and satisfactory.
- Modern fiberglass materials are much more durable than plaster, but even fiberglass will succumb to the wear and tear inflicted by children.
- Child abuse can produce virtually any type of fracture or soft-tissue injury. Although the small, undisplaced avulsion occurring at the corner of the metaphysis at its junction with the epiphysis is said to be diagnostic of child abuse, no other fracture is exclusive to such maltreatment. Virtually any fracture can occur in the absence of abuse, but the mechanism of some injuries (twisting) or the force required to inflict them (femoral fractures) should raise concern about the cause.

Apply immobilization devices well up the arm, forearm, thigh, or leg and to the full length of the hand or foot.

SUGGESTED READING

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PIR QUIZ

12. A 9-year-old girl falls from her horse onto her right shoulder. Examination reveals tenderness and mild swelling over the midpoint of the right clavicle. The *most likely* explanation is:
    A. Acromioclavicular separation.
    B. Complete midshaft fracture.
    C. Greenstick fracture.
    D. Isolated hematoma.
    E. Periosteal contusion.

13. A 7-year-old boy who has a diaphyseal fracture of his left radius and ulna is treated following closed reduction by immobilization in a long arm cast. Six hours after casting he begins to complain of severe pain in the arm. You suspect compartment syndrome. The decision to take further diagnostic and therapeutic steps can be based *most reliably* on:
    A. Grip strength.
    B. Pain on passive muscle stretch.
    C. Presence of pulse.
    D. Quality of capillary refill.
    E. Response to narcotic analgesics.

14. An 18-month-old boy falls while his right hand is being held by his mother. He immediately screams and thereafter refuses to use his entire right upper extremity. The *most likely* explanation is:
    A. Dislocated finger.
    B. Dislocated wrist.
    C. Radial head fracture.
    D. Radial head subluxation.
    E. Shoulder dislocation.

DEPARTMENT OF CORRECTIONS

Erratum

The Answer Key in the November 1997 issue contains one incorrect answer and one unusable answer. The correct answer for question 12 is B, and there is no question 13, so there should be no answer.