Injury in the Child

JOHN A. OGDEN, M.D.

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Professor of Surgery and Pediatrics, and Chief of Orthopaedics
Chief of Children's Orthopaedics
Director, Skeletal Growth and Development Laboratory
Yale University School of Medicine
New Haven, Connecticut

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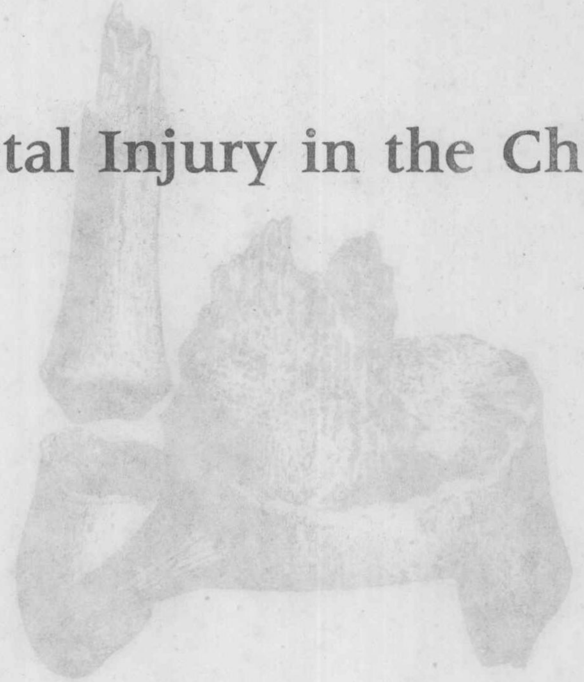

Skeletal

My Arm

This is strange . . .
I can't say it,
S'traction?
It makes your arm get better.
It holds your arm so it heals
  quicker
It feels funny
It's hard to get dressed
    change the sheets
    color
    eat.

By CARRIE S.

This poem was written by a seven-year-old girl as she lay in Dunlop's traction for a severe supracondylar humeral fracture.

Preface

INJURY and the subsequent reparative response of the developing skeleton are frequently disparate from the mature skeleton. This book is an outgrowth of a desire to attain a morphologic understanding of the nuances of pediatric orthopaedic trauma. As clinicians we all have a tendency to focus on specific injuries, often ignoring trauma mechanisms and the relevance of underlying anatomy to both the initial injury and long term consequences.

This book introduces the principles of diagnosis and treatment of fractures in children in a manner that first establishes a solid foundation of anatomy and pathomechanics on which treatment principles are based. Developmental anatomy is an overlooked facet of children's injuries, primarily because of the paucity of morphologic material available for use as source material. The unique opportunity to include the resources of the Skeletal Growth and Development Study Unit at Yale University allowed the inclusion of much material. In particular, I have attempted to translate the anatomic details into a form that will have practical value. I feel that the emphasis on normal structure and function and the mechanisms of response to trauma are essential to good clinical practice.

Decision making in orthopaedics is experience dependent, in that it requires a proper mental set for what is normal for the given anatomic part at a particular age. Because of the lack of available anatomic material, the orthopaedist must rely on whatever resources he can muster for normal references for most of development. One can more readily accept the importance and significance of basic anatomic developmental changes if these are presented in close relationship to current clinical situations in which the information is necessary.

This volume is primarily a clinical textbook, although discussions encompass aspects of skeletal developmental biology, particularly the response to trauma. My hope is that this book provides the medical student, the resident, and the practicing physician with a logical and progressive plan of approach to children's fractures that allows for the ready storage, retrieval, and utilization of knowledge concerning each of the specific regions of injury. Since the study of orthopaedics must be a lifelong process, this book is intended to serve both as an introduction to the study of skeletal injury, as well as a basic text for continuing study. Hopefully, it will also have import to pediatricians, general practitioners, and radiologists. The orientation is to furnish a reference book that comprehensively covers the field of musculoskeletal trauma in the child, and provides adequate information for both the specialist as well as the resident physician.

I have tried to develop a text for the teaching of basic and applied anatomy, mechanisms, concepts, and principles that are applicable to each area of injury in the pediatric patient. The factual and patient material has been carefully selected to support an understanding of these concepts and principles. In doing so I have attempted to integrate a scientific basis with the art of medicine. The test of the value of this book will be its effectiveness in stimulating further insight into the diagnosis and care of patients who face a lifetime of challenge. If this has been achieved, the work will have been worth the effort.

Sachem's Head, Connecticut
New Haven, Connecticut

JOHN A. OGDEN, M.D.

Acknowledgments

THERE are a great many individuals who generously contributed time and talent to this undertaking. This book is a synthesis of their labors and mine. Many of the cases have been contributed by fellow faculty members, residents, and orthopaedists throughout the world. I cannot name everyone, but I certainly do express my deep and sincere appreciation to each of them.

Although gratitude must be expressed to many people, I must particularly thank Dr. Wayne O. Southwick. Many years ago he had the insight to induce me to consider orthopaedics as a career. Throughout my training and subsequent affiliation on the Yale faculty, he has stimulated and encouraged my pursuits in pediatric orthopaedics and skeletal development. He has done so unselfishly and with an unceasing desire to see that each of us in the Yale program attained his maximum potential. I owe him an inexpressible debt of gratitude, and hope that this volume serves as an additional tribute to what he has given me.

Much of the morphologic research that has served as the basis for each chapter has been supported by several organizations. The Crippled Children's Aid Society has been a constant source of assistance to our Section as they have sought to continue the work and memory of Carl Henze, M.D., an early New Haven orthopaedist with a deep interest in the problems of crippled children. The Easter Seal Research Foundation and Ohse Foundation have each supplied support for the initial morphologic studies. The National Institutes of Health have given generous support to my desire to make developmental anatomy relevant to childhood trauma and disease (Grants R01-HD-10854 and K04-AM-00300). Some of the relevant animal studies have received support from the National Oceanographic and Atmospheric Administration. A Berg Fellowship through the Orthopaedic Research and Education Foundation allowed me a unique opportunity to study epiphyseal injuries in Finland with Anders Langenskiöld and pediatric orthopaedics at Oxford with Edgar Sommerville.

The photographic illustrations represent the constant efforts of Patricia Cosgrove, Mary Bronson, Gertrude Chaplin, John Braslin, and Sarah Whitaker. Processing and roentgenography of the anatomic specimens have been ingeniously accomplished by Gerald Conlogue.

Finally, I must thank Joanne Ciresi, Mary Villano, Susan Murphy, Suzanne Barnett, and Patti Milot for their unceasing efforts in typing the many drafts that went into the production of this book.

J. A. O.

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1

General Principles

Childhood injuries are a problem not only for treating physicians, but also for the entire community, and they rightfully may be considered a phase of public health education. Accidents are the leading cause of death, as well as an outstanding cause of permanent disability, among children older than one year of age. Skeletal injuries account for 10 to 15% of childhood injuries.[1] In patients with multisystem injuries, particularly if life-threatening, the tendency is to assign a low priority to fracture care, a factor which may lead to skeletal growth deformity. Adequate fracture care must be an integral part of both the emergency and the subsequent care of any multiply-injured child.[2,3]

Fractures involving the developing skeleton may be significantly different during any of the stages of chondro-osseous maturation, as well as during the stage of skeletal maturity (adulthood). Any physician treating skeletal injuries in children must be familiar with the probable mechanism of injury, the cause and long term biologic response of the injured part (particularly when a growth mechanism is involved), and the appropriate guidelines for treatment of the specific injury. These patients have all of their productive years ahead of them, and they must be treated with skills based upon experience and detailed knowledge of the capacities of repair and remodeling. If a physician relies upon principles of treatment applicable to injuries of mature bone, errors in judgement and technique may manifest themselves in permanent defects.

Basic Differences

Patient history

Unlike histories taken from conversant adults, historical details of actual injuries to children often are totally lacking, erroneous, or purposely deceptive. This is particularly true of the "battered child." Frequently, no responsible person has seen the accident. The child's account may be oversimplified, halting, or incomplete. Knowing how the injury occurred often enables the physician to anticipate the full extent of the injury, including important associated injuries. Because appropriate treatment is accomplished more satisfactorily when one has some knowledge of the mechanism of injury, the variable lack of historical data on childhood injuries requires that particular significance be attached to the physical examination, which must thoroughly assess the type of deformity, location, degree of concomitant soft tissue swelling, and integrity of innervation and circulation.

Parents

An adequate discussion with the parents is as important as the actual treatment of their child's fracture. It is essential to establish both a good doctor/child-patient relationship as well as a satisfactory doctor/parent relationship, since the latter may be instrumental in carrying out essentials of care. Elucidate the troublesome areas of diagnosis and treatment in words they can comprehend, and be absolutely certain that they do understand. Always prepare the parents for acute care as well as for potential chronic or long term problems. Discuss the possibilities of limping, loss of full range of motion, nerve injury, loss of reduction after initial treatment, and the need for re-manipulation, and emphasize the need for adequate follow-up care, which extends in many cases until skeletal maturity is attained. Proper follow-up care is probably the most difficult factor to gain compliance with, especially after the child appears outwardly normal, but it is probably the most important factor in anticipating and diagnosing problems of premature growth arrest in their early stages. During a growth spurt, seemingly minor problems may rapidly assume major importance, especially when dealing with growth mechanism injuries.

Special features

Several factors make fractures of the immature skeleton different from those of the mature skeleton. Among these are: (1) fractures are more common and more likely to occur following seemingly minimal trauma; (2) the periosteum is thicker, stronger, and more biologically active; (3) diagnosis presents special problems, in particular, the variable radiolucency of the epiphyses; (4) spontaneous correction occurs in certain, *but not all,* residual angular deformities; (5) complications are different; (6) different methods of treatment receive different emphasis; and (7) joint injuries, dislocations, or ligamentous disruptions are much less common.

Further major differences include the following: (1) Injuries may involve specific growth regions such as the physis or epiphyseal ossification center and lead to significant acute and/or chronic disturbances of growth. (2) Normal processes of bone remodeling in the diaphysis and metaphysis (particularly the latter) of a growing child will longitudinally realign many initially malunited fragments, making absolutely accurate anatomic reductions somewhat less important in a child than in an adult.[4,5] However, this tends to be an abused aspect of the treatment of children's fractures. Accurate anatomic reduction should be attempted whenever possible. (3) Fractures stimulate longitudinal growth by increasing blood supply to the metaphysis, physis, and epiphysis, and, at least as shown by experimental evidence, by circumferentially disrupting the periosteum and its tethering (restraint) mechanism on rates of longitudinal growth of the physis.[6] Therefore, some degree of overriding with bayonet (side-to-side) apposition may be acceptable in certain age groups and may even be desirable, particularly in fractures of the femur. (4) Bone healing is much more rapid in childhood because of the thickened, extremely osteogenic periosteum and the abundant blood supply to this region. The younger the child, the more rapid the union. The dependence of healing capacity on age is significant. Age affects the rates of skeletal healing more than it does any other tissue in the body. At birth, fracture healing is remarkably rapid, but becomes progressively less rapid during childhood and adolescence. The healing of a fracture of the femoral shaft in a newborn infant may take only 3 weeks, whereas 20 weeks is not an uncommon length in a young adult. The rate of healing in the bone is probably closely related to the osteogenic activity of the periosteum and endosteum. Nonunion usually does not occur in children. (5) It is necessary to follow the child until skeletal maturity in order to obtain meaningful conclusions. This applies to any study of the long term consequences of fractures in children. The tendency to cease follow-up care 6 to 12 months after the injury may result in subsequent presentation of significant growth deformities and irate parents.

Effect of age

Every age group from infancy to adolescence has its typical injury patterns. Children also have certain typical reactions to an injury, such as a pseudoparalysis of the newborn infant in response to a fracture of the upper extremity. Knowledge of these factors, when considered along with the mechanism of trauma, is often helpful in making a diagnosis and rendering treatment. During periods of rapid growth, children may twist or strain, a behavior which hardly seems to merit consideration by either the parent or the physician. However, this may cause chondro-osseous injury, particularly of the tibia, which is susceptible to spiral fracture in children between the ages of two and five (the so-called "toddler's" fracture).

Iqbal[7] showed that upper limb fractures in children were seven times more common than lower limb fractures, and that the incidence of fractures was much higher in the preschool period. The only fractures showing a major variation from this pattern were forearm fractures, which showed a progressive increase with age, attaining a maximum frequency in the prepubescent period, and dropping sharply in incidence after age 19. In contrast, clavicular fractures were most marked in infancy and preschool, and dropped off significantly in the school years.

The site, frequency, and nature of traumatic bone lesions are all conditioned by the age of the patient. The fetal bones, effectively protected from external trauma by the amniotic fluid and thick uterine wall, rarely are traumatized (see Chap. 8). However, chronic intrauterine stresses operating on a fetus that is in a faulty position may cause changes in the shape of fetal bones and joints, causing such postural disorders as prenatal bowing of the long bones, club feet, and hip dysplasia. Even severe local deformities, especially to the mandible, facial, and skull bones, and possibly even some types of tibial pseudarthrosis can occur.[8,9] During the birth process, and more frequently in breech deliveries, a wide variety of traumatic lesions may be incurred, including fractures of the shafts and epiphyseal cartilages. The most common obstetric fractures are those involving the skull and clavicles.[10]

During the first year, fractures are relatively rare. Multiple, severe fractures may develop, however, and may be the first indication of metabolic disorders or skeletal dysplasia (e.g., hypophosphatasia; osteogenesis imperfecta). Sides of cribs are sources of injuries to the bones of the legs and arms of infants. Most willful assaults on children occur during the first two years of life and cause the clinical syndrome of "battered child." From age two on, particularly from the time the child starts to walk, the most commonly fractured bone is the radius. The high incidence of this fracture continues and increases into adolescence, although the pattern appears to change from fractures of the shaft and distal metaphysis to fractures of the distal epiphyseal plate. Fractures of the phalanges and metacarpals are also common in the first two years while the child is learning to walk.[11] Toddler's fracture of the distal half of the tibia is common during the second to fifth years. Throughout childhood, fractures of the clavicle are common. At all ages, the automobile is the principal crippler of children, causing severe skeletal abnormalities. However, the serious hazards of snowmobiles, power lawn mowers, trail bikes, and other powered, small vehicles are becoming increasingly evident. Even non-powered "vehicles" such as skateboards are becoming an increasingly significant cause of childhood and adolescent fractures.

The age at which growth ceases varies greatly and depends on multiple factors. The skeletal age is the determining factor when considering the effect of trauma on the growing skeleton Trauma, mechanisms, and fracture types become different. Ligament injuries and joint dislocation become more common with the attainment of skeletal maturity.

Activity levels

Children tend to approach life at a more active level than adults. This must be considered in any treatment. Once pain subsides, the child tends to forget that an extremity is injured, and quickly will go back to normal levels of activity, which may not be conducive to fracture healing, and which may damage immobilization devices. Childhood is also a time of emphasis on competitive sports, often with a greater drive coming from the parents than from the child. Organized sports involving younger children predispose the improperly conditioned child to injury.[12-14] Furthermore, children often will try to get back into these programs as quickly as possible after the injury, often before complete healing. The additional stress from a parent to get the child back on the playing field makes medical care of these children even more difficult.

Biologic Differences

Many, if not all, of the aforementioned differences between the traumatized skeletons of an adult and a child relate to the fact that the child's skeletal elements are in a more dynamic, constantly changing growth mode, whereas the adult skeleton has ceased elongation and apposition, and is principally (and more slowly) remodeling the established elements in accord with stress responses (i.e., forming increasing patterns of secondary and tertiary osteons). The major differences between childhood and adult skeletal trauma relate to three categories: anatomy, physiology, and biomechanics.

Anatomy

Because of endochondral ossification, the chondro-osseous epiphyses of children are variably radiolucent, making roentgenographic evaluation difficult, if not impossible, unless specific, usually invasive procedures (e.g., arthrography) are used. Skeletal injury sometimes must be inferred on the basis of clinical judgement, for roentgenographic substantiation may not be immediately possible, although subsequently, new bone formation may make the diagnosis certain. The physis is constantly changing, both with active longitudinal and diametric growth and in its mechanical relation to other components. Modes of failure thus vary with the degree of chondro-osseous maturation. The periosteum also differs in a child, being thicker, more readily elevated from the diaphyseal and metaphyseal bone (as by a subperiosteal fracture hematoma), less readily completely disrupted, and exhibiting greater osteogenic potential.

Schenk[15] showed that the following properties of the developing skeleton are immensely important to fracture healing: (1) there is a pronounced reaction of periosteum and endosteum that is significant in the correction of longitudinal deformities; (2) the vascular pattern of cortical bone and its microscopic structure, as well as the vascular supply of the growth plate, assume great importance in specific fractures. This involvement of the growth plate and growing articular cartilage in angular deformities is important to certain fracture concepts.

Developing bone begins with fewer lamellar components and a relatively greater porosity than mature bone. Within any given anatomic region of a bone, changes occur with age, with the natural sequence beginning with increased lamellar bone in the diaphysis. There are also relative differences in the various regions within a given bone that predispose certain regions to fracture over others. These differences in microscopic and macroscopic architecture also affect the process of fracture healing, which is different in the more dense, lamellar bone of the diaphysis, as compared to the spongy, trabecular bone of the metaphysis or epiphysis.

Physiology

The skeleton is undergoing active, frequently rapid, growth and remodeling. Therefore, fractures usually heal rapidly; nonunion is rare; overgrowth may occur; and certain angular deformities may correct totally. However, damage to the capacity of the bone to accomplish these physiologic functions may impair subsequent growth and development in several ways. Various portions of the longitudinal bones respond differently to hormones, mechanical factors, vascular changes, and trauma.

Biomechanics

The major changes undergone by developing bone are increases in the density of the cortex, particularly in the diaphysis but also in the metaphysis, and changes in the proportions of trabecular (endosteal) and cortical bone in the diaphysis, metaphysis, and epiphysis. The porosity, in cross section, of a child's bone is much greater than that of an adult's, and this may play a role in stopping fracture propagation, much as a hole drilled in glass at the end of a crack may prevent a crack from continuing. This factor undoubtedly is important, since comminuted fractures are uncommon in children. The increased amount of bone in the epiphyseal ossification center undoubtedly alters the stress/strain response pattern of the epiphysis, and it is likely that establishment of the subchondral plate over the physis alters its response to fracture.[16] Adult bone usually fails in tension, whereas a child's bone may fail in either tension or compression.

Patterns of Injury

Satisfactory treatment necessitates an understanding of what comprises each specific fracture. In essence, a fracture may be defined as a disruption of the normal continuity of the bone and/or cartilage. The disruption may or may not cause a break in the continuity of the cortical bone, a factor that can occur in children when the cortical bone, because of a greater capacity for plastic deformation prior to failure, buckles rather than breaks. This represents compression, rather than tension, failure of bone, and can only occur in children. Tensile failure, which certainly may occur in children and is the prevailing mode of failure in adults, leads to a break in structural continuity of the bone.

Each fracture needs to be described adequately.[12,17] Such a description should include: (1) the anatomic location of the fracture; (2) the type of fracture; and (3) the physical changes caused by and associated with the fracture.

Anatomic location

Terminology should locate the lesion accurately, and becomes important for comparative treatment studies. As will be seen in the clinical section, slight differences in anatomic locale of the fracture in children may have a major impact on acute treatment and potential long term problems. These definitions are illustrated in Figure 1-1:

Diaphyseal. Involvement of the central shaft of a longitudinal bone, which is usually composed of mature, lamellar bone.

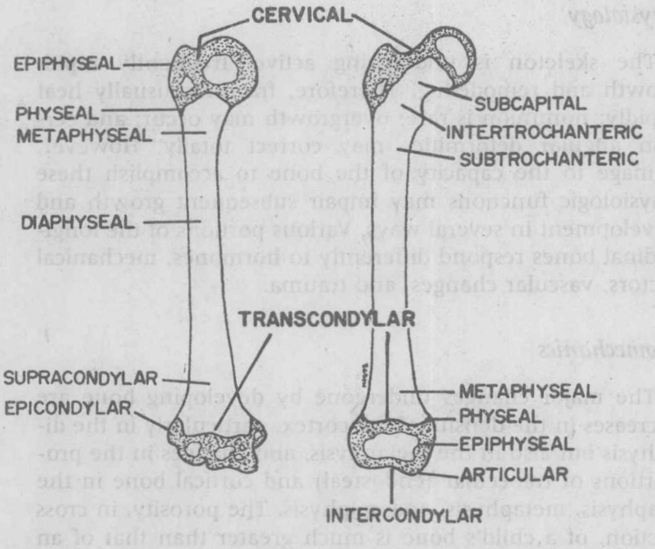


FIG. 1-1. Schematic of humerus (left) and femur (right) from a ten-year-old boy showing various anatomic locations and definitions. See text for details.

Metaphyseal. Involvement of the flaring ends of the central shaft of a longitudinal bone. The metaphyses are usually comprised of extensive endosteal trabecular bone and cortical immature fiber bone, both of which predispose the metaphyses to the torus type of fracture.

Physeal. Involvement of the endochondral growth mechanism. These fractures are discussed in detail in Chapter 4.

Epiphyseal. Involvement of the chondro-osseous end of a long bone. It is important to realize that the epiphysis may be injured only in the cartilaginous portion, which makes diagnosis extremely difficult. Again, these fractures are discussed in more detail in Chapter 4.

Articular. Involvement of the epiphyseal region that has formed the joint surface. The injury may be part of a more extensive epiphyseal injury, or it may be localized. In the latter case, the fragment may include only articular cartilage and juxtaposed, undifferentiated hyaline cartilage, or both subchondral bone and cartilage.

Epicondylar. Involvement of regions of the bone, especially around the elbow, that serve as major muscle attachments and have extensions of the physis and epiphysis.

Subcapital. Involvement just below the epiphyses of certain bones such as the proximal femur or radius.

Cervical (or Neck). Involvement along the neck of a specific bone, such as the proximal humerus or femur.

Supracondylar. Involvement above the level of the condyles and epicondyles (e.g., distal humerus).

Transcondylar. Located across the condyles, usually this is a physeal fracture of the distal humerus or femur.

Intercondylar (Intraepiphyseal). Involvement of the epiphysis, with fracture separating the normal condylar anatomic relationships.

Malleolar. Involvement of the distal regions of the fibula and tibia. Because of anatomic differences, there are significant differences in the fracture patterns of the medial and lateral malleoli.

Type of fracture

This method of description must be based on appropriate roentgenograms of the injury. The basic types, shown in Figure 1-2, are as follows:

A, Longitudinal. The fracture line follows the longitudinal axis of the diaphysis.

B, Transverse. The fracture line is at a right angle to the longitudinal axis.

C, Oblique. The fracture line is variably angled relative to the longitudinal axis, usually about 30 to 45°.

D, Spiral. The fracture line is oblique and encircles a portion of the shaft.

E, Impacted. This is a compression type injury in which the cortical and trabecular bone of each side of the fracture are crushed.

F, Comminuted. The fracture line propagates in several directions, creating multiple, variable-sized fragments. This is an uncommon type of fracture in infants and young children, but becomes more common in adolescence, particularly in the tibia.

G, Bowing. The bone is deformed beyond its capacity for full elastic recoil into permanent plastic deformation (see Chap. 2). The younger the child, the more likely it is that this type of skeletal injury will occur. It is particularly common in the fibula and the ulna, both of which may bow while the paired bone (i.e., tibia or radius) fractures. This permanent deformation may limit the reducibility of the fractured bone of the pair.

H, Greenstick. This is a common injury in children. The bone is completely fractured, with a portion of the cortex and periosteum remaining intact on the compression side. Since this intact cortical bone is usually plastically deformed (bowed), an angular deformity is common, which necessitates conversion to a complete fracture by reversal of the deformity.

I, Torus. This is an impacted injury occurring in childhood. Because of the differing response of the metaphyseal bone to a compression load, the bone buckles, rather than fracturing completely, and a relatively stable injury is created. This type of fracture primarily affects developing metaphyseal bone.

Physical change

While the aforementioned terms have been primarily descriptive, the following terms describe conditions that are of practical importance clinically. These terms indicate not only the nature of the clinical problem, but also the general type of treatment that will be required:

Extent. The fracture may be incomplete, in which case some of the cortex is intact, or it may be complete, in which case the fracture line crosses the entire circumference. Further, the fracture line may be simple (a single fracture line), segmental (separate fracture lines isolating a segment of bone), or comminuted (multiple fracture lines with multiple fragments).

Relationship of Fracture Fragments to Each Other (Fig. 1-3). These relationships define a deformity as it exists during the roentgenographic evaluation. However, because of elastic recoil, especially in children, these relationships may not represent the full extent of deformity present at the time of

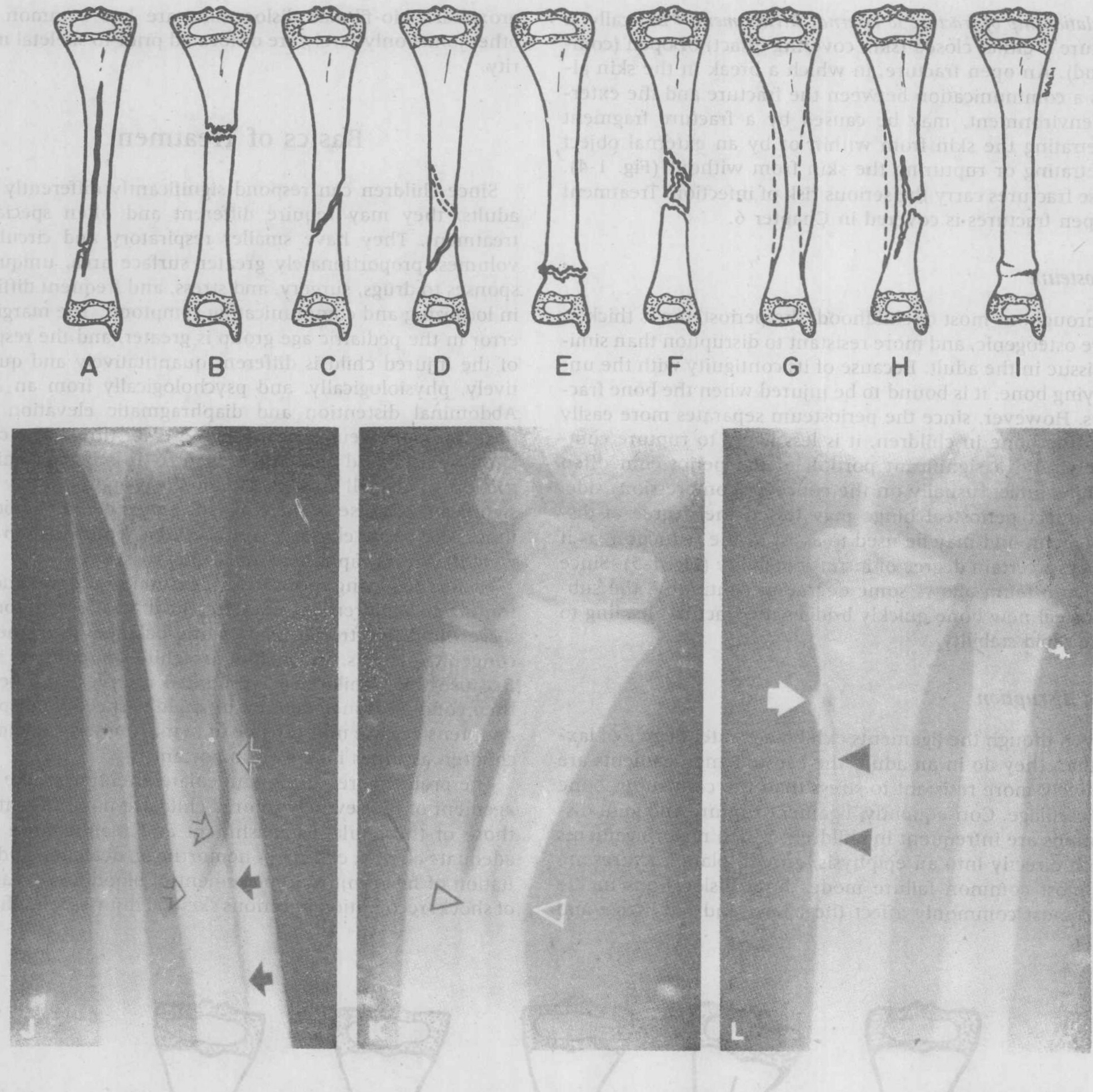


FIG. 1-2. *A–I,* Schematic of tibia from a three-year-old girl showing various types of fractures: *A,* longitudinal; *B,* transverse; *C,* oblique; *D,* spiral; *E,* impacted; *F,* comminuted; *G,* bowing (plastic deformation); *H,* greenstick; and *I,* torus. See text for details. *J–L,* Roentgenograms showing typical fracture patterns: *J,* Combination longitudinal (closed arrows) and spiral (open arrows) fracture. This is a pattern of "comminution" in the more resilient immature skeleton. *K,* Lateral view of radial and ulnar fractures in a six-year-old boy. The fracture of the radius shows an intact dorsal cortex (white arrow) and a fractured volar cortex (black arrow), a characteristic greenstick injury. The fracture is also angulated because of plastic deformation of the dorsal cortex. A significant ulnar injury is not evident in this projection. *L,* AP view of the same fracture. This view looks very different, with no angulation, a torus ulnar fracture, and a longitudinal fracture of the cortex (black arrows), which separates it from the endosteal bone and terminates in a torus injury (white arrow).

injury. The fracture may appear undisplaced or displaced, in which case the distal fragment is shifted away from its usual relationship to the proximal fragment. This shift may assume several types of deformation, which may be present singly or in any combination. These are: (1) sideways shift, (2) angulation, (3) overriding, (4) distraction, (5) impaction, and (6) rotation. The most important to correct are angular and rotational deformities. While the former will often correct spontaneously, though unpredictably, the latter will not correct, and must be adequately treated initially, or they may require subsequent derotational osteotomy. As long as the reduction emphasizes restoration of longitudinal and rotational alignment, sideways shifts and overriding may be acceptable.

Relationship of fracture to external environment. Basically, a fracture is either closed (skin covering intact) or open (compound). An open fracture, in which a break in the skin allows a communication between the fracture and the external environment, may be caused by a fracture fragment penetrating the skin from within or by an external object penetrating or rupturing the skin from without (Fig. 1-4). These fractures carry the serious risk of infection. Treatment of open fractures is covered in Chapter 6.

Periosteum

Throughout most of childhood, the periosteum is thicker, more osteogenic, and more resistant to disruption than similar tissue in the adult. Because of its contiguity with the underlying bone, it is bound to be injured when the bone fractures. However, since the periosteum separates more easily from the bone in children, it is less likely to rupture completely, and a significant portion of the periosteum often remains intact, usually on the concave (compression) side. This intact periosteal hinge may lessen the degree of displacement, and may be used to assist in the reduction, as it imparts a certain degree of intrinsic stability (Fig. 1-5). Since the periosteum allows some degree of continuity, the subperiosteal new bone quickly bridges the fracture, leading to more rapid stability.

Joint disruption

Even though the ligaments exhibit a greater degree of laxity than they do in an adult, the capsule and ligaments are relatively more resistant to stress than the contiguous bone and cartilage. Consequently, ligament rupture and joint dislocations are infrequent in children. When major ligaments attach directly into an epiphysis, growth plate fractures are the most common failure mode. Joint dislocations in the child most commonly affect the elbow and hip. Knee and proximal tibio-fibular dislocations are less common. The other joints only rarely are dislocated prior to skeletal maturity.

Basics of Treatment

Since children can respond significantly differently than adults, they may require different and often specialized treatment. They have smaller respiratory and circulatory volumes, proportionately greater surface area, unique responses to drugs, surgery, and stress, and frequent difficulty in localizing and communicating symptoms. The margin for error in the pediatric age group is greater, and the response of the injured child is different quantitatively and qualitatively, physiologically, and psychologically from an adult. Abdominal distention and diaphragmatic elevation from post-traumatic ileus pose a much greater threat to a child's chest volume and ventilation than to an adult's. Similarly, the loss of a small amount of blood is proportionately more significant because of the child's lessened overall blood volume. The relatively large surface area (compared to body weight) allows rapid heat and water losses.

Factors requiring special consideration in the treatment of trauma in children include size, heat loss, respiratory reserve, fluid, electrolyte and caloric balance, drug therapy, congenital defects, and lability of a child's response to stress. Because small children have limited reserves, and because their conditions may deteriorate rapidly, speedy transport to an intensive care unit capable of managing seriously injured children assumes increased importance.

The problems requiring immediate attention in the management of the severely injured child are not different from those of the adult. Establishment and maintenance of an adequate airway, control of hemorrhage, detection and evaluation of head injury, replacement of blood loss, treatment of shock, recognition of serious skeletal injuries, and the pre-

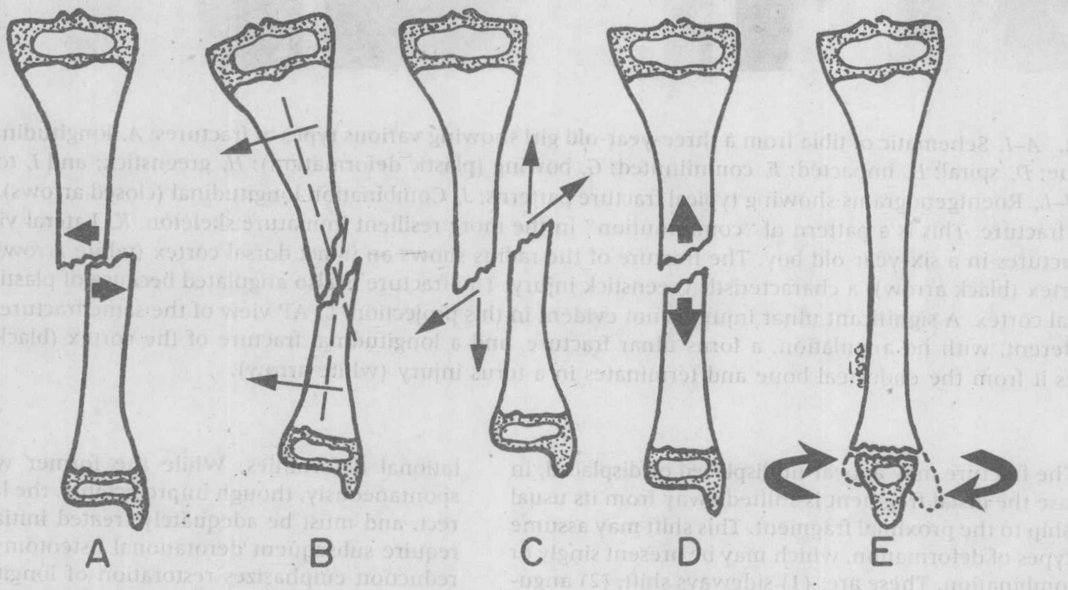
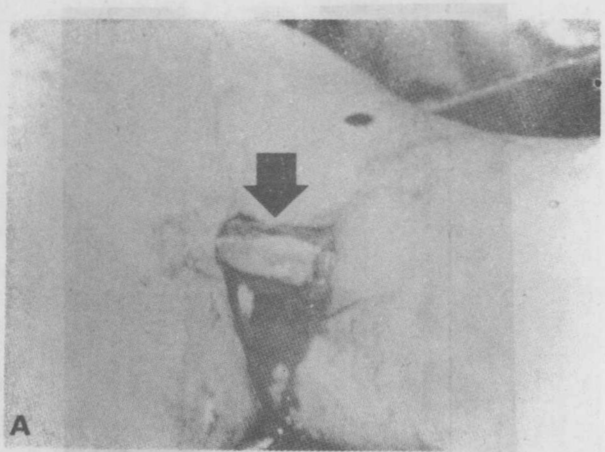


FIG. 1-3. Schematic of tibia from a six-year-old boy showing relationships of fracture fragments to each other. *A*, Translocation; *B*, angulation; *C*, overriding; *D*, distraction; and *E*, rotation in a distal epiphyseal fracture.



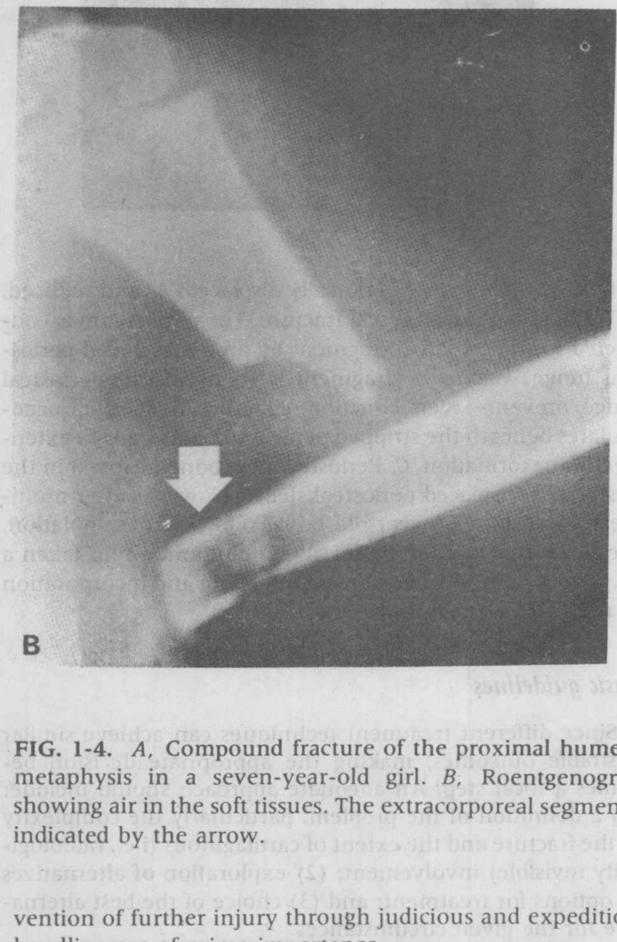


FIG. 1-4. *A*, Compound fracture of the proximal humeral metaphysis in a seven-year-old girl. *B*, Roentgenogram showing air in the soft tissues. The extracorporeal segment is indicated by the arrow.

vention of further injury through judicious and expeditious handling are of prime importance.

Head injury

Frequently, children injure their skull and brain, particularly if a vehicular accident is involved. The physician must be aware of some of the basic principles of treatment of head injuries. In children, fracture of the skull is generally less important than similar injury in an adult, unless the injury crosses a sinus or tears a nerve or blood vessel. The prime consideration is not the fracture, but damage to the brain. In the young infant with an elastic skull, much of the blow is absorbed by the osseous plates. Despite considerable depression of the bone, there may be little actual brain injury. Even the skull of a child with closing sutures and incomplete ossification absorbs a good deal of the blow in the osseous structure, transmitting less force to the brain itself. However, injuries to the tips of the frontal or temporal lobes may cause prolonged unconsciousness, extending for weeks or even months, but with complete recovery ultimately. Restlessness, agitation, and confusion may imply laceration and hemorrhage of the frontal and temporal lobes, whereas paralysis and deep shock suggest laceration of the brain itself. Extensor rigidity may be due to compression of portions of the temporal lobes, the cerebellum, or the brain stem. A child may fall and have momentary unconsciousness, followed by lucid intervals, then a second period of unconsciousness. This change in responsiveness suggests subdural or extradural hemorrhage. If the pupils are fixed, dilated, or contracted, or if the child cannot be aroused, serious brain damage must be suspected.

A child with head injury and multiple skeletal injuries should be permitted to assume a comfortable position in bed, unless he has a fracture of the cervical, dorsal, or lumbar spine, which would make such a posture inadvisable. Fractures of the extremities should be splinted for comfort, and treated more definitively several days later when the sensorium clears. Skeletal traction may be applied. Opiates, except codeine, should be avoided, and restlessness should be controlled by rectal aspirin or small doses of phenobarbitol. Lumbar puncture must be undertaken only after careful evaluation of the child, for elevation of pressure within the brain as a result of hemorrhage or soft tissue swelling may cause herniation through the tentorium, leading to further brain damage and death.

Sedation and anesthesia

Before satisfactory treatment can be provided, the fears and apprehensions of the child must be dispelled, and he must be given relief from pain. If reduction is necessary, proper levels of sedation and/or anesthesia are essential. In older, more cooperative children, one may infiltrate the fracture hematoma with a local anesthetic. Two points must be stressed in relation to this technique. First, unless the tip of the needle is in the fracture hematoma, as evidenced by aspiration of blood, anesthesia will be inadequate. Second, this must be done with rigidly sterile technique, after a thorough preparation of the skin with a bacteriocidal agent. Local infiltration may increase the risk of infection, with all its disastrous sequelae, because theoretically, local infiltration converts a closed fracture to an open fracture.

Intravenous regional block or even selective nerve blocks may be accomplished in the older child.[18] The use of intravenous diazepam must be undertaken with extreme caution. Appropriate anesthetic equipment must be available (mask, oxygen source, etc.). Further, one must remember that this latter drug is basically an amnesic, not an analgesic agent. The child will feel and react to pain, but will not remember doing so. The drug response may be delayed, and if the child must be sent to another area for postreduction films, he must be appropriately alert or a respiratory arrest may occur in an area where observation and resuscitation are difficult.