Child Abuse

MEDICAL DIAGNOSIS AND MANAGEMENT

Antoinette Laskey, MD, MPH, MBA, FAAP
Andrew Sirotnak, MD, FAAP

4th Edition

American Academy of Pediatrics
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With enduring gratitude to those who came before and laid the foundation on which we were able to build and grow and from whom we have learned so much

To my professional rocks APS, SPS, and TPH, who have helped me grow into the professional I am

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—ALL

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—APS

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Foreword

"To study the phenomena of disease without books is to sail an uncharted sea, while to study books without patients is not to go to sea at all."

Sir William Osler

Clinicians who evaluate patients to determine whether they have been harmed by neglect or sexual or physical maltreatment heed Olser's advice and use books along with peer-reviewed literature to complement their direct contact with these patients. It is, therefore, essential that authoritative books in the field of child abuse and neglect are available, current, and evidence based. This fourth edition of *Child Abuse: Medical Diagnosis and Management* continues its mission to present the best research available synthesized by leading experts.

The preface in the first edition, published in 1994, stated the "accumulation of understanding has appeared in such a diverse range of clinical and research journals that it requires constant vigilance to stay informed of recent advances. The practitioner needs an integrated resource for the strictly medical information when confronting a new case of child abuse." This is true to an even greater extent 25 years and more than 3,000 peer-reviewed articles published since Caffey's seminal article in 1946[1] and Kempe et al's article in 1962.[2] The relatively recent recognition of child maltreatment as a major contributor to morbidity and mortality in infancy, childhood, and adolescence has spawned the subspecialty of child abuse pediatrics. This new edition of *Child Abuse: Medical Diagnosis and Management* opens with a discussion of this evolving workforce.

In addition to the traditional core curriculum, comprehensively presented in the first 26 chapters, appropriate attention is also given to vicarious trauma and burnout, caring for the child in out-of-home care, and the medical and psychological sequelae of child abuse and neglect. The authors of the chapter on neurobiological consequences of child maltreatment address the central importance of adverse childhood experiences as critically significant in numerous adult pathologies. Finally, the concluding section discusses prevention and advocacy, persistently necessary approaches to the protection of children in a world fraught with challenges from all quarters of our social order.

Thanks are due to those who contributed chapters, the editors who selected them, and the American Academy of Pediatrics for publishing this book.

Robert M. Reece, MD, FAAP

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Acknowledgment

With this fourth edition, the editors and authors of the current edition wish to express their deep gratitude for the hard work and expertise of the previous editions' authors in creating a solid foundation on which we could build. Without their knowledge, effort, and mentorship, we would not be able to successfully advance this field of medicine.

Introduction

The Evolving Workforce

Antoinette Laskey, MD, MPH, MBA, FAAP
Andrew Sirotnak, MD, FAAP

Child maltreatment has affected children since long before medical professionals recognized the manifestations medically and psychologically in their patients. Over the years since the early publications identifying the specific findings that indicated a child had experienced sexual abuse, physical abuse, or neglect, there has been an increase in interest among certain medical professionals to care for these patients, to learn more about the conditions, and, importantly, to try to prevent the harm that can be done at the hands of a caregiver. The medical field has evolved from professionals without specific training but with a committed interest to this population to those who choose to obtain accredited fellowship training in child abuse pediatrics and to a growing interdisciplinary research community with a focus on the problem of child maltreatment.

There have also been important changes in how cases are handled among the multitude of professionals who are involved in the evaluation and management of the child who has potentially experienced abuse. What used to be a strictly siloed approach of each professional agency handling a case as it evolved is now an integrated, child-centered, ideally trauma-informed approach to caring for a child who has potentially experienced abuse. This is often accomplished through children's advocacy centers that bring together multidisciplinary teams committed to best practices and collaboration in working with children affected by violence. Partnerships between pediatricians and children's hospitals have been crucial in the development of a diverse range of programs, often associated or integrated within trauma, emergency, or pediatric medicine divisions. Building systems of care into communities, these programs often struggle to meet every need, ranging from medical evaluation, diagnosis, and management to follow-up care and trauma-informed behavioral therapy.

While some of us are attracted to pediatrics because we enjoy working with children, other medical professionals may think that child maltreatment is an issue that is irrelevant to them because they specifically chose *not* to go into the specialty of pediatrics. The truth is quite the opposite. As Robert Block, MD, one of the fathers of child abuse pediatrics and a former president of the American Academy of Pediatrics, once said, "All adults once were children, and who we are as adults is in many ways affected by our childhood experiences, environments, and relationships."

No matter the medical specialty, all medical professionals need to be aware of the prevalence, findings, and medical and psychological consequences of child maltreatment. It is important for all medical professionals to know what to do for current and past children who have experienced maltreatment to mitigate the potential negative health outcomes.

Since the first board certification examination offered in 2009, more than 400 pediatricians have obtained board certification from the American Board of Pediatrics in the subspecialty of child abuse pediatrics. Despite having these trained individuals who choose to focus on this aspect of pediatric medicine, there will always be a need for the frontline medical professionals around the country in community-based practices, community hospitals, and medical settings ranging from rural to urban, who see most of the children who have been maltreated. Some of these medical professionals have been informally and affectionately dubbed "Gen-CAPS" because they have a special interest in this population and are willing to work closely with their community partners such as law enforcement and child welfare agencies.

This new edition of *Child Abuse: Medical Diagnosis and Management* was developed with all these professionals in mind: the subspecialist trained in child abuse pediatrics, the Gen-CAP, the medical professional who sees children in his or her practice, and the medical learners who have yet to choose their clinical area of specialization. We hope that this edition will be a trusted education and clinical resource. We recognize that to effectively care for children who may have experienced maltreatment, there are many who must recognize maltreatment, respond, report when appropriate, and partner to provide ongoing medical and psychological care for the damage to be mitigated and the healing to begin.

PART 1

Physical Abuse

CHAPTER 4

Skeletal Manifestations of Child Abuse

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Historical Perspective

Skeletal injuries as a result of child abuse were first reported by Ambrose Tardieu in Paris in an 1860 report on children who experienced neglect and abuse.[1] In 1946, John Caffey noted the correlation between long bone fractures and subdural hematomas in infants.[2] This was even better described in his later article on shaken infants.[3] Subsequently, C. Henry Kempe coined the term "battered child syndrome" and included a number of children who had fractures and other bony injuries as a result of abuse in his seminal article.[4]

Presentation/Diagnosis

The most common presentation of a child with a fracture is when a child is brought in with a chief concern of a fall or other injury and has subsequent pain on manipulation or a gross deformity.[5] Infants are more difficult to evaluate because they are unable to properly localize and/or express pain. Although infants may also present with pain on movement or a gross deformity, they may present with only inconsolable crying and no obvious source. Fractures are a very common accidental injury and can occur in all

ages. However, fractures in younger, nonambulatory infants and children are more concerning for abuse. Almost 25% of infants who present with fractures are found to be abused, while only 3% of children aged 2 to 3 years who present with fractures are found to have experienced abuse.[6]

History of Present Illness

Whether or not a history is consistent with an injury is a strong indicator of whether the injury was the result of abuse. It is prudent for the medical professional to obtain a detailed history of the injury from the caregiver. This would include the circumstances surrounding the injury, how the child was injured, how the child landed, the flooring, other involved children and adults, and how the child reacted to the injury.[7] The child's developmental abilities will also assist in determining if the child's injury was accidental or not. Children who are nonambulatory (ie, not yet cruising) and especially those who are nonmobile are less likely to sustain a fracture accidentally. A lack of a detailed history of injury, a mechanism that is not consistent with the injury, a history that changes over time, and a delay in care are all historical indicators that are concerning for inflicted injury.[8] In instances where there is limited or no history of injury, obtaining the history of when the child was last well (uninjured) can help narrow the timing of the injury.

A past medical history should include medical conditions that would predispose a child to fragile bones and to injuries that are commonly seen in cases of abuse. This would include other injuries or fractures, hearing deficits, bruising history, and any other medical concerns. It is also necessary to obtain a complete birth history for prematurity, birth injuries, and prenatal conditions.

A thorough family history includes assessing if there are any other family members with a number of fractures or with fractures as a result of minor trauma. In addition, it is important to obtain the medical history of the parents and siblings as well as assess for dental and auditory issues.

The social history in suspected abuse cases includes any and all caregivers, including child care and babysitters and any other adults living in the home, and any prior contact with authorities. Social stressors such as money, job pressures, mental health conditions, and other children in the household should be evaluated. Families should be asked about prior social services contact, prescription and illegal drug use, and domestic violence because these can all contribute to abusive situations.

Physical Examination

The physical examination of children with fractures includes a thorough skin examination assessing the child for bruises, burns, or other marks concerning for inflicted injury, with special attention paid to oral and auricular injuries. A lack of bruising directly associated with the fractures

does not rule out abuse; in fact, fewer than 20% of inflicted fractures have associated bruises.[9] A detailed examination to determine if there are other areas of tenderness, crepitus, or swelling can assist in looking for other fractures. Features such as blue sclera, dentinogenesis imperfecta, gum disease, and bowed extremities can assist in identifying other conditions such as osteogenesis imperfecta (OI), which might predispose a child to fractures.

Radiographic Assessment

There are 2 main reasons to perform additional testing in children with suspected abuse. The first is to evaluate for other abusive injuries; the second is to rule out other causes for the child's condition. While some of the evaluation can be done in conjunction with other testing (eg, laboratory assessment), remember that the child's medical care takes priority; for example, a skeletal survey can be postponed until a child is clinically stable.

Imaging

In children with a fracture that is concerning for abuse, ensuring appropriate imaging of the fracture itself is paramount. This includes 2 or more views of the injured area and should also include views of adjacent joints or bones. Imaging the contralateral side may aid in diagnosing an injury. In a child for which plain radiograph results are negative, but for whom there is continued concern for bony injury, repeating radiographs in 10 to 14 days is prudent. An occult fracture will frequently become visible in that time frame through callus formation and/or remodeling.

Skeletal Survey

The skeletal survey is the most common study done to evaluate children for occult bony injuries or abnormalities. The skeletal survey is a series of images performed of each area of the body: at least 19 separate images as recommended by the American College of Radiology (ACR) (Box 4.1).[10] Some institutions add more studies, including oblique ribs, and may also reimage individual areas as needed. Unfortunately, there are still institutions (typically adult, more rural hospitals) that perform suboptimal studies. If a child is being transferred to a larger center, the skeletal survey can wait until after the transfer. The skeletal survey is recommended by the American Academy of Pediatrics and the ACR in children younger than 24 months, although newer research suggests that there may be yield in children up to 36 months or older.[8,10,11] There is little to support the utility of a skeletal survey in a child older than 5 years.

BOX 4.1
Complete Skeletal Survey Table

Appendicular Skeleton

Humeri (AP)
Forearms (AP)
Hands (PA)
Femurs (AP)
Lower legs (AP)
Feet (PA or AP)

Axial Skeleton

Thorax (AP and lateral), to include ribs, thoracic, and upper lumbar spine
Pelvis (AP), to include the mid lumbar spine
Lumbosacral spine (lateral)
Cervical spine (AP and lateral)
Skull (frontal and lateral)

Abbreviations: AP, anteroposterior; PA, posteroanterior

From American College of Radiology. ACR practice guideline for skeletal surveys in children (res. 47, 17, 35). In: *ACR Standards*. Reston, VA: American College of Radiology; 2006:203-207.

Follow-up Skeletal Survey

In cases where child abuse is strongly suspected, a follow-up skeletal survey (FUSS) 2 weeks later is recommended by the American Academy of Pediatrics.[8] Acute fractures, especially in the ribs and metaphyses, are easily missed and will become apparent later as the callus and/or periosteal elevation appear. A study by Harper and colleagues found that FUSSs yielded new information in 21.5% of children who had been referred to a hospital child protection team.[12] Radiation exposure is a common concern when repeating the skeletal survey, and more recent studies have shown that excluding the head, spine, and pelvis on the FUSS decreases radiation and has no significant effect on the yield.[13]

Postmortem skeletal surveys can be performed after death in cases of suspected abuse. Routine autopsy protocols do not include the appendicular skeleton, and injuries can be missed if they are not found prior to autopsy. As with routine skeletal surveys, these studies should be done under the observation of a trained radiologist according to the ACR recommendations.[10] Because each jurisdiction has different policies for consent and authority in such cases, a hospital should have preexisting protocols on how to handle postmortem skeletal surveys. In addition, there must be consideration of trauma to the staff in performing these studies.

Ultrasonography

Ultrasonography is particularly useful in diagnosing injury at the costochondral junction and in demonstrating subperiosteal abscess prior to the appearance of fracture or periosteal reaction on plain radiograph.[14–16] It can also be used to visualize the non-ossified epiphysis in cases of trans-physeal distal humerus fracture.[17] Advantages of ultrasonography are that it is quick and noninvasive and does not involve radiation. However, it is operator dependent, and the quality and interpretation of the studies vary with practitioner experience.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) can be used as an adjunctive study in cases in which clinical suspicion of diaphyseal fracture is high but plain radiographs are negative. However, whole-body MRI should not be used as a stand-alone screening test or in lieu of the skeletal survey, because it is not sensitive in picking up rib fractures or classic metaphyseal lesions (CMLs), both of which are injuries highly specific for abuse.[18] Magnetic resonance imaging has the advantage of not involving radiation, but it has the drawback of typically needing to be done under sedation or anesthesia in young children.

Positron Emission Tomography

Positron emission tomography scanning using sodium fluorine-18 can be a useful adjunct for the diagnosis of abusive fractures, although it does not replace the need for an initial skeletal survey.[19] One study has shown that it is more sensitive than initial skeletal survey in the diagnosis of thoracic and rib fractures, although less sensitive for visualizing CMLs.[20] Done in conjunction with the skeletal survey, it can, therefore, sometimes provide additional information prior to the 2-week waiting time for a FUSS. This can be helpful in cases in which follow-up cannot be assured or in which it is necessary to make immediate decisions about disposition. However, the test does involve radiation, generally requires sedation or anesthesia, and may not be available at all centers. Traditional bone scan is no longer commonly used in the diagnosis of non-accidental trauma, because it involves radiation, takes a significant amount of time to perform, and is not sensitive for skull fractures, CMLs, fractures in the vicinity of growth plates, and symmetrical bilateral fractures. It also gives no information on the age or stage of healing of fractures.

Evaluation of Siblings

Siblings and other children in the same environment (eg, child care) where the patient was injured are also at risk for inflicted injury and

should be appropriately evaluated. This evaluation includes a thorough physical examination and a radiologic evaluation depending on age. Skeletal surveys should be strongly considered for young (<2 years or so) siblings and other children in the same environment with a child who has experienced abuse, and head imaging should be considered in infants younger than 6 months.[8] A study by Lindberg and colleagues found that 16% of contacts of children who had experienced abuse had an occult fracture. Twin siblings were at highest risk.[21]

Laboratory Assessment

Laboratory evaluation should be done to rule out any medical conditions that might predispose a child to fracture more easily than expected. Calcium, phosphorus, and alkaline phosphatase levels can determine basic bone metabolism, although an elevated alkaline phosphatase level can be present with multiple healing fractures.[22] Occult abdominal injuries should be screened for with liver and pancreatic testing as well as a urinalysis. Other useful laboratory studies include 25-hydroxy vitamin D levels, parathyroid hormone levels, and urine calcium/creatinine excretion ratios in children with clear osteopenia or concerns for rickets. Serum copper, vitamin C, and genetic testing for medical conditions can be guided by the history and physical examination.

Dating of Injuries

Fractures of long bones and ribs commonly heal in an expected pattern. On radiograph, it is easy to distinguish acute fractures from those with clear callus formation. In most children, callus formation occurs about 7 to 10 days after the initial fracture. Periosteal reaction, a more accurate finding for dating fractures, is not present acutely and appears around 11 days' post-injury. More subtle findings, such as the presence of a fracture line and hard versus soft callus formation, are not useful for dating fractures[23] (Table 4.1).

TABLE 4.1
Estimating Fracture Age

Radiographic finding	Time From Injury
Periosteal new bone	10–14 d
Resorption of fracture line	14–21 d
Early callus	14–21 d
Bridging callus	21–42 d
Remodeling	≥6–12 mo

Adapted from Halliday KE, Broderick NJ, Somers JM, Hawkes R. Dating fractures in infants. *Clin Radiol.* 2011;66(11):1049–1054, with permission from Elsevier.

Biomechanics

Biomechanics is the scientific discipline that qualifies and quantifies the complex interplay between the structure and function of the musculoskeletal system. The human body is subject to a wide variety of internal and external forces.[24] *Internal forces* are those exerted by one part of the body on another (eg, muscle on bone). *External forces* are exerted on the body by the environment. In vivo, these interactions are extremely complex. In experimental or hypothetical settings, the goal is to control for enough variables to obtain meaningful, reproducible data without oversimplifying to the point where relevance to a clinical setting is compromised.

Material properties of a substance, such as bone, are independent of shape and include elasticity, brittleness, and toughness. They characterize the mechanical function and structural limitations of a substance.[24] Structural properties are dependent on the substance and its shape. Stiffness, which is the ability to resist failure in torsion, axial load, or bending, is a structural property. Bone is also anisotropic, meaning that its mechanical properties differ depending on the type of load applied to it. Bone is weakest in withstanding shear, followed by tension, and is strongest in compression. Cortical and cancellous bone have differing abilities to withstand force, and an individual's bone mineral density also plays a role. Another biomechanical feature of bone is that it is viscoelastic; its deformation characteristics depend on the rate of loading. An example is the trabecular bone, which is stiffer in compression the faster it is loaded.[25]

All these interacting variables complicate the ability to design in vitro experiments and laboratory models of fracture that accurately reproduce in vivo conditions.[24] It is challenging to reproduce the conditions of living bone that are present in a live human being, including a soft tissue envelope and blood flow, by using cadaver or artificial bone in a laboratory setting. Animal and computer models are useful but also have limitations. This is why it can be challenging to definitively answer questions in the clinical setting about how a fracture occurred or how much force it took to cause a fracture.

However, fracture morphology does give very basic information about the type of force that causes a fracture. Tension causes transverse fractures, axial load or compression causes torus or oblique fractures, bending causes transverse fractures with or without a butterfly fragment, and torsion causes spiral fractures.[25] Orthopedists typically use this simplified scheme to aid in planning surgical constructs (eg, a fracture that occurs in tension is fixed with a plate applied with compression).

Classic metaphyseal lesions are typically described as the result of shear, but a porcine model has reproduced CMLs via lateral bend, which is a tensile force.[26] Any of the types of forces described herein can be generated via accidental and intentional mechanisms.

The amount of force necessary to load a bone to failure in vivo is subject to many variables, including the size and shape of the bone, its cortical thickness and trabecular architecture, and the direction and speed of the force.

Fracture Specificity

Kleinman has delineated a pattern of specificity of abuse in childhood fractures (Box 4.2). In this scheme, he describes high-, mid-, and low-specificity fractures.[27]

High-Specificity Fractures

Long Bone Fractures in Nonambulatory Children

Any long bone fracture (diaphyseal, metaphyseal, or physeal) in a child who is too young to walk should raise concern for child abuse. A single, isolated, transverse long bone fracture is the most common fracture pattern in abusive trauma; it occurs in 13% of cases.[28] Various series show the humerus, tibia, and femur to be most commonly affected.[28–31] While earlier literature postulated that spiral fractures were particularly suspicious for abuse, numerous, more recent studies have found transverse fractures more common in cases of abuse, particularly in the femur.[7,28,32,33] One large meta-analysis showed no significant differences in distribution between spiral, transverse, and oblique patterns in abusive femur fractures.[30]

Other, more recent studies have focused on child age and developmental stage as a diagnostic aid. For femur fractures, nonambulatory status is the single most important predictive factor for likelihood of inflicted injury.[30,34,35] Abuse accounts for up to 80% of femur fractures in infants younger than 1 year.[29,36,37] In a study of 139 children aged 4 years or younger, Schwend et al found that 42% of diaphyseal femur fractures in nonambulatory children were attributable to abuse, compared with only 2.6% in the ambulatory cohort.[34] Another study, looking at a total of 138 femur fractures in children up to 4 years old, found that 74.1% of fractures in infants 12 months or younger were secondary to abuse, compared with 14.3%, 8.9%, and 5.3% in the 13- to 24-month-old, 25- to 36-month-old, and 37- to 48-month-old cohorts, respectively. There was also a statistically significant difference in the rate of abuse in infants 12 months or younger compared with all the other cohorts.[35] The American Academy of Orthopaedic Surgeons clinical practice guidelines on pediatric diaphyseal femur fractures recommends evaluation

BOX 4.2
Fracture Specificity

High-Specificity Fractures

Long bone fractures in nonambulatory children

- Trans-physeal distal humerus fractures
- Classic metaphyseal lesions
- Rib fractures
- Sternum, scapula, or pelvic fractures without history of major trauma

Multiple fractures

- In various stages of healing
- Bilateral symmetrical fractures (acute or healing)
- Fractures associated with other injuries

Mid-Specificity Fractures

Spine fractures

Fractures of the hands and feet

Skull fractures

Clavicle fractures

Isolated long bone fractures in ambulatory children without a plausible history

Low-Specificity Fractures

Toddler fracture

Distal radial and ulnar torus fractures

Supracondylar humerus fractures

Isolated long bone fractures in ambulatory children with a plausible history

From Kleinman PK, ed. *Diagnostic Imaging of Child Abuse*. 3rd ed. Cambridge, United Kingdom: Cambridge University Press; 2015.

for child abuse for all children younger than 36 months with a femur fracture (Figure 4.1).[38] Although several studies make similar recommendations, most acknowledge that infants younger than 1 year, and children who have not yet achieved ambulation, are most at risk.[32,34,39] Subsequently, this guideline was made by consensus, because of a lack of sufficient evidence-based medicine to support a specific evaluation age cutoff.

Two studies have looked at complete transverse metaphyseal fractures of the distal femur. Arkader et al found that these fractures were a "harbinger" of abuse in children younger than walking age, with 75% of patients younger than 1 year presenting with this injury found to have experienced abuse.[40] However, Haney et al determined a much lower rate of abuse (28%) in a series of comparable size and similar fractures. They proposed a "plausible accidental mechanism" for such fractures (eg, the parent falls while carrying the child straddled across one hip,

FIGURE 4.1
Diaphyseal femur fracture.

compressing the child's distal femur, which lands beneath the parent's body), particularly if there are no other concerning corroborative findings on the physical examination or skeletal survey.[41] Of note, all 5 of the infants in their series who had experienced abuse were younger than 1 year, once again highlighting the need to maintain a low threshold to investigate long bone fractures in nonambulatory children. Coffey et al found that 96% of tibia and fibular fractures in a cohort of children younger than 18 months were secondary to abuse.[42] Similarly, 54% of humerus fractures in children younger than 3 years are likely the result of abuse, with the prevalence statistically significantly higher in children 15 months or younger.[30,43,44]

Displaced physeal fractures are sometimes referred to as "epiphyseal separations," although most orthopedists prefer to describe these injuries

more specifically by using the Salter-Harris classification.[45] The Salter-Harris classification has strong intra- and interobserver reliability and is generally prognostic (ie, a Salter-Harris type 1 fracture usually has a better prognosis than a Salter-Harris type 2 fracture, and so on).[45,46] An example of a physeal fracture frequently associated with abuse is the trans-physeal distal humerus fracture (figures 4.2 and 4.3). The fracture pattern is usually a displaced Salter-Harris type 1 fracture of the distal humeral physis. However, these fractures typically occur in infants younger than 1 year, in whom the distal humeral epiphysis is completely non-ossified; therefore, the entire distal fracture fragment is not visible on plain radiograph, making diagnosis challenging. Subsequently, these fractures are often diagnosed late, once periosteal reaction is visible on plain radiograph. Acutely, ultrasonography, MRI, or arthrogram can aid in diagnosis. A recent study found the diagnosis missed on 56% of plain radiographs but confirmed by ultrasonography in 100% of cases, with 38% of cases (all in infants younger than 1 month) secondary to birth trauma and 40% the result of abuse.[17]

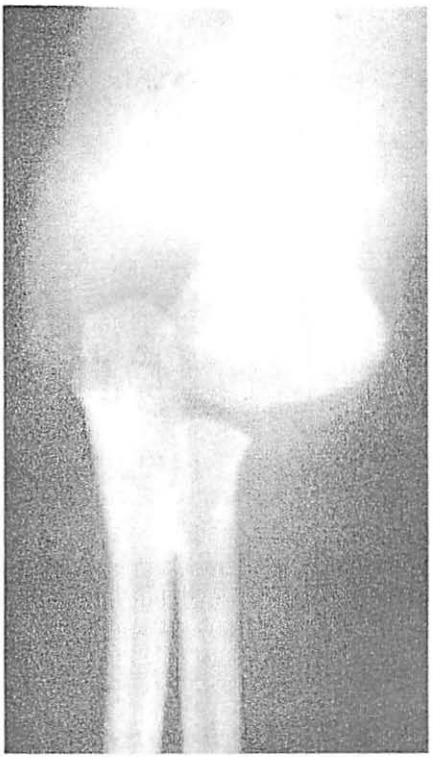

FIGURE 4.2
Trans-physeal distal humerus fracture.

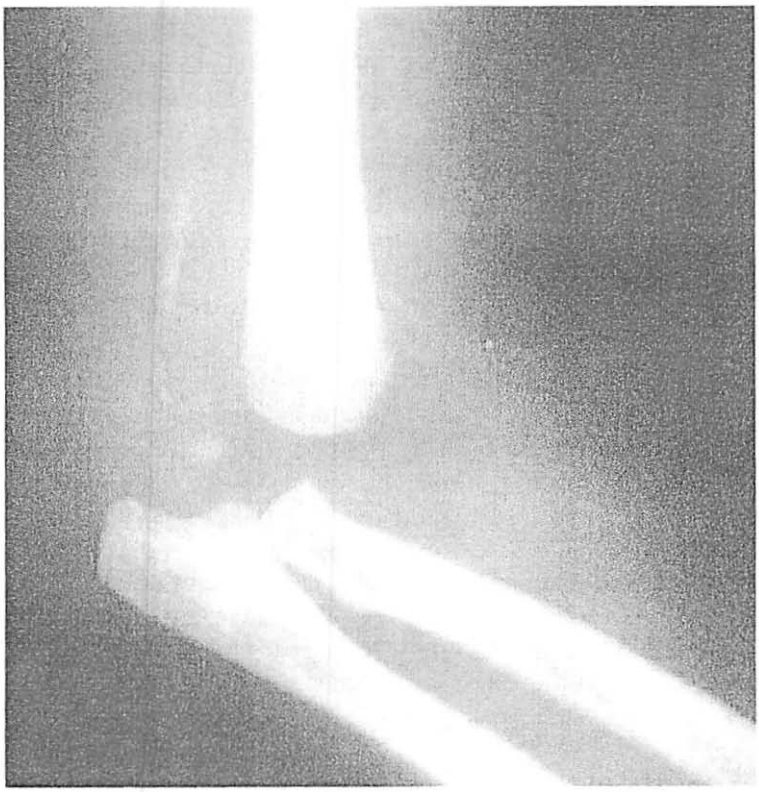

FIGURE 4.3
Trans-physeal distal humerus fracture.

Classic Metaphyseal Lesions

Classic metaphyseal lesions, although relatively uncommon, are highly specific for abuse, particularly if they are found to be present in more than 1 long bone.[47–49] They account for up to 28% of abusive long bone fractures.[28,50,51] They are speculated to occur via a mechanism of combined traction and torsion, causing shearing forces through the periphery of the metaphysis.[52] However, an experimental porcine model has produced CMLs by applying a tensile stress through varus and valgus loading.[26] The resultant fracture consists of a peripheral fragment of metaphysis, which includes the subperiosteal bone collar, and abuts but does not affect the physis (figures 4.4 and 4.5). The fragment is typically discoid and wider peripherally than centrally. Fragment appearance on radiography depends on the view and is the source of the historical descriptions of the CML: on a tangential anteroposterior or lateral view, the fracture appears as wedge-shaped fragments at the edge of the metaphysis ("corner" fracture); on an oblique or angulated view, curvilinear fragments adjacent to the

metaphysis are visible (bucket-handle fracture) (figures 4.6 and 4.7). Classic metaphyseal lesions also have a characteristic histological appearance of sub-physeal microfractures through the primary spongiosa and calcified cartilage of the metaphysis.[53]

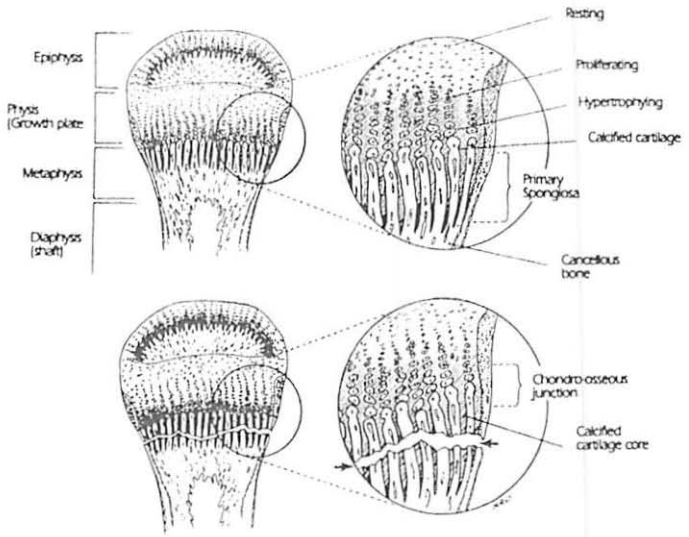

FIGURE 4.4
Common metaphyseal lesion.

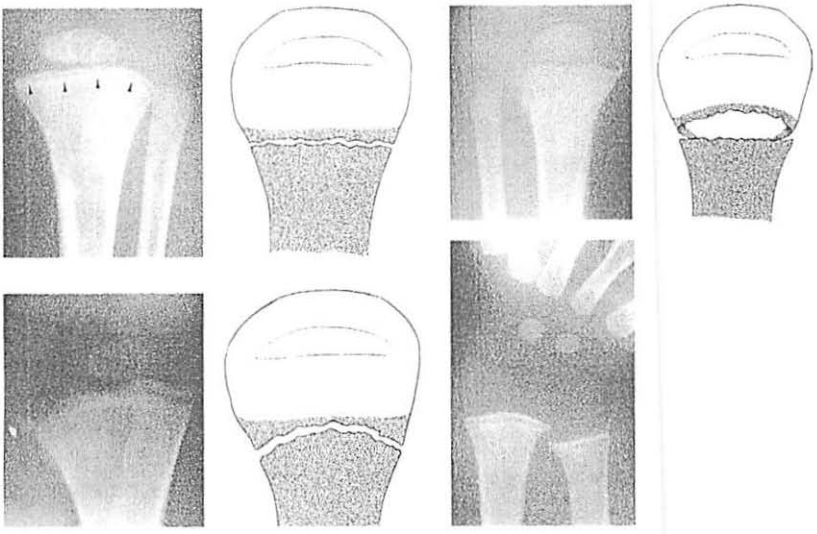

FIGURE 4.5
Common metaphyseal lesions.

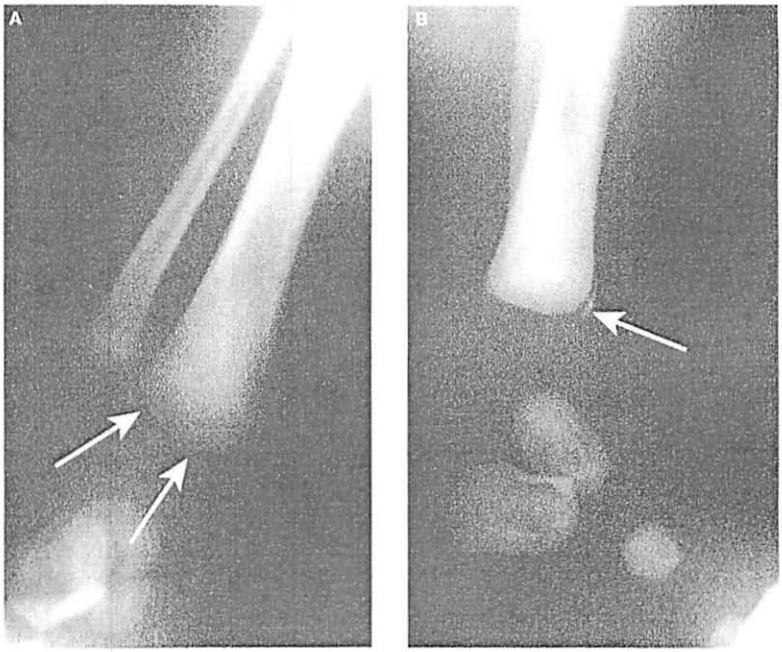

FIGURE 4.6
A 1-month-old had a swollen left leg. A, Radiography shows a bucket-handle fracture (arrows) of the distal tibial metaphysis. B, Viewed in a lateral projection, it appears as a "corner" fracture (arrow).

FIGURE 4.7
Distal tibia classic metaphyseal lesion with a "chip" appearance.

Because the periosteum is firmly adherent to the bone in the region where CMLs typically occur, they sometimes produce little subperiosteal hemorrhage. Subsequently, it is possible for them to heal without generating a large amount of periosteal reaction. However, in such cases, it is often possible to visualize healing of the fracture on plain radiograph by using highly detailed radiographic techniques.[54,55] Because CMLs are highly specific for abusive trauma in infants, it has been suggested that high-detail radiography and histologic evaluation of metaphyseal bone samples be a part of the postmortem evaluation of infants in cases of suspected abuse or unexplained death.[54] Although the traction-torsion mechanism thought to be responsible for most CMLs is rare in the setting of accidental trauma, particularly in infants younger than 1 year,[40] there have been reports of CMLs occurring accidentally during cesarean delivery and during therapeutic manipulation and casting of clubfeet being treated by the Ponseti method.[56,57]

Rib Fractures

Rib fractures are highly specific for abusive trauma (Figure 4.8). A meta-analysis calculated the probability of abuse in a child with a rib fracture at 71% (95% CI, 42%–91%).[30] Similarly to the case of long bone fractures, prevalence of abuse associated with rib fractures increases as the age of the child decreases, with 80% of rib fractures in infants younger than 1 year found to be inflicted.[58] Historically, a classic pattern of 3 or 4 posterior fractures of consecutive ribs, corresponding with the placement of the perpetrator's fingers while squeezing or shaking the child, has been described[47,59] (Figure 4.9). However, in Kemp's meta-analysis, 2 included studies[60,61] showed anterior rib fractures to be most common in abuse, and the predictive value of posterior rib fractures was not consistent.[60–62] Overall, the specific location of the rib fractures was not directly correlated to the likelihood of abuse.[30]

Children's ribs are relatively strong and flexible; therefore, rib fractures are a marker for high-energy trauma, with an increased risk of mortality.[47] It is imperative to carefully examine children with rib fractures for other fractures, head trauma, and visceral injuries. Chest compressions administered while performing cardiopulmonary resuscitation have not been found to result in rib fractures.[59,63,64] A study in 2014 reviewed 546 chest radiographs in 80 infants who received cardiopulmonary resuscitation via the "2-thumb" technique and identified no rib fractures.[65] In the absence of a documented high-energy injury, such as a motor vehicle crash or a fall from a significant height, rib fractures in young children should raise concern for child abuse.[47,48,66]

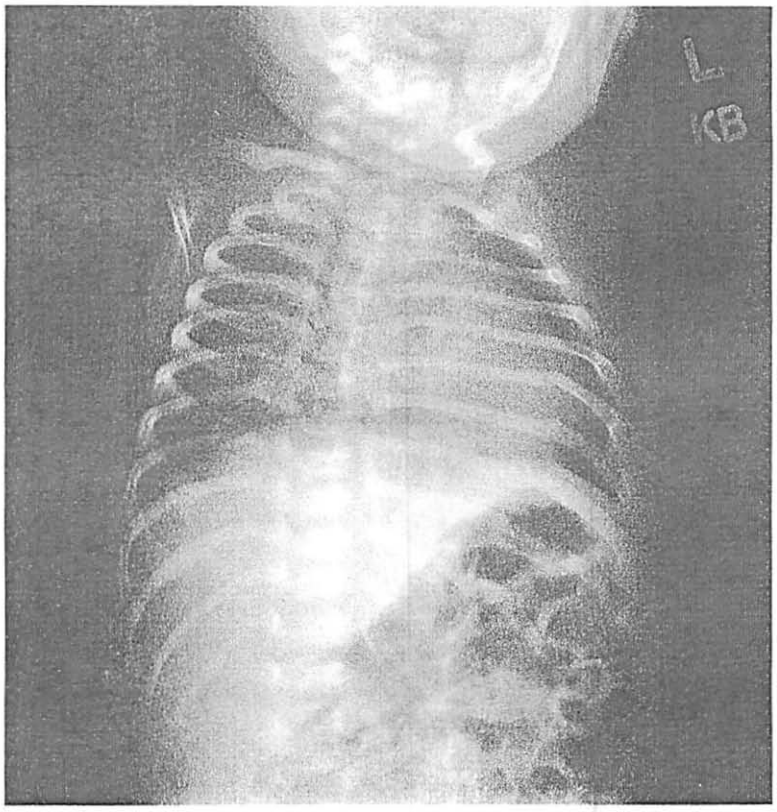

FIGURE 4.8
Rib fractures.

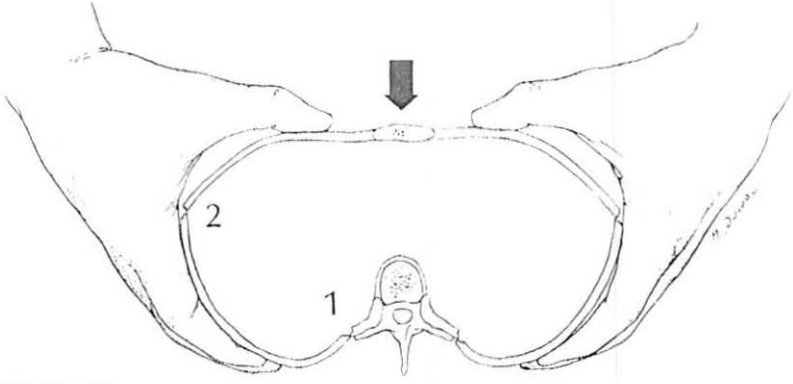

FIGURE 4.9
With anteroposterior compression of the chest, rib fractures occur initially in the proximal rib over the transverse process of the adjacent vertebrae (1) and more laterally along the posterior arc of the rib to the midaxillary line (2).

Sternum, Scapula, and Pelvic Fractures

Fractures of the sternum, scapula, and pelvis are rare in children and are almost always the result of high-energy trauma. They should trigger concern for abuse in the absence of a verifiable, plausible mechanism, such as a motor vehicle crash or a fall from a significant height.[47,67–71]

Multiple Fractures

Multiple fractures, either acute or in various stages of healing, are highly specific for abuse.[6,30,72] (Figure 4.10). Fifty percent overall of children who have experienced abuse, and 80% of those younger than 1 year, will be diagnosed with more than 1 fracture.[47,49,73] There is an odds ratio for likelihood of abuse of 4 to 6 for children with 3 or more fractures, compared with those with only 1 fracture.[6] A specific common pattern is bilateral acute femoral, tibial, or humeral fractures, consistent with the child being held and shaken by the extremities.[3,74–76]

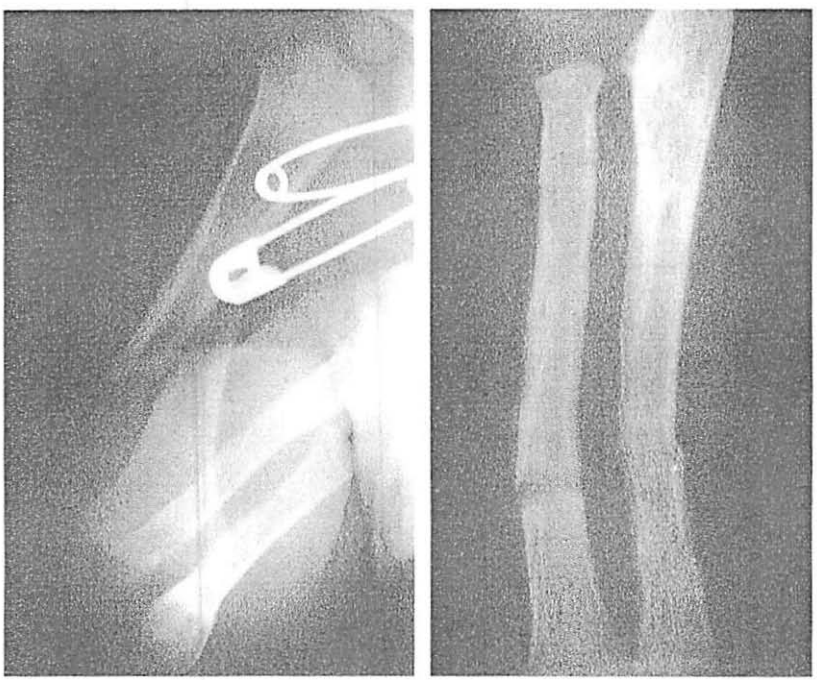

FIGURE 4.10

Multiple fractures in various stages of healing in the same individual. The humerus is acute in appearance with no signs of healing, while the radius and ulna have periosteal elevation and callus formation.

Skull Fractures

Corroborative history is important in the evaluation of skull fractures, because the most common fracture pattern is the same in accidental and abusive trauma: a simple, linear parietal fracture.[83–85] Abuse should be suspected in cases of inconsistent or implausible history. The literature varies on whether or not more complex skull fractures (stellate, depressed, diastatic, multiple, bilateral, or crossing suture lines) are more likely than simple fractures to be associated with abuse[83,85–87] (Figure 4.13). Short falls (<3 feet) are unlikely to cause a complex skull fracture.[88,89]

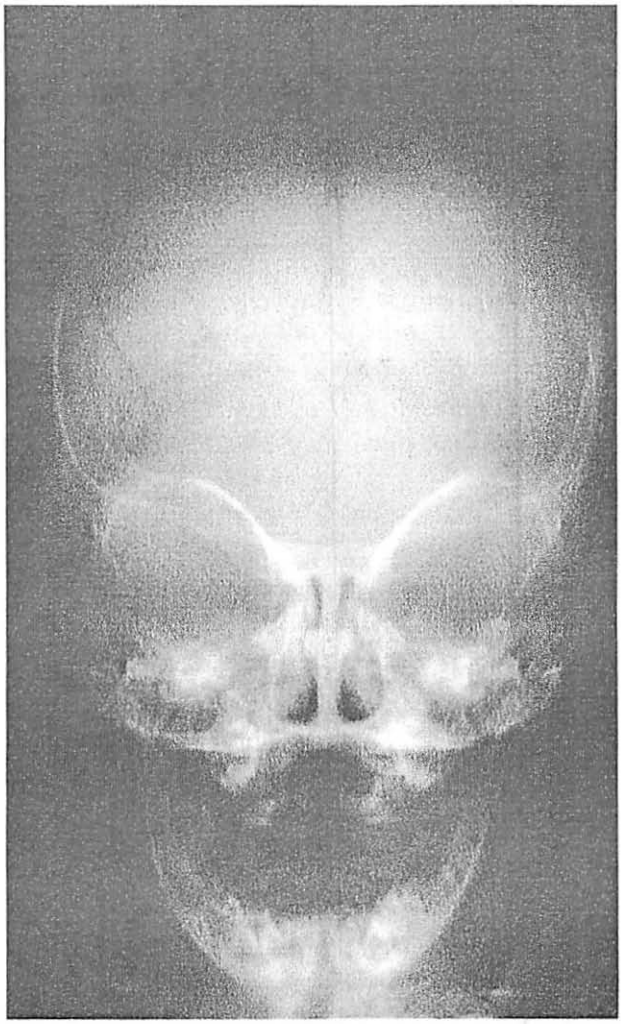

FIGURE 4.13
Complex or stellate skull fracture.

Clavicle Fractures

Fractures of the clavicle are a common result of birth trauma. In such cases, callus formation will be visible on radiography when the baby is 7 to 10 days old. An acute clavicle fracture (Figure 4.14), without evidence of healing callus, in a neonate older than 10 days should raise concern for abuse. Most clavicle fractures, both accidental and inflicted, occur in the mid-shaft region. Distal and proximal clavicle fractures are uncommon in children younger than 3 years; in this cohort, they can be the result of shaking.[68] In various studies, clavicle fractures have been reported in 3% to 10% of cases of abuse.[28,67,90,91]

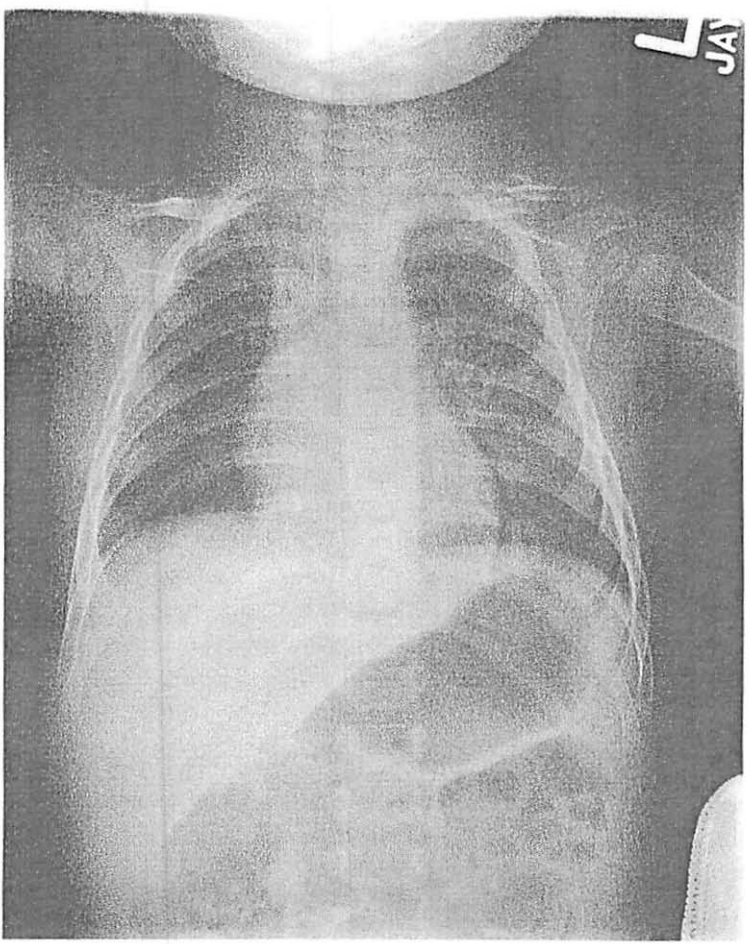

FIGURE 4.14

A 6-month-old presents after 2 episodes of altered breathing and cyanosis. Evaluation revealed a biparietal skull fracture, bilateral subdural hematomas, left clavicular fracture with minimal callus formation, and bruising of the leg, forehead, and foot. No history of trauma was offered.

Isolated Long Bone Fracture in an Ambulatory Child Without a Plausible History

A long bone fracture in an ambulatory child that results from an unwitnessed injury or for which no plausible explanation is given presents a diagnostic challenge. It should raise concern for abuse and, therefore, should be evaluated with a workup for abuse. However, this situation is not as suspicious as that of a nonambulatory child with a fracture. In all these cases, a thorough history and physical examination, including a detailed social history, can assist in determining the likelihood of an accidental or abusive injury.

Low-Specificity Fractures

Toddler Fracture

A toddler fracture typically presents as an isolated, non-displaced spiral fracture of the distal tibial metaphysis, although it can be diaphyseal as well. Often, it is necessary to obtain an oblique radiograph of the tibia to adequately visualize the fracture. These fractures are sustained by ambulatory children and can result from seemingly trivial injury; parents often report a misstep off a stair or curb or a simple standing-height fall. A well-documented etiology for this fracture pattern is a child getting his or her foot caught along the edge of a playground slide while going down the slide seated on an adult's lap.[92] This particular mechanism can occur in nonambulatory children. However, keep in mind that a radiology report of "toddler fracture" is by no means a guarantee of accidental etiology, and, with the exception of the slide mechanism noted previously, a child must be ambulatory to sustain a true toddler fracture. Another low-specificity variation of tibia fracture is a transverse or torus fracture of the proximal tibial metaphysis, caused by the recoil of the mat of a trampoline.[93]

Distal Radial and Ulnar Torus Fractures

Buckle fractures of the distal radius and ulna are the result of compressive forces that typically occur from a fall on an outstretched arm or from running into a barrier with the arm outstretched. They are extremely common and are almost always accidental.

Supracondylar Humerus Fractures

Supracondylar humerus fractures are typically accidental and occur from a fall, often from playground equipment or a trampoline.[43,44,94] In one study of 388 supracondylar humerus fractures, the mechanism was a fall

in 79% and child abuse in 0.5%.[94] However, as is the case with other types of fractures, it is still necessary to maintain a higher index of suspicion the younger the child is. Another study found 30% (3 of 10) supracondylar fractures in children younger than 3 years to be abusive.[44]

Differential Diagnosis

Fracture mechanisms other than abuse should always be considered as part of the evaluation. A thorough past medical and family history can help to narrow down possible medical conditions that may contribute to fractures. The workup and management of medical conditions can be improved with the assistance of other subspecialties including orthopedic surgery, endocrinology, and genetics.

The most common cause of a fracture in a child is an accidental injury. Medical conditions such as OI, rickets, and disuse osteopenia can predispose children to fracture with minimal force. These conditions are commonly brought up by families and defense attorneys in cases of suspected child abuse. It is important that medical professionals evaluate each suspected abuse case individually to ensure that alternate causes have been properly ruled in or out. However, a child who is found to have a medical condition can still experience abuse.

Accidental Fractures

Accidental fractures represent a significant number of injuries every year. In children younger than 3 years, more than 70% of fractures are the result of an accidental injury.[6] It is not uncommon in cases of inflicted injury for the caregiver to provide a false history of injury, most commonly involving a household fall. However, children can be unpredictable and have been reported to have some rather unexpected injuries from normal play. The presenting history must be carefully considered in light of the child's developmental abilities and the pattern of fracture presented.

Obstetric Trauma

Birth trauma, especially clavicular fractures, can be occult and missed in the newborn period. Clavicular fractures are very common in typical newborn deliveries and should be considered in an infant who presents within a month or two of delivery. Long bone and skull fractures are rarer and are usually only seen in traumatic deliveries. Rib fractures have been reported as a result of birth trauma but are rare and associated with large neonates and traumatic deliveries.[62]

Nutritional and Metabolic Causes

Rickets

Vitamin D deficiency rickets is rare in developed countries. While children may be found to have laboratory evidence of vitamin D deficiency or insufficiency, rickets and the resultant increase in bony fragility is only seen when there are clear findings on radiography.[95] These findings include demineralization, loss of zone of provisional calcification, widening of the physes, and metaphyseal cupping (Figure 4.15).

Abnormal bone metabolism can also be the result of renal disease (renal osteodystrophy). Chronic kidney disease results in abnormalities in phosphorus, calcium, vitamin D, and parathyroid levels in the bones.[96] Patients can develop significant bony fragility, especially if their condition is inadequately managed. These conditions are rarely confused with abuse because of the clear medical history of renal disease.

FIGURE 4.15
Rickets with widening of the physes and metaphyseal cupping.

Preterm Birth

Preterm birth, especially when the child is severely preterm or very ill, can result in bony fragility as a result of inadequate bone mineralization.[97] The third trimester is the period during which a fetus's bony skeleton is mineralized; the loss of that trimester can contribute to poor bone development. In addition, use of diuretics or prolonged parenteral nutrition can also contribute to poor bone mineralization. Some of these neonates even sustain iatrogenic fractures while hospitalized.

Osteogenesis Imperfecta

Skeletal dysplasias such as OI are rare genetic conditions that may result in fragile bones that are more prone to fracture. Osteogenesis imperfecta is caused by defects in the formation of type I collagen. The most common mutations are seen in the *COL1A1* and *COL1A2* genes. Depending on the variant, these can present at or near birth with in utero fractures and severe bowing of the extremities, conditions that are unlikely to be mistaken for abuse (Figure 4.16). Less severe types of OI typically manifest with fractures that could be mistaken for abuse, including extremity

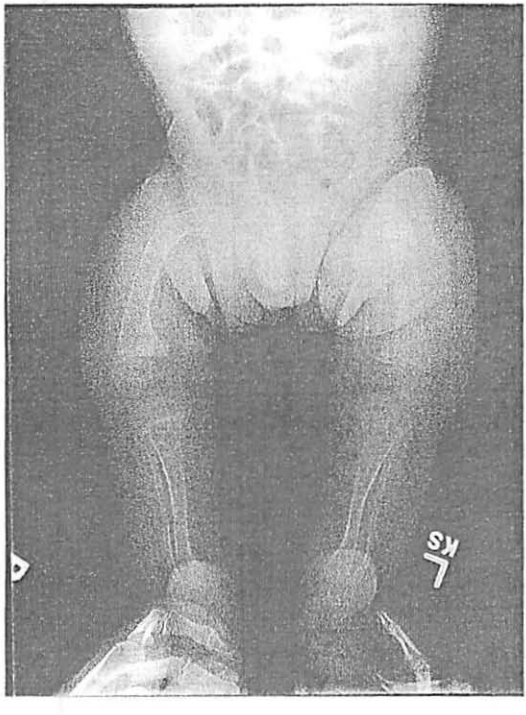

FIGURE 4.16
Osteogenesis imperfecta as shown with severe osteopenia and bowing of the long bones.

fractures; however, these typically present in ambulatory children. Common findings include wormian bones in the skull (Figure 4.17), blue sclera, and dentinogenesis imperfecta.[98] A family history of easily fractured bones or dental anomalies may assist in determining if the child is at risk for a skeletal dysplasia; however, many of these are de novo genetic abnormalities, and the lack of a family history does not rule out a skeletal dysplasia. In cases where there is significant concern for bony fragility, consultation with a geneticist and/or more detailed genetic testing for the common genetic findings in OI can assist in diagnosis.

Other Conditions

Scurvy, or vitamin C deficiency, is rare with appropriate nutrition but is still seen in cases of food fads and other limited diets.[99] Children with scurvy have metaphyseal changes that may mimic CMLs, but other findings, including the diet history, osteopenia, and mucous membrane hemorrhages, can assist in assigning the proper diagnosis.[100] Menkes disease is a rare x-linked recessive genetic condition that results from a defect in copper metabolism. Metaphyseal changes and subperiosteal new bone formation may be seen on radiographs. However, children with Menkes disease commonly have identifiable sparse, kinky hair as well as

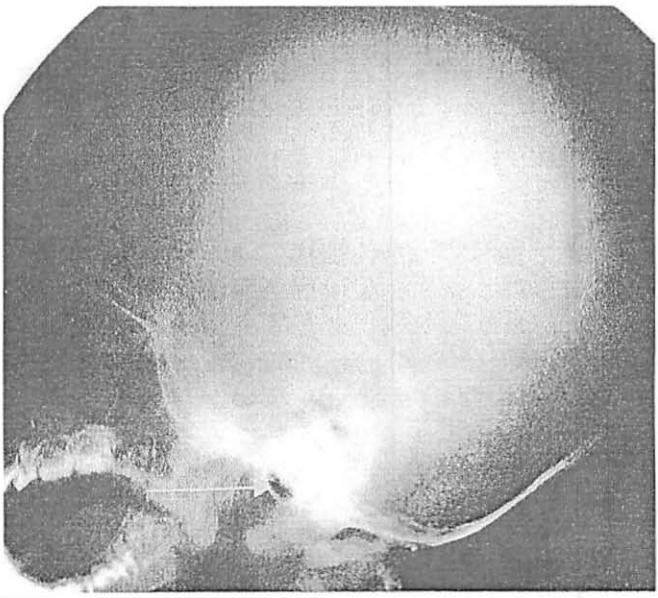

FIGURE 4.17
Osteogenesis imperfecta with wormian bones.

failure to thrive, developmental delay, wormian bones, and anterior rib flaring.[101] There are other rare genetic diseases that can predispose infants and children to fractures. These are usually readily apparent with physical examination and radiographs.[102]

Infection/Neoplasm

Bony infections (osteomyelitis) and neoplasms can lead to bony fragility and pathologic fractures. These are usually easy to distinguish from abuse with history, physical examination, laboratory evaluation, and radiography. Osteomyelitis can be present with septic arthritis and may have irregularities at the metaphyses that may resemble CMLs. Examination and laboratory assessment will reveal systemic concerns such as fever, elevated white blood cell count, erythrocyte sedimentation rate, C-reactive protein, and other markers for infection.[8] Lytic bony lesions can be malignant or benign but are usually clearly visible on radiograph, especially to a trained radiologist. Bony metastases can also cause bony fragility and leave children more prone to fracture, but again, these conditions should be readily identified with routine laboratory assessment.

Disuse Osteopenia

Children with musculoskeletal conditions that prohibit them from typical ambulation and movement are at risk for demineralization as a result of the lack of weight-bearing and movement.[103] These children can develop fractures as a result of routine caregiving, such as physical therapy and transfers. Difficulty also arises because these children are at increased risk of abuse due to their vulnerable status.[22]

Normal Variants

Some normal variation in bony structure on radiography can be misinterpreted as a fracture or a sign of abuse. The most common finding misinterpreted as abuse is subperiosteal new bone formation (Figure 4.18). While this is a frequent finding in healing fractures, it may also be present in normal, uninjured infants, especially when the finding is bilateral and does not extend to the metaphysis.[104] There are many variations in the appearance of the metaphysis in infants. Some of these, like a beaked appearance, can mimic a CML. Vessel tracts in the bones can have the appearance of non-displaced fractures. Obtaining repeat radiographs in 2 to 3 weeks can assist in determining if the irregularities are indeed fractures (with interval healing or bony changes) or bony variants (no interval changes).[105]

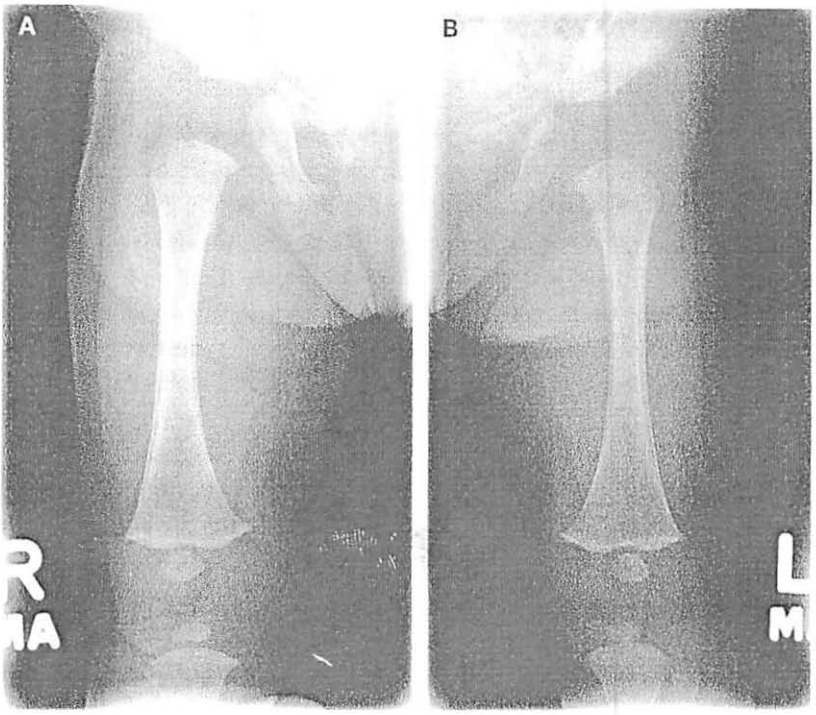

FIGURE 4.18
Femur periosteal reaction. A, Right. B, Left.

Management and Follow-up of Fractures

Because closed fractures in very young children have great healing and remodeling potential, most fractures secondary to inflicted injury can be treated nonoperatively. Asymptomatic, healing fractures (ie, those exhibiting periosteal reaction or callus formation), as are often found on skeletal survey, may not require any acute treatment or immobilization. For acute, symptomatic fractures, casts or splints may be used. Femur fractures in infants younger than 6 months can be treated in a Pavlik harness.[38] Proximal humerus or clavicle fractures in infants can be immobilized with a simple, non-constricting swathe or by connecting the long sleeve of the child's shirt to the front of the shirt with a safety pin. Fractures that may require operative treatment include open fractures, intraarticular fractures, or displaced physeal fractures. An example would be a displaced trans-physeal distal humerus fracture, which, if diagnosed acutely, usually requires operative reduction and pinning.

Short-term complications and long-term sequelae from childhood fractures are uncommon, although delay in diagnosis holds up initiation

of appropriate pain management. Most uncomplicated fractures are fully healed within 3 months and completely remodeled within 1 year. Fractures involving the physis are typically followed with serial radiographs for 1 to 2 years, depending on the age of the child, to monitor growth plate function. If premature physeal arrest does occur, treatment is typically surgical but depends on the age of the child, location of the injury, and extent of limb length difference or angular deformity.

Conclusion

Fractures are a frequent physical finding in cases of child abuse, second in incidence only to cutaneous soft tissue injuries.[106] Up to 55% of children who have experienced physical abuse are reported to have sustained an inflicted fracture.[28,47] These children are generally quite young; 85% of non-accidental fractures are diagnosed in children younger than 3 years, with 69% diagnosed in infants younger than 12 months.[28,67,83] Developmental stage consistent with the ability to independently ambulate is an important factor; until children can walk on their own, they are far less likely to engage in activities in which an accidental injury can occur.

Despite fractures being a common manifestation of inflicted trauma, they can pose a diagnostic dilemma. There is no fracture pattern, location, or morphology that is pathognomonic for child abuse. However, certain fractures and fracture patterns are more or less suggestive of inflicted trauma. Knowing the differences between the high-, mid-, and low-specificity fractures can aid in workup and diagnosis.

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