18 Non-accidental Trauma

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Contents

Abstract

This chapter presents the different imaging modalities that may be used in the radiographic diagnosis of non-accidental trauma, with particular emphasis on the skeletal survey. The different fracture patterns related to non-accidental trauma are then reviewed, including high-, moderate-, and low-specificity lesions. Fracture aging is also presented. Finally, mimics of non-accidental trauma are discussed, with more detailed presentation of osteogenesis imperfecta and rickets.

Child abuse, as defined by the World Health Report 2002, “constitutes all forms of physical and/or emotional ill-treatment, sexual abuse, neglect or negligent treatment or commercial or other exploitation, resulting in actual or potential harm to the child’s health, survival, development or dignity in the context of a relationship of responsibility, trust or power” [1]. In one study, child abuse has been classified into three different forms: battered child syndrome, sexual abuse, and neglect [2]. Imaging—and thus the radiologist—plays a vital role in cases of battered child syndrome and sometimes in cases of neglect. For

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the purpose of this discussion, the terms "battered child syndrome," "non-accidental trauma," and "child abuse" are used interchangeably.

Child abuse is probably underreported, and official reports probably also underestimate the extent of the problem [3]. There is an inverse relationship between non-accidental trauma and patient age [4]. Children aged 3 years and less are the most vulnerable, as they are least able to defend themselves or explain how they got their injuries; they are thus at greatest risk for fatal or near-fatal trauma. Infants less than 1 year old are at greatest danger [5].

Failure of physicians to properly diagnose child abuse has enormous consequences for the patient, the patient's family, and the physician. Children who have been intentionally injured must be identified, as they are likely to receive further injury if returned to the care of the perpetrator [6]. Misdiagnosis carries a high degree of morbidity and mortality, with a 50 % reinjury rate and 10 % mortality rate for unprotected children [7]. It is also extremely important to correctly diagnose fractures that arise from underlying bone abnormalities rather than from non-accidental trauma, as misdiagnosis of child abuse can also have devastating consequences. The radiologist must therefore be able to differentiate pathology from normal anatomic variants, differentiate traumatic from nontraumatic abnormalities, suggest a mechanism of injury, offer a reasonable estimate for time of injury, and identify or suggest an underlying abnormality that may predispose the child to fractures [6].

1 Imaging Techniques

The skeletal survey is the primary diagnostic imaging modality for the evaluation, documentation, and follow-up of suspected and confirmed cases of child abuse. High-quality skeletal survey protocol requires that the extremities be imaged in at least a frontal projection with coned views; images of the wrists, knees, and ankles may also be obtained, centered on each joint. The axial skeleton should be imaged in at least two projections. Additional right and left posterior oblique views of the ribs demonstrate additional fractures not routinely seen on standard frontal and lateral radiographs [8, 9] (Table 18.1). Additional views may be acquired, especially if equivocal abnormalities are identified. Coned views of the ankles are often helpful in addition to the routine skeletal survey.

Table 18.1 ACR-SPR imaging protocol for the skeletal survey of known or suspected child abuse

Axial skeleton	Appendicular skeleton
Chest (AP, lateral, and bilateral obliques to include the upper lumbar spine	Humeri (AP)
Pelvis (AP), to include the mid-lumbar spine	Forearms (AP)
Lumbosacral spine (lateral)	Femurs (AP)
Cervical spine (AP and lateral)	Lower legs (AP)
Skull (frontal and lateral)	Hands and feet (AP)

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The *babygram*, which is a single image of the entire chest and abdomen as well as the extremities, is inadequate. Peripheral areas are incorrectly exposed, and subtle fractures can be missed. Proper radiographic technique, positioning, collimation, and shielding are vital to optimize visualization of osseous structures and allow diagnosis of pathology with high sensitivity while keeping radiation dose levels within acceptable limits. A follow-up skeletal survey, usually in 2 weeks, may increase the diagnostic yield, particularly if findings are equivocal on the initial study and there is strong clinical suspicion for abuse. The repeat study also helps with accurate dating of individual injuries.

Although the complete skeletal survey is almost always mandatory in suspected child abuse cases for patients under 2 years of age, its utility diminishes and provides little value after age 5. Between the ages of 2 and 5 years, imaging is guided by specific clinical indicators of abuse and should be individually prescribed [10].

Bone scintigraphy is generally limited in the evaluation of non-accidental injury. Its primary use is in the identification of subtle rib fractures, but it is not particularly good at demonstrating epiphyseal and metaphyseal fractures, as these areas are obscured by normal physiologic activity and high periphyseal uptake of radiopharmaceutical [11]. Skull fractures are notoriously difficult to visualize on routine bone scans [12]. Equally important, bone scans require sedation and expose the child to a relative high radiation dose [13]. They are mainly used if clinical suspicion is high and routine imaging fails to document acute or healing fractures.

There has been recent interest in computed tomography (CT) for initial imaging of rib fractures, especially if routine skeletal survey fails to document fractures in highly suspicious cases [14]. Magnetic resonance imaging is very sensitive for evaluating spine, pelvis, and long bone occult skeletal trauma in children [15] but is limited for evaluating rib and skull fractures. It may not show classic metaphyseal lesions [16]. Ultrasonography can be valuable for assessing epiphyseal separations that are suspected on routine radiographs. However, its operator dependence, lack of correlative data for dating fractures, and limited utility for follow-up imaging make it the least useful modality for evaluating non-accidental trauma.

2 Fracture Patterns

The classification of fractures into high, moderate, and low specificity for child abuse is well established (Box 18.1). High-specificity injuries include the classic metaphyseal lesion (CML) and rib, scapular, sternal, and spinous process fractures. Moderately specific fractures include multiple and/or bilateral fractures of varying ages and vertebral, digital, and complex skull fractures. Long bone diaphyseal fractures as well as clavicular and linear skull fractures are considered low-specificity injuries [17].

Box 18.1: Specificity of Skeletal Fractures

Specificity	Types of fractures
High	Classic metaphyseal lesions (CML)/corner fractures
	Rib fractures, especially posteromedial
	Scapular fractures
	Sternal fractures
	Multiple fractures of varying ages
	Vertebral body fractures
	Digital fractures
	Complex skull fractures
Low	Linear skull fractures
	Clavicular fractures
	Long bone shaft fractures especially in ambulatory children

Modified from Kleinman [17] and Dwek [11]

2.1 Classic Metaphyseal Lesions (CML)

The terms "corner fracture" and "bucket handle fracture" describe fractures at the metaphyses of the long bones that are highly specific for non-accidental trauma, since nonambulatory children cannot inflict this type of injury on themselves (Box 18.2). The fractures result from tractional and torsional force applied to an extremity and are virtually diagnostic of child abuse, particularly in children under 1 year of age. Violent shaking of an infant causes tearing and injury at the level of the zone of provisional calcification of the physis; the detached bone creates a curvilinear density that constitutes the bucket handle fracture [11] (Fig. 18.1). If this fragment is viewed in tangent, it appears as a detached corner, whereas if it is viewed partially en face it appears as a bucket handle. CMLs involve the metaphyses of long bones and are most common at the proximal or distal tibias, distal femurs, and proximal humeri; they are frequently bilateral [18]. They usually involve the posteromedial aspect of the distal femurs, proximal tibias, and distal tibias. At the proximal humeri, they are usually lateral and are best seen with external rotation.

Box 18.2: Corner Metaphyseal Lesions

Traction/torsion cause tearing at zone of provisional calcification

Bucket handle vs. corner fragment appearance results from difference in projection

Most common: proximal/distal tibias, distal femurs, proximal humeri

- Posteromedial: tibia, femur
- Lateral: humeri

Differential: birth trauma, orthopedic manipulation, normal metaphyseal spur

Fig. 18.1 Classic metaphyseal lesions (CML) showing bucket handle configuration at the distal tibia and fibula (*arrows*)

Rarely, a similar lesion may result from birth trauma [19] or from manipulation during orthopedic procedures. The timing of injury and the clinical history differentiate such fractures from abusive trauma. These fractures should also be differentiated from the normal subperiosteal bone collar and normal metaphyseal spur seen in rapidly growing long bones of young children, which are attached to the adjacent bone with no intervening lucency (Fig. 18.2) (see Chap. 2).

2.2 Rib Fractures

Rib fractures are the most common and highly specific injury found in abused children, with positive predictive values as high as 95 % in children less than 3 years of age [18]. Furthermore, in some patients, rib fractures are the only skeletal manifestation of child abuse. Although involvement can be anywhere along the rib, unilateral, bilateral, or multiple posteromedial rib fractures are most specific for child abuse (Fig. 18.3). This is in keeping with the mechanism of how these fractures are sustained when the chest is squeezed in the anteroposterior direction, levering the posteromedial ribs against the transverse processes. For similar fractures to occur in the setting of accidental trauma, massive forces must be generated, such as in deceleration dashboard injuries or high-velocity vehicular impact. Cardiopulmonary resuscitation does not cause posteromedial rib fractures [20].

Routine chest radiography may not clearly demonstrate rib fractures, particularly if they are acute, incomplete, and non-displaced or if they are posterior. For this reason, oblique views, follow-up imaging after 2 weeks, and bone scintigraphy have been suggested to improve detection of such fractures. CT of the chest has also been advocated in highly suspicious situations [14] (Fig. 18.4).

2.3 Skull Fractures

Skull fractures are common in both accidental and non-accidental injury and are therefore low-specificity lesions. Linear skull fractures occur most frequently, usually upon impact after low-velocity falls. However, complex fractures (such as concentric, star-shaped, or eggshell fractures)

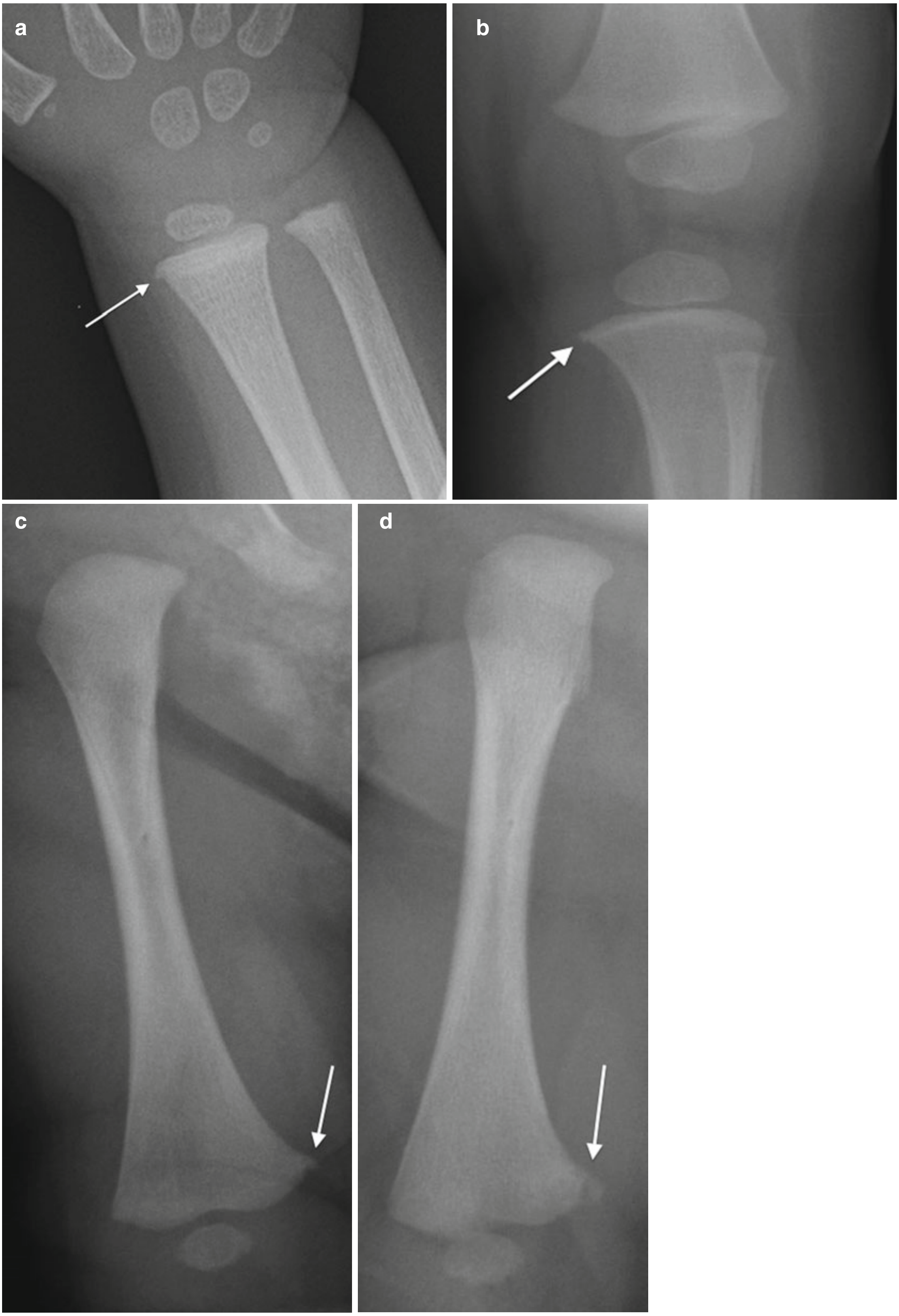

Fig. 18.2 Normal metaphyseal spurs and collars, contrasted with corner fracture. No lucency separates the metaphysis from the normal bone collar (*arrows*) at the distal radius (**a**) and proximal tibia (**b**), or the normal distal femoral spur (*arrow*, **c**). (**d**) Lucency separates the CML (with corner fracture configuration) (*arrow*) from the metaphysis

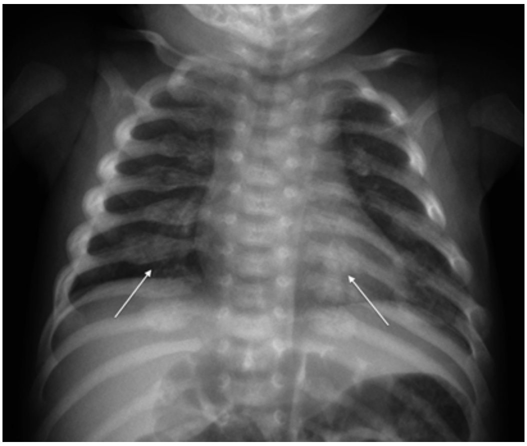

Fig. 18.3 Healing posteromedial rib fractures at almost every level are highly suggestive of child abuse (*arrows* indicate two of the many fractures). Multiple posterolateral rib fractures as well

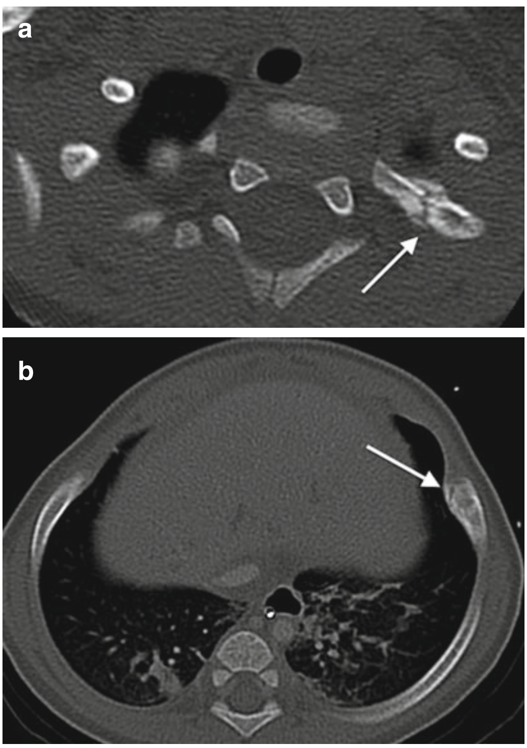

Fig. 18.4 Healing rib fractures on CT. (**a**) Axial CT shows healing second rib fracture that was not evident on contemporaneous radiograph. (**b**) Axial CT of a different patient with a healing left anterior rib fracture not evident even on oblique views (*arrow*)

imply high-velocity/high-energy trauma and carry a higher positive predictive value for abuse [21, 22] (Fig. 18.5).

A skull fracture is often the only evidence of abuse. It is therefore important that even these low-specificity lesions are accurately identified and correlated with the clinical history and reported mechanism of injury. This can sometimes present difficulties, especially in subtle cases, where the complex development of the infantile skull may make it difficult to differentiate between a linear fracture and an accessory suture. CT with three-dimensional (3D) reconstruction is very helpful in evaluating a suspicious fracture. Characteristics which favor fracture include a sharp lucency with non-sclerotic edges, fracture line widening as it approaches a suture, and associated soft tissue swelling [23] (Fig. 18.6).

2.4 Long Bone Diaphyseal Fractures

The presence of long bone diaphyseal fractures in a nonambulatory infant should raise concern for non-accidental injury. Such fractures usually result from application of a bending or rotational force, as the extremity is grabbed [22].

However, in older children, long bone fractures usually result from accidental trauma. These fractures are therefore generally of low specificity for abuse. Although spiral midshaft fractures have long been associated with abuse, more recent studies have concluded that the type (spiral, transverse, or oblique) as well as the location of the fracture (diaphyseal or metaphyseal) does not necessarily differentiate accidental from abusive injury. Given the appropriate mechanism of injury, these fracture types can occur in the setting of accidental trauma [24, 25].

2.5 Fractures in Unusual Sites

Fractures from child abuse have been described in virtually every bone [4]. However, spine fractures in the absence of documented high-energy trauma

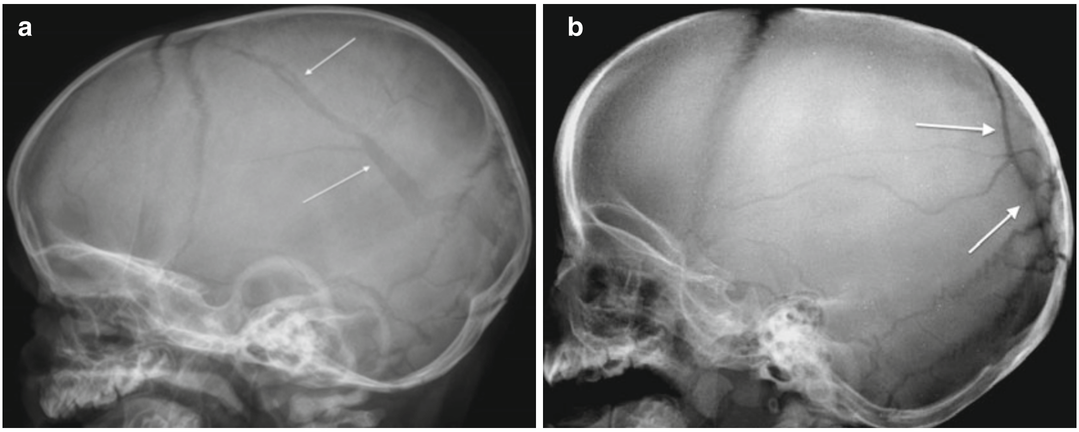

Fig. 18.5 Skull fractures. (**a**) Linear fracture of the parietal and occipital bones (*arrows*), a nonspecific fracture that can be accidental or result from abuse. However, diastasis, vague tangential fracture lines, and the fact that the fracture crosses a suture, all features that are less common in the typical fall from a low-height accidental injury, increase the suspicion for abuse. (**b**) Complex, star-shaped/eggshell fracture (*arrows*) of the parieto-occipital region indicates a high-impact injury, highly suggestive of abuse

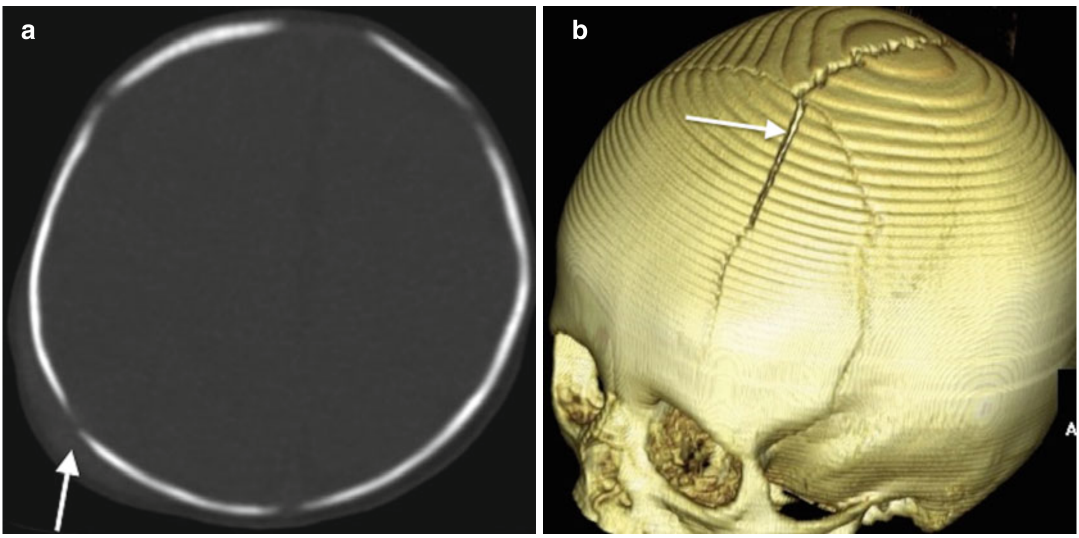

Fig. 18.6 Differentiating skull fractures from accessory cranial sutures. (**a**) Axial CT shows soft tissue swelling and step-off, which indicate that the lucency in the occipital bone represents fracture (*arrow*). (**b**) Three-dimensional CT reconstruction shows a linear lucency in the frontal bone which widens as it approaches the sagittal suture (*arrow*), also a feature of skull fracture

are rare in childhood and should suggest abuse. Mechanisms include hyperextension, hyperflexion, and/or axial loading from violent shaking, deliberate dropping, or throwing. Injury usually involves multiple vertebral levels, often near the thoracolumbar junction (see Chap. 4). Spinous process fractures, as well as vertebral body compression fractures with associated endplate defects, may be seen [26].

Other unusual fracture sites in infants and toddlers include the scapula (Fig. 18.7), sternum, phalanges, metacarpals, metatarsals, and pelvis. Fractures in these locations should also raise the possibility of non-accidental trauma, unless there

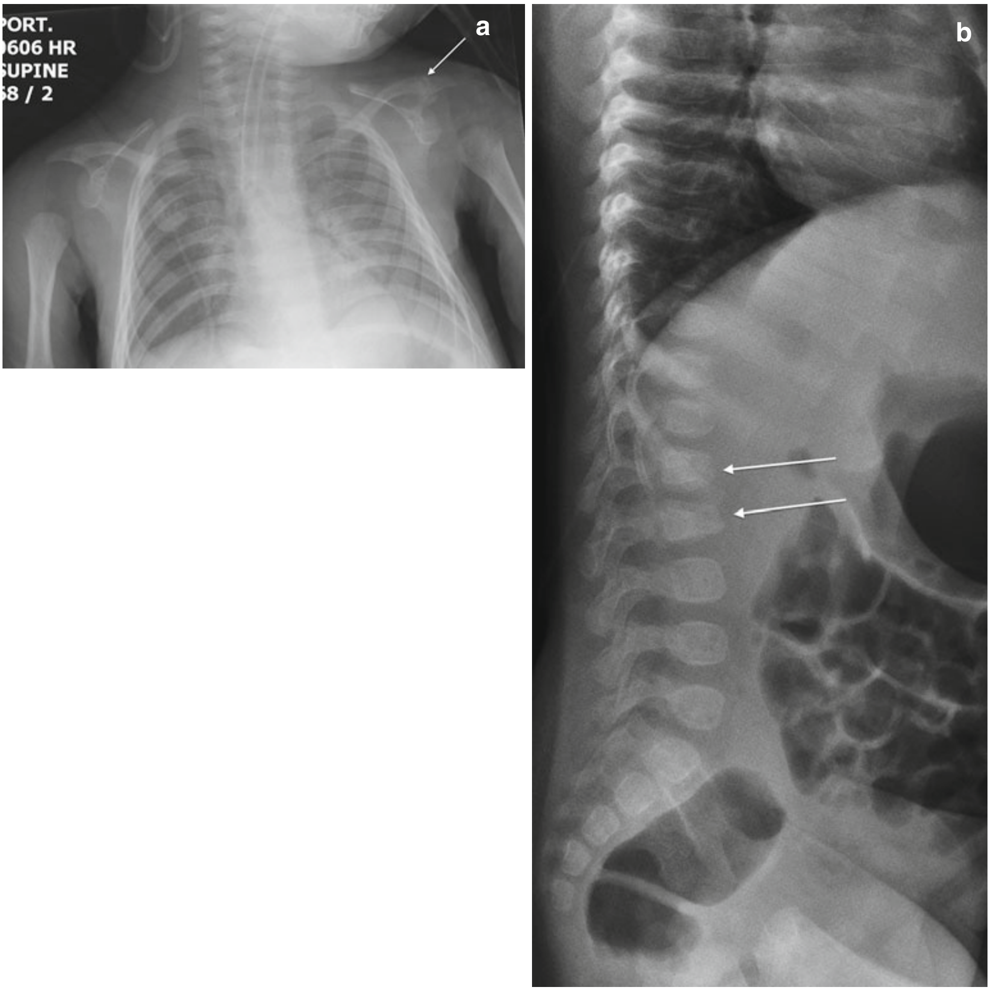

Fig. 18.7 Unusual fractures with high specificity for abuse. (**a**) Left acromion fracture (*arrow*), often a result of either non-accidental trauma or high-impact injury. (**b**) Lumbar vertebral body fractures (*arrows*) in a nonambulatory infant

is a legitimate history of an unusual mechanism of injury. Clavicular fractures—especially involving the middle third—are common and thus in general low-specificity lesions. They may also result from birth trauma but should be attributed to birth only if callus is apparent by age 11 days [11].

2.6 Multiple Fractures of Varying Ages

The presence of multiple fractures without a convincing history of accidental trauma should also raise suspicion for child abuse. There is a significant association between multiple unexplained fractures and child abuse: up to 74 % of abused children have two or more fractures [27]. Bilateral, symmetrical fractures involving the upper or lower extremities in non-ambulatory children are also associated with child abuse (Fig. 18.8).

The location and stage of healing of every fracture must be correlated with the clinical history, mechanism, and date of injury. Of course, the clinical history remains paramount in the final analysis, since children with metabolic abnormalities that predispose to bone fragility can present with multiple fractures of different ages.

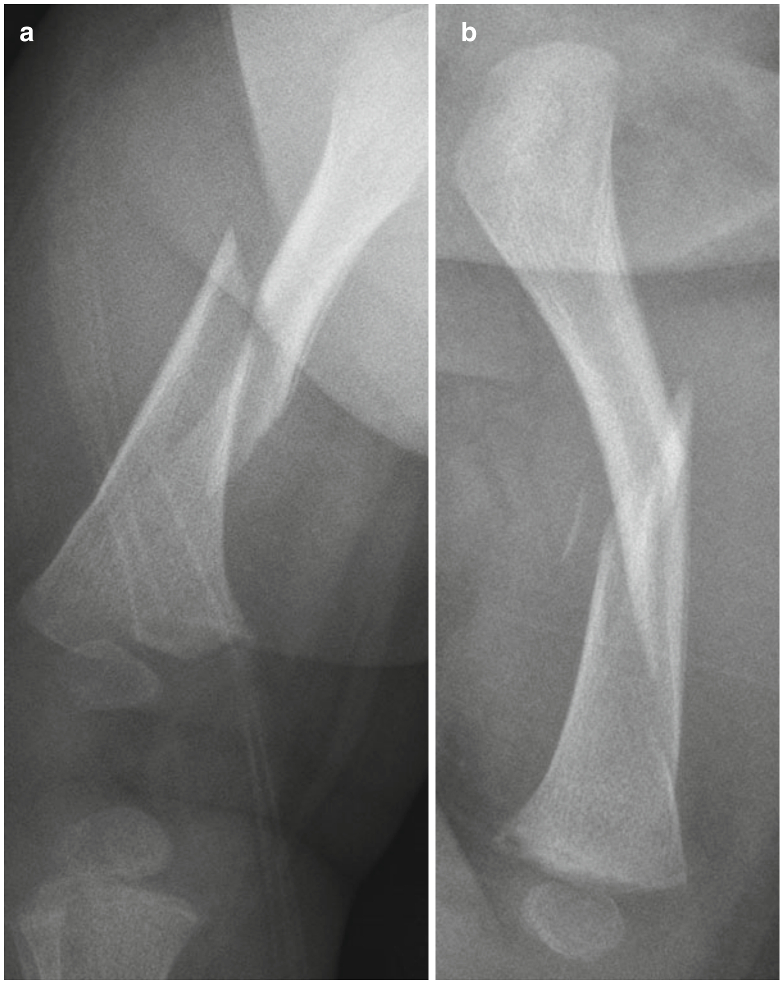

Fig. 18.8 Bilateral acute spiral fractures of the femurs in a 7-month-old victim of non-accidental trauma (**a**, **b**)

2.7 Subperiosteal New Bone Formation

Subperiosteal new bone forms when the periosteum separates from the underlying cortex. This may occur with trauma, as well as with infectious, metabolic, and neoplastic disease. Physiologic subperiosteal new bone formation is normal in long bones during the first 4 months of life, presumably due to rapid intramembranous ossification (see Chap. 2). It is usually bilateral but can be asymmetrical and should be no thicker than 2 mm [28]. Whereas posttraumatic subperiosteal new bone formation can extend to the metaphysis (Fig. 18.9), the physiologic process extends only as far as the metadiaphysis (see Chap. 2).

3 Fracture Dating

Fracture dating is important in the evaluation of child abuse injuries. Injury dating can unmask inconsistencies between the clinical history and radiographic findings and determine whether multiple fractures have been sustained over a period of time. Published material addresses the stages and timing of fracture healing [29–32], but the appearance at different time intervals overlaps considerably. Furthermore, the application of this data to non-accidental trauma may be inexact, since most studies deal with a wide age range of subjects and describe fractures that have been immobilized. Still, knowledge of the radiologic

Fig. 18.9 Thick, wavy, posttraumatic subperiosteal new bone formation representing calcification of the periosteum, elevated likely due to subperiosteal hemorrhage. Corner fractures of the tibia and fibula (*arrows*)

features of fracture healing along with a general sense of timing can help the radiologist approximate fracture age.

Long bone fractures in children can be estimated as acute (less than 1 week old), recent (8–35 days), and old (more than 35 days), based on the appearance of periosteal reaction and callus [33] (Fig. 18.10). Rib fractures are more difficult to date, in part because they are never casted and can be subjected to repeated trauma. However, callus thickness can help guide assessment of rib fracture age [34] (Fig. 18.11).

4 Mimics of Child Abuse (Box 18.3)

Box 18.3: Mimics of Child Abuse

Osteogenesis imperfecta types I and IV
- Multiple accessory sutures (wormian bones)
- Osteoporosis
- Blue sclerae
- Associated long bone, lateral rib, diaphyseal fractures

Rickets
- Osteopenia
- Irregular/cupped metaphyses, wide physes
- Wrists and knees affected most severely

4.1 Osteogenesis Imperfecta

Osteogenesis imperfecta (OI) is a rare disorder of abnormal type 1 collagen quality and/or quantity, characterized by abnormal bone fragility and osteoporosis. Infants and children with OI manifest with multiple fractures and may resemble victims of non-accidental trauma. Other major characteristic features of OI that may suggest the diagnosis in infants include blue sclerae and multiple wormian bones; older children may demonstrate defective dentition, short stature, bowing deformities, and early onset hearing impairment [35]. Inheritance is autosomal dominant or autosomal recessive.

Types I and IV are most likely to be confused with non-accidental trauma (types II and III present with in utero or perinatal fractures). Type I is the most common and also the mildest form of OI; these patients usually have normal stature and few fractures or skeletal deformities. Their characteristically blue sclerae can facilitate diagnosis. Type IV is least common and has

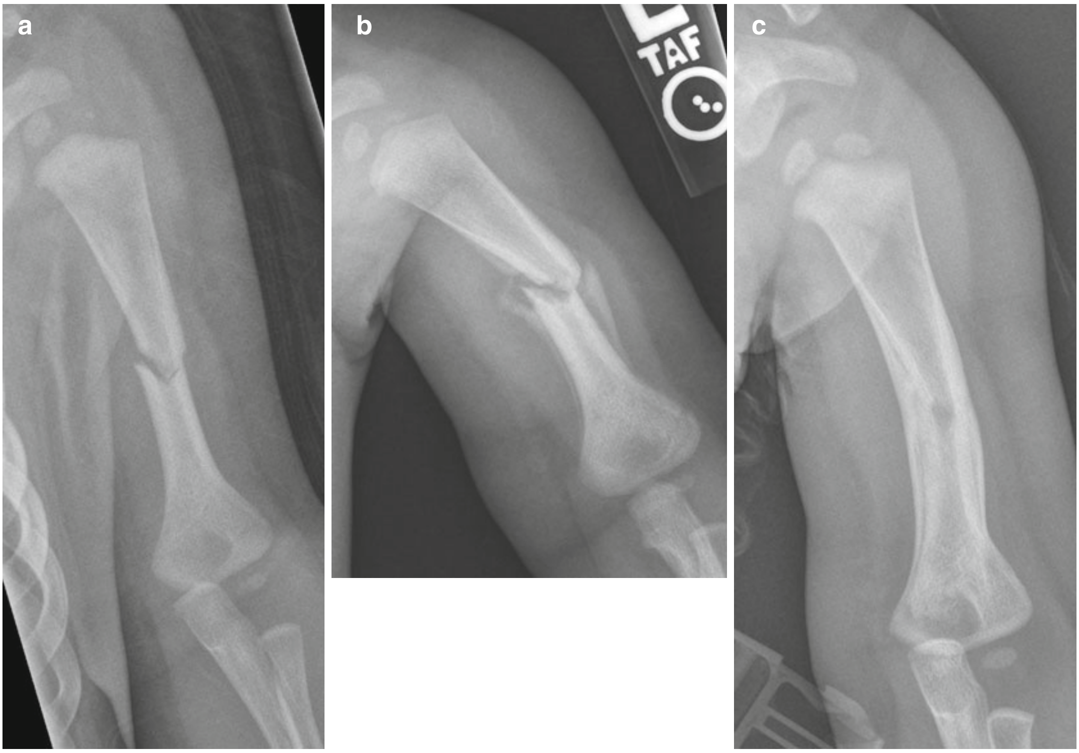

Fig. 18.10 Stages of long bone fracture healing. (**a**) Acute fracture without callus formation. (**b**) Two weeks later, there is early callus formation. (**c**) After 3 months, there are near total bridging of the fracture line and smooth cortical thickening

the mildest skeletal abnormalities. Biochemical analysis of collagen may help diagnose types I and IV but is not completely reliable. (See Chap. 23 for further discussion of the multiple subtypes of OI.)

It is important to recognize that the pattern of injury in OI differs from that encountered in non-accidental trauma. Patients with OI typically fracture the diaphyses of long bones and the lateral aspects of the ribs (Fig. 18.12). Therefore, if an infant with OI presents with fracture patterns that are typical of abuse (CMLs and posteromedial rib fractures), the possibility of abuse should still be entertained [11].

Temporary brittle bone disease has been proposed as a differential diagnosis for child abuse. As the name implies, affected infants are only transiently susceptible to fractures, and after spontaneous resolution of the condition, there is no further evidence of disease. The proponents of this entity suggest that it results from a transient defect in collagen synthesis or mineralization. However, extensive review of the scientific evidence has found no definitive proof that this condition exists, and it has largely been discredited as evidence against child abuse [36].

4.2 Rickets

Rickets is a common deficiency of bone mineralization that affects the zone of provisional calcification and is characterized radiographically

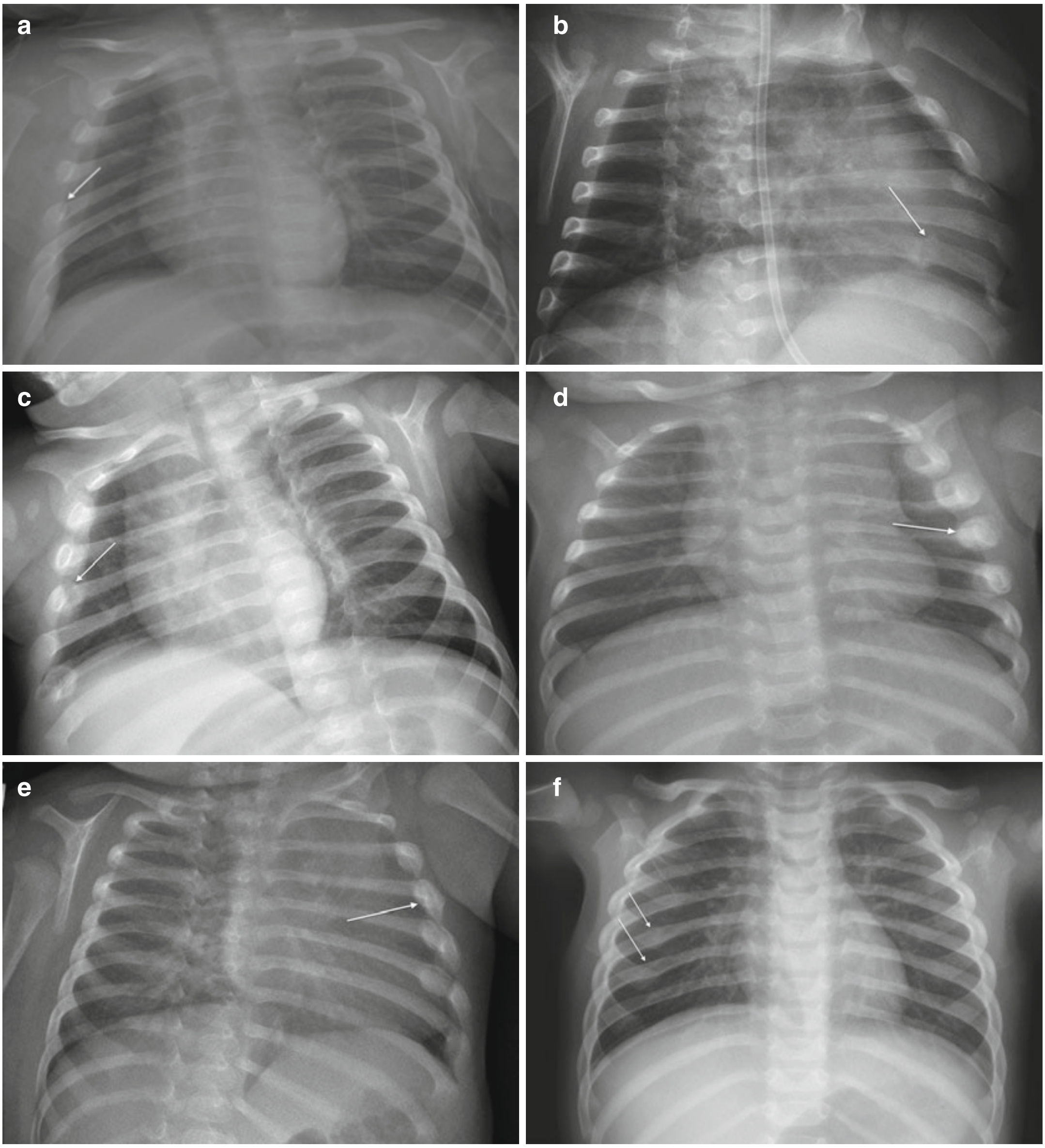

Fig. 18.11 Sequential healing of infantile rib fractures. (**a**) Acute injury with slight step-off (*arrow*) and absence of periosteal reaction (0–1 week). (**b**) Minimal periosteal reaction (*arrow*) and early resorption at the fracture site (1–3 weeks). (**c**) Progressive thickening of the callus (*arrow*) and widening of the fracture line (3–5 weeks). (**d**) Callus formation (*arrow*) is thickest at this stage (around 5–7 weeks). (**e**) Cortical thickening and remodeling of callus (*arrow*), with fracture line no longer visible (7–9 weeks). (**f**) After 9–11 weeks, the fracture is healed and the only indications of prior injury are cortical thickening and mild irregularity (*arrows*)

Fig. 18.12 Osteogenesis imperfecta in a newborn. The bones are diffusely osteopenic and thin, with fractures of both arms, the scapulae, and many ribs, at varying stages of healing. Multilevel platyspondyly

by osteopenia, metaphyseal irregularity and cupping, and physeal widening (Fig. 18.13). These changes are most evident in the faster growing areas of the appendicular skeleton, such as the wrists, ankles, and knees. Diffuse osteopenia precedes the classic metaphyseal findings, but radiographs are insensitive at evaluating bone mineralization since more than 30 % of bone must be lost before they demonstrate osteopenia [37]. The presence of osteopenia along with symmetrical involvement of the extremities makes differentiation from non-accidental trauma straightforward, even if corner fractures are present. However, it is important to recognize that in some patients nutritional deficiency results from neglect, which is also a form of child abuse, and that children with rickets can also suffer from physical abuse.

The existence of subclinical vitamin D deficiency is controversial. Some maintain that a

Fig. 18.13 Classic rickets showing metaphyseal flaring, fraying, and cupping (**a** lower extremity; **b** upper extremity). The hip and elbow contribute less to overall bone growth and are less severely affected

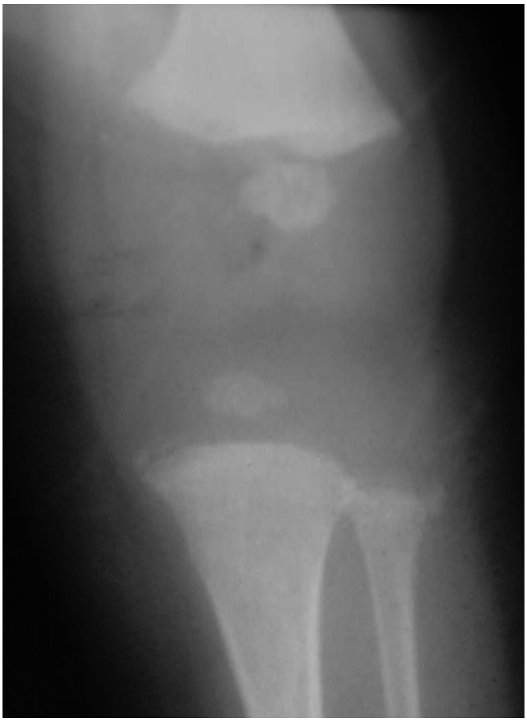

Fig. 18.14 Menkes kinky hair syndrome. Proximal tibial bony lesions mimic CMLs (Courtesy of Sandra L. Wootton-Gorges)

Fig. 18.15 Neonatal Caffey disease. Bowing deformity of the right femur and diffuse periosteal thickening of all long bones (Courtesy of Sandra L. Wootton-Gorges)

mild form of rickets typically seen in breast-fed infants results in multiple fractures, with some resembling CMLs [38]. However, there is no definite evidence at this time to support the existence of metaphyseal injuries characteristic of abuse in infants who have no clinical, laboratory, or radiographic evidence of rickets. Although CMLs can occur with rickets [39], these are usually seen only when there is already overt radiographic evidence of the disease. As with OI, the presence of posteromedial rib fractures in an infant with rickets strongly suggests abuse [38].

4.3 Other Less Common Mimics

Other conditions that may be considered in the differential diagnosis of child abuse include copper deficiency, fractures secondary to demineralization from paralysis, Menkes kinky hair syndrome (Fig. 18.14), scurvy, vitamin A intoxication, leukemia, congenital syphilis, Caffey disease (Fig. 18.15), metabolic storage diseases (Fig. 18.16), and prostaglandin administration (Fig. 18.17). Careful attention to history and physical examination, as well as correlation with distinctive laboratory parameters and radiographic findings, usually allows ready differentiation from non-accidental injury [40].

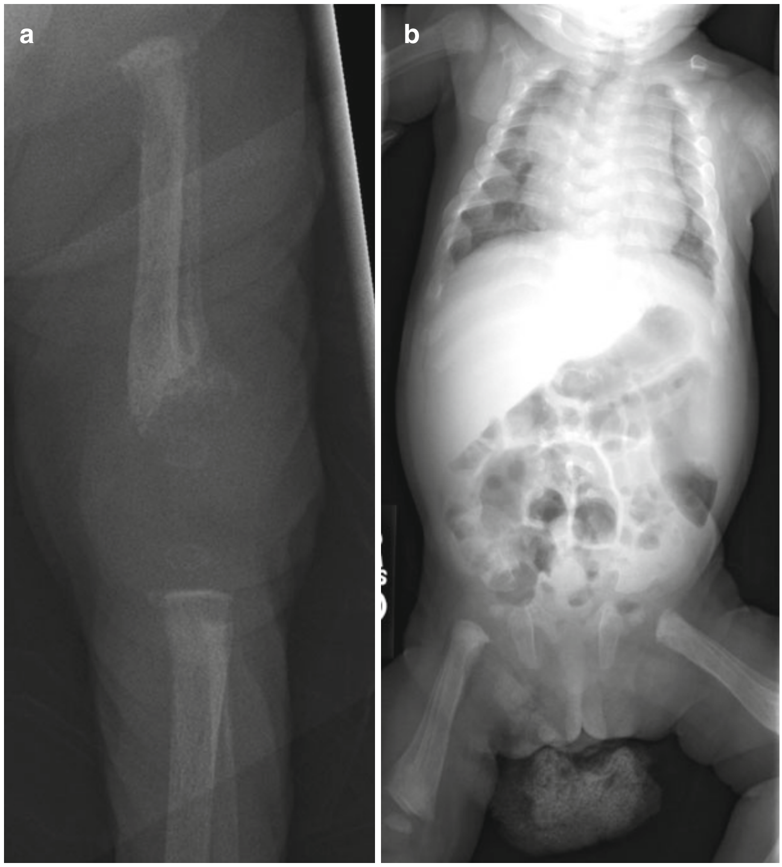

Fig. 18.16 Mucolipidosis in an infant. (**a**) Metaphyseal lytic lesions and diffuse periostitis in the lower extremity. These findings were also present at all long bones, suggesting either a metabolic abnormality (such as a storage disease) or infectious etiology (such as syphilis). (**b**) After several months of treatment, periosteal reaction is thicker and the metaphyses are reconstituted

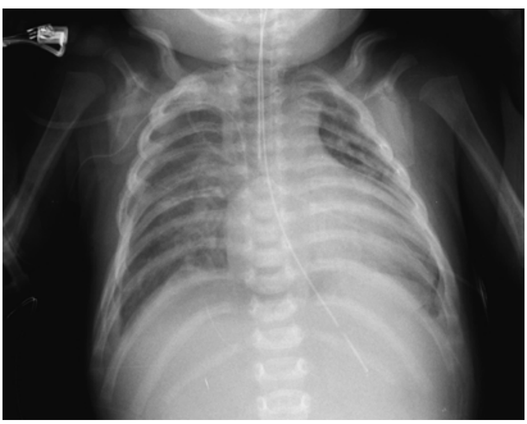

Fig. 18.17 Prostaglandin-induced periostitis in an infant with hypoplastic left heart syndrome. There is periosteal new bone formation along the humeri, clavicles, and ribs (Courtesy of Sandra L. Wootton-Gorges)

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