27 Pediatric Trauma: Imaging Pitfalls

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Contents

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Abbreviations

CT	Computed tomography
MRI	Magnetic resonance imaging
NAI	Non-accidental injury
US	Ultrasound

27.1 Introduction

There are many pitfalls in pediatric trauma radiology that occur because of the clinician's unfamiliarity with pediatric pattern of injury and assumption that children are just "little adults." Being aware of the developmental changes that occur in children and understanding the impact these changes have on the pattern of trauma assist in the prompt recognition of an injury and its significance. For the purposes of this discussion, pitfalls have been divided into categories that reflect the cause of the variation from common "adult trauma." Children will have varying amounts of non-ossified cartilage that can be injured. Also, the ligaments and tendons are relatively stronger than the more pliable bones.

The growth plates and non-united apophyses in children are associated with unique complications of trauma and can mimic fractures. Intra-articular disks and cartilage may be vascularized during growth, giving different imaging characteristics,

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compared to adults. While children are developing motor skills, they transition from immobile animals unable to fend for themselves through an awkward phase where suboptimal coordination and a desire to explore the world give an increased risk of injury. The development of their perception of the world around them will also influence their ability to describe their symptoms and cooperate with healthcare providers. Trauma can sometimes lead to identification of other pathologies; hence an understanding of conditions more common in children will reduce the risk of mistaking a significant mass or lesion as traumatic in etiology.

27.2 Imaging Techniques in Children

Radiographs remain the imaging investigation of choice in most circumstances. Orthogonal views are required, and images of the long bones should include both ends of the bone. However, if there are symptoms related to a joint, coned views of that joint are essential to accurately diagnose metaphyseal or epiphyseal injury. It is important that standard views are obtained, despite the fact children are sometimes incapable of cooperating with the imaging procedure due to pain or lack of understanding. Careful and patient examination of a child will sometimes facilitate localizing the symptoms. This is important to avoid imaging requests such as "X-ray limb – unable to localize site of pain." Further clues as to the site of a bone or joint injury can be obtained by carefully reviewing the fat-muscle soft tissue planes. A fracture or significant local trauma will often cause edema within the subcutaneous fat that will help focus the attention of the radiologist to the bone close to the soft tissue swelling.

As with imaging of adult-type fractures, computed tomography (CT) can be invaluable when analyzing fractures that involve joints or the spine. In children, CT is also useful in complex fractures that involve growth plates, particularly when the fracture is in multiple planes. CT demonstrates the separate components of the fracture, allowing the orthopedic surgeon to understand the relationship of all fragments and plan the realignment and stabilization/fixation of the injury. For example, a comminuted Salter-Harris type IV fracture of the distal tibia with fragmentation of the tibial articular surface is well depicted on CT (Fig. 27.1). CT can also be useful during growth plate fracture healing, where bony

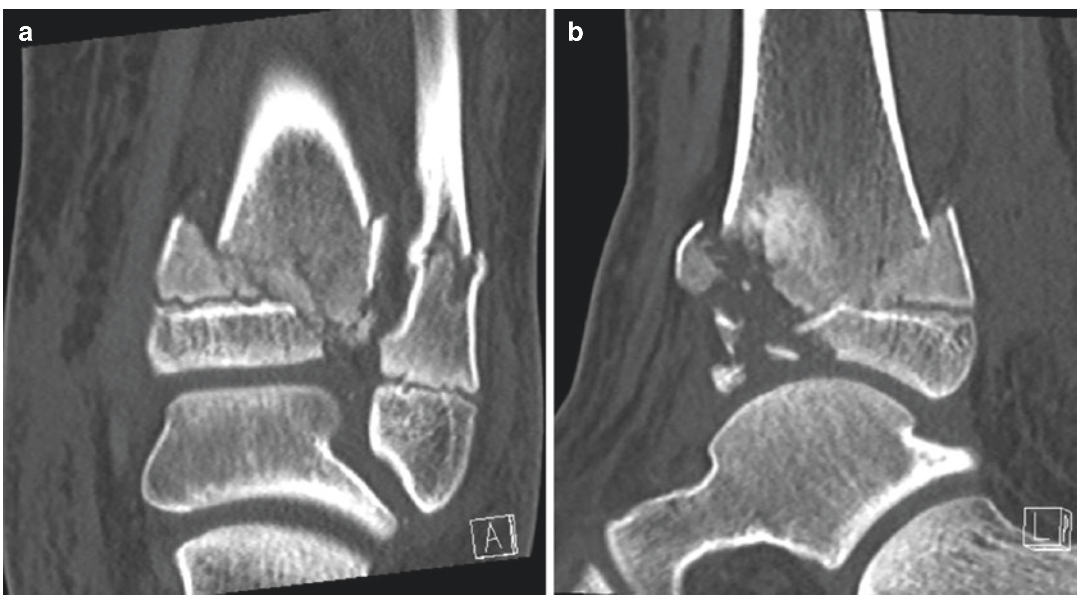

Fig. 27.1 Comminuted distal tibial Salter-Harris type IV fracture in a 15-year-old boy. (**a**) Coronal and (**b**) sagittal reformatted CT images of the left ankle show fragmentation of the articular surface and a distal fibula shaft fracture

bridges across the growth plate indicate damage to the physis and disruption to normal growth. Failure to recognize these changes in growth can cause long-term disability or predispose to degenerative joint changes.

It can be difficult to localize the site of injury requiring imaging when there is unobserved trauma and nonspecific clinical signs and symptoms. Radiographs may also be normal if the injury predominately involves the soft tissues or where the fracture is undisplaced, such as in toddler fracture of the tibia or a stress fracture. Magnetic resonance imaging (MRI), ultrasound (US) imaging, and bone scintigraphy are useful in children, particularly when the radiographs are normal. US imaging and MRI are preferred due to the absence of ionizing radiation. US is portable and provides real-time imaging suited to young children with limited ability to cooperate. It is particularly useful when there is possible injury to muscles or tendons or if a foreign body is suspected.

MRI requires a longer period of cooperation and is usually reserved for problem-solving or treatment planning. As with adult imaging, it is particularly useful for injuries involving a joint or the spine. Signal changes in the bone marrow may reveal sites of bone bruising where there is no macroscopic cortical fracture. Bone scintigraphy can be very useful in young patients where the radiographs are normal, particularly when the child presents with a limp of unknown etiology. While toddler fractures are the most common traumatic cause of a non-weight-bearing child, there are many times when the differential diagnosis is osteomyelitis or septic arthritis. As the origin of infection causing the limp may be in the spine (diskitis), foot, or anywhere in between, the ability of bone scintigraphy to easily screen the whole body is an advantage. Although the time required for nuclear medicine imaging may be similar to an MRI, the nuclear medicine gamma camera is less intimidating to young children and, in the authors' experience, has a much lower requirement for general anesthesia.

Young children pose additional challenges for successful motion-free imaging when they are too young to be able to cooperate with requests to keep still. The skill and patience of the medical imaging technologist is invaluable. This is particularly true when attempting to successfully obtain diagnostic images from young patients who are too young to understand the circumstances in which they find themselves; in pain and in a strange and unfamiliar environment. Time must be taken to gain the trust of the patient's parents (or carer) as a child will often adopt their anxiety. Preventing parental stress being relayed to the child may just require an explanation of the imaging requirements and reassurance that the imaging will be performed with as little additional pain to the patient as possible. On some occasions, the parent will need specific counseling on the impact of their emotions on their child's perception of the healthcare interaction and some guidance regarding their choice of words and nonverbal communications; this is preferable to having the parents leave the child. Educational play therapists (child life specialists) will greatly assist when greater cooperation is required for more complex imaging.

Radiographs can usually be obtained with minimal anxiety, particularly if a child-friendly environment is available and if the patient's parents or carers familiar to the patient are used to assist with patient positioning. Patience is required for successful positioning of the patient to allow standard views to be obtained. This is important to reduce the risk of poor radiographic technique being responsible for errors of interpretation. CT will often only require a few moments of absolute cooperation, but patience is still required for the patient not to be intimidated by the unfamiliar and complex-appearing equipment. MRI will require much greater patient preparation as well as the utilization of appropriate distraction techniques. The use of a "mock" or practice MRI will reduce the incidence of sedation and anesthesia, when used effectively. Nuclear medicine studies will involve the additional challenge of intravenous administration of a radiopharmaceutical, but there are many techniques available to minimize the distress associated with this intervention.

Oral sucrose, local anesthetic creams, ice packs, vibration devices, and distraction therapy all have their role in minimizing the distress associated with an intravenous injection, and age- appropriate techniques should be utilized routinely. Decorating medical equipment with child-friendly motifs will create a distraction that can also assist in placating an anxious child. The long-term importance of being sensitive to children's "imaging-associated anxiety" cannot be overemphasized, as fear generated by bad experiences can make future important health interventions much more complex. It is a mistake to think that it is all right to be forceful holding a child against his will and that it will always be forgotten. Appropriate explanation of a procedure and the use of distraction therapy, sedation, pain relief, or general anesthesia are important for the patient, their carers, and healthcare providers who wish to provide accurate and efficient patient services, as well as a safe and satisfying work environment for their staff.

27.3 Pitfalls Due to Non-ossified Bone and Pattern of Growth

Ossification of bones begins *in utero*, but many bones are mostly cartilage at birth, and some will not be ossified until early childhood or reach skeletal maturation until the second or third decade of life. Trauma to the neonatal musculoskeletal system is uncommon but is a recognized complication of difficult deliveries. Fractures of the clavicles occur as a complication of shoulder dystocia, but injuries to the humerus or femur can occur, depending on the presenting limb. Ribs can be but are rarely fractured during delivery (Bhat et al. 1994; Bulloch et al. 2000).

On radiographs, it can be difficult to differentiate between fractures of cartilaginous bone and dislocation of a joint, when the injury is to the cartilaginous bone of a neonate. Recognition of the injury partly relies on the knowledge that the ligaments and tendons are stronger than the forming bone, so it is more likely to suffer a fracture than a dislocation. Figure 27.2 demonstrates an injury first interpreted as a dislocation but recognized and confirmed later as a fracture of the proximal tibia. The initial image shows malalignment of the knee, but careful examination of the soft tissues shows that the patella tendon attaches normally to the cartilaginous proximal tibia which is aligned normally with the femoral articular cartilage. Images obtained during healing show that the fracture in the tibia was distal to the growth plate and through the non-ossified diaphyseal cartilage.

Neonates and infants are not able to generate sufficient force to injure themselves, so injuries occur due to accidents (e.g., motor vehicle, dropped by carer) or non-accidental injury (NAI).

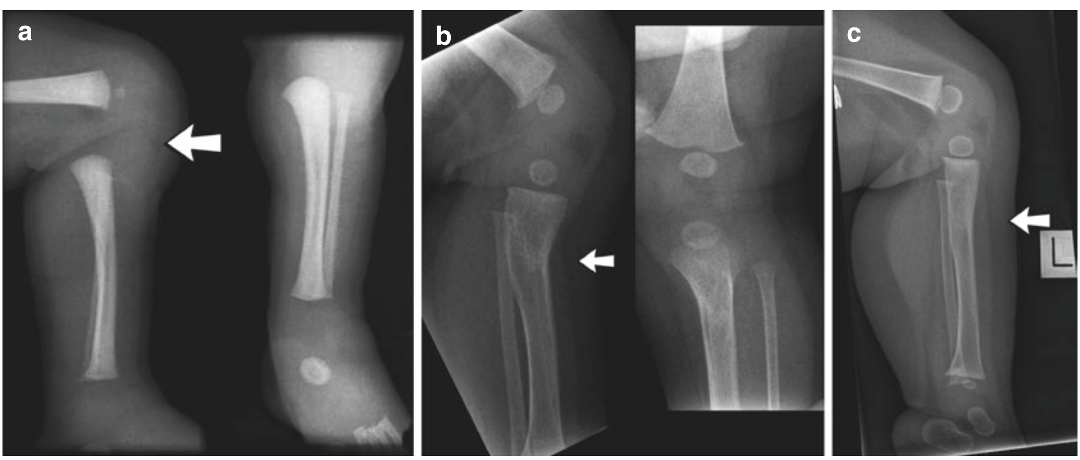

Fig. 27.2 (**a**) Lateral and AP radiographs of the tibia taken at presentation on the day of birth show a fracture of the proximal tibia. Note the normal attachment of the patella tendon to the cartilaginous proximal tibia (*arrow*). Subsequent radiographs taken at (**b**) day 83 and (**c**) at 9 months. The two most recent lateral radiographs also show significant post-injury remodeling at the site of the fracture (*arrow*) that can occur in growing bones

Other congenital conditions such as osteogenesis imperfecta and metabolic bone disease that predispose the bones to fracture should also be considered when reviewing skeletal trauma in neonates, infants, and young children.

27.4 Pitfalls Due to Pliable Pediatric Bone

Certain subtle patterns of fracture occur specifically in the pediatric population because the bone is more pliable than adult bones and will undergo a greater degree of plastic deformation before fracturing. The most classic of these is the greenstick fracture, which produces discontinuity of part of the bony cortex, but the fracture is incomplete, and part of the bone maintains integrity of its periosteum and cortical outline. However, there are micro-fractures associated with the deformity, which can sometimes be subtle (Fig. 27.3).

Torus or buckle fractures represent a variant of the incomplete greenstick fractures associated with relatively soft and pliable bone. The buckle injury is seen in the metaphysis where the cortical bone is thin. They occur as a result of compression forces that disrupt the normal trabecular pattern of the peripheral medullary bone and cause micro-fractures in the cortex without significant periosteal disruption. There is a variable contour irregularity on only one side of a bone that can be easily overlooked and may only be visible on one projection of a pair of orthogonal radiographic images. The cortical buckle is usually associated with a subtle change in the contour of the adjacent bony trabeculae where a focal curve or wave can be seen in the alignment of the medullary trabeculae.

On some occasions, a subtle torus fracture may only be recognized retrospectively on a follow-up radiograph as a subtle band of sclerosis across the metaphysis or diametaphysis that represents the osteoblastic activity associated with fracture healing (Fig. 27.4). This is different to the growth arrest lines associated with systemic illness or immobilization. It is important to differentiate a greenstick fracture with a buckled cortex together with a cortical break from a torus fracture; the latter is considered more stable with treatment often involving a shorter period of less rigid immobilization. Figure 27.5 demonstrates what appears to be a torus fracture of the distal radius in a child who suffered non-accidental injury (NAI), but the presence of an associated longitudinal component indicates a significant cortical breach and a greenstick fracture.

Plastic bowing fractures are another variant of incomplete fractures that do not have a discrete break in the cortical bone. These fractures may only be visible in one projection and can be overlooked

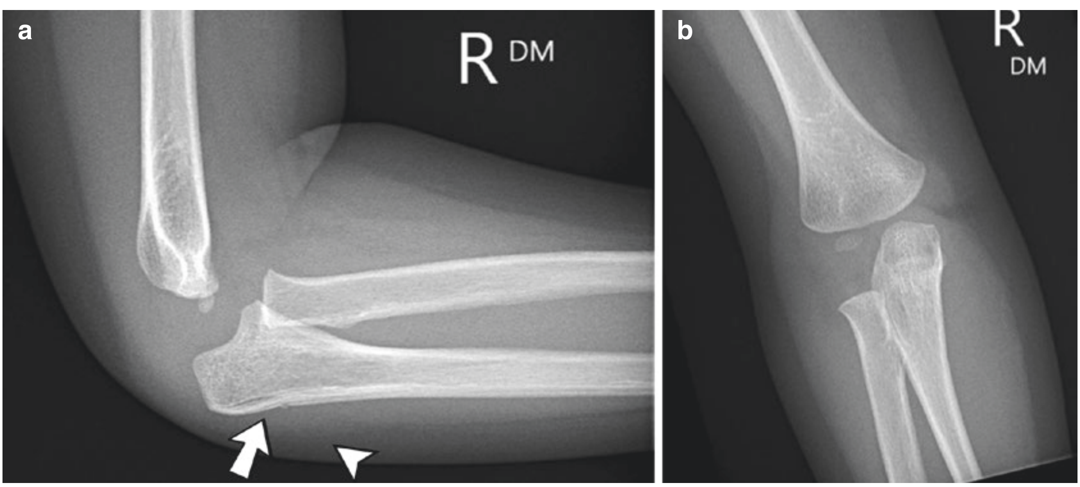

Fig. 27.3 (**a**) Lateral and (**b**) AP radiographs of the proximal ulna of a 28-month-old boy show cortical irregularity (*arrow*) as well as focal change in the clarity of the subcutaneous fat-muscle interface due to edema (*arrowhead*) associated with the proximal ulna greenstick fracture

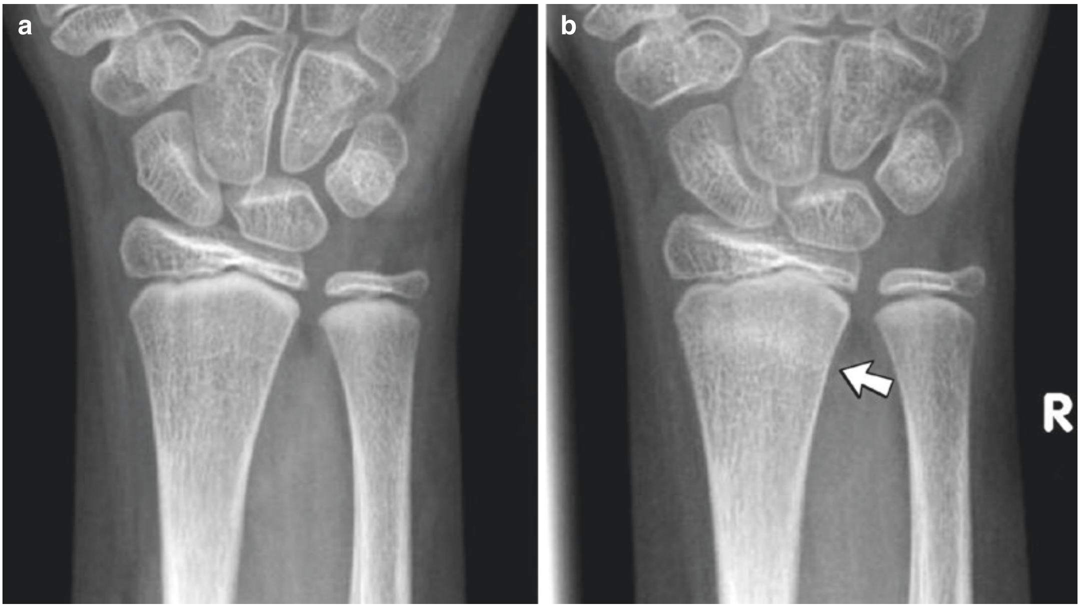

Fig. 27.4 PA radiograph of the distal radius of an 11-year-old girl taken (**a**) at time of injury when the lateral radiograph was considered normal and (**b**) 1 month after injury which shows a band of sclerosis from a healing torus fracture (*arrow*)

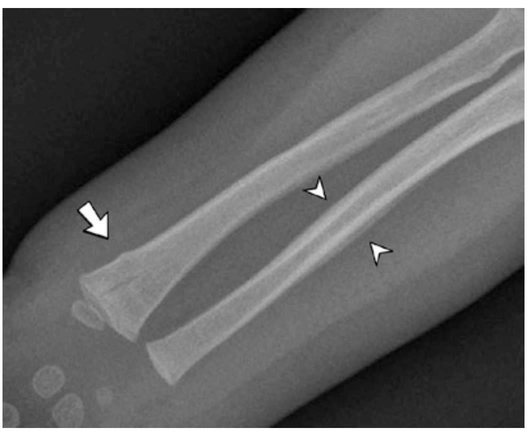

Fig. 27.5 Radiograph of the forearm of a 17-month-old girl shows a torus fracture and longitudinal greenstick fracture of the metaphyseal cortex (*arrow*) together with localized periosteal new bone over the midshaft of the ulnar from previous non-accidental injury (*arrowheads*)

as a normal variant, if not carefully reviewed. They are most commonly seen in the forearm bones with increased curvature of one of the long bones but without a discrete cortical break or evidence of dislocation (Fig. 27.6). The bowing seen in the lower legs in young children (tibial bowing) is a different entity and not considered a result of trauma.

Fig. 27.6 AP and lateral radiographs of the forearm of a 4-year-old boy shows plastic bowing fracture of radius on only the lateral view

27.5 Pitfalls Related to the Growth Plates (Physes)

Growth plates found at both ends of long bones and one end of short bones represent sites of bone growth, particularly responsible for increasing length. The growth plate is made up of resting cartilage on the epiphyseal side, but the diaphyseal side of the growth plate has a zone of proliferating cartilage which is calcified in the metaphysis and grows toward the diaphysis. The bony margins of the growth plate on the epiphyseal and diaphyseal sides of the growth plate gradually become flatter and undulating as the epiphysis approaches skeletal maturity. These roughly parallel lines of calcification define the growth plate.

Fractures through growth plates are a common injury of long bones in children, and the Salter-Harris classification is used as an effective method to describe the type of injury. It is important to identify fractures that involve the physis due to the impact on growth of the bone. Fractures that damage most of the growth plate can result in reduced longitudinal growth and relative bone shortening (Fig. 27.7). This is significant if it involves only one of the paired forearm or lower leg bones or if the growth disruption causes a limp. Damage to only part of the growth plate is more common and can result in asymmetrical growth of the bone, causing angulation of the adjacent articular surface and an increased incidence of joint symptoms in the future.

Salter-Harris type I fractures can be difficult to diagnose and can present as a diagnostic dilemma. Injuries to the ankle causing soft tissue swelling over the lateral malleolus will often cause the radiologist to wonder whether the distal fibular growth plate is slightly widened. A similar dilemma can present with injuries to the wrist and with the distal ulnar growth plate. In both these situations, the growth plate is relatively small, and it is hard to assess the relationship of the undulating parallel lines of the bony margins of the physis. If there is no malalignment, then the patient can be treated symptomatically and reviewed with reassurance that Salter-Harris type I fractures generally have a good prognosis. Slipped upper femoral epiphysis (slipped femoral capital epiphysis) is a variation of a Salter-Harris type I fracture that has long-term complications if missed. To avoid missing this "chronic" fracture, orthogonal radiographs of the femoral heads are required, and careful review of the alignment of the bony margins of the diaphyseal and epiphyseal sides of the growth plate is necessary.

An obvious fracture that involves the growth plate is not a diagnostic dilemma, and clinicians managing these should know when to ask for additional imaging in order to plan treatment appropriately. Not recognizing physeal bars that indicate focal growth plate arrest is a pitfall of interpretation that can be minimized by awareness and appropriate cross-sectional imaging, when the radiographs are inconclusive. A localized physeal bar can be surgically resected, with fat, Silastic, or other materials interposed to prevent bone bridge formation. Alternative methods of treatment include performing an epiphysiodesis of the contralateral or ipsilateral growth plates.

Most growth plates are disk-like and lie mostly in one plane, making them easy to image and recognize. When the growth plate has a more complex shape, its appearance can be misinterpreted as a fracture. This is particularly true for the proximal humerus and, to a lesser degree, the proximal tibia. Looking for the parallel lines of the growth plate and being aware of the normal appearance will avoid this error of interpretation. When the growth plate lies in a plane that is not perpendicular to the long axis of the long bone, it can be difficult to profile on standard imaging of the long bones. This is particularly true for the growth centers around the elbow joint. The complex arrangement can be confusing for radiologists unfamiliar with the pattern and order of ossification. Figure 27.8 demonstrates a fracture of the lateral condyle of the distal humerus that is only clearly seen on the oblique view.

Apophyses have a similar appearance to epiphyses but are found at sites of attachment of muscles/tendons and do not contribute to increase in length of a long bone. Medial epicondyle avulsion fractures of the distal humerus are associated with dislocation of the elbow, and the

Fig. 27.7 (**a**) Lateral and (**b**) AP radiographs of a 12-year-old boy taken at the time of original injury show a distal radius fracture with growth plate involvement. (**c**) PA radiograph of the same boy taken when aged 16 years shows asymmetrical growth of the radius and ulna due to post-traumatic premature growth plate closure

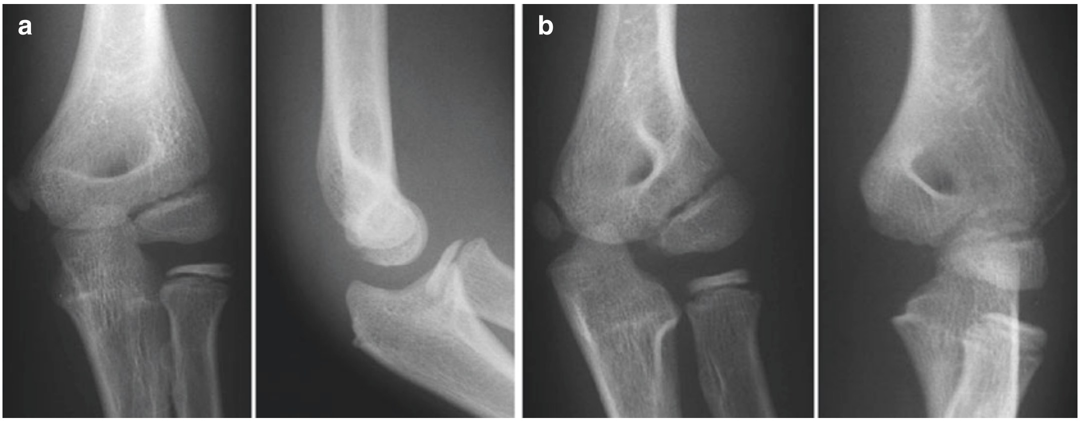

Fig. 27.8 (**a**, **b**) Radiographs of the distal humerus show a fracture of the lateral condyle that is only seen on the (**b**) internal oblique view

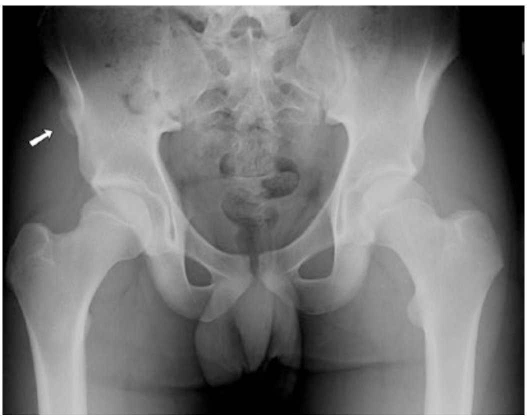

Fig. 27.9 AP radiograph shows an avulsion fracture of anterior inferior iliac spine (*arrow*) in a 15-year-old male sprinter

displaced medial epicondyle can be easily overlooked if it is not searched for. The problem can be exacerbated by the often suboptimal images obtained from a child with a painful dislocated elbow that is difficult to position for standard radiographic projections.

Avulsion fractures of the anterior inferior iliac spines can present with "hip pain," requiring careful review of the bony pelvis adjacent to the hip joint for the injury to not be overlooked. Initially, the displacement is often minimal, and the injury may only be detected after a period of ongoing pain (Fig. 27.9). The fifth metatarsal base apophysis has a typical appearance, with the long axis of the apophysis parallel to the long axis of the fifth metatarsal. Fractures of the fifth metatarsal base are characteristically perpendicular to the long axis of the metatarsal. The patella can also have anterior and inferior apophyses that can be mistaken for sleeve fractures. Careful attention to the presence or absence of parallel lines of the normal apophysis, or the hallmarks of a fracture being ill defined or angular margins and the associated clinical findings will often allow an astute clinician to differentiate between a normal variant and a localized injury.

27.6 Pitfalls Related to Ossification of Epiphyses and Apophyses

During development of the epiphyses, the changing appearance presents a number of stages which may be potentially confused with traumatic injury. Typically, the epiphysis has a smooth contour defined on radiographs by a continuous, initially ovoid line of bone. Sometimes, the epiphysis can have more than one center of ossification and appear bifid or even as an apparent conglomeration of small ossification centers. At the very outset of epiphyseal development, the site of the secondary ossification center may be transiently seen as a focus of T2 hyperintensity within the cartilage, referred to as the pre-ossification center, before the development of epiphyseal bone. Most frequently seen in the

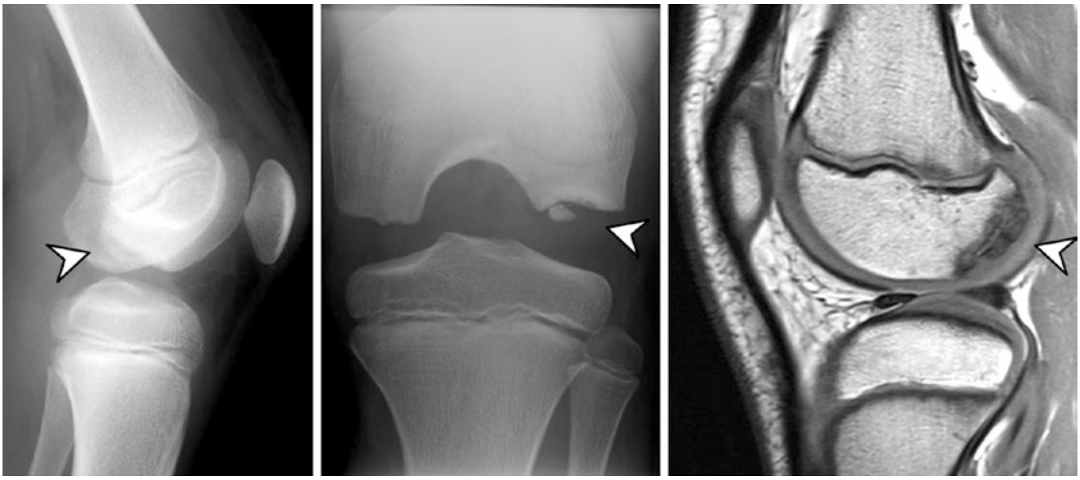

Fig. 27.10 Initial (**a**) lateral and (**b**) AP knee radiographs in a 10-year-old boy show an ossific body (*arrowheads*) separate from the remainder of the lateral condyle, which is particularly conspicuous on the intercondylar view. The corticated ovoid appearance and typical posterior location indicate variant ossification. This was confirmed on the (**c**) sagittal T1-W MR image which shows intact cartilage (*arrowhead*) between these accessory ossification centers and the femoral epiphysis

humeral trochlea and distal femur, these can develop at any site where ossification is occurring within cartilage and should not be mistaken for injury to the cartilage. In general, these can be recognized by the small ovoid appearance at a typical site and by recognizing the age of the developing ossification center.

Accessory ossification centers can present further dilemmas, once they begin to ossify. In particular, it can be difficult to distinguish an unfused accessory ossification center from a fracture, such as at the tip of the fibula or margin of the glenoid. In some cases, the rounded and corticated appearance of an accessory ossification center will be clear on radiographs, but there may be a question of whether the ossification center has been displaced following an injury through the non-ossified cartilage. Distinguishing accessory ossification centers from osteochondral injury in the distal femur has been discussed in the literature. Accessory ossification centers typically lie posteriorly in the femoral condyles, while osteochondral defects are most frequently seen in the most inferior aspect, especially where they abut the tibial spines. At other locations where the distinction is less clear, MRI may be necessary to assess whether the suspect areas of bone show features of intervening fracture, or are connected by intact cartilage indicating variant ossification (Fig. 27.10).

The foot is a common site of injury and secondary ossification centers. These can be difficult to differentiate from fractures, particularly those forming adjacent to the distal fibula and the inferior tip of the medial malleolus. Some of these will remain non-united, to become the os subfibulare adjacent to the distal fibula and the os subtibiale adjacent to the medial malleolus of the distal tibia. It is often speculated and sometimes proven that the small bone “fragments” masquerading as non-united secondary ossification centers are the result of previous trauma (Pill et al. 2013). When the bone fragment margins appear well defined and smooth or the adjacent epiphysis is still mostly cartilaginous and immature, a normal variant should be considered (Fig. 27.11). The presence of localized soft tissue swelling and point tenderness from injury to the adjacent ligaments can make it difficult to make a definitive diagnosis. Ongoing symptoms, such as ankle joint instability, may be the only finding that allows the correct diagnosis to be made. Other common sites where an apophysis or non-united

Fig. 27.11 AP radiograph of the right ankle of an 8-year-old girl shows smooth and corticated secondary ossification centers adjacent to the medial and lateral malleolus

Fig. 27.12 Oblique radiograph of the foot shows a cleft in the base of the third metatarsal that appears as a result of variant non-epiphyseal ossification. The smooth margins aid differentiation from a fracture

secondary ossification center may be mistaken for bone injury are the navicular, scapula, acetabulum, ischial tuberosity, and the femoral greater and lesser trochanters.

There are a large number of variations in the appearances of epiphyses, apophyses, and synchondroses, particularly early in their development. Generally, variants will be symmetrical and be accompanied by similar variations in adjacent or similar ossification centers. However, asymmetrical development is not unusual and should be considered. For example, a cleft in the base of the third metatarsal represents variant non-epiphyseal growth rather than a fracture (Ogden et al. 1994) (Fig. 27.12). Texts devoted to these variations are an essential resource for even experienced musculoskeletal radiologists. Review of these references is preferable to routine imaging of contralateral limbs for comparison and minimizes radiation exposure.

27.7 Pitfalls Related to the Metaphysis

The concept of bone growth occurring at the growth plate is commonly understood, but it can easily be forgotten that there is considerable remodeling of the bone formed at the metaphysis of long bones. The metaphysis is wider than the diaphysis, especially for the long bones of the upper and lower limbs. As the bone initially formed at the physis comes to form part of the diaphysis, there is resorption of subperiosteal bone and laying down of endosteal bone, which results in the thicker and stronger cortex of the diaphysis of a mature skeleton. Remodeling of the subcortical bone at the metaphysis results in a wide variation in appearance of the metaphyseal margins of the growth plate. When this marginal metaphyseal bone is "pointed," it may be mistaken for a classic metaphyseal lesion (corner fracture), and if it is "squared off," it may be mistaken for a buckle fracture. The absence of cortical breaks and the often similar appearance of other metaphyses will aid differentiation from classic metaphyseal lesions. The absence of disruption to adjacent trabeculae will allow differentiation from buckle fractures.

This metabolically active area around the circumference of the metaphysis can be seen, especially early in development, as a thin stripe of hyperintense signal on proton density or T2-weighted MRI in a subperiosteal location, extending from the growth plate and tapering toward the diaphysis. Referred to as the "metaphyseal stripe" (Laor and Jaramillo 2009), this appears linear when imaged along the bone, or as a circumferential rim in cross section. It will generally enhance brightly with contrast agent administration and should not be mistaken for injury or other pathology.

27.8 Pitfalls Due to Variations in Physeal Closure

Around the time of growth plate closure, a further phenomenon can be seen in adolescent patients that can mimic fracture. It is not infrequent that small areas of the physis narrow and begin to close earlier than the remainder. This results in localized stress and a striation of marrow edema extending typically into the metaphysis, sometimes also into the epiphysis from the focus of early closure. This appearance of edema is referred to as a "focus of periphyseal edema" or FOPE (Zbojniewicz and Laor 2012) and commonly encountered around the knee (Fig. 27.13). These are not of clinical significance, if small and occurring close to the time of normal growth plate closure, but the edema can mimic trabecular fracture in some cases.

Perhaps the growth plate responsible for the most consternation around the time of closure is the ischiopubic synchondrosis joining the

Fig. 27.13 Focus of periphyseal edema (FOPE). Sagittal (**a**) fat-suppressed T2-W and (**b**) PD-W MR images of the knee in an active 13-year-old boy show focal marrow edema around a small focus of early growth plate closure in the distal femur. The edema extends more into the metaphysis than the epiphysis

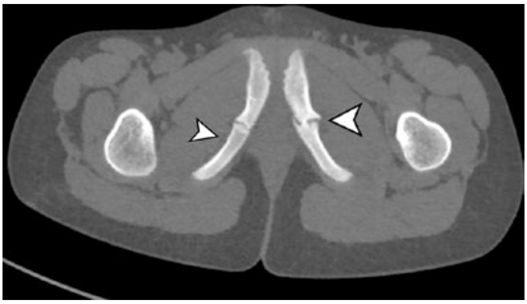

Fig. 27.14 Axial CT image taken following trauma shows unfused ischiopubic synchondroses bilaterally. The left synchondrosis has been fractured (*larger arrowhead*), and a very subtle buckle fracture is identified in the right ischium (*smaller arrowhead*) a short distance posterior to the right synchondrosis

inferior pubic ramus to the ischium. Fusion here is very variable, though typically occurring before or early in puberty, and asymmetry is the rule rather than the exception. The unique feature of the ischiopubic synchondrosis is that it may frequently enlarge just prior to closure, presumably due to mechanical stresses. Generally, this is asymptomatic and considered normal development. However, the appearances on radiographs can be striking due to the asymmetry and can mimic a healing fracture or expansile lucent lesion. When symptomatic, this is considered to represent an osteochondrosis, which has been referred to as van Neck-Odelberg disease. More rarely, other pathologies can be present, including fracture (Fig. 27.14). However, it should be borne in mind that most frequently, enlargement of this synchondrosis prior to closure is a normal developmental variant.

27.9 Pitfalls Due to Vascularity

Prominent vascularity in musculoskeletal structures can be more conspicuous in the pediatric population than in adults, due to the metabolic demands of growth. As an example, pediatric knee MRI can show higher signal within the substance of the menisci, related to increased extent of the "vascular zone," and instances have been reported where this has been misinterpreted as a meniscal tear (Takeda et al. 1998). MR arthrography has been suggested to clarify difficult cases, but, in general, this should not be necessary if the normal range of pediatric appearance is borne in mind, particularly with the improved resolution of modern MRI systems. A related phenomenon can be observed in pediatric spinal MRI, where the epidural venous plexus and small veins around the spinous processes can be more conspicuous than usually seen in adults. Hyperintense signal related to these vascular structures can mimic ligamentous injuries, particularly with partial volume effects on sagittal images of the cervical spine. Awareness of this mimic and review of multiple image planes are therefore important.

27.10 Agility/Coordination/Vulnerability Injuries

Attaining effective control of an increasingly capable musculoskeletal system is one of the tasks of childhood. Children can appear clumsy while learning to walk, run, jump, and tumble as their muscles and bones develop strength, and their central nervous system acquires the ability to adequately coordinate their actions. Falling and tripping is part of the process by which children learn to become more coordinated and to use their increasingly versatile limbs effectively. Consequently, they often present for medical care with injuries to the limbs sustained during a failure of adequate musculoskeletal coordination. Fractures of the distal forearm and the distal humerus are the most common injuries sustained by children, followed by injuries to the ankles and lower limb long bones. Recognizing common patterns of injuries and the circumstances of the injury can be useful in differentiating genuine accidental trauma from NAI; the latter commonly having an implausible explanation for the injury.

Toddler fractures occur when a torsional force is applied to the tibia, usually by having the foot relatively fixed as the body turns. The fracture occurs while the child is developing coordination and before the bone has reached full weight-bearing strength. The fracture is frequently minimally displaced due to largely intact periosteum, and the oblique line of the fracture may result in the fracture line not being visible on routine radiographs. Repeat imaging at 5–10 days may demonstrate fracture margins due to the initial bone resorption phase of fracture healing or only demonstrate periosteal new bone formation as the radiological sign of bone injury. The fracture may be diagnosed with bone scintigraphy or MRI, as nontraumatic causes of a limp may be considered if the initial radiograph is considered normal. A similar fracture can occur in the femur of walking children but is much less common.

27.11 Pitfalls of Pediatric Spine Imaging

The pattern of cervical spine injury is different in children compared to adults. The head of a child is disproportionately large, and their neck muscles are weaker compared to adults; both factors compounding the challenge of maintaining control of the head and preventing injury. In addition, the vertebral bodies have a larger proportion of more pliable cartilage, and the articular facet joints are more horizontally orientated. The immature vertebral bodies can have an irregular and almost wedge-shaped appearance, mimicking a vertebral crush fracture.

The relative mobility of the vertebral segments will also often give rise to minor malalignment in the cervical spine, referred to as “pseudo-subluxation.” This is a subtle malalignment that is most commonly seen in the upper cervical spine at the C2-3 and C3-4 levels, with the superior vertebra anteriorly displaced relative to the vertebra below. This anterior subluxation is less than 4 mm, and the posterior arches should remain well aligned. Specifically, in pseudo-subluxation, the posterior arch of C2 vertebra should not be seen more than 2 mm anterior to the “Swischuk line” between the C1 and C3 posterior arches (Swischuk 1977). This phenomenon can be seen on both horizontal ray supine and erect lateral radiographs of the cervical spine.

Prevertebral soft tissue prominence can vary significantly with respiration and swallowing, especially in infants. While it is a recognized sign of spine trauma, it is important to remember that it may be present due to the timing of the radiograph. In some cases, it can be absent, despite significant spine injury. Cervical rotatory subluxation is a phenomenon which is rare in adults and can be difficult to distinguish from rotation due to muscular spasm alone. The atlantoaxial joint is held in a relatively fixed rotation to one side or the other, due to a fixed subluxation of the lateral articular surfaces. It is more readily diagnosed when severe and usually associated with a transverse ligament injury. Definitive diagnosis requires imaging to exclude unstable fractures, followed by separate imaging sequences with careful left and right rotation of the head (Fig. 27.15), typically with CT, in order to show the presence of fixed relationship of the C1 and C2 lateral masses and a fixed degree of rotation of C1 on C2 vertebrae.

The dens of the C2 vertebra has a varied pattern of ossification, and an accessory ossification center may appear to represent a fracture before skeletal maturity. An incidental os odontoideum will have well-defined bony margins, and no other signs of traumatic injury. Ancillary imaging findings such as soft tissue swelling or MRI evidence of bone marrow edema and ligamentous disruption may be required to confidently differentiate a normal variation from a significant spinal column injury. It should be remembered that fractures can occur through synchondroses (Fassett et al. 2006), and this should be considered if there is any widening of a synchondrosis or if there are any associated signs of spinal column or spinal cord injury. Similarly, the variable pattern of the synchondroses present during ossification of the C2 vertebral body can present problems for clinicians wishing to exclude significant bony trauma.

Cervical spine injuries during childhood are more commonly found in the upper cervical

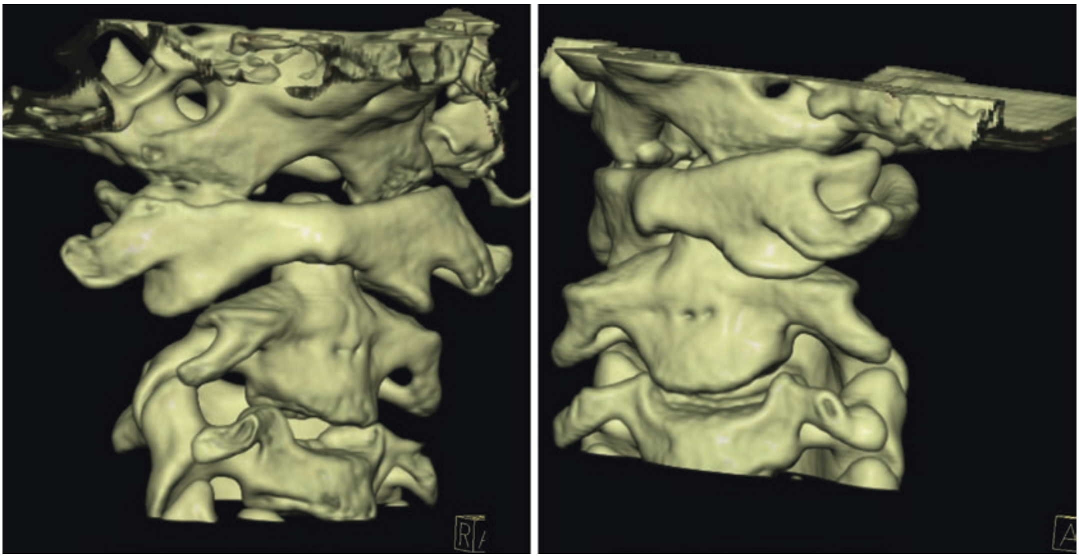

Fig. 27.15 Rotational subluxation in the cervical spine generally occurs as a consequence of trauma, subluxing one of the C1–C2 lateral articulations and producing relatively fixed rotation of C1 on C2. This can be difficult to distinguish from muscular spasm or poor positioning. Sequential CT imaging with left and then right rotation of the head may be necessary to demonstrate the limitation of rotation at the C1-C2 level

spine, with the relative frequency of upper spine injuries reducing with age as the spine reaches skeletal maturity. There is also a higher incidence of craniocervical disruption and spinal cord injury without radiological (radiographic or CT) abnormality – also known as SCIWORA. Craniocervical disruption is difficult to detect due to the relative width of the articular cartilage and the possibility that the subluxation is reduced with clinical stabilization of the cervical spine during initial emergency room treatment. The spinal column made of bone, cartilage, and ligaments is paradoxically more pliable and able to resist tension forces to a greater degree than the soft tissues of the spinal cord and nerve roots. Radiographs and CT of the spinal column can appear normal despite spinal cord disruption (Fig. 27.16). This emphasizes the importance of clinical correlation and MRI in the assessment of spinal cord injury in children.

The Chance fracture is another spinal injury that is more common in children in whom the interspinous ligaments are relatively stronger than the bone. The horizontal (axial plane) distraction fracture through the spinous process and posterior elements extends anteriorly into the vertebral body as a compression injury. The flexion-distraction injury is frequently associated with intra-abdominal injuries and although the fracture is unstable due to its disruption of all vertebral columns, it is not often associated with neurological symptoms. It most commonly occurs as a consequence of a patient wearing a lap-sash seat belt in a motor vehicle accident. The fracture may be subtle and can be overlooked; it is most easily identified on sagittal plane imaging.

An incidental finding that may be confused for an acute injury is a limbus vertebra. This entity is caused by herniation of the nucleus pulposus of an intervertebral disk between the ring apophysis and the vertebral body prior to fusion of the ring apophysis at skeletal maturity. It is considered likely to be a result of previous trauma and is most commonly seen at the anterosuperior endplate of a lumbar vertebra, but it can occur laterally or posteriorly and may be seen in the thoracic spine. The triangular bone fragment and the defect in the vertebral body usually have corticated margins, which aid in the differentiation from an acute vertebral fracture for those unfamiliar with the appearance or when the location

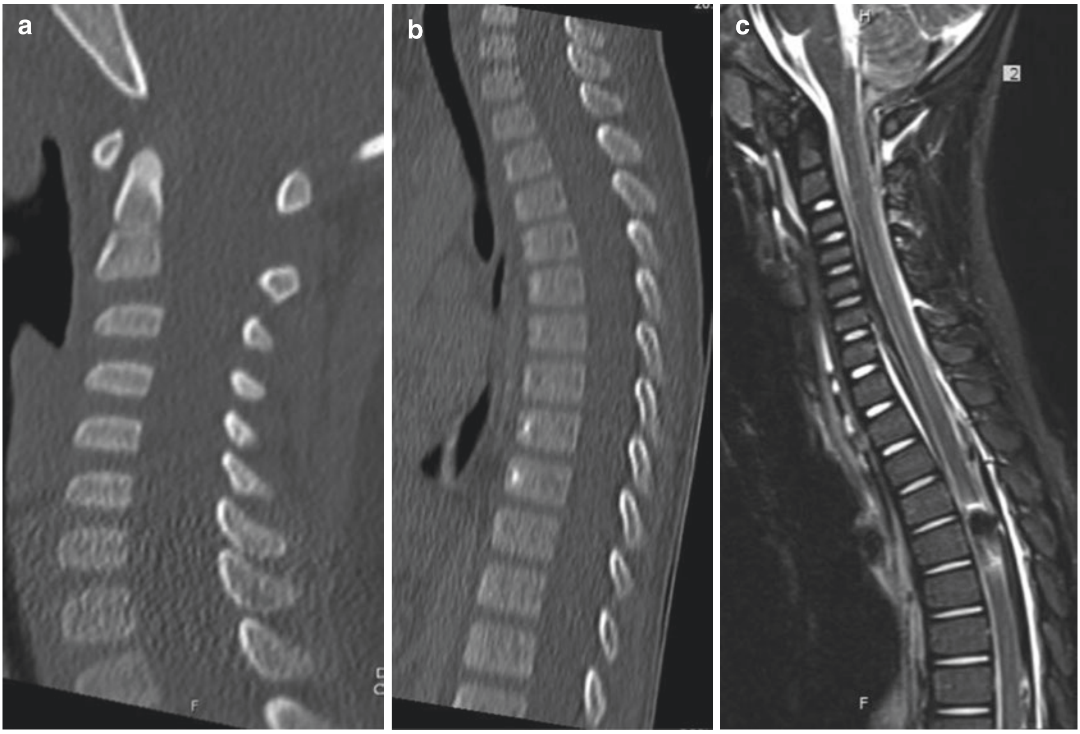

Fig. 27.16 A 3-year-old boy injured in a motor vehicle accident. Sagittal CT images of the (**a**) cervical and (**b**) thoracic spine show no bony abnormality compared with the (**c**) sagittal T2-W MR image which shows a transected spinal cord at T5 level

is uncommon. They are usually asymptomatic, the exception being posterior ring apophysis lesions that may cause nerve root compression (Yen et al. 2009).

27.12 Miscellaneous Pediatric Injuries

Ligament and tendon injuries are much less common than bony injury in children as they are relatively stronger than the bony skeleton. Bone contusions suggestive of ligamentous injury may be demonstrated on MRI, without evidence of the ligamentous injury usually found in adults with the same constellation of bone marrow changes, particularly around the knee. Tibial spine fractures occur with increased frequency in children compared to adults due to the relative weakness of the bone compared to the anterior cruciate ligament (Mitchell et al. 2015).

Radial head subluxation is an injury that is associated with normal or near-normal elbow radiographs without a joint effusion. The injury is most commonly caused by traction on the arm of a young child, often by a carer lifting a child by their arm; hence the name "nursemaid elbow" was given. The radial head is held in position relatively loosely by the immature annular ligament, facilitating subluxation with minor force. The subluxation is often reduced during radiography, if the positioning for the diagnostic imaging includes flexion of the elbow for the lateral elbow image and supination or pronation of the wrist for the anteroposterior (AP) image.

Children do get stress fractures despite the bones of children generally being more pliable until skeletal maturity, and these are particularly seen during adolescence. Repetitive stress injuries in children and adolescents have similar distribution and causation as in adults. In addition to sports and other repetitive use injuries, children

Fig. 27.17 Stress fracture of the fourth metatarsal in a 14-year-old boy with a past history of calcaneo-varus (club) foot. Oblique radiograph of the foot shows a stress fracture of the fourth metatarsal (*arrow*)

with gait disorders and congenital abnormalities are prone to stress fractures associated with the abnormal load bearing, particularly of the feet (Fig. 27.17).

27.13 Soft Tissues

Inflammation of a bursa may present after minor trauma and require clinical correlation to differentiate idiopathic inflammatory causes from infection and repetitive/overuse injuries. Common sites include the femoral greater trochanter, olecranon process, knee (prepatellar), supraspinatus, and calcaneum. Vascular malformations may come to clinical attention after local trauma. Those that have associated skin pigmentation may not be a diagnostic dilemma, but some lymphatic malformations may present as a lump after minor trauma. Lymphatic malformations usually present as slow-growing painless lumps but can present after trauma due to intralesional hemorrhage. The large cystic or multicystic lesion should not be confused with a muscle hematoma but may require MRI to fully define the extent of the lesion. Vascular malformations presenting as soft tissue lumps after minor trauma are usually more likely to require differentiation from a soft tissue tumor than a traumatic hematoma, if the preexisting nature of the abnormality was not recognized.

Foreign bodies can also cause a diagnostic dilemma, when the symptoms appear to be related to an unobserved period of physical activity. An easily identifiable skin entry point may not be apparent, and an abscess does not always form soon after the injury. If the foreign body is radiolucent, US imaging will often be required to assist diagnosis and localization. When examining soft tissues for foreign bodies using US, it is important that sufficient transducer coupling gel is used in the region of interest to allow the angle of insonation to be varied during the examination. This will facilitate the detection of small foreign bodies that can only be seen when the US beam is perpendicular to the foreign body.

Complex regional pain syndrome (CRPS) type I has previously been known as reflex sympathetic dystrophy and Sudeck atrophy. It is a poorly understood condition, probably originating from the sympathetic nervous system, which results in pain that occurs days or up to months after a sometimes minor episode of trauma. The symptoms are usually worse than the clinical findings, which include pain, swelling, skin atrophy, and extreme sensitivity to touch. The radiological findings are often subtle or absent but include patchy osteoporosis. MRI can show quite striking but generally patchy marrow edema, and care must be taken to differentiate this pattern of hyperintense T2 marrow signal from a fracture.

Bone scintigraphy in patients with CRPS type I often shows an abnormal pattern of activity on the blood flow, blood pool, and delayed scan images. The pattern of uptake can vary during disease evolution; in adults, there is typically increased activity in the affected region on all three phases of the bone scintiscan at presentation, changing to decreased activity on all three phases when long standing. However, children most commonly present with a vasospastic form of CRPS where the blood flow, blood pool, and delayed scintiscan activity are reduced, generally within the affected limb at the time of presentation (Low et al. 2007). This pattern of radiopharmaceutical distribution can also be seen with non-weight-bearing, particularly if there is effective immobilization of a limb, such as with application of a splint and use of crutches.

27.14 Cooperation/Poor History

Children are not always able to accurately convey the nature of their symptoms and some complaints are only appreciated after a period of time. This can mean that there is a delay between the onset of symptoms and the recognition of the symptoms. As children are often falling over or bumping into things, trauma can sometimes be attributed as the cause of symptoms when it is not, or the temporal relationship of the symptoms to the trauma may be ignored. Clinicians must be aware of the possibility that unrecognized trauma may be a cause of symptoms. Limb symptoms caused by osteomyelitis may be inappropriately attributed to an undisplaced fracture when patients present with normal radiographs and equivocal laboratory markers of infection. Bone scintigraphy and MRI are particularly useful in identifying bone marrow abnormalities that are not demonstrated on radiographs in patients who have unexplained symptoms.

Juvenile idiopathic arthritis can also present as a diagnostic dilemma to clinicians who forget that children may also be afflicted with joint inflammation. This is most commonly a transient reactive (post-viral) arthritis and is most common in the hip but can affect almost any synovial joint. More debilitating inflammatory arthritis can also present after what is interpreted as bone, joint, or soft tissue trauma. The relapsing/intermittent nature of the presentation and the absence of objective clinical signs can make the diagnosis difficult. US imaging and MRI may show evidence of synovial thickening and/or inflammation, or a joint effusion. Bone scintigraphy may show increased synovial blood pool activity and delayed uptake involving both sides of the joint but it often shows no focal abnormality. As the joint symptoms can be transient and the radiographs normal, the symptoms may not be recognized as a primary inflammatory arthritis, until many episodes have been reported or many joints involved.

Children with lower limb pathology due to trauma or inflammation will often present with nonspecific symptoms that are difficult to localize. A limp may be due to pathology anywhere in the lower limb or lumbar spine. Symptoms apparently arising from the knee can require extension of the radiological survey proximally to include the hip and or distally to include the ankle joints and foot, if the initial knee examination is normal.

27.15 Trauma as the Presentation of Underlying Pediatric Conditions

In many instances, a child will present after trauma, but while the trauma is the cause for the presentation, the more important diagnosis is of an underlying condition. Children can present with pathological fractures not only due to focal bone lesions but also due to bone dysplasias and other systemic conditions. Osteogenesis imperfecta may be diagnosed antenatally, as intrauterine fractures are identified by US imaging, but more commonly after presentation with fractures that occur with relatively minor trauma. The connective tissue disorder is commonly associated with other clinical features such as blue sclera and “loose” joints which can be an aid to diagnosis of the milder forms. Osteogenesis imperfecta can present with unusual patterns of fracture or evidence of fractures of different ages – the major differential in such cases is NAI – and it is not infrequent that one must consider both these possibilities at the first such presentation. NAI is an important topic in its own right, discussed below in Sect. 27.16.

The role of vitamin D deficiency in bone weakness in the general population is controversial (Clark et al. 2006), although vitamin D-resistant rickets and other recognized abnormalities of the calcium metabolic pathways are important considerations in the differential diagnosis of bones prone to fracture or curvature. The diagnosis of bone dysplasias and metabolic bone diseases used to rely heavily on the radiological findings, but genetic and histopathological markers now give more accurate diagnosis and at an earlier stage of clinical presentation. Children with gracile and osteopenic bones due to cerebral palsy and other neuromuscular disorders are also prone to bone fractures.

Pathological fractures in children most commonly occur through benign tumors, tumor-like lesions, bone abnormalities due to underlying metabolic disease or infection, and only rarely through metastatic lesions (De Mattos et al. 2012). The most common lesion found is unicameral bone cyst. Malignant sarcomas may be identified as a consequence of minor trauma but are usually easily identified as primary bone tumors on radiographs at presentation. Some pediatric musculoskeletal sarcomas can present as soft tissue masses requiring US imaging or MRI for differentiation from a hematoma.

27.16 Non-accidental Injury

Non-accidental injury (NAI) is a condition that reflects the vulnerability of children to trauma inflicted intentionally by others and is the form of child abuse/neglect that requires radiological assessment. Very young children are especially vulnerable, as they are unable to escape from their attacker and are prone to skull, rib, and metaphyseal injuries. Defense-type forearm fractures can be seen in older children. Although there are some fractures commonly seen in children who have been the subject of NAI, virtually any fracture can be seen as an inflicted injury.

The key role for the radiologist reviewing the images is to recognize fractures with high specificity for NAI, identify injuries with more than one point of trauma (e.g., nonadjacent rib fractures), describe injuries that have different ages, and assess whether the pattern of injury matches the offered explanation. Figure 27.5 demonstrates fractures of different ages in the one limb; this requires explanation for at least two episodes of trauma. Figure 27.18 shows a typical metaphyseal injury received during a shaking injury and how the injury to the ossifying cartilage and periosteum may not be evident on radiographs until there is calcifying callus. It is not the radiologist who must decide who inflicted the injury or why it happened, but he/she does have to assess whether the explanation provided with the clinical history is consistent with the radiological findings. They may also be asked to offer likely mechanisms of injury and approximate age of the injuries. Familiarity with the common injuries of birth trauma can be very useful when dealing with the radiological assessment of possible NAI.

Determining the age of fractures is difficult and not always possible to the degree requested by lawyers or the justice system. It is important to recognize the limitations of fracture age estimation and not feel obliged to make an estimation that would not survive scientific scrutiny or aggressive cross examination in a court of law. Another pitfall in describing injuries associated with NAI is to feel obliged to make a diagnosis of an inflicted injury when there is insufficient evidence. Radiological investigation is only one component in the assessment of child abuse which can have radiologically occult soft tissue injuries or neglect as more definitive evidence.

Injury to the periosteum of a long bone can result in subperiosteal hemorrhage which elevates the periosteum from the cortical bone. The healing process often involves formation of periosteal new bone. This subperiosteal ossification can also be seen associated with bone tumor, infection, and metabolic bone disease but are accompanied by other radiological findings. However, infants often demonstrate periosteal new bone that is physiological and not associated with focal bone trauma. The features which help differentiate physiological subperiosteal

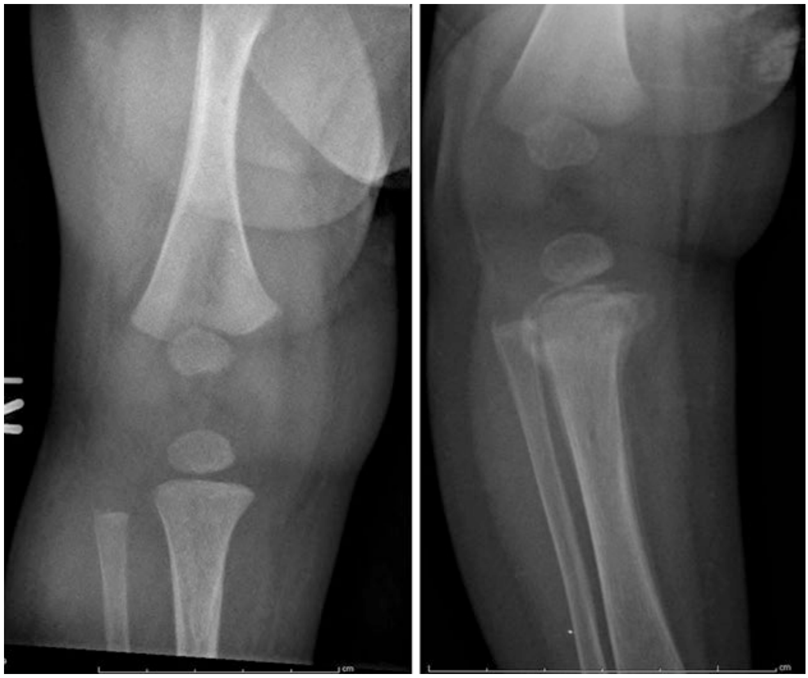

Fig. 27.18 Non-accidental injury. AP radiographs of the right knee show a classic metaphyseal fracture obtained at the time of presentation (*left image*) and obtained 10 days later (*right image*). The later image (*right*) shows extensive changes to the metaphysis associated with disruption of the immature bone adjacent to the growth plate

ossification from traumatic periosteal injury are that the physiological new bone is smooth, symmetrical, and extends the length of the diaphysis of upper and lower limb long bones. It can be seen in about a third of infants aged 1–4 months (Kwon et al. 2002). Traumatic periosteal injury is more likely to be asymmetrical, undulating, and associated with other signs of local bone injury, especially classic metaphyseal lesions (Figs. 27.5 and 27.18).

Conclusion

Imaging in pediatric trauma presents a number of challenges for the general radiologist. In the broadest terms, some features of true injury may not be noticed because in some circumstances, the injuries are different and more subtle than in the adult population. Familiarity with these subtle features, and understanding the reasons for these different patterns of injury, is critical to interpretation of pediatric trauma imaging. As a second broad area, many aspects of normal pediatric appearance can mimic the expected appearance of trauma in an adult, in many cases, due to incomplete or variant ossification on radiographs or CT or due to areas of high signal on MRI in locations not seen in the adult population. A third broad class of pitfalls in pediatric trauma are those cases where a traumatic injury is correctly recognized as such, but atypical features are present which indicate an important underlying condition, such as a pathological fracture due to a lesion, e.g., osteogenesis imperfecta or, perhaps even more importantly, NAI. Failure by the radiologist to recognize such features can have catastrophic consequences, particularly in the case of NAI. Instances where the suspicion is raised inappropriately can also have significant consequences for the child and family.

The final class of pitfalls faced by the general radiologist is not related to interpretation but occur even before the images are obtained – the challenge of imaging in children differs significantly from adults. This relates not only to choice of modality and minimizing radiation exposure, but understanding how the imaging algorithm may differ in pediatric injury and obtaining quality imaging despite difficulties with cooperation. Careful clinical assessment and good communication with referrers is required to best target imaging, for choice of modality, as well as for interpretation of findings. In all circumstances, upset and anxiety for both patients and parents should be minimized. With skilled staff and, ideally, a well-designed environment, imaging can be performed with the least possible need for sedation or forcible immobilization. Awareness of these areas of difference and potential pitfalls, and care and attention to performing best imaging, is vital to providing best diagnosis and doing so while dealing most gently with pediatric patients and their parents.

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