Emerg Radiol (2008) 15:391–398
DOI 10.1007/s10140-008-0733-2

PICTORIAL ESSAY

# Commonly missed subtle skeletal injuries in children: a pictorial review

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Received: 18 February 2008 / Accepted: 16 April 2008 / Published online: 28 May 2008


**Abstract** Children are distinctive as compared to adults when it comes to musculoskeletal injuries. This is due to the relative elasticity of bones and the presence of epiphyseal plates. There are many subtle injuries which will be missed if the radiologist is not aware of them and is not actively searching for them. The common elusive injuries include: (1) plastic bending fractures, (2) sterno-clavicular dislocation, (3) epiphyseal–metaphyseal injuries in older child, (4) buckle fractures, and (5) Toddler fracture types I and II. Detection of these injuries needs an accurate history, a good physical examination, and, in particular, a thorough search by the radiologist. In many cases, it is the radiologist who suggests likelihood of the injury and guides management. In this respect, the use of comparative views and, in some cases, additional imaging is warranted. Here, we review the elusive musculoskeletal injuries in children in pictorial form.

**Keywords** Trauma · Radiology · Imaging · Pediatric radiology · Radiograph

Adapted from a poster presented at the 18th Annual Scientific Meeting of the American Society of Emergency Radiology, San Diego, October 3–6, 2007.

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## Introduction

Children are distinctive as compared to adults when it comes to musculoskeletal injuries [1]. This is mostly due to the relative elasticity of bones. In addition, the presence of epiphyseal plates leads to the unique Salter–Harris type of epiphyseal–metaphyseal injuries which can have devastating effects on bone growth if not detected in time. Toddlers are susceptible to unique fractures of the tibia, fibula, and the foot collectively and aptly named “Toddler’s fractures”. Many injuries are quite subtle and are likely to be missed if not actively searched for. The common elusive injuries include: (1) plastic bending fractures, (2) sternoclavicular dislocation, (3) epiphyseal–metaphyseal injuries in older child, (4) buckle (torus) fractures, and (5) Toddler fracture types I and II.

Detection of these injuries needs an accurate history in regards to the mechanism of injury, a good physical examination, and, in particular, a thorough search by the radiologist. Children pose a challenge to the physician when it comes to skeletal trauma due to the lack of adequate history which is the case more often than not. Also, the child is often incapable of localizing the site of pain. Limping or refusal to use a limb may be the only symptom without other localizing findings. In such cases, the physician has to rely on the radiologist to pinpoint the diagnosis. In many cases, it is the radiologist who suggests the likelihood of the injury when it was not suspected clinically.

Here, we present a pictorial review of the aforementioned skeletal injuries in children while briefly touching on the pathophysiology and mechanism of each injury which are essential in making the diagnosis. Salient imaging findings which need to be actively searched for will be emphasized. In this respect, the importance of using comparative views [2] and, in some cases, additional imaging is also highlighted when necessary.

## Discussion

### Plastic bending fractures

Plastic bending fractures are caused by an axial loading force which leads to numerous "microfractures" along the convex aspect of the deformed bone that are not visible at radiography [3]. Additional loading force will lead to a greenstick fracture. The most common bones involved include the radius, ulna, clavicle, and fibula. Use of comparative views is important to increase the degree of confidence in making the diagnosis. High degree of suspicion on part of the radiologist is imperative for the diagnosis. Forearm bones are the most common site for bending fractures. These fractures are frequently missed [4]. Forearm fractures may be isolated. However, more commonly both the forearm bones fracture together and the presence of fracture in one bone should initiate a search for fracture in the other. In children, this is often a bending fracture (Fig. 1). The fibula is also commonly affected (Fig. 2). The fibula is normally curved inwards and, hence, comparative views are

**Fig. 1** Seventeen-year-old male with history of fall. Subtle bending fractures of *right* distal radius and ulna (*arrows*) are seen. Compare to the normal *left side*

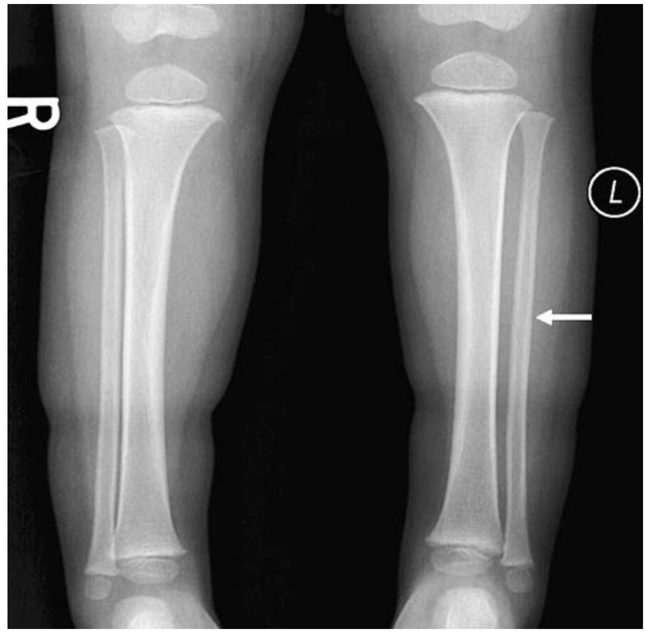



**Fig. 2** Three-year-old child with a limp. Note the subtle bending of the *left* fibula (*arrow*) when compared to the *right*. Diagnosis will be difficult in the absence of comparative views due to the normal variable curvature of the fibula

imperative to suggest the diagnosis. These will show the increase in curvature on the affected side. The clavicle is another bone which is commonly involved and unless the radiologist is awake to the possibility of this fracture, it will be missed. Such an injury is rare in adults but is often seen in children and occurs due to the transmission of forces to the clavicle from fall on outstretched hand or direct blow to shoulder. The diagnosis is often suggested by asymmetry of the clavicles. This subtle fracture is usually diagnosed on the chest radiograph (Fig. 3) rather than the unilateral shoulder radiographs which often are obtained to rule out shoulder injury.

### Sternoclavicular dislocation

Sternoclavicular joint dislocations are rare [5]. Significant history of compressive or violent force is usually required to cause sternoclavicular dislocation [6, 7]. Anterior

**Fig. 3** Fifteen-year-old male with fall on outstretched hand. The *left* clavicle is bent upwards (*arrow*) as compared to the normal contour on the *right*. A fairly well-centered radiograph is required for proper comparison

dislocation usually results from an indirect mechanism such as a blow to the anterior shoulder. More than two thirds of anterior dislocations are associated with serious injuries, including pneumothorax, hemothorax, pulmonary contusion, and rib fractures [8]. Posterior dislocations result from trauma to the posterior shoulder driving the shoulder forward and causing posterior sternoclavicular dislocation. Direct impact to the sternoclavicular region can also lead to posterior dislocation. Posterior dislocation may injure structures of the thoracic outlet and the mediastinum, including the trachea, esophagus, and the great vessels (superior vena cava, aortic arch, and its branches). Because the medial epiphysis is the last to ossify and close (approximately at 19 years and between 23 and 25 years, respectively), clavicle shaft displacements seen with physeal disruptions at the medial end of the clavicle in adolescents and young adults may mimic sternoclavicular dislocations [8]. Although these injuries are commonly referred to as sternoclavicular dislocations, they are in fact fracture (Salter–Harris) dislocations rather than pure dislocations. Diagnosis may be suggested on the chest radiograph in the correct clinical setting if the medial ends of the clavicles are offset with respect to each other. On well-centralized frontal radiographs, a difference in relative craniocaudal position of the medial clavicles greater than 50% of the width of the heads of the clavicles suggests fracture dislocation (Fig. 4a). Clinical evaluation and diagnosis is notoriously difficult which can lead to delay in diagnosis [9]. A contrast-enhanced thin section computed tomography (CT) scan should be obtained for final diagnosis and to rule out the compression and injury of the great vessels in the superior mediastinum (Fig. 4b).

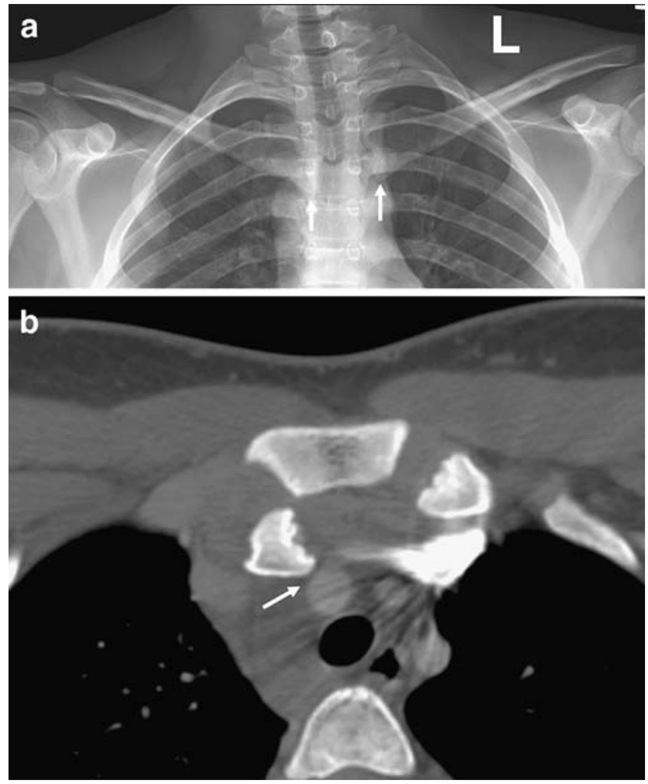



**Fig. 4** Sternoclavicular dislocation in a 17-year-old male with history of motor vehicle accident and direct impact over the *right* shoulder. **a** Note the mild offset of the medial ends of the clavicles (*arrows*). A sternoclavicular dislocation was suspected and CT scan with contrast was obtained. **b** CT scan—there is posterior dislocation of the *right* clavicle. Note the medial end of the *right* clavicle abutting the brachiocephalic artery (*arrow*)

## Epiphyseal–metaphyseal injuries in older child

Children are unique in terms of skeletal injuries because of the presence of epiphyseal plates which result in Salter–Harris epiphyseal–metaphyseal injuries. Salter–Harris I and II injuries pose the most difficulty in diagnosis. Salter–Harris I injury causes widening of the epiphyseal plate with or without displacement. In Salter–Harris II injuries, force from trauma is transmitted to the metaphysis leading to a metaphyseal component in addition to the epiphyseal plate injury. Since the growth plate is involved, these injuries can lead to premature fusion of the involved plate and subsequent varus or valgus angulations as well as limb length discrepancies. Radiography remains the mainstay of diagnosis. In the wrist, ankle, and knee joints, the epiphyseal plate of the adjacent bone can act as a control (Fig. 5). At other sites, comparative views are required to make the diagnosis of a nondisplaced Salter–Harris I injury (Fig. 6). Adjacent soft tissue swelling can often be an important clue to the presence of growth plate injury.

**Fig. 5** Salter–Harris I injury of the distal radius (*arrow*) in a 15-year-old female. Compare the widened epiphyseal plate to that of the normal ulna

**Fig. 6** Salter–Harris I injury of the right proximal humerus in a 17-year-old. Compare the widened growth plate (*arrow*) with the normal contralateral side

## Role of MRI in epiphyseal–metaphyseal injuries

Magnetic resonance imaging (MRI) is playing an increasingly important part in the management of patients with suspected Salter–Harris injuries particularly when diagnostic uncertainty persists after conventional radiographs. Direct visualization of cartilage afforded by MRI improves the evaluation of growth plate injury [10, 11]. MRI is the investigation of choice in acute complex physeal injuries and is particularly appropriate for use prior to the appearance of the secondary ossification center [12]. Carey et al. [13] and Smith et al. [14] found that MRI can change Salter–Harris classification in patients with fractures visualized on conventional radiographs. MRI also allows detection of radiographically occult fractures and results in a change in patient management [13]. Petit et al. [15], in their study, concluded that MR imaging should be limited to complex fractures and to cases in which the classification of a fracture on the basis of plain film evaluation is uncertain. In their study, only one of the 29 fractures involving the distal tibial physis was misclassified by plain film radiography and MR imaging never caused the treatment plan to be modified. However, the position of fracture fragments in Salter–Harris IV and triplane fractures was always better appreciated on MR images, facilitating more accurate surgical treatment. Lohman et al. [16] had similar findings in their study. In our experience, MRI is

**Fig. 8** Salter–Harris II injury in a 14-year-old. The metaphyseal fracture line on the lateral aspect is very well-visualized on MRI. A small joint effusion is present. In addition, there is a mild distraction of the distal femoral growth plate medially (*arrow*)

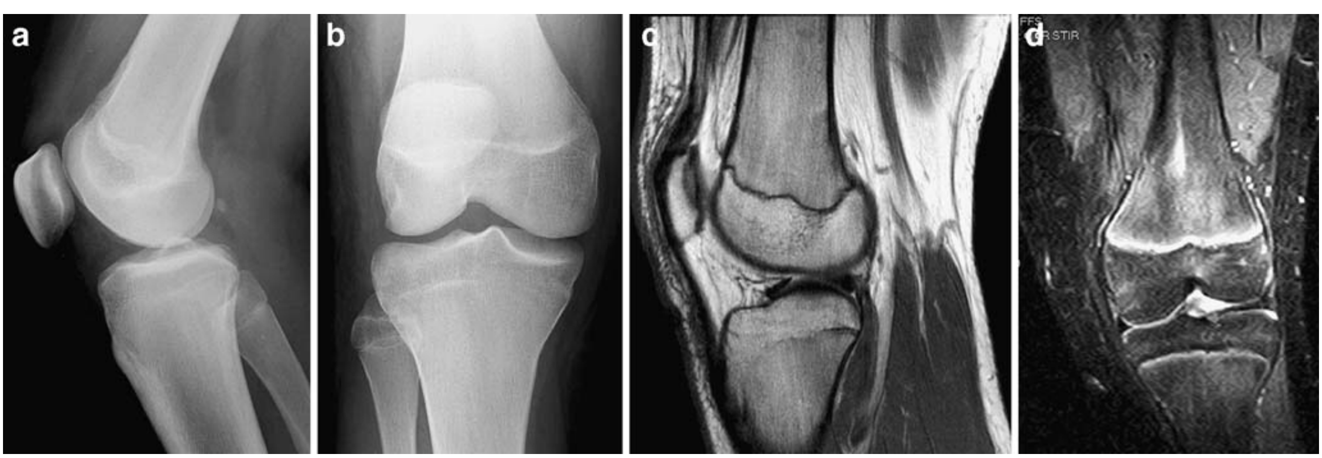



**Fig. 7** Salter–Harris I injury of the distal femur in a 16-year-old. **a**, **b** The proximal tibial epiphyseal plate has almost fused while that of the distal femur is still open. **c**, **d** This is better appreciated on the MRI. In addition, bone edema within the femoral metaphysis in the coronal STIR image suggests the diagnosis of Salter–Harris I injury

Fig. 9 Torus fracture of the distal radius in a 7-year-old male seen as cortical buckling (*arrow*) with no fracture line evident

particularly useful to detect nondisplaced Salter–Harris I injuries around the knee (Fig. 7). Normally the distal femoral and proximal tibial growth plates are comparable with respect to their signal intensity on short-tau inversion recovery (STIR) images and, hence, they can be used as a reliable control to detect subtle injuries confined to the growth plate. MRI is also useful in detecting subtle Salter–Harris II injuries with the clear depiction of extension to the growth plate which may be missed on radiographs (Fig. 8).

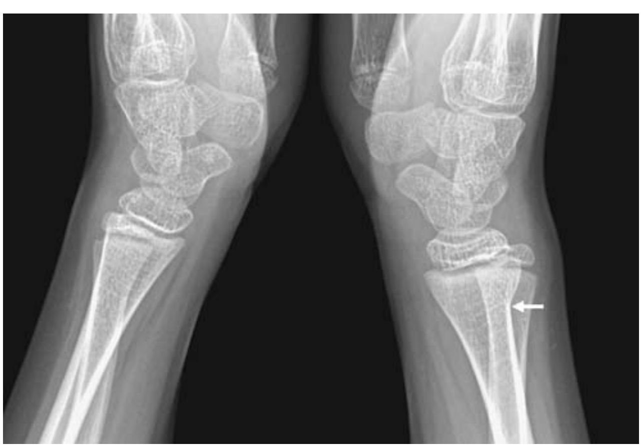


Fig. 10 Buckle fracture of the dorsal cortex of the distal radius in an 11-year-old male which was seen on the lateral view only (*arrow*). Compare with the smooth dorsal cortex on the contralateral side which is routinely obtained at our institution

Fig. 11 Buckle fracture of the right scaphoid (*arrow*) with overlying soft tissue swelling in a 12-year-old male with fall on outstretched hand. In these fractures, soft tissue swelling and obliteration of the navicular fad pad is often the only clue which can lead the radiologist to a thorough search for scaphoid fracture

## Buckle (torus) fractures

Pure axial loading produces typical buckle fracture with outward buckling of the cortex. This type of injury is easier to detect and does not usually warrant comparative views. Combination of axial loading with hyperextension, hyper-

Fig. 12 Buckle fracture of the right proximal radius (*arrow*) in a 6-year-old male. This is a relatively common fracture causing elbow joint effusion

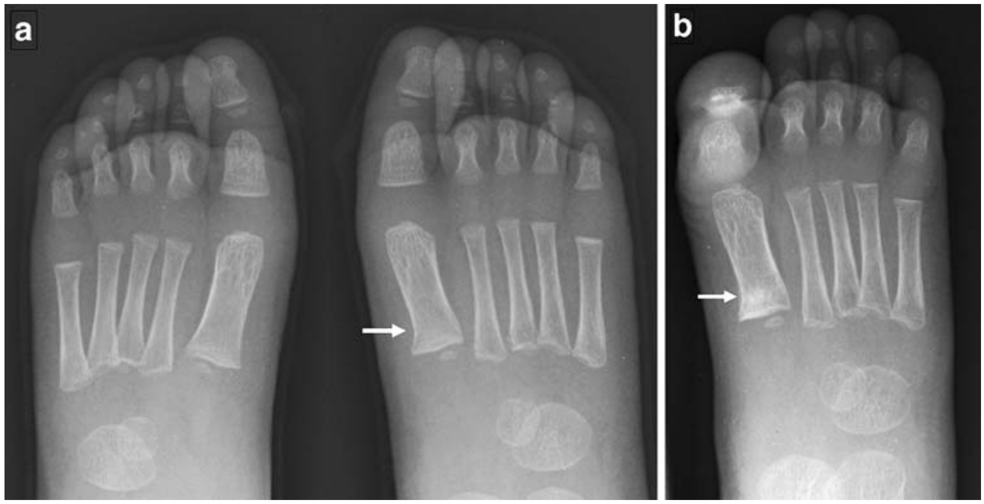



**Fig. 13** Angled buckle fracture—bunk-bed fracture. **a** Angled buckle fracture at the base of the *right* first metatarsal (*arrow*) in a 3-year-old male. Note the smooth contour contralaterally. **b** Follow-up radiograph shows healing with sclerosis (*arrow*) at the fracture site

flexion, valgus, or varus forces produces an angled buckle fracture where just angulation of cortex is present. These are one of the commonest fractures in children and the most easily missed if particular attention is not paid to the contour of the bone especially at the metaphysis [17]. These fractures often are very subtle and comparative views are almost indispensable in some cases. Common sites affected include the wrist, ankle, and elbow. The distal radius is the commonest site involved (Fig. 9). Often the buckling involves the dorsal cortex and is seen only on the lateral view (Fig. 10). As with Salter–Harris I injuries, soft tissue swelling is an important clue to the diagnosis of buckle fractures (Fig. 11). The proximal radius also is a common site for the missed buckle fractures (Fig. 12). Elbow effusion indicated by an elevated anterior fat pad is often the only clue to the presence of a fracture around the elbow. This should prompt close inspection of the radial neck contour to rule out a buckle fracture at this site. Comparative views are helpful if doubt exists. Angled buckle fracture through the base of the first metatarsal is often referred to as the bunk-bed fracture [18]. This is part of the spectrum of fractures included in the expanded concept of Toddler's fracture [3]. It is caused by axial loading of the foot in a plantar-flexed position [18, 19]. Once again, the


**Fig. 14** Toddler's fracture type I in a 3-year-old. **a**. A hairline fracture (*arrow*) is visible in the distal tibia on this ankle radiograph. **b**. Confirmation on the anteroposterior radiograph of the leg (*arrow*)


**Fig. 15** Another toddler's I fracture in a 3-year-old. **a**, **b** In this case, it is seen well only on the lateral projections (*arrows*)

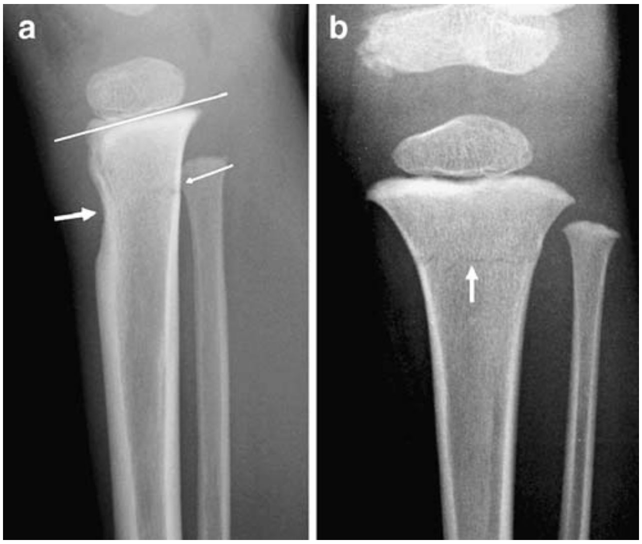



**Fig. 16** **a**, **b** Pathophysiology of classical toddler type II fracture in a 2-year-old (see text for explanation)

radiographic finding of adjacent, localized soft tissue swelling is a valuable aid in the detection of these subtle fractures (Fig. 13).

### Toddler's fractures

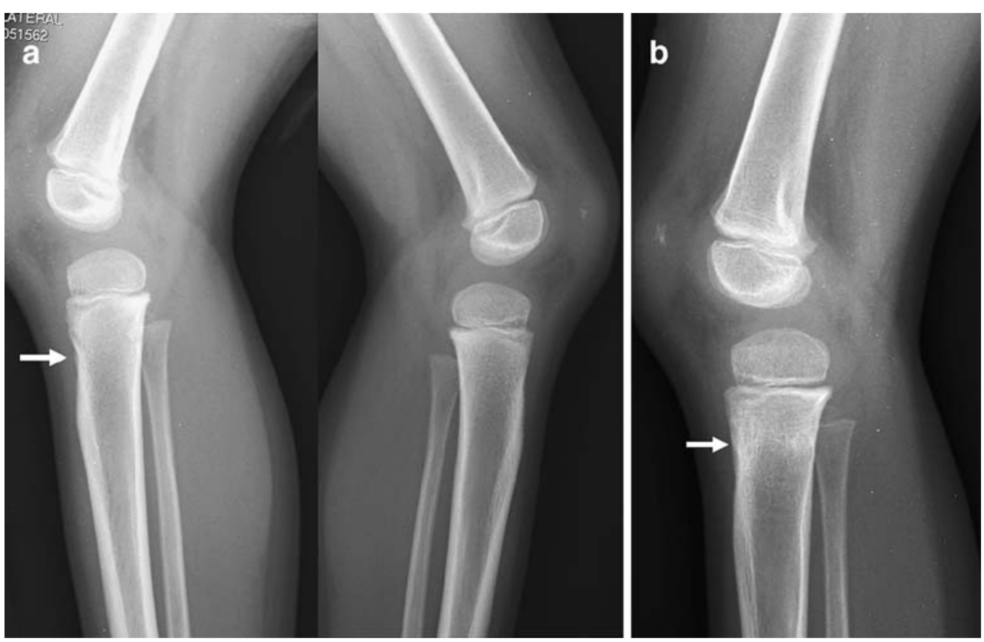
The classical toddler's fracture was first described by Dunbar et al. [20] and is often called Toddler's fracture type I. It is a spiral hairline fracture of the tibial shaft that results from a twisting or rotational force applied to the foot and lower extremity [3]. Clinically, an ankle injury is often suspected; hence, ankle radiographs are usually ordered. The fracture is often evident on the oblique view of the ankle but it is easily missed if not closely searched for (Fig. 14). On the lower leg radiograph, the fracture is seen as a faint; spiral hairline fracture generally seen better on one view than the other (Fig. 15).

Upper tibial hyperextension injury often referred to as Toddler's fracture type II was first described by Swischuk et al. [21]. Pathophysiology of a typical Toddler's type II fracture (Fig. 16a) consists of a hyperextension injury leading to a posterior-distracting fracture (thin arrow), anterior compression with buckling of the cortex and deepening of the notch for tibial tubercle (thick arrow), and anterior tilting of the epiphyseal plate (white line). The fracture line seen in Fig. 16b (arrow) is not evident in majority of the cases. Comparative views are helpful in such cases. Often the only clue to the diagnosis is deepening of the notch for tibial tubercle on one side as compared to the other (Fig. 17). The diagnosis can be confirmed clinically wherein the pain is reproduced on hyperextension of the tibia.

## Conclusion

Children are unique when it comes to musculoskeletal injuries. There are many elusive injuries which will be missed if the radiologist is not aware of them and is not actively searching for them. Some of these injuries have serious consequences if not managed promptly. In many cases, the radiologist can suggest an injury not suspected clinically and thereby guide management. Awareness of the normal epiphyseal centers and their expected time of

**Fig. 17** A more subtle Toddler type II fracture in a 3-year-old with no obvious fracture line requiring comparative views for final diagnosis. **a** Note the deepening of the notch for tibial tubercle on the *right* (*arrow*) as compared to the *left*. **b** A follow-up radiograph shows healing with sclerosis (*arrow*) at the fracture site



closure are important. Due to variability in appearances of the epiphyseal centers and their time of closure, the use of comparative views can aid in the diagnosis. Comparative views are also imperative for the diagnosis of subtle fractures especially bending, Salter–Harris I, Toddlers type II, and angled buckle fractures. Additional imaging in the form of CT scan (sternoclavicular dislocation), follow-up imaging, and MRI (scaphoid fractures and epiphyseal–metaphyseal injuries) is necessitated at certain times and should be obtained.

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