

Skeletal survey normal variants, artefacts and commonly misinterpreted findings not to be confused with non-accidental injury

Alan J. Quigley · Samuel Stafrace

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Abstract Radiology plays a key part in the investigation of non-accidental injury. Many normal variants and artefacts can simulate an abnormality associated with non-accidental injury. It is essential that radiologists reporting skeletal surveys in cases of suspected child abuse are aware of these. We present a pictorial essay to aid the reporting radiologist in the differentiation between normal variants or artefacts and true traumatic injury. We show plain film examples of potential pitfalls throughout the body.

Keywords Skeletal survey · Radiography · Non-accidental injury · Normal variants · Children

Introduction

Non-accidental injury results from an abusive act by a parent or guardian perpetrated on a child. Approximately 1.2% of people experience severe physical violence at the hands of an adult during childhood [1]. The thorough investigation of children with suspected non-accidental injury is critical to ensure the

child's safety [2]. After soft-tissue bruising and burns, fractures are the most common presentation of non-accidental injury [3]. As a result, radiologists play a key role in the diagnosis of suspected cases. If non-accidental injury is suspected, a skeletal survey is the imaging method of choice and a specific set of radiographs is recommended (Table 1) [2].

Several normal anatomical variants can simulate an abnormality associated with non-accidental injury. These include physiological periosteal reaction, metaphyseal variants and nutrient foramina. Also, various artefacts can be confused for traumatic injury. It is important that the reporting radiologist be aware of these normal variants and commonly seen artefacts so that traumatic injury and, more important, non-accidental injury are not over-reported. These appearances are presented below in a craniocaudal approach.

Skull

Sutures

Skull sutures can be mistaken for acute traumatic injury on plain film. The parietal and occipital bones are common sites for accessory sutures because of their numerous ossification centres [4]. Accessory sutures are often bilateral and symmetrical and are more numerous in the occipital region because of increased numbers of ossification centres. Features on plain film that suggest a suture rather than a fracture include a zig-zag pattern with sclerotic borders, an absence of any diastasis, bilateral and fairly symmetrical orientation and an absence of any adjacent soft-tissue swelling [4]. Fractures, on the other hand, are typically unilateral, sharp lucencies with non-sclerotic edges. They tend to widen as they approach a suture

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A. J. Quigley (✉)
In-Patient Radiology Department, Aberdeen Royal Infirmary,
NHS Grampian, Aberdeen AB25 2ZN, UK
e-mail: alanquigley@nhs.net

S. Stafrace
Radiology Department, Royal Aberdeen Children's Hospital,
NHS Grampian, Aberdeen, UK

Table 1 Standard skeletal survey projections recommended by the Royal College of Radiologists & Royal College of Paediatrics and Child Health in cases of suspected non-accidental injury

Standard skeletal survey for suspected non-accidental injury

- Skull radiograph (AP and lateral; plus Townes view if clinically indicated)
- AP chest
- Left and right oblique rib views
- AP of the abdomen (including the pelvis)
- Lateral cervical, thoracic and lumbar spine radiographs
- AP of both upper arms
- AP of both forearms
- AP of both femurs
- AP of both lower legs
- PA of both hands
- DP of both feet

and sometimes cross the suture. There is usually associated soft-tissue swelling. Any doubt about whether the abnormality represents a fracture or a suture can be resolved by correlating radiographs with the bone windows on the CT head examination.

Occipital synchondrosis

The occipital bone at birth is composed of a squamous segment (composed of an interparietal portion and supraoccipital portion), a basioccipital segment and paired exoccipital segments [5]. The occipital synchondrosis occurs between the exoccipital segments and supraoccipital portion of the



Fig. 1 Lateral skull radiograph in a 1-month-old boy. The innominate synchondrosis appears as a lucency in the region of the occipital bone (white arrow). The mendosal suture is also visualised (black arrow)

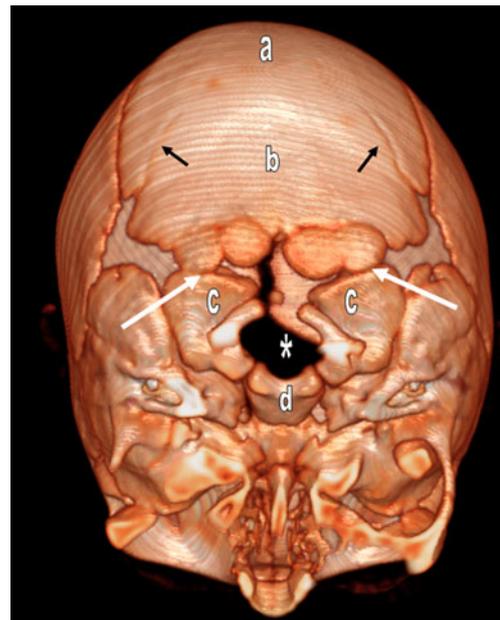


Fig. 2 Reformatted CT of the same 1-month-old boy as in Fig. 1. **a** The interparietal portion of the occipital bone. **b, c** The innominate suture (white arrows) is visualised bilaterally between the supraoccipital portion (**b**) and basioccipital segments (**c**) of the occipital bone. **d** The basioccipital segment of the occipital bone. Note the bilateral mendosal sutures (black arrows) and the foramen magnum (asterisk)

occipital bone (Figs. 1 and 2). It begins to fuse from birth, being complete by 4 years of age. It should not be mistaken for a fracture.

Mendosal suture

The mendosal suture separates the supraoccipital portion of the squamous segment of the occipital bone from the interparietal portion [6]. It usually persists for several weeks after birth [7, 8]. It can often simulate a fracture, especially if there is a slightly oblique projection of the skull (Fig. 3).

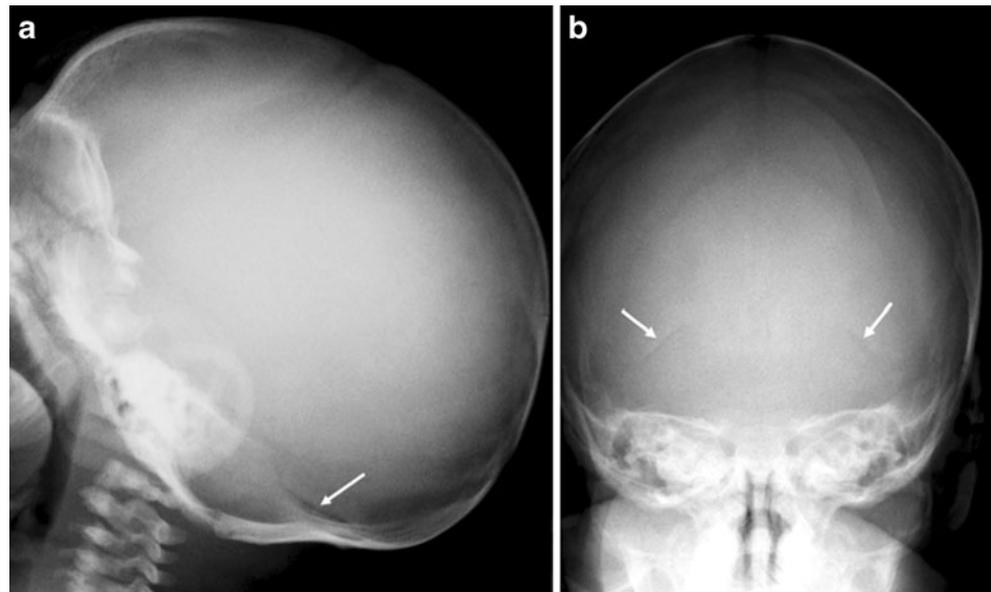
Metopic suture

The metopic, or frontal, suture is found in the midline of the frontal bone. Fusion usually occurs by approximately 9 months although some studies have shown it to persist in children up to 8 years of age and even into adulthood [9–11]. Like the mendosal suture, it can mimic a fracture if the child is rotated (Fig. 4).

Inca bone

The interparietal portion of the occipital bone develops from three or four pairs of ossification centres [12]. Failure to fuse

Fig. 3 Bilateral mendosal sutures in a 1-month-old girl. On plain film, symmetrical linear lucencies are noted within the occipital region in the lateral (a) and coronal (b) views (arrows)



leads to formation of the Inca bone (also known as the interparietal bone or os interparietale) (Fig. 5) [12, 13]. This Inca bone may be subdivided by both longitudinal and transverse sutures to form a bipartite, tripartite or multipartite Inca bone.

Wormian bones

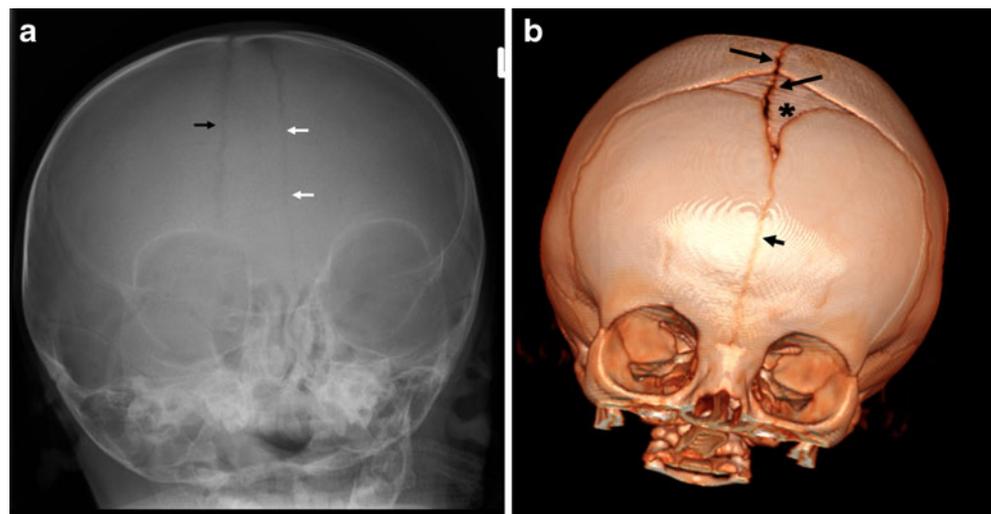
Wormian bones are small intra-sutural bones that can be found in up to 53% of children (Fig. 6) [14]. The lambdoid suture is the most common location. Wormian bones arise less

commonly in relation to the coronal and sagittal sutures. They are thought to result from mechanical factors that spread sutures apart [15]. Usually a number greater than ten is considered abnormal, as is a size greater than 6×4 mm, and conditions such as osteogenesis imperfecta should be considered in these children [16].

Cephalohaematoma

A cephalohaematoma is a traumatic subperiosteal haematoma of the skull [17]. Although they can occur in non-accidental

Fig. 4 Metopic suture. a Slightly rotated AP skull radiograph in an 8-month-old boy shows the metopic suture (white arrows) to the left of the sagittal suture (black arrow), simulating a fracture. b A metopic suture is confirmed on the CT (small arrow). The sagittal suture (long arrows) can be seen adjacent to, and through, the anterior fontanelle (asterisk)



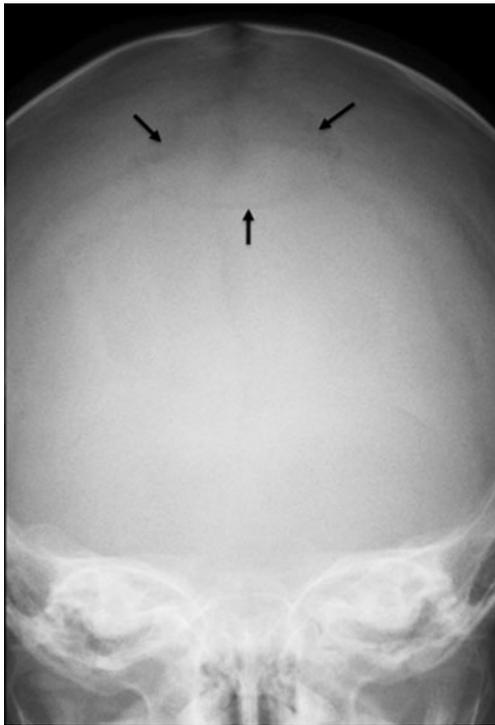


Fig. 5 The Inca bone. Townes view of a 4-month-old girl shows the Inca bone (arrows) on radiograph

injury, they usually occur post-instrumental delivery, more commonly with vacuum delivery than forceps [18]. It is important, therefore, to get appropriate clinical information about the method of delivery so not to misdiagnose a birth-related injury. A cephalohaematoma is seen as a soft-tissue density overlying the skull and is restricted by the periosteum and sutures (Fig. 6).



Fig. 6 A cephalohaematoma overlying the right parietal bone (white arrows) in a 6-week-old girl with a history of vacuum-assisted delivery. Radiograph shows wormian bones in relation to the lambdoid suture (black arrows)

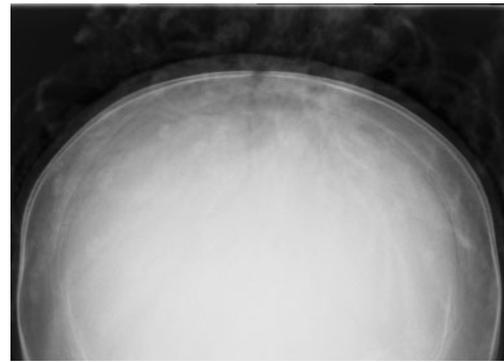


Fig. 7 Prominent hair artefact on a skull radiograph of a 9-month-old girl

It therefore cannot cross the midline. Older haematomas can calcify peripherally. A cephalohaematoma normally resolves spontaneously.

Hair artefact

In an older child hair artefact can cause interpretation issues on radiographs, usually chest radiographs, where it can mimic surgical emphysema. On skull radiographs it can appear as linear high-density structures that might confuse the reporting radiologist, masking or mimicking a bony injury (Fig. 7).

Spine

Cervical spine

Cervical spine injuries in children younger than 8 years are uncommon but when they do occur, they usually occur in the



Fig. 8 Lateral cervical spine radiograph in a 13-month-old boy shows the normal synchondrosis between the centres for the dens and the body of C2 (arrow)

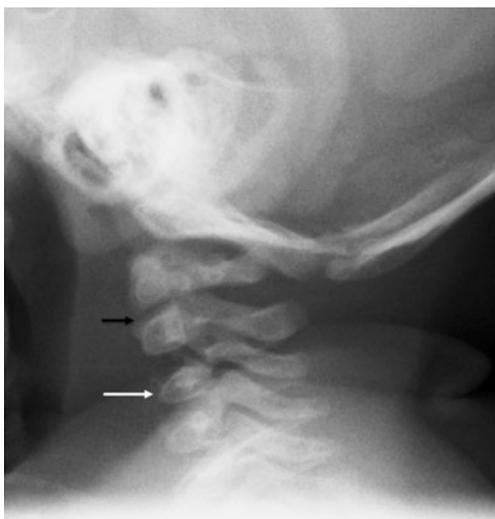


Fig. 9 Lateral cervical spine radiograph in a 2-month-old girl shows wedging of the cervical vertebrae, most noticeable at C3 (white arrow). A normal C2 synchondrosis is again seen (black arrow)

upper cervical spine from the level of the occiput to C3 [19, 20]. Cervical spine injury is reported in cases of non-accidental injury [21–23]; however several normal variants can be mistaken for traumatic pathology.

Ossification centres

The normal odontoid ossification centre should not be mistaken for a traumatic injury. The basilar odontoid synchondrosis is thought to close between 3 years and 6 years of age but can persist in older children (Figs. 8 and 9) [24, 25].

Wedging of the cervical vertebrae

Anterior wedging of up to 3 mm can be seen in the cervical vertebrae and should not be mistaken for vertebral body compression fractures [19, 24, 26]. This wedging is often most prominent at the level of C3 (Fig. 9). Wedging becomes less apparent with increased age, with the vertebral bodies taking on a more rectangular appearance.

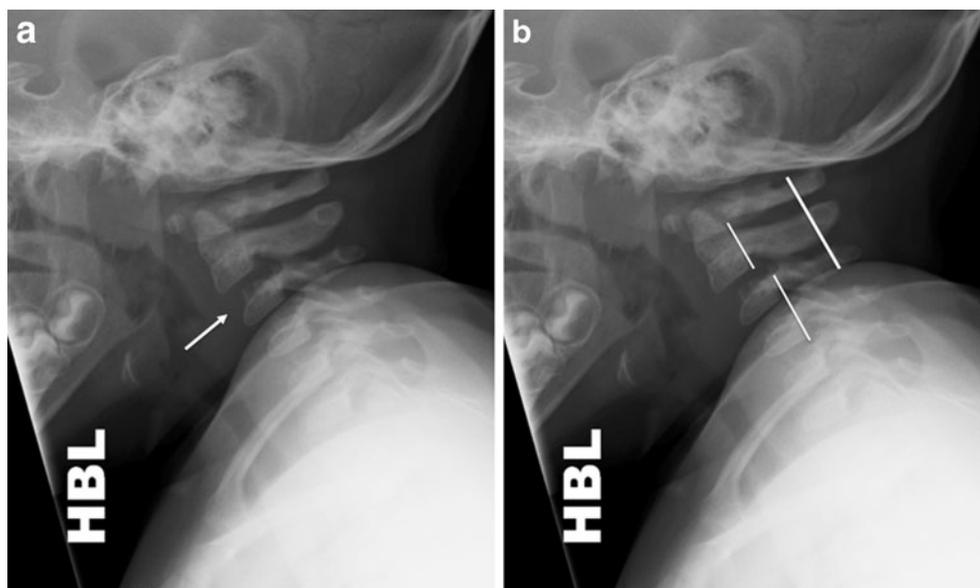
Pseudosubluxation

In almost half of children younger than 8 years there is subluxation at the C2-C3 level [19, 24, 27, 28]. However this normal physiological displacement can be differentiated from traumatic injury by appreciating the posterior cervical line [24]. This line is drawn from the anterior aspect of the C1 spinous process to the anterior aspect of the C3 spinous process. The anterior aspect of the C1, C2 and C3 spinous processes should line up within 1 mm of one another on flexion and extension views (Fig. 10).

Thoracic spine

In the newborn, the vertebral bodies are initially an oval shape [29]. Lucent notches are seen in the anterior and posterior margins of the vertebral bodies. These represent remnants of intersegmental clefts in the embryonic spine and contain nutrient canals through which arteries and veins enter the vertebral body (Fig. 11).

Fig. 10 Lateral cervical radiograph shows pseudosubluxation of C2 on C3 in a 22-month-old boy. **a** A step at the C2-C3 level (arrow). **b** Using the posterior cervical line (a line drawn along the anterior aspects of the spinous processes of C1 to C3) (continuous line), no traumatic subluxation is identified despite the step at the vertebral body (broken white line) along posterior aspect of the vertebral bodies



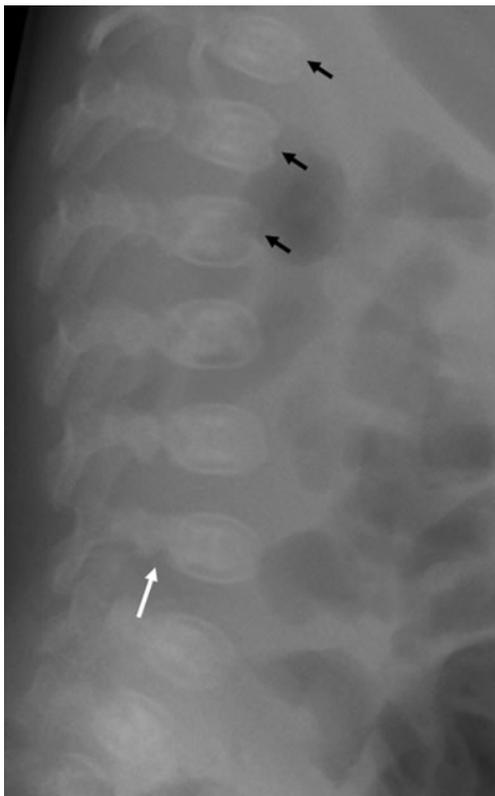


Fig. 11 Lateral thoracolumbar spine radiograph in a 1-month-old boy shows open neurocentral synchondroses (*white arrow*) as well as lucent clefts in the anterior aspect of the visualised T11 to L1 vertebrae (*black arrows*)

Lumbar spine

The neurocentral synchondroses are bilateral cartilaginous growth plates between the single anterior and the bilateral neural arch ossification centres [29]. These allow the vertebral arch to grow. On a lateral lumbar radiograph the unfused neurocentral synchondroses can be seen as lucencies between the ossified vertebral body and the ossified neural arch (Fig. 11).

Appendicular skeleton

Physiological periosteal reaction

This is a commonly seen normal variant found in the long bones of infants, most frequently at 2–3 months, although it is reported at 1–4 months [30]. The most common sites for physiological periosteal reaction are the tibia, femur, humerus, ulna and radius, and it can be unilateral or bilateral (Figs. 12 and 13) [30]. The usual appearance is a single layer of thin, smooth periosteal reaction less than 2 mm affecting one aspect of the long bones. This runs parallel to the underlying normal



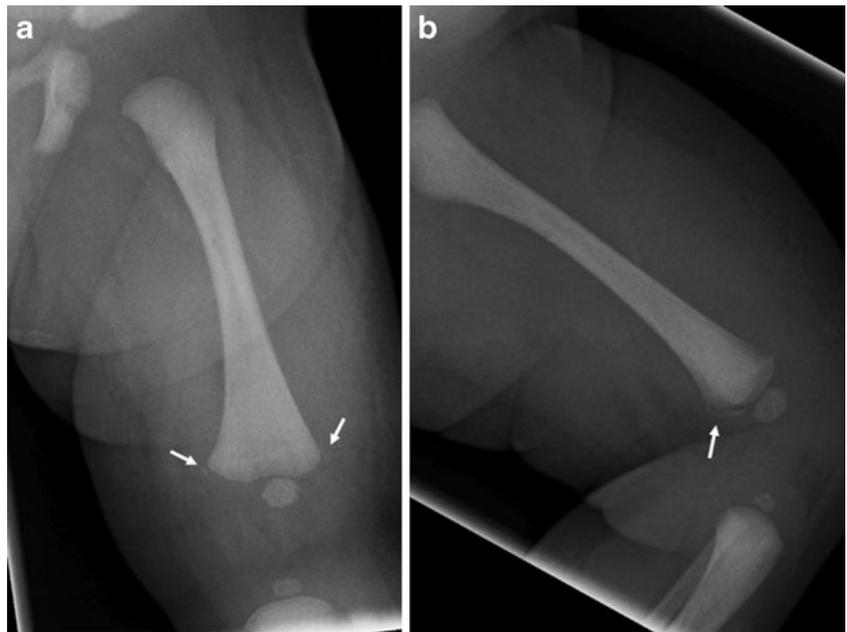
Fig. 12 Anteroposterior radiograph shows bilateral symmetrical physiological periosteal reaction measuring 1.7 mm along both femurs of a 2-month-old boy (*white arrows*). Bilateral proximal metaphyseal beaks are noted in both femora (*black arrows*), as well as distal metaphyseal step-off at the distal right femoral metaphysis (*asterisk*)



Fig. 13 Radiograph shows physiological periosteal reaction in the left ulna of a 6-week-old girl (*arrow*). No periosteal reaction was seen in the right ulna

cortex along the diaphysis, separated from the underlying cortex by a radiolucent zone. The exact mechanism for this is uncertain, but it is thought to relate to the rapid growth of the infant and the loosely adherent periosteum [30, 31]. When

Fig. 14 Classic metaphyseal lesion in a 2-week-old girl. **a** AP and **(b)** lateral radiographs show a classic metaphyseal lesion (bucket-handle fracture) in the distal left femur (*arrows*)



physiological periosteal reaction has a thickness greater than 2 mm or occurs in infants older than 4 months, an underlying pathology such as non-accidental injury should be considered.

Normal metaphyseal variants versus classic metaphyseal lesion

The classic metaphyseal lesion, or bucket-handle fracture, is a type of fracture very specific for non-accidental injury

(Fig. 14) [32, 33]. It occurs when a torsional force is applied to the immature bone adjacent to a growth plate (physis). The fracture extends transversely across the metaphysis and is thicker peripherally than in the centre. Its appearance varies according to the position of the limb to the radiograph. The corner fragments are the parts of the handle seen when the remainder of the fracture is hidden because of projectional factors (Fig. 14). Common sites include the proximal tibia, the distal tibia and the proximal humerus [34–36]. Acute fractures

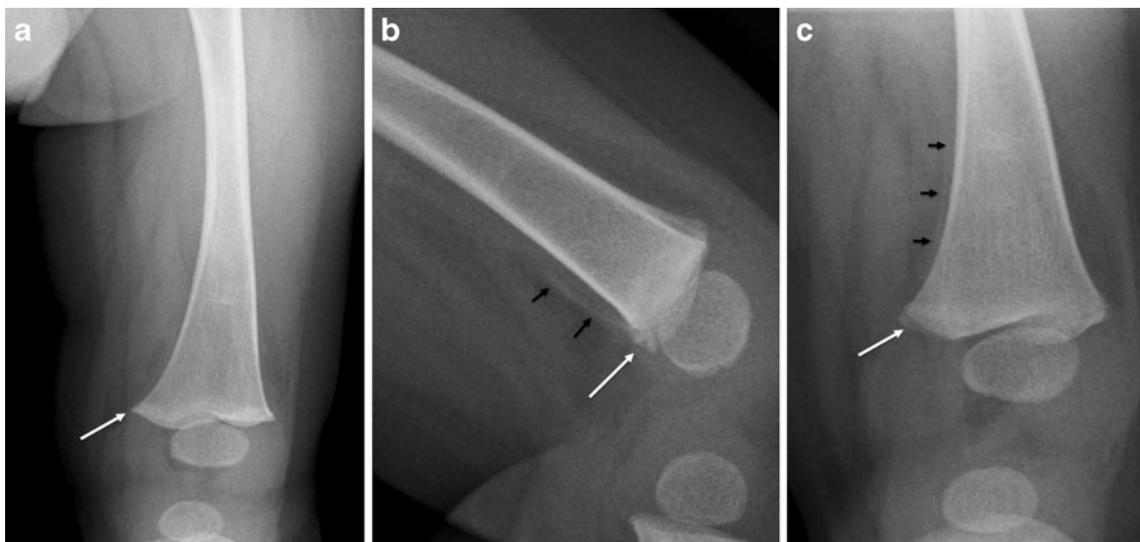


Fig. 15 Series of radiographs indicates a classic metaphyseal fracture in an 8-month-old boy; the fracture could initially be mistaken for a normal variant. **a** AP view of the left distal femur. There is an indeterminate area (*arrow*), possibly a metaphyseal step-off, a normal variant. However given the presence of multiple other fractures, repeat views were obtained

the following day, including a lateral view (**b**) and an oblique view (**c**). These confirmed the presence of a classic metaphyseal lesion (*white arrows*). Pathological metadiaphyseal periosteal reaction is also identified (*black arrows*) in (**b**) and (**c**)

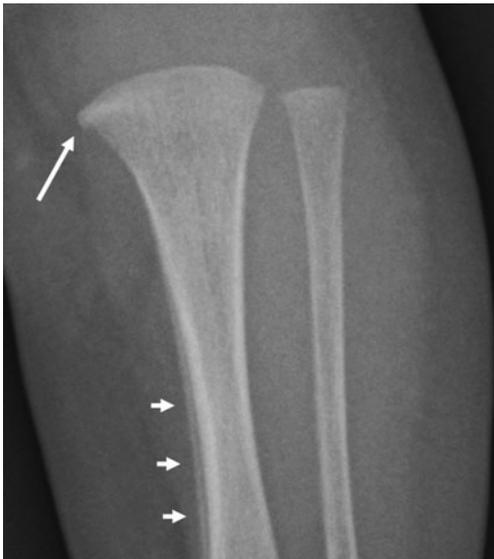


Fig. 16 Metaphyseal step-off variant in the proximal left tibia in a 2-month-old girl (*long white arrow*). Radiograph also shows incidental periosteal reaction along the shaft of the tibia (*small white arrows*)

can be easily missed because they are not always identified radiographically. Because healing fractures are more easily visualised, these classic metaphyseal fractures are better seen on follow-up radiographs [34–36].

Several metaphyseal variants should not be confused with the classic metaphyseal lesion [37]. When differentiating between normal variants and pathology, AP and lateral coned views taken tangentially to the metaphyses are beneficial



Fig. 17 Radiograph shows metaphyseal step-off variant in the distal radius of a 10-month-old boy (*arrow*)



Fig. 18 Metaphyseal beak is seen on this radiograph in the proximal right tibia of a 1-month-old boy (*arrow*)

(Fig. 15) [2]. As mentioned above, follow-up radiographs are beneficial if there remains clinical concern. Although an isotope bone scan is less sensitive than plain film in the detection of metaphyseal fractures, it can be used to identify the more difficult to visualise acute fractures because they are positive within 7 h of a bone injury [2, 38].



Fig. 19 A small metaphyseal spur (*arrow*) is noted at the medial aspect of the distal ulna on this radiograph in a 4-month-old boy

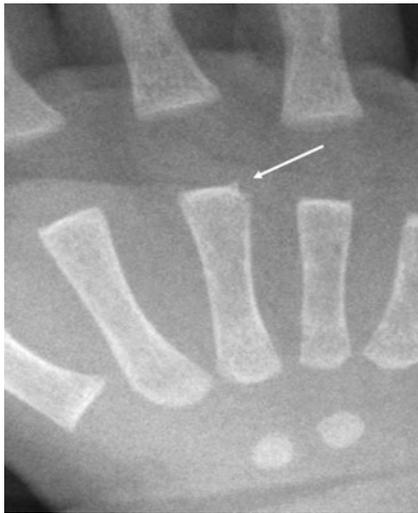


Fig. 20 Radiograph shows a small metaphyseal spur (*arrow*) at the distal aspect of the third metacarpal of the right hand in the same 4-month-old boy as in Fig. 19

Metaphyseal step-off

The area of the distal metaphysis adjacent to the physis is called the metaphyseal collar and is 1–3 mm in children as old as 7 years [39]. The metaphyseal step-off is an acute (nearly 90-degree) angle between the metaphyseal collar and the curvilinear metaphysis (Figs. 12, 16 and 17). The adjacent

cortical margin might be indistinct but the trabecular pattern is maintained. This is usually seen in the long bones near the knee and wrist [37, 39].

Metaphyseal beak

A metaphyseal beak is a medial projection off the proximal humerus or proximal tibia (Figs. 12 and 18). It is well-defined and often dense, although the beak occurring at the proximal tibia is often less distinct [37].

Metaphyseal spur

This is a discrete longitudinal projection of bone continuous with the cortex that extends beyond the metaphyseal margin (Figs. 19 and 20). The most common sites are the lateral aspect of the distal femur, the lateral aspect of the distal radius, the medial aspect of the distal ulna and the metacarpals and metatarsals [37].

Distal ulna metaphyseal cupping

Cupping of the distal ulna is a known anatomical variant and the presence of this does not necessarily indicate underlying rickets if it is the only finding [40–42] (Fig. 21).

Fig. 21 AP and lateral radiographs of the left forearm in a 2-month-old girl show cupping of the distal left ulna (*arrows*)



Metaphyseal fragmentation

Metaphyseal fragmentation can be seen in up to 11% of children [43]. Most commonly found in the distal femur and proximal tibia, it can occur unilaterally or bilaterally (Fig. 22). The bony fragments vary in size and shape but are usually elongated along the long axis of the adjacent bone, extending proximally along the metaphyseal margin. Metaphyseal fragmentation tends to occur in children 15 months and older, later than the age when a classic metaphyseal lesion would be suspected.

Proximal tibial cortical irregularity

This occurs at the medial aspect of the proximal tibial metadiaphysis and is seen as a focal area of irregularity in the cortex (Fig. 23) [37, 44]. There may be associated physiological periosteal reaction and it is seen bilaterally in 25% of cases [37, 44]. It should not be confused with a buckle fracture. If there is any doubt, further imaging such as follow-up radiographs, nuclear medicine bone scintigraphy or MRI should be performed.

Nutrient vessels

A long bone is supplied by a nutrient artery that enters the bone at an oblique angle through the nutrient foramen. This is directed away from the growing end of the bone. Nutrient vessels as they pass through the cortex of a long bone shaft can be mistaken for oblique fractures (Figs. 24 and 25) [45].



Fig. 23 Proximal tibial cortical irregularity in a 2-month-old boy. Radiograph shows a focal area of irregularity at the medial aspect of the left proximal tibial metadiaphysis (*long arrow*). Physiological periosteal reaction is also noted along the tibial shaft (*short arrows*)

Skin folds

Skin folds are frequently seen on radiographs and the lucent line made by the fold can easily be dismissed as unrelated to underlying bone (Fig. 26). Occasionally a fold simulates a fracture and in the case of a skeletal survey for non-accidental injury, it causes the reporting radiologist to misinterpret it as suspicious (Fig. 26).



Fig. 22 Lateral radiograph of the right knee in a 17-month-old boy shows fragmentation of the proximal tibial metaphysis posteriorly (*arrow*)



Fig. 24 Radiograph shows a nutrient vessel passing through the lateral cortex of the distal ulna of a 6-month-old boy (*arrow*)

Fig. 25 Radiograph shows a nutrient vessel in the left tibia of a 9-month-old girl (*arrow*)



Fig. 27 Radiograph shows intraosseous needle tract (*arrow*) in the right tibia of a 10-month-old boy

been told of a history of such use, the site of bone puncture might be mistaken for non-resuscitation-related injury (Fig. 27).

Intraosseous cannulae

Artefacts related to resuscitation are also seen on subsequent skeletal surveys. Intraosseous cannulae are used for paediatric patients who need rapid fluids or medications where intravenous access is limited. Unless the reporting radiologist has

Conclusion

Non-accidental injury is a condition in which the radiologist plays a key role. It is essential that the reporting radiologist can differentiate between normal variants or artefacts and true traumatic injuries. Awareness of these possible pitfalls helps radiologists avoid missing a diagnosis of non-accidental injury or erroneously deeming a normal finding pathological.



Fig. 26 Skin folds on radiograph. **a** Skin fold overlies the distal humerus of a 2-month-old boy (*arrow*). This clearly extends outside the bone cortex and is dismissed as such. **b** Another example of a skin fold, this one overlying the distal humerus of a 3-month-old boy (*arrow*). This

radiograph is more difficult to interpret but close inspection demonstrates the fold to extend past the lateral aspect of the distal humerus. **c** Skull skin folds in a 1-month-old boy can be mistaken for an underlying skull fracture (*arrows*)

Conflicts of interest None.

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