Radiological features of non-accidental injury

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Non-accidental injury is not uncommonly met in clinical practice. One should be aware of its presentation, the radiographic signs suspicious of abuse and the appropriate further imaging assessment to confirm or refute the diagnosis. Erroneous diagnosis can have grave consequences.

Child abuse, real or suspected, has created an extensive medical and social administration for its investigation and subsequent care. John Caffey (1946) first described six children with skeletal injury, and subdural haematoma occurring in some instances in children unwanted by their carers, although the direct connection with abuse was not initially realized. The term 'battered child' (Kempe et al, 1962) was used for many years but the less disturbing term of 'child abuse' was adopted in the American Child Abuse Prevention and Treatment Act 1974.

Children are injured non-accidentally as a result of inadequate care or wilful abuse. The abused child may present with physical injuries or less commonly a history suggesting abuse. This prompts a skeletal survey since skeletal injuries are the most commonly seen abnormality on imaging of child abuse. However, the radiological abnormalities suggesting abuse may be detected on a film, particularly a chest film, taken for other medical reasons.

Often the child presents to the medical practitioner with non-specific symptoms of failing to thrive, feeding difficulties, irritability or lethargy that may be related to recurrent brain injury. There may be a more acute presentation with fits and neurological signs, often with a clinical diagnosis of meningitis.

The initial investigation may well be a chest radiograph which reveals unexplained rib fractures. They are almost specific for child abuse providing there is no underlying bone disease. Even in the event of major trauma, rib fractures are uncommon. These fractures can be very easily overlooked, especially if there is overlying lung pathology. This is particularly true if there are bilateral, symmetrical multiple fractures as they may be easily misinterpreted as the transverse process overlying the posterior end of the rib, and require oblique views of the ribs for clarification. Delayed films at 2 weeks show callus formation.

Presentation with internal thoracic and abdominal injuries is relatively uncommon. When they do occur they are usually of a serious nature. Visceral injuries are non-specific and often occur in the older child with an average age of 2 years. Since the injury is produced by a punch or kick it is the central portion of the abdomen which receives the impact, therefore the bowel, pancreas and mesenteries are more commonly damaged (Cooper et al, 1988). The liver, spleen, kidneys and colon are rarely injured because of their lateral location and the history is all-important in these cases.

These children may present acutely in shock as a result of a perforated hollow viscus, with a pneumoperitoneum or with acute pancreatitis, or present more insidiously with pancreatic pseudocyst or duodenal haematoma. The majority of children present with either soft tissue bruising suggesting non-accidental injury, or by the detection of an unexplained fracture. In both these instances the first examination carried out after the initial radiograph is a skeletal survey.

SKELETAL SURVEY

Fractures fall into two main groups:

1. Specific fractures that are almost pathognomonic of non-accidental injury, which are rib or metaphyseal fractures
2. Fractures that have a high suspicion of non-accidental injury because of their location or the patient's age.

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Fractures that are almost pathognomonic of non-accidental injury

Rib fractures: Rib fractures in non-accidental injury occur via squeezing or compressive forces that fracture the posterior ribs, as a result of levering the rib over the transverse process, and the lateral axillary portion of the ribs (*Figure 1*). Costochondral junction fractures also occur and are associated with significant abdominal injuries (Ng and Hall, 1998). They are more difficult to identify and heal with little periosteal reaction.

The first rib, because of its position, is rarely injured in accidental injury and is considered almost diagnostic for non-accidental injury especially if located laterally (Strouse and Owings, 1995). Because of the pliability of the child's ribs, fractures resulting from cardiopulmonary resuscitation, which is often put forward as a defence in litigation, is very unlikely to produce rib fractures (Feldman and Brewer, 1984). Because these fractures are usually caused by the thorax being compressed, they occur when the child is small, usually under the age of 1 year. With undisplaced fractures, overlying structures and poor radiographs may well conceal fractures. They become more obvious as callus forms during healing.

Metaphyseal fractures: These fractures occur transversely across the metaphysis through the primary sponginosa. If there is no displacement and the radiographic beam is tangential to this plate-like fragment, then a corner fracture is seen (*Figure 2*). They may be easily missed as they are often symmetrical and bilateral, and may be misinterpreted as a normal variant. A film taken within 2–3 weeks will show healing with incorporation of the fragment into the metaphysis.

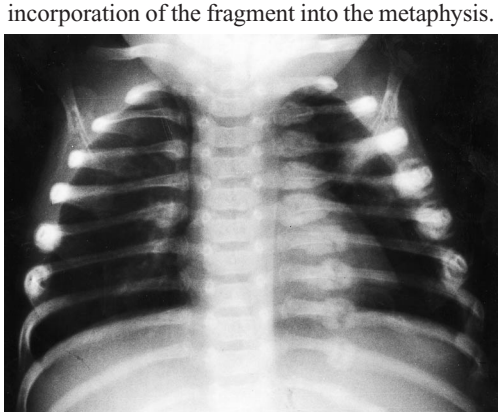

Figure 1. Typical posterior rib fractures with marked callus formation producing a localized fusiform 'expansion' to the posterior aspects of the ribs. There are also lateral fractures with callus formation producing a 'ring-like' formation of callus around the fracture site as it is seen end-on. There is also a small amount of pleural fluid on the left which is most likely blood.

If the radiographic beam or the avulsed fragment is angled, then it appears as a bucket-handle fracture (*Figure 3*) (Kleinman et al, 1986). In metaphyseal fractures the fracture line produces a plate-like fragment of bone with the edge of the fracture being deeper, producing the appearance of a rim of bone in the periphery. Because of the thickness of this rim in relation to the thinner, more central portion, only the rim is of sufficient density to be seen on an X-ray. In *Figure 3c* the beam is tangential to this plate-like fragment and there is no angulation of the fragment, so this rim is seen as a small triangle producing the 'corner fracture' appearance.

In *Figure 3d*, when this rim is angled, like the lifting of a metallic cap on a bottle, or if the beam is centred in the middle of the shaft of the bone, the radiographic beam in the metaphyseal region will be angled in relation to this rim of the plate-like fragment of bone. The more proximal portion of rim will be projected upwards further than that of the posterior rim, which will be obscured by the anterior portion of the metaphyseal region. This produces the so-called 'bucket-handle' fracture at the metaphyseal region.

If the periosteum is not elevated, periosteal reaction may not be seen. These fractures were considered to be caused by a shearing and twisting force but are also likely to occur during shaking of the child's body where the dependant limbs are subject to accelerating and decelerating forces. They are more common in the distal femur, tibia and proxi-

Figure 2. Small corner fracture is seen on the medial aspect of the right femur. These can be difficult to differentiate from the small periosteal collar seen end-on, and subsequent films after 2 or 3 weeks will show the incorporation of this fragment into the cortical bone whereas if it is the anatomical collar, then the appearances will remain unchanged.

mal humeri. Fractures of different ages indicate that the injuries have been concealed and again have a high specificity for non-accidental injury.

Fracture with a high index of suspicion for abuse

Location: Because of their location the scapula fractures and fractures of the outer third of the clavicle, vertebral fractures, especially dorso-lumbar junction and C2–C3 fracture dislocation, and digital injuries are highly suspicious for non-accidental injury (*Figure 4*).

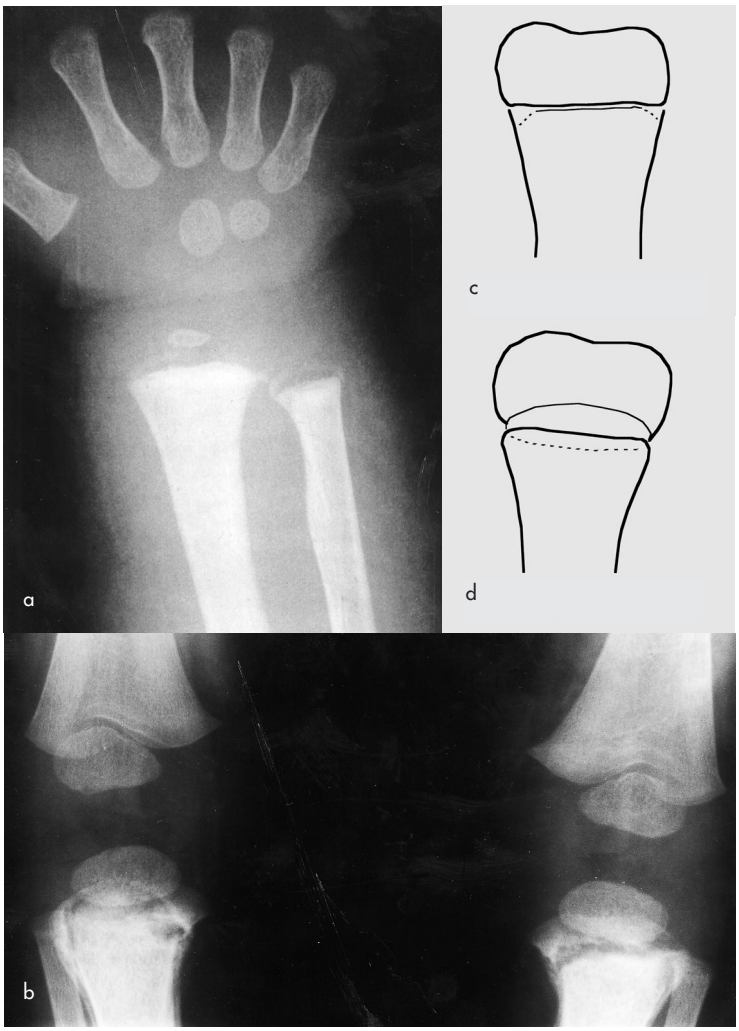

Figure 3. a. Typical 'bucket-handle' fracture of the distal metaphysis of the radius and ulna. There is very little disturbance to the rest of the metaphyseal region. This appearance was actually produced by displacement of the metaphyseal fracture as was seen on the lateral projection. b. The 'bucket-handle' fractures in the upper metaphyseal regions of the tibiae are particularly well demonstrated in the right side. Medially the fracture line can be seen on the left side, partially producing a 'bucket-handle' and corner fracture. There is marked periosteal reaction indicating stripping of the periosteum with the gap between the cortical bone and the periosteum particularly well seen on the right side. A lateral projection will demonstrate whether there is displacement. It is important to demonstrate displacement since if it is present, it would require more active treatment than an undisplaced 'bucket-handle' fracture that is produced by projection only.

Patient's age: Diaphyseal fractures, although less specific than metaphyseal fractures, occur four times more frequently (Loder and Bookout, 1991). A child under 1 year of age is unable to be sufficiently mobile to produce fractures that in an older age group would be considered as possibly accidental. The toddler's spiral fracture of the femur or tibia (Dunbar et al, 1964) and upper transverse tibial fractures occur accidentally in a mobile child (Swischuk et al, 1999). Unless there is an unusual specific history to explain these fractures they are the result of non-accidental injury in children under 1 year of age. Similarly, spiral humeral fractures are unlikely to occur non-accidentally in the younger age group, especially those too young to climb and subsequently fall.

In both metaphyseal and diaphyseal fractures periosteal reaction will depend on whether the periosteum is stripped or elevated by haematoma. Sub-periosteal new bone without fracture is the result of a twisting force. It must not be confused with the physiological periosteal reaction that occurs between 6 weeks and 6 months, peaking at between 3 and 5 months. These are symmetrical and never extend to the metaphyseal region.

DATING OF FRACTURES

Dating fractures may be useful in determining the perpetrator of the crime. However, there is a considerable overlap in the stages of fracture healing. Studies of injuries where the timing is known usually involve immobilization. Unfortunately in

Figure 4. There is a fracture in the proximal metaphyseal region of the proximal phalanx of the 2nd and 3rd digits with some angulation. This was of some duration as there is callus formation. The unusual location, absence of a history of trauma and florid periosteal reaction may lead the unwary to mistake the appearances for acute osteomyelitis.

non-accidental injury the fractures are not immobilized and therefore the periosteal reaction may be greater, preventing a direct comparison. The reaction where there is continuous movement will allow further bleeding to occur and may produce a florid reaction that can mimic osteomyelitis, metabolic bone disease or bone dysplasia.

The first periosteal reaction seen is usually between 6 and 10 days. The gap remains between the periosteal reaction, the callus formation and the cortical bone for up to about 4 weeks (*Figure 5*), when there is gradual fusion of the periosteal reaction and callus with the underlying bone (Duncan et al, 1986).

MISDIAGNOSIS IN SKELETAL INJURIES

Variants such as metaphyseal collars, especially in rapid remodelling, may mimic corner fractures. Rickets, if partially treated, may appear as discrete osseous fragments resembling corner fractures. Metaphyseal fractures may occur in premature infants and in infants with rickets undergoing passive physiotherapy and can be indistinguishable from those seen in infant abuse (Kleinman, 1998). Birth injuries can be confused with the abused child but this is rarely seen in modern obstetrics and detailed reference should be made to the delivery history of the child.

Bone dysplasia rarely mimics child abuse but metaphyseal chondrodysplasia of Schmidt and spondylometaphyseal dysplasia may confuse. A skeletal survey shows other diagnostic features of a dysplasia and if there is still doubt radiography of the area of suspicion after several weeks will show no change in dysplasias, and in variants such as metaphyseal collars.

Children with osteogenesis imperfecta usually have demineralized bones and Wormian bones, but in the mild types (IV) these may be absent. In these, fractures usually involve the long bones, often in the diaphyseal regions.

Poorly mineralized bone from any cause such as prematurity with a birth weight under 1500 g, rickets or the rare copper deficiency, requires less force to fracture, but there is usually radiological evidence of demineralization, and it is unusual to see metaphyseal fractures. These may occur in neurological disorders such as spina bifida or cerebral palsy and especially where there is sensory deficit. Temporary brittle bone disease, sometimes produced as a defence in the courts, is a doubtful entity. Cardiopulmonary resuscitation rarely produces a fracture and almost never posteriorly. Acromial fractures occur in non-accidental injury and in the rare entity of tetanus neonatonium. More commonly the acromial ossical is misinterpreted as a fracture (*Figure 6*). Unusual appearances on a chest radiograph as a result of projection may mimic a fracture (*Figure 7*).

Diaphyseal fractures are usually spiral or transverse depending on age. Falls from a bed are unlikely to cause a fracture in children under 1 year, but falling with a child in the arms of the carer can result in fractures.

Figure 5. Metaphyseal fracture with some callus formation. In addition there is periosteal reaction along the length of the shaft indicating stripping of the periosteum from the cortical bone. A gap is still visible between the new bone formation and the cortical bone. The duration of this would be 2–3 weeks.

Figure 6. This variation in ossification of the acromium may, to the unwary, be misinterpreted as a fracture, particularly if the appearances are more prominent on one side.

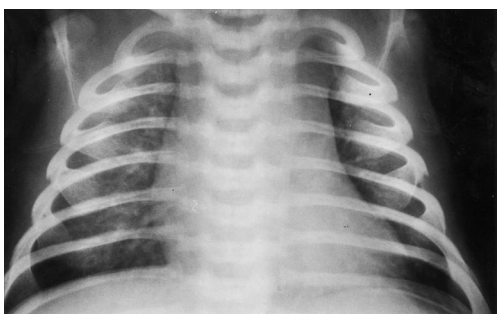

Figure 7. Because of the projection, the lateral aspect of the 4th ribs appeared jagged as though there was a fracture. This is projectional and if the film was taken in a less lordotic view or oblique projection the appearances would be undoubtedly normal.

INTRACRANIAL INJURIES

Either the skeletal survey will demonstrate a fractured skull or there will be clinical signs to suggest that there is intracranial damage. Under 2 years of age, non-accidental injury is the major cause of serious head injuries. There are no specific signs that would indicate that the fracture of a skull is the result of non-accidental injury. Parietal site is common in both accidental and non-accidental injuries, but multiple fractures and complex fractures, particularly involving both sides of the skull, are suggestive of non-accidental injury without clinical evidence of serious head injury.

Since there is no periosteal reaction the dating of fractures is extremely difficult although they may become more indistinct over a period of a few weeks. Overlying soft tissue swelling usually indicates that a fracture is recent. Where there is a single fracture the history is important. Generally falls from less than 4 feet rarely produce serious head injury (Chadwick et al, 1991). Depressed fractures, whether accidental or non-accidental, are more serious in nature. It is the intracranial damage to the brain that is serious and can produce long-term sequelae.

The injuries are often produced by the child being held and shaken, causing acceleration and deceleration to the brain enclosed in the cranium. This can produce subdural haematoma as a result of the tearing of veins that traverse the subdural space on rotation (Guthkelch, 1997). The rotation of the head produces cerebral contusion and haemorrhage over the surface of the brain (Ommaya et al, 1968). Because the child is held, these injuries usually occur in children under the age of 1 year and the compression on the chest may increase the central venous pressure leading to intracerebral damage. Shaking alone can produce these features, although direct impact with associated deceleration can also cause intracranial damage. Hypoxia as a result of the chest being squeezed, or as a result of strangulation or suffocation, adds to the cerebral damage.

In the absence of bleeding diathesis, haemorrhagic meningitis or accidental trauma, subdural haematoma is virtually pathognomonic of non-accidental injury (*Figure 8*). Accidental causes of subdural haematoma in infants are rare even in major traffic accidents (Lloyd et al, 1997). Subdural haematomas without a skull fracture, particularly if they are bilateral and of different ages, associated with interhemispheric fissure, subdural or falx haemorrhage, are indicative of non-accidental injury. If there is clinical evidence of retinal haemorrhages, this renders the diagnosis of non-accidental injury almost certain (Rao and Carty, 1999).

Hypoxic ischaemic cerebral injury produces the reversal sign on computed tomography (Han et al, 1989). There is loss of the normal grey matter differentiation with a density in the thalami and basal ganglia, and the cerebella remaining normal. This produces an image where there is relative brightness of these areas in relation to the more peripheral, darker, decreased density of the cerebral cortical grey-white matter. This is caused by anoxia. If this appearance is associated with acute interhemispheric fissure subdural haemorrhage, the appearances are almost pathognomonic of non-accidental injury. Punctate haemorrhage in the basal ganglia as a result of hypoxic change or with some haemorrhagic infarcts as a result of disruption of the perforating vessels is also said to be pathognomonic of a shaking injury.

INVESTIGATIONS

Once non-accidental injury is suspected, the first investigation is a skeletal survey. This is to demonstrate fractures and to date them. It may be necessary to repeat the radiographs after 2–3 weeks in order to provide more accurate dating of the fractures. If there is a high suspicion of non-accidental injury, bone scintigraphy will demonstrate unseen fractures on the radiographs or resolve regions where there is doubt about the presence of a fracture. Isotope studies are much

Figure 8. There is a chronic left subdural collection with displacement of the midline structures to the right side. The midline shift is greater than that produced by the subdural collection, because of the mass effect of the oedema in the left cerebral hemisphere. In addition there is fresh subarachnoid blood. The appearance of the chronic subdural plus the intracranial bleed is almost pathognomonic of non-accidental injury.

more sensitive than plain films but they are less specific and should be interpreted with the radiographs. Metaphyseal regions are particularly difficult to interpret because of normal high uptake at the growth plate. Vertebral body and skull regions have a low pick-up rate.

Whenever there are unexplained fractures the possibility of underlying bone disease should be considered. This is often put forward as a defence in medicolegal circles, often with expert witnesses postulating temporary brittle bone disease, a doubtful entity. This has been addressed in various articles (Chapman and Hall, 1997).

Any child who is suspected of having neurological problems should undergo cross-sectional brain imaging. Any child with suspicion of abuse where a skull fracture is detected, even in the absence of neurological signs, should undergo neuroradiological imaging (Saulsbury and Alford, 1982). Computed tomography is usually the investigation of choice as it is superior in detecting acute subarachnoid haemorrhage and bone fractures. This is performed without contrast enhancement. If there is an equivocal scan or if there is suspicion of an isodense subdural collection, intravenous contrast may be of value. Follow-up scans may be of value where there is changing neurology. Magnetic resonance imaging (MRI) should be reserved for difficult cases or more chronic subdural collections. Both in computed tomography and MRI there can be ageing of the collections. If in any of these scans there is the suggestion of bleeding of different ages then, like the skeletal survey, it is highly suspicious of non-accidental injury.

Ultrasound is of value for intracranial injuries where the anterior fontanelle is open, although it is not as comprehensive as computed tomography or MRI. Ultrasound is also useful for abdominal injuries, for detecting peripheral skeletal injuries before epiphyseal ossification and in joint effusions. CT is more sensitive for abdominal injuries.

In suspicion of injury of the spine, particularly the cervical spine, MRI is the investigation of choice, as it will show bone and soft tissue lesions (Rooks et al, 1998).

CONCLUSIONS

One should always be alert to the possibility of non-accidental injury and with any child admitted with failure to thrive or meningitis, or non-specific symptoms, the ribs should be examined carefully on the chest radiograph for signs of fracture. Where there is clear abuse, management is easy. However, where there is doubt with regard to the diagnosis, one must ensure that one is not missing unsuspected bone disease, as subjecting families to rigorous interrogation and separation from their infants can produce long-term harm. The rights of the parents to care for the child and the protection of the child need to be balanced, and there is often a fine line between justice and injustice. HM

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KEY POINTS

- The first radiological investigation in child abuse is the skeletal radiograph.
- Fractures fall into two main groups: almost pathognomic of non-accidental injury and high suspicion of non-accidental injury.
- Clinicians should be aware of the pitfalls in the misdiagnosis of non-accidental injury.
- Computed tomography is the examination of choice in suspected intracranial problems.
- Magnetic resonance imaging is useful for further assessment if required.
- Ultrasound and computed tomography are best for abdominal injuries.
- Isotope studies are useful for fractures in difficult cases.