CHILDREN

Non-accidental injury

Louise Hattingh*

Department of Radiology, Bradford Royal Infirmary, Bradford Teaching Hospitals NHS Foundation Trust, Bradford BD9 6RJ, UK

KEYWORDS
Child abuse; Diagnostic imaging; Battered child syndrome

Summary
Orthopaedic surgeons dealing with children in their practice are likely to be faced with the problem of non-accidental injury (NAI). Clues in the history may point to the possibility of child abuse. The range and radiographic appearances of skeletal injuries, some more specific to abuse than others, are discussed. Recognition of the classical metaphyseal lesion is paramount. Further investigation and differential diagnosis of NAI is considered, with emphasis on the use of follow-up radiographs in difficult cases. Imaging should be directed by experienced radiologists privy to all clinical information. Controversies surrounding the use of other imaging modalities are mentioned. A brief description of the legal issues and multidisciplinary approach to NAI is included.

© 2007 Published by Elsevier Ltd.

Introduction

The phrase “non-accidental injury” (NAI) is often coined when referring to suspected physical abuse in children. Other forms of abuse such as neglect, psychological and sexual abuse should not be overlooked, but it is the physical injury to an infant or small child that can provide the tangible evidence of inflicted injury.

The presence of child abuse in our society is now generally accepted and the responsibility to recognise abuse lies with all those involved in the care of children. An orthopaedic surgeon or radiologist may be the first to suspect abuse following skeletal injury. This must lead to the initiation of appropriate child protection procedures.

The paediatric radiologist John Caffey was the first to describe long bone fractures associated with subdural haematomas in young children. His later description of the metaphyseal fracture, followed by the extensive work of Paul Kleinman and colleagues, have contributed to the understanding of injury mechanisms in abused infants.

When a young child with a skeletal injury is referred to an orthopaedic surgeon for further management, several clues may raise the suspicion of NAI. These will be discussed in further detail.

This article concentrates mainly on the range of skeletal injuries to physically abused children, but both visceral and head injuries will be mentioned as these may at first be overlooked with dire consequences. Controversies around radiological investigation of NAI will be discussed.

Virtually any bone in the body may be involved in NAI. Certain injury patterns are highly specific to abuse. In infants, metaphyseal, rib and skull fractures are seen more frequently. In older children, skull and long bone diaphyseal fractures are more common.

The classic metaphyseal lesion (CML)

The CML is regarded as the most specific finding to suggest that injury was inflicted (Fig. 1). The radiographic appearance
is frequently that of subtle lucency in the subphyseal region of the metaphysis. Appearances will also depend on the angle at which the radiograph was taken, as well as the stage of healing. It may not be visible on all radiographic projections. On some views, a small fragment at the periphery will be seen as a typical corner fracture. On other views, a classical bucket-handle appearance is attributed to the fracture disrupting the primary spongiosa of the metaphysis and producing a disk-like fragment. The peripheral margins, or corners, of the fragment are thicker as they encompass the subperiosteal bone collar. It is important to note that although often the only radiographic abnormality is a corner fragment, the plane of injury is typically trans-metaphyseal.

Forces required to produce such an injury are shearing, as occurs when an infant is shaken with the limbs unsupported or with the child held and shaken by the arms or legs. This explains the prevalence of the CML almost entirely in children under the age of 2 years. Forces leading to the CML do not occur during falls or normal handling of an infant.

Radiologically, the CML is difficult to date and these injuries are typically asymptomatic. Subperiosteal new bone formation (SPNBF) may be absent. Early healing may appear similar to the acute injury. If present, hypertrophic cartilage growth into the metaphysis, seen as lucent extension of the growth plate into the metaphysis, is indicative of healing. However, the assessment of healing is best performed by an experienced radiologist.

### Subperiosteal new bone formation

Most typically seen as part of the healing process following a fracture (Fig. 2), SPNBF also may occur in isolation. When a force leads to subperiosteal haemorrhage, the periosteum is lifted from the bony cortex. After 5–15 days, a thin layer of subperiosteal new bone is evident on radiographs. It may be difficult to differentiate from “physiologic” periosteal reaction in infants (Fig. 3). When innocent, it usually is bilateral, seldom greater than 2 mm in thickness, preferentially occurring in the femur, tibia and less likely the
humerus and forearm. If there is uncertainty, follow-up radiographs are very helpful in demonstrating an interval change in traumatic SPNBF. Bone scintigraphy (BS) is a powerful adjunct to demonstrate injury (Fig. 4).

SPNBF is a non-specific finding seen in a wide range of other conditions, including infectious, metabolic and idiopathic causes.

Rib fractures

Fractures may occur anywhere along the rib arc, but particularly the posterior fractures carry high specificity for abuse. The mechanism of injury has been shown to be due to manual compression, the child held by the rib cage and forcefully squeezed. Posterior fractures occur because the rib acts as a lever, the vertebral transverse process being the fulcrum. This mechanism does not occur during cardiopulmonary resuscitation (CPR). Indeed, research has demonstrated that rib fractures are extremely rare, even in prolonged CPR. When present, such fractures do not involve the posterior rib arcs.

In a cohort of 467 children suspected of suffering abuse, Carty and Pierce found that 408 children had a total of 1689 fractures. Rib fractures occurred in 154 (38%). Interestingly, in 11 children (2.4%) a single rib fracture was the only fracture found, but there were other clinical signs of abuse. This demonstrates that even a single rib fracture found on a young child’s X-ray should raise concern and initiate a thorough clinical examination.

Radiological appearances vary considerably. Acute posterior fractures are frequently undetectable on initial anteroposterior radiographs. Healing becomes evident as subtle widening of the rib neck, faint sclerosis along the fracture margins or obvious callus formation and SPNBF. The conspicuity of findings is very variable. A further clue may be the presence of pleural fluid or extrapleural soft tissue density.

Detection of occult rib fractures is improved by the inclusion of oblique rib views in the skeletal survey (SS). Some institutions also advocate the use of BS. Follow-up

Figure 2 Subperiosteal new bone formation accompanying a spiral fracture of the shaft of the right tibia. Note also the presence of a distal tibial CML.

Figure 3 Physiological subperiosteal new bone formation along the shaft of the proximal right femur.

Figure 4 Bone scintigram. The increased uptake along the left femoral shaft confirmed the presence of traumatic SPNBF in this abused infant.
radiographs, usually 2 weeks after the presenting X-rays, are valuable (Fig. 5).

Scapular and sternal fractures

Sternal and scapular fractures are thought to be rare, but carry high specificity for abuse. Detection of sternal fractures rely on a lateral view and therefore Kleinman advocates the use of a lateral film of the thorax as part of the SS in cases of suspected abuse. Fractures of the acromion, coracoid and rarely the scapular body may be detected by meticulous radiographic scrutiny.

Vertebral injuries

Spinal injuries are infrequently seen in abused children. In the British cohort studied by Carty and Pierce,9 there were five instances of spinal fractures. Vertebral body compression fractures (Fig. 6) are most frequently encountered following a hyperflexion force or axial loading. In some instances the vertebral body height is maintained, but a fracture through the superior end plate may be seen. Radiologically, the appearances may be of irregularity at the anterosuperior margin of the vertebral body or a discrete bony fragment at this margin.

Unlike vertebral body fractures, which are moderately specific, spinous process fractures are highly specific of inflicted injury. Forceful hyperflexion may avulse the tips of the spinous processes at the insertion of the interspinous ligament. If the avulsed fragment is cartilage, it may only become obvious on delayed imaging when calcification and ossification is apparent. Due to the nature of the applied force, associated vertebral fractures are common.

Stating the obvious, the spine serves as protection to the spinal cord. Sadly, severe spinal fractures and dislocations may present with paralysis. Hyperflexion spinal injuries may also direct the clinician to visceral injury. The life-threatening injuries require appropriate management, but should not be to the detriment of documenting all other injuries. An MRI may demonstrate spinal cord and ligamentous injury well, but the SS should not be forgotten once the patient is stabilised in a safe environment.

Figure 5  (a) Presenting chest X-ray in an abused child. The fractures of the posterior shafts of the left second and third ribs are difficult to identify. (b) A radiograph taken 2 weeks later. Callus formation now makes the rib fractures (arrows) much more conspicuous.

Figure 6  Lateral view of the thoraco-lumbar region demonstrates a wedge compression fracture of one of the lower thoracic vertebrae in an abused child.
Skull fractures

These fractures may occur following a direct blow with an object or as part of shaking injury ending in an impact. Shaken infants do not always have skull fractures, hence the need for head computed tomography (CT) when such an injury is suspected. The excellent review by Lonergan et al.\textsuperscript{11} includes a detailed description of the radiological and pathological appearances of intracranial injury seen in child abuse.

Simple skull fractures are seen in NAI and have no differentiating features from accidental injuries. Complex fractures are more worrying. They may cross sutures, have more than one fracture line or have a stellate pattern. Depressed fractures, multiple, compound and comminuted fractures are further concerning features (Fig. 7). Diastasis of fracture margins is sometimes seen, usually in association with underlying dural injury. Traumatic sutural diastasis must be differentiated from the more symmetrical diastasis seen with chronically raised intracranial pressure.

Skull fractures may be difficult to appreciate on CT scans and BS, hence the inclusion of skull radiographs in the SS.

Long bone fractures

Fractures to the shaft of long bones occur both in accidental and non-accidental incidents. When assessing an infant or young child presenting with a fracture, it is important to take the child’s age and developmental capabilities into consideration. The proposed mechanism of accidental injury and time of presentation may provide significant clues.

Spiral fractures of the femur and humerus are uncommon in young children and should raise concern\textsuperscript{12} (Fig. 8). “Acute” fractures showing evidence of healing on the presenting radiographs must also be viewed with suspicion. Sometimes there is a delayed presentation without adequate explanation.

In pre-mobile children, fractures of the bones in the fingers and toes should be regarded with suspicion: they may be the victims of beating or forceful squeezing of the hands or feet (Fig. 9).

Soft tissue and visceral injury

The wide range of other injuries found in abused children is beyond the scope of this article, but it is important to remember that these are often the injuries that cause death. In the clinical setting of a child presenting with skeletal injury, a thorough clinical examination is required to search for evidence of soft tissue, brain or visceral trauma. Injury to the central nervous system is a leading cause of mortality and long-term morbidity in NAI. Visceral injuries, although less common, occur in a higher age group, and carry a mortality of up to 50% (Fig. 10). Delayed presentation and delay in diagnosis are thought to contribute to this high rate of death.

Pancreatitis and pancreatic pseudocyst formation warrant special consideration. In adults, this is commonly secondary to alcohol abuse, but in children blunt abdominal trauma is the most common cause of pancreatic pseudocysts. A rare complication may be the presence of multiple, painful lytic lesions in the bone secondary to medullary fat necrosis following systemic release of pancreatic enzymes. The lesions may raise the suspicion of disseminated malignancy, but elevated amylase levels may point to the correct diagnosis.\textsuperscript{13}
Differential diagnosis

As already discussed, accidents are often offered as explanations for NAI. It is the duty of the court to decide whether this was the case. The role of investigating clinicians and radiologists is to provide the information required by the court to make its decision. A knowledge and understanding of the forces required to produce specific fractures in young children cannot be overemphasised.

There are many conditions which may mimic NAI. Included in this list are normal variants, obstetric injuries, osteogenesis imperfecta, other inherited bone dysplasias, infections, malignant and metabolic disorders. The rare condition of congenital indifference to pain, also known as asymbolia, deserves special mention, as the radiological appearances can be identical to NAI (Fig. 11). A careful examination should provide the correct diagnosis. Sometimes the presence of an underlying generalised bone disorder can be difficult to prove and specialist expertise should be sought in these cases. A controversial entity called “temporary brittle bone disease” (TBBD) has been suggested as a cause of fractures in suspected abuse. However, in a joint statement by the Society for Pediatric Radiology and the European Society of Paediatric Radiology, the scientific grounds for such an entity are strongly questioned. In the field of paediatric radiology, TBBD is not generally accepted as a diagnosis.

Investigation

Once the possibility of NAI has been raised, appropriate steps are taken to protect the child from further harm. Further investigation is aimed at confirming or refuting the

Figure 9  There is a fracture of the proximal aspect of the big toe metatarsal bone. Skeletal survey detected many other fractures in this abused child.

Figure 10  Axial CT scan of the abdomen in a fatally abused child. Note the small aorta and brightly enhancing adrenal glands as signs of acute shock. There is a large amount of peritoneal blood.

Figure 11  Congenital indifference to pain. The ulnar fracture is non-united and there is considerable periosteal new bone formation. The child continued to use the arm despite the presence of a fracture.
diagnosis of NAI. This is the stage at which other possibilities in the differential diagnosis should be considered.

A diagnosis of NAI, if made incorrectly, can be catastrophic for a family. However, if NAI is overlooked, it may have fatal consequences for the abused child. A multidisciplinary approach is imperative. Protocols and management may vary within countries. In the United Kingdom (UK), many hospitals will have a "lead clinician" who is experienced in dealing with suspected NAI. Early involvement by appropriate clinical and social services specialists is important. Meticulous and legible documentation of the social history, clinical examination and radiological findings are often later required in court. This may include photographic evidence of inflicted injuries.

The radiologist can provide advice on the most appropriate further investigations. Both the British Society of Paediatric Radiology and the American Academy of Pediatrics have issued guidelines for imaging suspected NAI. In children under the age of three, a full SS is performed by staff experienced in paediatric radiography, during normal working hours (Table 1). A so-called "babygram", in which the entire infant is imaged on a single projection, is no longer an acceptable practice. In the UK, the paediatrician caring for the child has the responsibility of explaining the need for further imaging to the next of kin. The SS images are reviewed by a radiologist, who may request further views if there are areas of concern. Follow-up films of such areas may also be arranged at this time and in many institutions it is normal practice to perform a follow-up chest X-ray (CXR) in 1–2 weeks. Delayed films can be valuable in dating injuries.

Controversy still surrounds the routine use of other imaging modalities in the initial radiological investigation of NAI. In the UK, many believe that all pre-mobile infants suspected of being victims of NAI should be considered for a CT scan of the brain. Even when CT has been performed, the skull X-ray must not be omitted from the SS. If the CT is equivocal or if intracranial haemorrhage requires more accurate dating, an MRI may be indicated.

The role of BS is a further source of debate. Some advocate the use of routine BS in suspected NAI. A recently published comprehensive review of the literature on this subject suggests that both the SS and BS may miss injuries: the SS most often misses rib fractures (but the routine use of oblique rib views should reduce the number of missed rib fractures), whereas the BS can miss skull, metaphyseal and epiphyseal injuries. Both studies are more sensitive when combined. There is evidence that a repeat SS after 2 weeks can yield significant information and that this should be considered in cases where physical abuse is strongly suspected.

Most of our knowledge of NAI is based on research using high-detail film–screen combinations. Worldwide, use of digital radiography is increasing. These imaging systems used in general radiography do not perform at the same high spatial resolution achievable with film–screen combinations. Further research is required to ensure that the high standards of imaging in suspected NAI are not compromised.

### Dating fractures

Fracture dating is frequently a difficult task and exact timing of injury based purely on radiological appearances is impossible.

O’Connor and Cohen provide valuable guidelines in the radiographic dating of fractures: SPNBF can be seen as early as 4 days following injury and by 20 days fractures will almost always have SPNBF. Soft callus formation can be seen from 10 days onwards, peaking at 2–3 weeks. Remodelling occurs as early as 3 months and peaks at 1 year, but can continue well beyond this time.

The radiologist should always be provided with as much clinical history as possible. As an example, if the history suggests an injury less than 1 day old and the fracture shows evidence of SPNBF, the radiologist can report the discrepancy with certainty. A well-informed report will also be of greater value as evidence in a court of law.

### Legal issues

Laws governing the welfare of children will vary between countries. In the UK, Section 47 of the Children Act 1989 stipulates that councils with social services responsibilities must conduct enquiries when they receive information that a child is suffering or likely to suffer significant harm. It is the duty of all other agencies, including the National Health Service, to assist in these enquiries. Central to the act is the belief that children are best cared for within their family, with both parents playing a full role and without the need to resort to legal proceedings. This is the ideal situation to which society should strive.

In England, during the year ending March 2002, councils conducted 69,900 enquiries under section 47 of the Children Act. This led to 34,800 initial child protection

---

**Table 1** The skeletal survey.

<table>
<thead>
<tr>
<th>Area</th>
<th>Examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skull</td>
<td>AP and lateral</td>
</tr>
<tr>
<td></td>
<td>Towne’s view if suspected occipital injury</td>
</tr>
<tr>
<td>Chest</td>
<td>AP thorax</td>
</tr>
<tr>
<td></td>
<td>Left and right oblique rib views</td>
</tr>
<tr>
<td>Abdomen</td>
<td>AP, including pelvis and hips</td>
</tr>
<tr>
<td>Spine</td>
<td>Lateral cervical, thoracic and lumbar</td>
</tr>
<tr>
<td>Upper limbs</td>
<td>AP both humeri</td>
</tr>
<tr>
<td></td>
<td>AP both forearms</td>
</tr>
<tr>
<td></td>
<td>DP both hands</td>
</tr>
<tr>
<td>Lower limbs</td>
<td>AP both femora</td>
</tr>
<tr>
<td></td>
<td>AP both tibiae and fibulae</td>
</tr>
<tr>
<td></td>
<td>AP both feet</td>
</tr>
<tr>
<td>Additional</td>
<td>Lateral view of any fracture</td>
</tr>
<tr>
<td></td>
<td>Coned views of suspicious areas, as directed by supervising radiologist</td>
</tr>
</tbody>
</table>
expertise. They should not attempt to provide opinions outside their area of expertise when the time comes to provide a medical report. Medical professionals may be asked to provide legal statements outlining their involvement in the management and investigation of a case. Those experienced in dealing with NAI can be asked to act as expert witnesses. Good record keeping in all cases of child abuse will be rewarding when the time comes to provide a medical report. Medical witnesses should also be aware of their own limitations and should not attempt to provide opinions outside their area of expertise.

Practice points

- Clues in the history and radiographic appearances of a fracture may alert the surgeon or radiologist to the possibility of abuse
- Failure to recognise non-accidental injuries may expose the infant or child to life-threatening danger
- The classical metaphyseal lesion is highly specific to abuse under the age of 2
- A single rib fracture found incidentally on a young child’s CXR should raise alarm bells
- Spiral fractures of the femur and humerus are uncommon in young children
- Visceral injuries carry a high mortality as they may at first be overlooked
- The SS is paramount in the investigation of suspected child abuse
- Follow-up radiographs often detect fractures initially missed
- A multiagency approach aims to ensure the child’s physical protection as well as protecting the legal rights of the child

Conclusion

All children have the right to humane treatment. Society must not turn a blind eye to the abuse of children. Where physical abuse has led to fractures, the orthopaedic surgeon or radiologist may be the first to raise the alarm. Failure to do so can result in serious harm to the child. A working knowledge of the features suggestive of abuse is essential. An understanding of further investigations, including their limitations, will aid the clinician in arriving at the correct diagnosis in individual cases.

Acknowledgements

The author wishes to thank Dr. R.J. Arthur for kindly providing the cases used for illustration.

References


