The role of radiology in child abuse

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The role of radiology in child abuse is vital. The radiologist is required to differentiate trauma from other medical conditions, give an estimate of the age of the injury, suggest a possible mechanism of injury and highlight safeguarding concerns taking the age of the child into account.

In 2014 in the author's practice, of all the age groups admitted with safeguarding concerns who then went on to have a radiological skeletal survey (excluding those children who had suffered from sudden infant death), more than 50% were under one year of age. Age is an most important risk factor in abuse-related skeletal injury, with up to 75% of inflicted skeletal trauma occurring in children younger than three years.[1]

Accordingly, although this article largely relates to general paediatric medicine, the reader should remember that infants present a particularly vulnerable portion of the population and a large proportion of children who are admitted with safeguarding concerns.

It is a sobering fact that children from all walks of society suffer abuse, which may be physical and/or due to neglect. The World Health Organization (WHO) has a very broad definition for the problem:

'Child maltreatment, sometimes referred to as child abuse and neglect, includes all forms of physical and emotional ill-treatment, sexual abuse, neglect, and exploitation that results in actual or potential harm to the child's health, development or dignity. Within this broad definition, five subtypes can be distinguished – physical abuse; sexual abuse; neglect and negligent treatment; emotional abuse, and exploitation.'[2]

When the National Society for the Prevention of Cruelty to Children commissioned research, it found that approximately 7% of children experience serious physical abuse at the hands of their parents or carers during their childhood,[3] although the exact incidence and prevalence is not known.[4] By logical extension a significant proportion of children who present to the emergency department each day will have suffered an injury at the hands of carers and guardians. Neglect and emotional abuse is particularly difficult to identify in the acute setting but physical abuse may also be overlooked and healthcare workers have to be vigilant to ensure no child is missed.

The violent death of Victoria Climbié on 25th February 2000 and other, sadly too numerous, high profile safeguarding cases, stimulated the development of national and local guidelines and procedures relating to child protection. There are many, but of particular note to the paediatric radiologist, are the *Standards for Radiological Investigation of Suspected Non-accidental Injury*, produced as an intercollegic report by the Royal College of Radiologists and the Royal College of Paediatrics and Child Health (2008),[5] and the NICE (National Institute for Health and Care Excellence) guidelines *When to Suspect Maltreatment*.[6]

The Standards for Radiological Investigation is a comprehensive document discussing the indications, timings and protocols for imaging examinations. Indications for the standard child protection skeletal survey are discussed together with neuroimaging of suspected cases (CT, computerised tomography, and MRI, magnetic resonance imaging). The role of scintigraphy (nuclear medicine bone scans) is also mentioned with regards to the role and general protocol for examination but this is rarely used in the UK and will not be further discussed in this article. Ultrasound does not have a validated role in child protection and its use is not recommended.

Bone trauma in non-accidental injury

It is well recognised that fractures are not equal in terms of the likelihood of non-accidental injury (NAI) and multiple fractures are more common in abuse. While long bone injuries are commonest (**FIGURE 1**), posterior rib fractures and classical metaphyseal lesions (CMLs, **FIGURE 2**) are the most specific.

Both posterior rib fractures and CMLs are seen in younger children because the mechanism of injury is not possible in older and larger children. Abusive rib fractures are said to occur when the thoracic cage is squeezed beyond the normal range of bone plasticity, possibly by hands placed around the child; it is sobering to note that while it is not possible to know the actual force required to cause these fractures very few rib injuries are seen following cardio-pulmonary resuscitation. CMLs are almost exclusively seen in children less

FIGURE 1 (left) Long bone injury in a non-ambulatory child. Expansion of the tenth rib at the edge of the radiograph is callus from an earlier rib fracture.

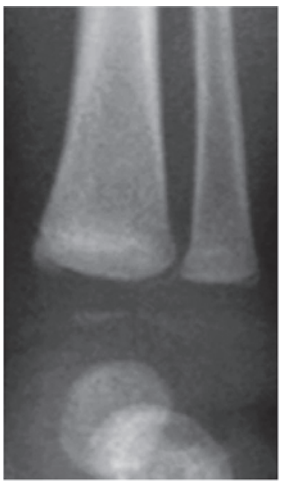

FIGURE 2 (right) The classical metaphyseal lesion. Micro-fractures through the meta-physis parallel to the growth plate result in disconnection of the growth plate. The avulsed fragment has a broad and flat centre with a wider edge – a 'bucket handle fracture'.

than two years old and are thought to occur by one of two mechanisms, either a twisting pulling motion, or as a consequence of flailing limbs when a child is shaken violently. They are most frequently found around the knee, ankle and shoulder although they may also be seen at the elbow and wrist.

As well as the site of injury, the probability that a fracture is due to abuse varies according to the age of the child, and non-ambulatory children presenting with long bone fractures should be viewed with suspicion, since both femoral and humeral fractures have a high probability (43% and 48% respectively) for abuse. Up to a third of children investigated for abuse have a bony injury, some of which may have not been previously suspected clinically, due to a lack of symptoms or signs, and these are termed occult fractures.

Once a fracture is identified it is important to determine whether there are any radiological features of healing, since this may indicate a delay in presentation. These features can be divided into acute (0-8 days), subacute (8-35 days) and older. The first radiologically visible signs are soft tissue changes, which are usually present in the acute stages and become more obvious during the first week to 10 days before gradually resolving. Sub-periosteal new bone formation is not visible immediately but is generally present between 10-14 days. The periosteum is a membrane that covers almost all of every bone and is capable of producing bone when it is appropriately stimulated, such as following trauma. The sub-periosteal reaction from a healing injury needs to be distinguished from a physiological periosteal reaction, which may be seen in children up to five months old, or from the periosteal reaction seen with metabolic disorders, infections and malignancies. Sub-periosteal new bone formation from a fracture is usually readily identifiable since the line of injury may be visible, but it may also be distinguished by other features such as the limited area of abnormality or the underlying appearance of the affected bone.

Following the development of soft callus the fracture line becomes ill defined and this usually appears around 2-3 weeks. Soft callus is so named because of its rather amorphous, 'fluffy' appearance, and careful observers may note that the fracture line may appear less distinct and slightly wider, which is due to the local action of osteoclasts and reabsorption of the damaged bone.

Hard callus is not generally visible before 2-3 weeks and is the solid new bone at the fracture site. Initially this may not follow the normal line of the bone but over time remodelling occurs as the fracture heals completely. It must be remembered that a very fine fracture requiring little remodelling may heal extremely quickly and be invisible after 2-3 weeks following the original injury; this is the reason why follow-up radiographs should not be delayed for more than 11-14 days.

Some fractures cannot be seen radiologically in the acute phase. The difficulty arises because of the flexibility of the young skeleton, so undisplaced fractures or those that only affect one side of the bone without changing the line of the bone may be beyond the resolution capability of the radiograph. Such injuries may be identified once healing has started and the sub-periosteal reaction and callus has developed.

All of the features of bone healing have a variable time range for both development and resolution but notably (other than soft tissue changes) are not present in the first 5-7 days. Therefore if any of the features are identified when the child initially presents, safeguarding concerns should be raised.

Head injury

Head injury is a major cause of pathology in children from both accidental and non-accidental causes and particularly affects younger children who have not developed the physical strength to protect themselves when they fall. Children presenting with a head injury sufficient to require an immediate CT scan are usually clinically obvious, but other forms of injury may present more slowly with gradual neurological impairment.

The skull of a young child is thinner than that of an adult and fractures are associated with intracranial haemorrhages in approximately 30% of cases. The majority of skull fractures are simple linear injuries (74-90%) that usually result from contact with a flat surface when the force of impact is spread over a large area. Generally these are confined to one skull bone but may extend into adjacent bones depending on the force and site of injury; intracranial injury may be seen in 15-30% of cases. Complex fractures may be star shaped or result in a completely shattered skull and result from high-energy forces directed over a smaller area; they are always associated with some degree of intracranial haemorrhage.

There are different types of intracranial haemorrhage that result from different mechanisms of injury.

Extradural haemorrhages result from an insult to the skull vault that ruptures a meningeal vessel, external to the dura mater (inner skull periosteum) which is then peeled away from the inner table of the skull by the bleed. This type of intracranial haemorrhage is infrequent in children but may result from a direct blow.

Subdural haematomas occur when the veins crossing the potential space between the dura mater and arachnoid mater are ruptured and blood tracks between the inner table of the skull and the brain. In the absence of a history of an appropriate mechanism these injuries are of great concern for non-accidental head injury (NAHI) and may result from high-speed trauma resulting from shaking. During shaking the child's head may be violently thrown back and forth, injuring the intracranial vessels by the repetitive acceleration and deceleration forces. This may have occurred on more than one occasion and may result in either a gradual or acute neurological deterioration depending on the degree of haemorrhage and underlying cerebral compromise. MRI has the ability to distinguish repetitive insults because the signal returned from a haematoma alters over time and consequently this imaging modality is of particular forensic value (**FIGURE 3**).

Subarachnoid haemorrhages, when blood is seen to track over the surface of the brain, are uncommon in NAHI. These result from damage to vessels close to the surface of the brain, such as rupture of an aneurysm, but may also be seen following massive cerebral insult.

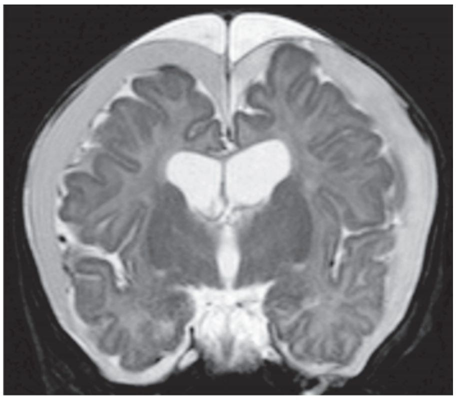

FIGURE 3
A coronal T2W MRI showing different signal intensities from the bilateral subdural haematomas indicating injury on more than one occasion.

FIGURE 4 Non-accidental abdominal trauma due to a direct central blow causing rupture of the duodenum. There is pneumoperitoneum, pneumomediastinum and surgical emphysema within the anterior soft tissues of the abdominal wall. Air has also passed into the portal vein. Bilateral pleural effusions can also be seen. Nasogastric and endo-tracheal tubes are *in situ*.

Antero-posterior skull	Both humeri
Lateral skull	Both radius and ulna
Antero-posterior chest	Both lateral elbows
Oblique chest (both sides)	Both hands
Antero-posterior abdomen (including pelvis)	Both femora
	Both tibia and fibula
Lateral spine	Both lateral knees
Both shoulders (if not clearly seen on the chest radiograph)	Both lateral ankles
	Both feet

TABLE 1 The set of radiographs comprising the child protection skeletal examination.

Cerebral parenchymal injuries with or without small petechial haemorrhages are common in children but are generally beyond the resolution capability of a CT scan and may only be identified when the child is examined with an MRI. Diffuse axonal injury results from shearing forces at the grey and white matter junction, and the resulting oedema and blood may be identified on an MRI scan as an altered signal with restricted water movement on diffusion-weighted images.

Blunt abdominal trauma

Skeletal and cranial injuries are well known, and there is a wealth of published research together with local and national protocols for their identification and investigation.[7-10] Less familiar are radiological findings that suggest abuse in a child presenting with blunt abdominal trauma. A recent American study demonstrated that more than a quarter of children under one year of age admitted with blunt abdominal trauma had suffered NAI, with abuse accounting for at least 15% of blunt abdominal injuries in children aged between 0-4 years old. The mechanisms must vary but the author has come across several cases where the abuser stamped on the abdomen of the child as they lay on the ground causing profound intra-abdominal damage (**FIGURE 4**).

Children suffer a different pattern of injury to adults from major blunt body trauma. The abdomen is the usual site of pathology whether the insult is accidental or deliberate, and visceral lacerations predominate. Notably, however, bowel and pancreatic injury is rare in accidental injury but disproportionately high in abused children.

The imaging modality of choice for all major blunt abdominal trauma is a CT scan. The radiological skill is in both identifying the pathology and suggesting abuse as a mechanism. However, although bowel injury is relatively high in NAI, the intra-abdominal viscera still bear the brunt of the damage but with a different pattern of injury. Pancreatic involvement is uncommon in accidental trauma and while liver injury is common to both, the left lobe of the liver is more frequently injured in abuse, most likely due to blows delivered centrally from an assault. Kidney damage is common with both accidental trauma and NAI, but conversely the spleen is less frequently injured, possibly due to protection by the rib cage.

It is imperative that all infants and children who present with abdominal trauma and a dubious history are thoroughly examined.[11] Careful evaluation of the regional skeleton may also offer clues if healing fractures are identified.

Skeletal imaging

The standard child protection skeletal survey is used to identify skeletal injuries when concerns have been raised in the acute setting, particularly if about to initiate care order proceedings when evidence to support the theory of abuse is needed. Delayed films (taken between 11-14 days later) are to identify fractures not visible in the acute phase, for additional forensic corroboration.

The examination is a legal documentation of any bone injury and should be performed by radiographers who have received training in paediatric radiographic techniques; it is recommended that two radiographers work together with another professional who should be responsible for the child's safety within the department. Ideally the examination should only take place during normal working hours since it would place a huge burden on the on-call staff that may not be appropriately trained. Children presenting out of normal working hours should have radiographs required to confirm an acute injury and then be admitted to a place of safety until such time as the formal skeletal survey can be undertaken. Usually the survey is performed within 24 hours from the referral but occasionally children present at the weekend and it is then considered acceptable to delay the survey for up to 72 hours. Similarly, children may be too unwell or unstable to come to the radiology department, in which case the investigation has to be delayed until the child is well enough; it is not acceptable to perform the examination as a mobile study.

The examination has to be of the highest radiographic quality and all radiographs should have the patients name, side marker, dates and time clearly visible. With picture archiving and communication systems now in the majority of departments much of the patient's data will be applied automatically to the radiographs. Side-markers however must be placed next to the child during imaging so that there is no ambiguity or confusion if radiographs are post-processed and 'flipped'. The examination is a set of approximately 25 individual radiographs (**TABLE 1**) and any movement of the child causing blurring, or other loss of radiographic quality must be repeated. In order to ensure that no anatomical region is overlooked, the radiographers at St George's Hospital refer to a protocol sheet that is signed and countersigned by both the attending radiographers and any other healthcare professionals present. On completion of the examination the full series is reviewed by a senior radiologist – preferably one with a paediatric interest – for quality assurance purposes and to sign the examination off, allowing the patient to be discharged back to the ward. It is at this point that further repeat views or supplementary images may be requested.

The procedure is time consuming and generally takes well over an hour to perform and at the end of the examination the study is printed onto a CD, which is also signed by both radiographers as witnesses.

Any repeat radiographs are included in the study and the survey is double reported by two paediatric radiologists who are usually voluntarily blind to each other's report so there is no confounding bias. In hospitals where there is only a single practising radiologist, networks have been formed either informally or with formal service level agreements between local hospitals. Very occasionally there is disagreement between the reports and then a third opinion may be sought. Delayed films of the areas of concern may also be requested to settle any disagreement.

Delayed radiographs are usually but not invariably requested. Repeat views of the chest with oblique ribs are recommended in the Standards for Radiological Investigation since rib fractures may be particularly difficult to see in the acute phase and only visible once callus has started to form. These radiographs, together with any others to re-examine areas of concern, should be taken between 11-14 days after the presenting injury to maximise the potential for identifying or confirming injuries. Delay beyond this time may result in very fine occult fractures having healed completely and thus no longer radiologically apparent.

Summary

The role of the radiologist depends both on the nature and timing of the examination requested. For patients presenting acutely to the emergency department with a long bone injury, the radiologist is required to differentiate trauma from other medical conditions, give an estimated of the age of the injury, suggest a possible mechanism of injury and highlight safeguarding concerns taking the age of the child into account.

For children presenting with a head injury that necessitates a CT examination, the imaging findings should be related back to the mechanism of injury and any concerns regarding the severity of injury as predicted by the mechanism should be flagged up to the attending clinician.

Similarly when children present with an acute abdomen or clinical signs suggesting blunt abdominal trauma, non-accidental trauma should be considered so that no subtle signs are overlooked.

Skeletal surveys and follow-up films, performed for forensic corroboration must be performed to the highest radiographic standards and should always be double reported to ensure no small injury is overlooked and any underlying bone disease that may predispose to fractures should be considered and actively looked for.

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