Patterns and mechanisms of injury in non-accidental injury in children (NAI)

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Abstract

The relationship between the family practitioner and the radiographer and radiologist is of utmost importance. Radiographers are among the healthcare workers who are at the first point of care and often only communicate with a radiologist after an x-ray examination is performed. The role of the radiographer has been extended to pattern recognition of skeletal images and selected ultrasound examinations. In some countries radiographers perform and report on invasive radiological techniques. The communication among healthcare workers about the possibility of child abuse is of utmost importance in the suspicion/recognition of abuse. Non-accidental injury in children may or may not be accompanied by sexual abuse, but in any situation where telltale signs of abuse are recognised, further investigation is necessary. The aim of this article is to assist the family practitioner in recognising some of the unusual radiographic patterns seen in paediatric radiography together with mechanisms of what may have contributed to the debilitating injuries sustained by survivors of abuse.

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Introduction

The initial recognition or suspicion of non-accidental injury (NAI) in children is the most important step in the child protection process. This may be done by a variety of individuals, such as social workers, health visitors, neighbours, teachers, family practitioners and many other people involved with children.[1] Radiographers and radiologists are among the health care workers who are at the first point of care in the assessment and radiological management of NAI in infants and play an integral role in preserving the chain of evidence in proven cases of abuse. The role of radiological imaging in NAI is twofold: (1) to identify foci of inflicted injury and (2) to document that the observed images are as a result of NAI.[2]

Fractures and injuries to the brain and abdominal parenchyma are serious manifestations of NAI in children. Considerable force is needed to cause such injuries. An extensive literature review was conducted for graphics of mechanisms of injury and the only examples that could be found were line diagrams or artistic impressions of the 'shaken baby syndrome'[3,4] and rib fractures.[5] It is for this reason that a rag doll was used to simulate some of the mechanisms of injury based on descriptions in the literature.[1–5] The purpose of these simulations is to create a better understanding of how some of the intentional injuries are meted out to children, all of whom were below three years of age.

Assessing the child

Swift professional intervention using a standardised approach is crucial in protecting the child from NAI. The approaches used in the Derby clinical area are as follows[6]:

- The parents are told at once that battery is suspected.
- The police and social services department co-operate in verifying the facts, offering the family support and protecting the child.
- The psychiatric assessment of the parent assists the social workers in deciding on the long-term care of the child.
- Assistance is sought from the forensic physician in cases where court proceedings are required.

In South Africa a similar procedure is followed depending on who accompanies the child to the family practitioner. According to Saayman, "it is at the discretion of the clinician to remove the child from the domestic environment by admitting him/her to a hospital or clinic ward" and a second opinion should be obtained.[7]

At this stage communication between the accident and emergency medical doctor and the radiologist or radiographer is important. The completion of the request form using a standardised protocol must be in place. All details pertaining to the correct spelling of the name, the age and the date must be provided. A special code could be developed to bring to the attention that the request is for a suspected abuse. While good, legible notes and accurate physical examination are of the utmost importance, so too are clinical histories recorded on radiography request forms and any other documentation required by other support services. These documents are potential forensic evidence and may be required in a court of law long after the first contact with the patient.

The aforementioned will ensure that the radiographer elicits the assistance of another radiographer to verify all the identification details, including his/her signature and that of a witness.[8] The courts play a significant role in the overall process of childcare. While courts are directed to act in the best interests of the child, in practice, the process remains an adversarial one, with evidence being led on behalf of the interested parties involved. The physician involved in the detection of child abuse must be familiar with the law in this

area. Questions often arise about consent for assessment, documentation in the medical records, filing of mandated child abuse and confidentiality.[5]

The role of the radiologist is usually that of a consultant, and information related to clinical and laboratory tests are limited. The introduction of telemedicine to deliver medical care poses risks to the privacy of patient records. The issue of who has access to this information needs to be considered and resolved in advance.[9] Radiologists rarely file abuse reports. However, if, after discussions with the referring doctor, there is unwillingness on his/her part to report despite compelling radiological evidence confirming abuse, the radiologist has the legal responsibility to do so.[5] The radiologist may need to seek further clarifying information from the physician, radiographer, nurse or social worker where there is a discrepancy between the history and the radiographic findings.[5]

Copious literature is available on how the physical examination should be conducted and it is also recommended that this article be read in conjunction with two previous publications on the same topic, featured in this journal in 2003.[7,10] However, the adapted checklist presented in Table I may assist the family practitioner in the decision-making process regarding the possibility of skeletal and soft tissue injuries that may require radiological investigations.[5,11,12,13]

Children may present with bizarre marks such as tattoos and fork mark punctures, circumferential tie marks (ankles and wrists), gag marks, trunk encirclement bruises or small pin-sized marks.[5,10,11,12]

The guide to staging bruises is included below (see Table II). However, there is much debate surrounding the staging of bruises.[13]

According to Schwartz et al, "visual aging of bruises remains an inexact science, despite recent composite charts that suggest otherwise".[13] However, the family practitioner should continue to describe the size, shape, location and colour of each bruise accurately. This is ideally done by written descriptions, drawings and, if possible, photographic representation of each bruise. The documentation of bruises remains a study for future research.[13]

Other significant signs and behavioural patterns[14,15]

- Aggression
- Attention seeking
- Frozen watchfulness

Table I: Visual diagnosis of non-accidental injury

Anatomical region	Observations
Buttocks and lower back	Burns – cigarette, match tip/incense, ring shaped (stove), branding burns (heated metal) Slap marks Sexual abuse (anus)
Genitals and inner thighs	Bruising (possible sexual abuse)
Spine	Bruising on bony prominences, tenderness
Upper and lower limbs	Bowing, angulation near the joints, bruising on bony prominences
Pelvis	Bruising on bony prominences
Abdomen	Bruising, distention
Chest	Depressed sternum, flail chest, asymmetrical shape, flattened, bruising
Head	Swelling, prominent anterior fontanel, patchy hair loss
Forehead	Bruising
Eyes	Peri-ocular bruising, intra-ocular haemorrhage
Cheeks	Slap marks, swelling
Earlobes	Pinch marks
Upper lip and frenulum	Forced feeding, forced oral sex
Neck	Choke marks

Table II: Staging of bruises[11]

Age	Colour
0–2 days	Swollen and tender (no visible colour)
2–5 days	Red, blue
5–7 days	Green
7–10 days	Yellow
10–14 days	Brown
2–4 weeks	Clear

- Distress
- Anxiousness
- Inhibited crying
- Overall sad demeanour
- Excessive self-control
- Fear of parent
- Inhibited verbal response
- Indiscriminate seeking of attention
- Inability to sit or stand
- Inability or reluctance to lift arms

The above indicators may also assist the radiographer and radiologist in the decision-making process regarding the type of imaging modality that would best demonstrate possible fractures, bone bruising and associated soft tissue injuries. It also assists in the physical handling and the application of immobilisation techniques during radiography to avoid being accused of injuring the patient while in care of the radiographer or radiologist.

It is no longer good radiological practice to perform a babygram on NAI in infants (see Figure 1).

Figure 1: Babygram

This examination is of no value to the clinician, since invariably there is:

- a degree of rotation of either the skeletal system or the chest and abdominal parenchyma; or
- the radiograph is either over- or under-exposed; or
- there may be a degree of motional unsharpness due to the fact that the baby could not be properly immobilised,[5] thus resulting in repeat radiographs and unnecessary exposure to ionising radiation to both the infant and the accompanying adult.

Caffey's observations

"The modern medical concept of child abuse has its origins with Caffey's seminal description of long bone fractures associated with subdural haematomas".[16] Despite Caffey's observations, clinicians were still either missing the signs of intentional injury or misdiagnosing their findings.

The classic metaphyseal lesion

Caffey was also the first to describe the classic metaphyseal injury. This fracture extends transversely across the extreme ends of the metaphysis separating a disc of bone from the primary spongiosa of the metaphyses and the zone of the provisional calcification of the physis. The disc is usually thicker in its periphery than in its centrum, and depending on the radiographic projection, may appear as a transverse fracture line, a metaphyseal chip or as a "bucket handle fracture"[17] (see Figure 2 and 2a). These metaphyseal injuries are commonly located at the knees, ankles and distal humerus. The mechanism of injury is often "pulling the limb till a 'click' is heard or violent traction or rotation".[2] The metaphyseal fragments or 'corner fragments' are projections of the handle seen as such when the rest of it is obscured behind the long bone when the

x-ray beam is directed perpendicularly to the joint.

Figure 2: Graphic of the classic metaphyseal injury

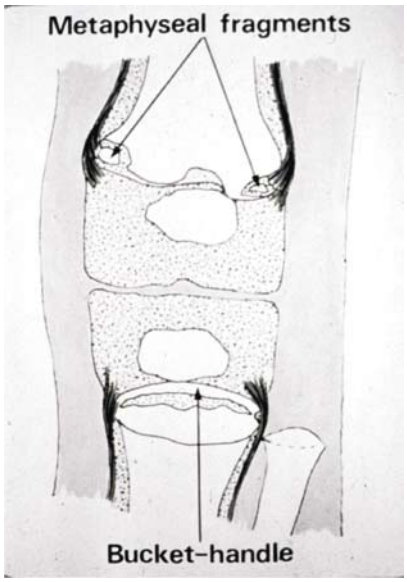


Figure 2a: Radiograph of the classic metaphyseal injury

The following cases demonstrate a range of injuries and how radiological imaging can assist in diagnosing NIA.

Patient 1

A four-month-old child accompanied by the clinical history 'fell off the bed' was brought into the casualty department. The clinician also noted that the child was coughing. The child presents with:

- a linear fracture of the skull – the mechanism of injury is either that the child was struck with a solid object or flung again a wall (see Figure 3 and 3a).

Skull fractures may be classified into simple (linear) or complex (more than one fracture line).[5]

Figure 3: Skull fracture

Figure 3(a): Mechanism of injury (skull fracture)

- A spiral or oblique fracture of the tibia (see Figure 4). It is difficult to differentiate a spiral fracture from an oblique fracture because, depending on the radiographic projection, either pattern may be discernible – the mechanism of injury is either that the leg is gripped by both hands and twisted or the leg is held and the child is swung through the air.[3,5] Refer mechanism of injury (Figure 4a). This injury can also be a result of slamming or throwing the child.

Figure 4: Spiral fracture of the tibia

Figure 4(a): Mechanism of injury – spiral fracture

- A chest x-ray was requested to exclude lung pathology. The radiograph revealed fractures of the ribs in keeping with squeezing of the thoracic cage,[1] i.e. anterior compression of the chest (Figure 5 and 5a).

Figure 5: Rib fractures

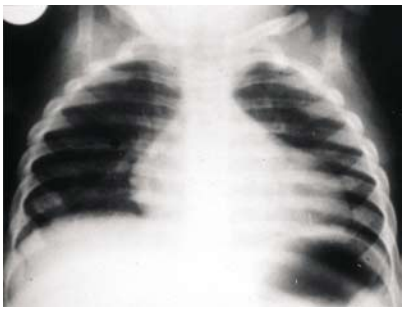
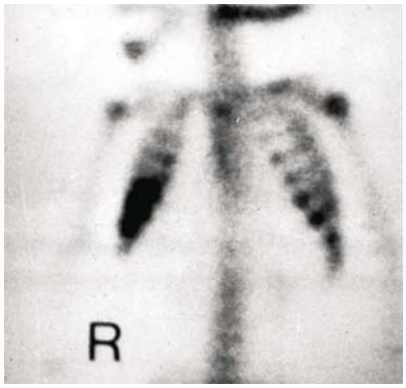


Figure 5(a): Mechanism of injury – rib fracture

Rib fractures may be difficult to see, as in this case, especially if they are recent injuries. It is important for the family practitioner to request a radio-isotope scan, as was done in this case, where one is able to see uptake (hot spots) at the costo-chondral junctions (see Figure 6). These are regarded as atypical fractures since the thoracic cage in children is extremely supple. The uptake of the isotope displays the typical 'rosary beads' appearance[7]

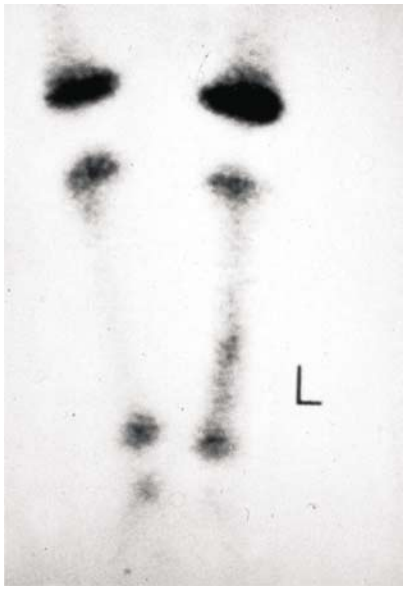
– which can also be referred to as 'string of beads' or 'worry beads' ('tasbeeh') (Arabic for a collection of beads strung together) appearance – analogies that the author uses for individuals who come from a variety of cultural and religious backgrounds.

Figure 6: Technecium radio-isotope scan of the ribs (note the rosary bead patterns)



- The technecium radio-isotope scan of the lower limbs revealed uptake at the condylar regions of the knees and ankles, highly suspicious of the classic metaphyseal lesions, or the child may have been beaten with a sold object (see Figure 7).

Figure 7: Technecium radio-isotope scan of the lower limb



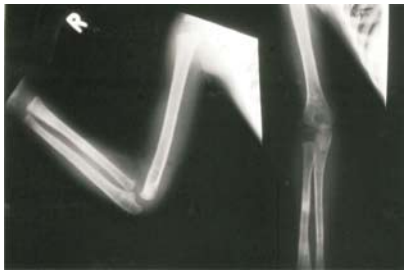
Patient 2

A concerned neighbour brought this child to hospital. The child presents with:

- a complicated fracture of the distal end of the left humerus involving both condyles and a large displace fragment from an oblique fracture (see Figure 8). Note the old healed fractures of the radius displaying callus formation indicating that the child's arm was previously fractured, the right arm also displays regions of subperiosteal new bone formation (SPNBF)[5] typical of direct blows or associated epiphyseal separation or subtle underlying fractures (see Figure 9).

Figure 8: Left arm

Figure 9: Right arm



- radiographs of the right arm also demonstrate areas of SPNBF.
- radiographs of the hands revealed fractures of the metacarpals (see Figure 10) confirmed by radio-isotope scanning (see Figure 11). The mechanism of injury is most likely stamping on the hands (see Figure 11a).

Figure 10: Fracture of metacarpals

Figure 11: Technecium radio-isotope scan of hands clearly demonstrating traumatised areas in the metacarpals and distal forearm bones

Figure 11(a): Mechanism of injury

- the radio-isotope skeletal survey demonstrates all of the above injuries including rosary patterns of the ribs, a fracture of the ischial bone (the child had been raped) and knee injuries (see Figure 12).
- radio-isotope scanning of the feet also revealed bilateral tarsal and navicular fractures (see Figure 13).

Figure 12: Technecium radio-isotope skeletal survey showing extensive skeletal injuries – the kidneys are also visualised possibly bilateral renal trauma

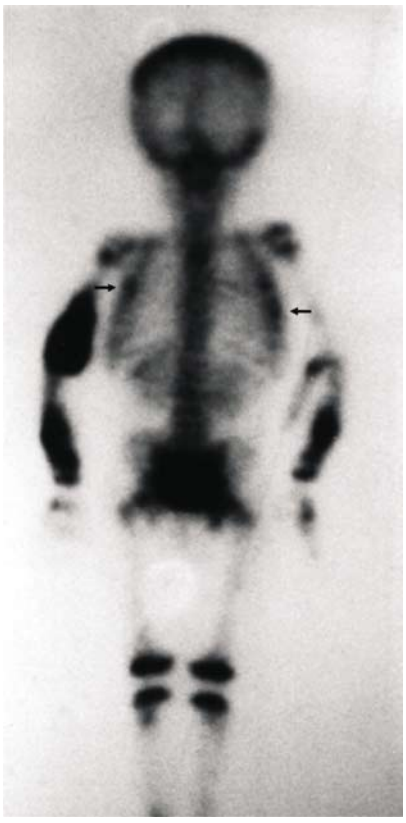
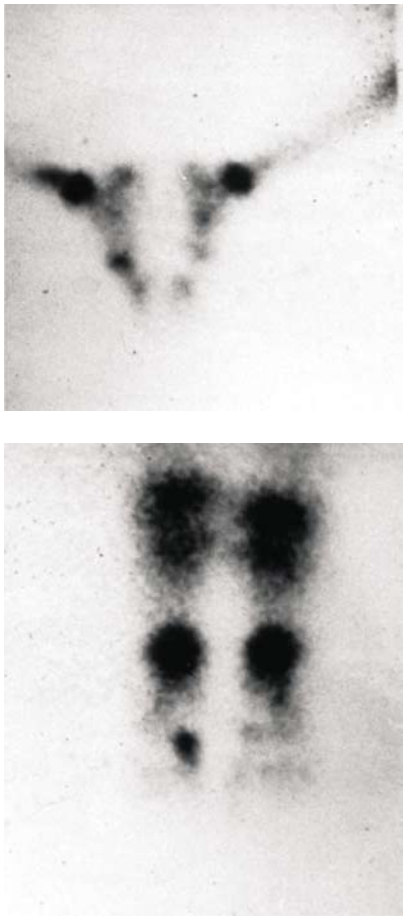


Figure 13: Technecium radio-isotope scan of feet and ankles



Patient 3

This child presents with typical bilateral peri-ocular bruising of the face (see Figure 14). The shape of the bruises is in keeping with injuries sustained from punching (see Figure 14a). It is important that the family practitioner refers the child to the ophthalmologist. The fluoroscene angiogram shows extensive intra-ocular bleeding (see Figure 14b).

Patient 4

This two-month-old child presents with a fractured skull (see Figure 15). The computerised axial brain scan revealed an epidural effusion with midline shift (see Figure 15a).

Skull x-rays play a valuable role in suspected abuse. Radiographs are often useful in the documentation of inflicted injury and are 'mandatory components' of the skeletal survey.[5] It is important to note that brain injury

Figure 14: Peri-ocular bruising

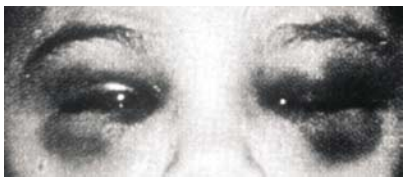


Figure 14(a): Mechanism of injury

Figure 14(b): Fluoroscene angiogram – confirming intra-ocular bleeding

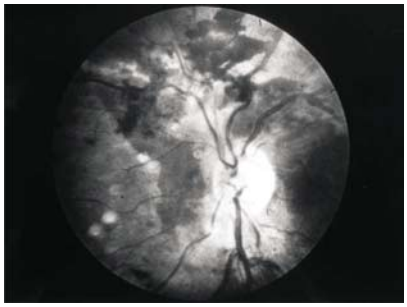


Figure 15: Lateral skull x-ray demonstrating a well-defined posterior fracture crossing the parieto-occipital suture (very suspicious of NAI)

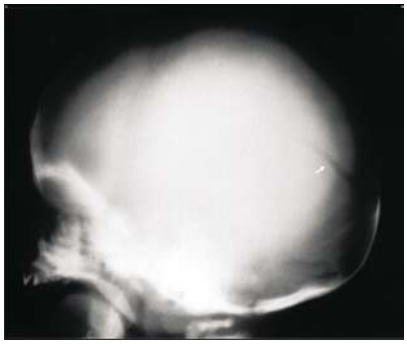
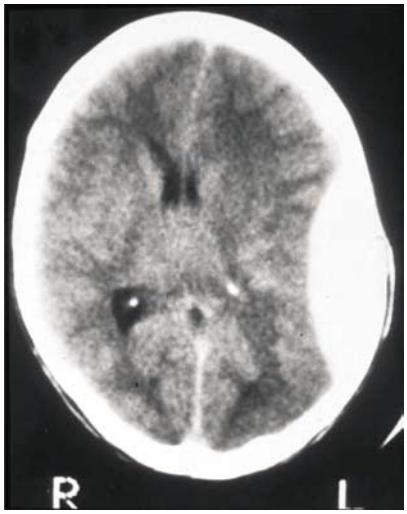


Figure 15(a): Epidural effusion with midline shift to the right and oedematous brain



can occur without external signs as was the case of the next two patients, where it was suspected that these children were violently shaken (see Figure 16).

Figure 16: Mechanism of injury – The shaken baby syndrome

"The shaken baby syndrome is characterised by retinal haemorrhages, subdural and/or subarachnoid haemorrhage with minimal or absent signs of external craniofacial trauma."[4]

The head of the infant is large, heavy and is supported by a relatively long, narrow and weak neck; the rapid repetitive flexion and extension of the infant's head and neck relative to the torso results in the brain inside the calvaria moving at a different speed and becoming asynchronous with the bony envelope, resulting in shearing injuries of vascular structures, intracranial haemorrhages, brain swelling and death.[3] The claim of primacy may belong to Weston who described three instances of subdural haematoma in infants who have been violently shaken.[18]

The infant can present with:

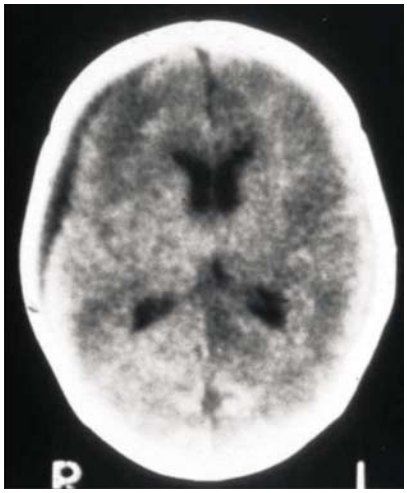
- Lethargy, poor feeding
- Vomiting
- Stops in breathing
- Pallor
- Variable consciousness
- Irritability
- Convulsions

The following two patients show different types of brain injury due to the shaken baby syndrome.

Patient 5

This child presents with a subdural effusion (see Figure 17).

Figure 17: Subdural effusion with dilate ventricles and a slight midline shift to the left



Patient 6

An example of brain infarction with a communicating hydrocephalus (see Figure 18).

Figure 18: Brain infarction with a communicating hydrocephalus

Patient 7

This is an 11-month-old child who presents with the following history. He is the youngest of five children. His mother is a single parent who had two female children and two male children who died of 'unknown causes'. Her boyfriend noticed that he has never seen his son awake. The child is asleep in the morning when he leaves for work and on his return at night the child would be asleep in bed. He became suspicious and took the child to hospital. The child presents with a notch-shaped defect on the anterior aspect of the first lumbar vertebra (see Figure 19). This injury is often associated with axial loading[5] as demonstrated in figures 19a and 19b. Fractures of the spine may also occur due to exaggerated hyperflexion of the spine resulting in fracture dislocation.[5]

Figure 19: Lumbar vertebra demonstrating notch-shaped defect L1

Figure 19(a): Notch-shaped defect L1; Mechanism of injury 1 – Slamming the child on the knees

Figure 19(b): Notch-shaped defect L1; Mechanism of injury 2 – Slamming the child on the table

Figure 20: Chest x-ray – Right opaque lung occupied by lymphatic fluid (note the proximal metaphyseal torsion fracture of the left humerus)

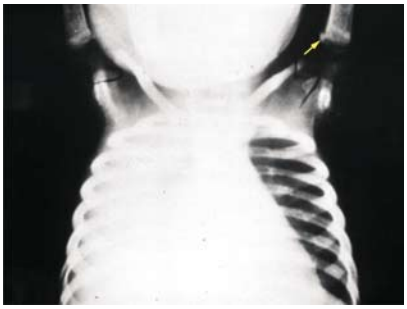


Figure 20 shows a right pleural effusion. On insertion of an intercostals drain, it was found that the fluid was lymphatic fluid – the thoracic duct was punctured. The child also presented with a proximal metaphyseal torsion fracture of the left humerus.

The child was referred for a computerised axial (CT) scan of the abdomen, which revealed areas of mixed density in the liver in keeping with direct trauma to the upper abdominal cavity (see Figure 21). The ultrasound scan (see Figure 22) showed a haematoma in the liver with areas of breakdown (note the demarcated fluid-filled sites), and a swollen pancreas (see Figure 23) due to traumatic pancreatitis.

Figure 21: CT scan liver – mixed density in the liver

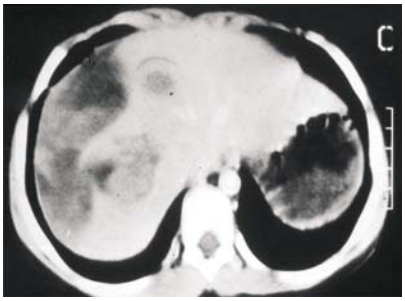


Figure 22: Ultrasound scan liver – haematoma in the liver with areas of breakdown

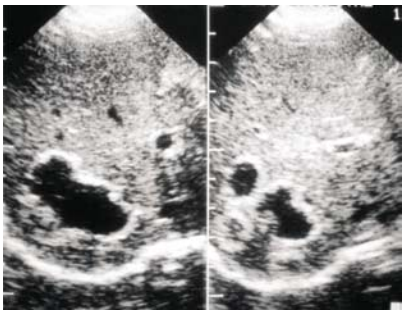
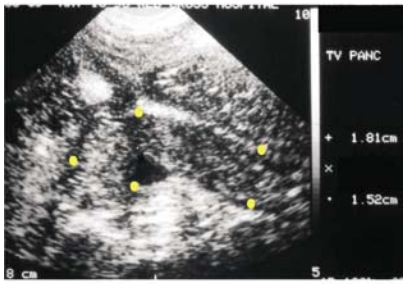


Figure 23: Ultrasound of the pancreas – swollen, enlarged inhomogeneous pancreas due to traumatic pancreatitis



The abdomen is a fairly common site for abusive trauma due to kicking or hitting; blunt forces in the form of a fist or a knee can cause severe intra-abdominal visceral damage and have a high mortality rate.[1,3]

Patient 8

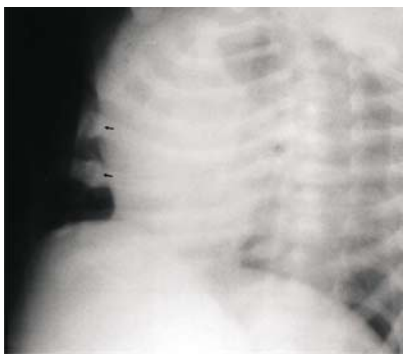
This child presents with:

- a swollen mouth and right cheek and is salivating (see Figure 24). The gums, teeth and frenulum should be examined for tears due to forced feeding or **sexual abuse**.

Figure 24: Swollen mouth and right cheek and salivating

- fractured ribs – note the rosary bead sign (see Figure 25) on this oblique projection.

Figure 25: Oblique projection of the ribs demonstrating fractured ribs (note the nodules of increased density that are healed fractures – rosary bead sign)



- a depressed manubrium sternum due to a massive force applied to the thorax (see Figure 26).
- a fractured coracoid process due to torsion of the arm (see Figure 27 and 27a).

Figure 26: Depressed manubrium sternum

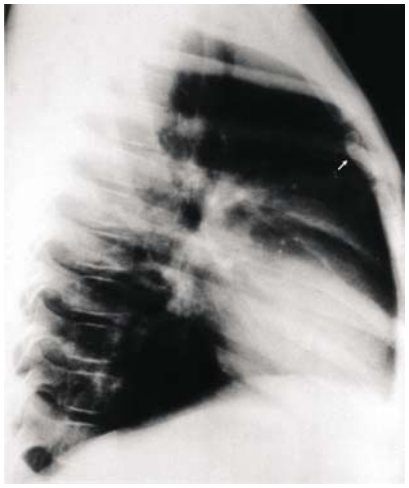


Figure 27: Widely spread fracture of the coracoid process with a bucket handle fracture of the right proximal humerus

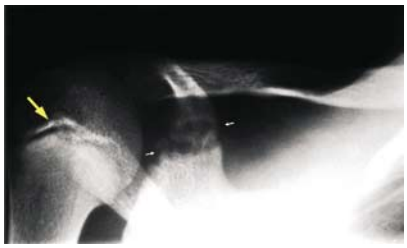


Figure 27(a): Mechanism of injury 1 – Fracture of the coracoid process

Figure 27(b): Mechanism of injury 2 – Fracture of the coracoid process

- an old healed fracture of the shaft of the femur as a result of a high impact direct trauma to the thigh – the child was unable to sit (see Figure 28).

Figure 28: Old healed fracture of the shaft of the femur

Patient 9

This child presents with a fractured skull (see Figure 29). The computerised axial scan demonstrates a porencephalic cyst with liquefaction (see Figure 30). There is a 'growing fracture' – the fracture site is bulging due to enlargement of the cyst.

Figure 29: CT scan demonstrating a skull fracture

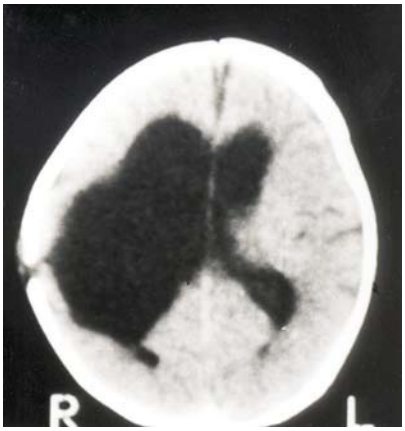
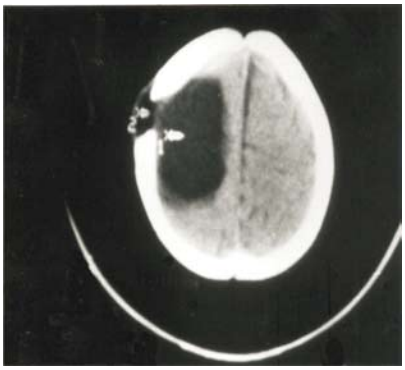


Figure 30: CT scan demonstrating porencephalic cyst with a 'growing fracture'



Other unusual manifestations of physical injury

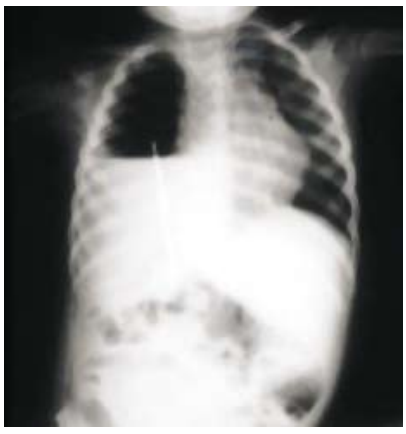
Munschausen's syndrome by proxy (MSBP)

This is a form of child abuse in which the abuser, who may be a parent or a caretaker, fabricates or produces an illness. The child is frequently taken to the family practitioner or local clinic to seek medical attention. The types of abuse include poisoning by foreign bodies, injection of saliva into the body and insertion of stones in body cavities.[5] According to Hanon, it is not unusual for abuse such as the injection of faecal matter into the victim or suffocation and revival to take place while the child is hospitalised, and therefore hospital staff should be diligent with regard to the storage of syringes and other medical equipment.[19] Although MSBP offenders intentionally abuse their children, it is purported that they truly love them and it is this emotional turmoil that takes them to a state beyond the fear of punishment and shame and leads to dialogue between the offender and the interviewer, which is critical in cases of unidentified poisoning.[21] MSBP is a problem recognised by mental health workers. However, it must also be recognised by the law enforcement community as part of prevention campaigns, because if it remains unrecognised by this professional group homicide among children will continue to be a major problem.

Impalement

Needles and other sharp objects may be inserted into a child.[5] It is not unusual to find needles inserted into discreet regions such as under the breasts, into the armpits or between the folds of the skin on the anterior abdomen. Figure 31 is an example of a crochet needle inserted into the anus of a child.

Figure 31: Crochet needle pushed through the anus, perforating the diaphragm resulting in a haemo-pneumothorax



Differential diagnoses

The following are examples but not inclusive of patterns seen in disease orders simulating abuse (see Figure 32, 33, 34 and 35):

Figure 32: This is a case of gross osteopaenia demonstrating osteoporosis due to protein energy malformation. Note also the marked reduction of the muscle and soft tissues.

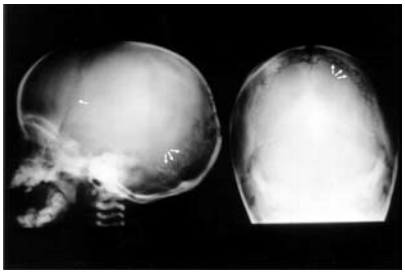
Figure 33: A case of scurvy – demonstrating osteoporosis with bleeding into the muscles. Note the Pelken's spurs at the zone of provisional calcification (ZPC).[5]

Repetitive injuries

This term is commonly associated with the diagnosis of abuse fractures and is taken to mean that two or more 'inflicted injuries to the same bone or in the same area of bone is visible'. This term should be restricted to a single bone in the same set of circumstances. Repeated injury to the child affecting different parts of the skeletal system is also of medical and forensic importance. This is often seen at the first presentation when the radiographic images are pathognomonic of different stages of healing.[5] (See patient 2.)

Figure 34: Osteogenesis Imperfecta – inherited generalised disorder of the connective tissue characterised by multiple fractures

Figure 35: Osteogenesis Imperfecta Tarda. Note the ossification of the skull progresses slowly, leaving wide sutures and multiple juxta-sutural accessory bones within the sutures referred to as "Wormian Bones"



Multiple injury

This means injuries to more than one bone, system or viscus incurred simultaneously. A distinction is made between injuries inflicted simultaneously and injuries inflicted at different times.[5] This distinction is important for the forensic pathologist in terms of dating the injuries.

Conclusion

NAI in children may involve any part of the anatomic focus and organ system. Awareness of patterns of injuries and an understanding of the mechanism thereof serve to identify victims of abuse and hopefully stimulate more thorough clinical and radiological investigations. With the advent of non-ionising radiation imaging modalities becoming more available in radiology departments, the risks associated with exposure to ionising radiation is minimised, and some of these examinations, for example ultrasound and magnetic resonance imaging, have become the imaging

modalities of choice for paediatric radiology.[5] While reporting of abuse is a shared responsibility, the burden lies predominantly with the family practitioner. The process of identifying and reporting NAI involves a complex procedure. At any point during this process the family practitioner's behaviour may be influenced by a number of factors. These factors may include being associated with the case, being associated with the referring individual, the setting in which the doctor works, the fear of recrimination – which are all understandable. However, education about or changes in current reporting procedures focusing on positive outcomes for the child, the families and the physician may be the most appealing approach. Warner and Hanson propose that 'many physicians may not have accurate information about the probability of encountering negative consequences of reporting', and they suggest that these consequences could be gathered in a survey of physicians who have experience with reporting.[20]

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