Radiological aspects of non-accidental injury

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Keywords: radiology; non-accidental injury

Paper read to Section of Clinical Forensic Medicine, 18 February 1989

Introduction

In 1946 John Caffey described a syndrome in which subdural haematoma was associated with fractures of long bones, often multiple or repetitive, and in varying stages of repair[1]. In none of the six cases was there evidence of skeletal disease predisposing to injury and the injuries which caused the fractures 'were either not observed or were denied when observed'. Since that time the problem of unexplained fractures in infancy has received widespread attention but difficulties remain when guardians vehemently deny injuring their child.

The role of the radiologist is to:

(1) differentiate pathology from the borderlands of normality

(2) define the radiological abnormality

(3) offer a differential diagnosis

(4) suggest the aetiology of any fractures that are noted and to decide if that is consistent with the explanation offered by the guardians.

(5) date the injuries.

Historical milestones

There have been a number of historical milestones[2]. In 1860, Ambroise Tardeau who was professor of legal medicine in the University of Paris published an article[3] which appears to be the first in which the concept of the battered child, as presented by Kempe 101 years later, was clearly stated. He described 32 children; 17 were less than 5 years and 18 died. He reported fractures prior to the discovery of X-rays. In 1939 Ingraham and Heyl demonstrated that subdural haematomas in children were generally of traumatic origin[4]; since 1856 they had been ascribed to infection. In 1946 John Caffey described the association of subdural haematoma with fractures of long bones. Snedecor and Wilson, in 1949, described traumatic lesions, including metaphyseal fractures, found in newborns after breech deliveries[5].

In 1953 Astley pointed out some important new clinical observations[6]. He found that the metaphyseal lesions caused surprisingly little pain or tenderness and he was surprised that his patients were usually in such good health. Most of the fractures were clinically undetectable and became evident only after the entire skeleton had been X-rayed. He reported rib and spine fractures. He believed the parents to be normal, sensible people and found it hard to believe that normal children could have such extensive lesions without a definite history of trauma and without considerable pain. This same doubt may play a part in opinions expressed by other doctors 35 years later. Astley believed, at that time, that the fractures were the result of excessive fragility and coined the term 'Metaphyseal Fragility of Bone'. In 1961 Kempe coined the term 'Battered Child' for a meeting of the American Academy of Paediatrics[7].

In attempting to interpret correctly the radiographs of young children I believe it is essential to enlist the experience of a paediatric radiologist who is fully cognizant of all the normal variations which may mimic disease. The list is lengthy but the most important are probably the normal metaphyseal cupping and beaking[8] which may lead the unwary into an erroneous diagnosis of metabolic bone disease. Periosteal reactions have also been shown to be common in young infants[9], probably reflecting active bone growth, but they are always bilateral. Unilateral periosteal reaction is pathological.

Skeletal injuries

Although the radiologist has an important role in the diagnosis of cerebral and visceral trauma this paper will be confined to skeletal injuries. Reports of the frequency of fractures in cases of abuse vary from 11% to 55%. Skeletal injuries are significantly more common in the younger child. One study showed that 94% of the fractures occurred in patients less than 3 years of age, although only 58% of the children were less than 3 years[10]. A number of patterns of skeletal injury are discernible.

Periosteal injuries

Subperiosteal haemorrhage from any cause produces elevation of the periosteum. The periosteum is only loosely adherent to the shaft but tightly adherent at the epiphyseal growth plate. Thus maximum haemorrhage thickness is along the diaphysis, with gradual tapering towards the epiphysis. In the acute stage, apart from soft tissue swelling, the radiographs are initially negative. In 5-14 days (earliest in the younger child, later in the older child) periosteal new bone appears. The first appearance and subsequent maturation of a periosteal reaction enables the radiologist to date that injury. If massive bleeding is present ultrasonography may clearly elucidate the morbid anatomy and radionuclide bone scanning is extremely useful in detecting early subperiosteal haemorrhage.

Focal or generalized periosteal new bone formation is, in itself a non-specific finding being seen in infectious, traumatic, metabolic and a variety of other entities. In child abuse it is due to tractional and torsional forces on the periosteum. This is usually the result of pulling or twisting an extremity or when the extremities are used as a 'handle' for shaking. Periosteal reaction and callus formation may also, of course be the sequela of a fracture which disrupts the periosteum.

Metaphyseal fractures

Metaphyseal fractures are, again, due to pulling and twisting forces on limbs, the forces often being applied at a site remote from the site of the resulting fracture.

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Identical lesions can be encountered in infants who have been shaken while gripped around the thorax. The massive acceleration and deceleration forces that develop as the extremities flail about produce identical changes. Previously the mechanism was believed to be a metaphyseal avulsion by the tightly adherent periosteal insertion at the growth plate. However, recent evidence has shown that the fundamental histological lesion is a transmetaphyseal disruption of the most immature metaphyseal primary spongiosa[11]. The most subtle indication of injury is a transverse lucency within the subepiphyseal region of the metaphysis. The fracture may be visible in only one projection and its appearance is influenced by the severity of the bony injury, the degree of displacement of the fragments and the chronicity of the process. In those children who die, fractures may be demonstrable histologically in the presence of normal radiology and it is recommended that children dying from suspected abuse have selected metaphyses examined histologically when radiology is non-contributory[11]. Peripherally the fracture line may undermine and isolate a thicker fragment of bone and it is this thick peripheral margin of bone that produces the corner fractures (Figure 1) and bucket handle configurations (Figure 2).

It is also important to remember that a metaphyseal fracture which does not disrupt the tightly adherent periosteum will not be accompanied by a periosteal reaction during the healing phase and, like old soldiers, may simply fade away. Thus the absence of physical signs of a fracture together with the absence of signs of healing should not lead one to deduce that the fracture either was not a fracture at all or that the bone must have been abnormally fragile.

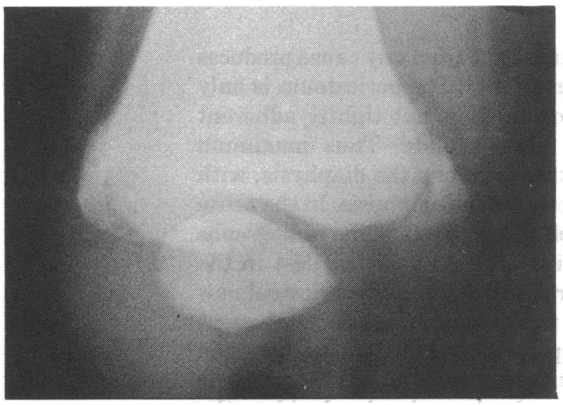

Figure 1. A typical metaphyseal fracture of the distal femur. Note the thicker fragment of bone peripherally

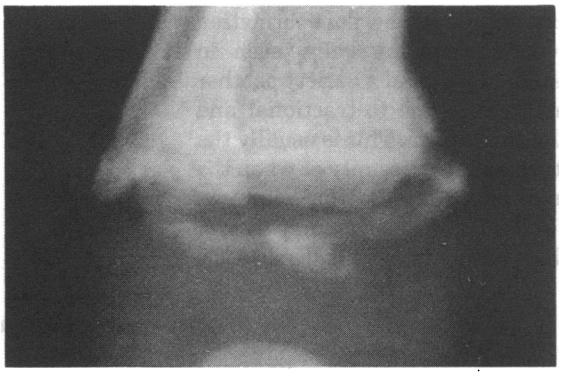

Figure 2. Bucket handle metaphyseal fracture of the distal tibia

Figure 3. Spiral fracture of the right humerus. The fracture is unstable as indicated by the fracture line breaching the callus already present. There is, in addition, a rib fracture which shows more mature callus and antedates the humeral fracture

Metaphyseal fractures are the most valuable single sign of non-accidental injury[12].

Diaphyseal fractures

Unlike metaphyseal fractures there are no diaphyseal fractures specific for child abuse and they present the greatest difficulty in assigning a radiological diagnosis. Other features of the case will then be important in deciding the short and long term future of the child. However, a recent study comparing fractures in abused children with those occurring accidentally has shown spiral fracture of the humerus to be significantly more common in the abused child than in the child suffering an accidental injury[13]. Diaphyseal fractures may, of course, coexist with rib or metaphyseal fractures and then the diagnosis of abuse may be made more readily (Figure 3).

Rib fractures

Rib fractures comprise 5-27% of all fractures in abused children and are probably even more common than published figures suggest because of the difficulty in demonstrating them radiologically. Rib fractures in infancy are unusual because ribs are so pliable. In the absence of prematurity, birth injury, metabolic disorders, bone dysplasias and major trauma such as road traffic accidents, rib fractures may be considered specific for abuse[13,14]. Cardio-pulmonary resuscitation only very rarely results in rib fractures[15]. In contrast to diaphyseal appendicular fractures the majority (over 80%) are occult[16]. They most commonly result from a compressive, squeezing force applied to the chest with AP compression producing lateral fractures and lateral squeezing resulting in fractures posteriorly or anteriorly. Posterior fractures occur when the rib is bent over the adjacent transverse process and are most common in

non-accidental injury. It is frequently very difficult to see fresh fractures because the X-ray beam may not align with the fracture line. The fracture may only become visible during the healing phase with the appearance of callus. In a recent study of posterior rib fractures in non-accidental injury Kleinman[17] showed that no posterior rib fractures could be diagnosed in the acute stage and in those infants who died acutely even postmortem radiographs of resected ribs only showed the fractures in the axial supero inferior view. Thus failure to observe the fracture at presentation and the appearance of callus after admission to hospital is not necessarily evidence of injury after admission.

Less common skeletal injuries

Metaphyseal fractures and posterior rib fractures are highly specific for abuse. In infants and young children certain other fractures also have a high specificity for abuse owing to their unusual locations. These include scapular injuries, injuries involving the small bones of the hands and feet, lateral clavicular fractures, sternal and spinal injuries. It should also be remembered that lesions which have a low specificity for abuse, eg long bone fractures, achieve a higher specificity when a history of trauma is absent or inconsistent with the injuries.

Skull injuries

Most accidental skull fractures result from falls ranging from 3 to 5½ feet and are generally linear, narrow and uncomplicated. Falls out of bed only rarely result in a fracture[18]. Severe accidental fractures result from falls down stairs or from heights greater than 6 feet. The following features to be more likely in non-accidental injury are[19]:

(a) multiple fractures
(b) diastatic fractures greater than 5 mm in width
(c) non-parietal fractures
(d) depressed fractures
(e) complex fractures
(f) growing fractures (leptomeningeal cysts)

A depressed occipital fracture is virtually pathognomonic of abuse.

Differential diagnosis

It is not possible in a review of this length to comment in detail on the differential diagnoses which will include normal developmental variations as well as pathology. A brief summary is presented in Table 1. However, I will mention three diagnoses, birth injuries, osteogenesis imperfecta and copper deficiency, in more detail. Three out of four of all birth associated fractures of long bones occur during vaginal breech deliveries and I have already cited the 1935 study of Snedecor and Wilson. Caesarean section has reduced the incidence of fractures considerably but they still occur following difficult breech delivery by caesarean section where considerable traction is necessary. Two cases of femoral metaphyseal fractures following easy caesarean section deliveries were reported in 1987[20] and so the accurate dating of fractures is mandatory lest innocent parents be wrongly accused. Accurate dating may also, of course, exclude birth related trauma (Figure 4). In Cumming's series of fractures in 23 newborns, the fracture sites were the clavicle, humerus and femur[21]. Fracture at an unusual site or absence of calcification 11 days after birth should suggest the possibility of abuse.

Osteogenesis imperfecta

Osteogenesis imperfecta is now classifiable into one of four major types[22]. Types II and III have obvious bony disease and are relatively easy to exclude from the differential diagnosis. Type I, the classical form with a positive family history and blue sclerae, with

Table 1. Differential diagnosis of skeletal lesions in child abuse

Disease	*Shaft fractures*	*Abnormal metaphysis*	*Osteopenia*	*Periosteal reaction*	*Comments*
Child abuse	+	+	−	+	
Accidental trauma	+	−	−	−	
Birth trauma	+	+/−	−	+/−	Clavicle, humerus and femur are most frequent fractures
Osteogenesis imperfecta	+	+/−	+	callus	Highly unlikely in the absence of osteopenia, Wormian bones, dentinogenesis imperfecta and a relevant family history
Osteomyelitis	−	+	localized	+	May be multifocal
Rickets	+	+	+	+	↑Alkaline phosphatase
Scurvy	−	+	+	+	Not before 6 months age
Congenital syphilis	−	+	−	+	
Congenital insensitivity to pain	+	+	−	+	
Paraplegia	+	+	+	with fractures	Lower limb changes only
Prostaglandin E_1 therapy	−	−	−	+	
Menke's syndrome	−	+	+	+	Males only. Abnormal hair. Retardation. Wormian bones.
Copper deficiency	+	+	+	+/−	See text

Modified from Kleinman (1987)[27]

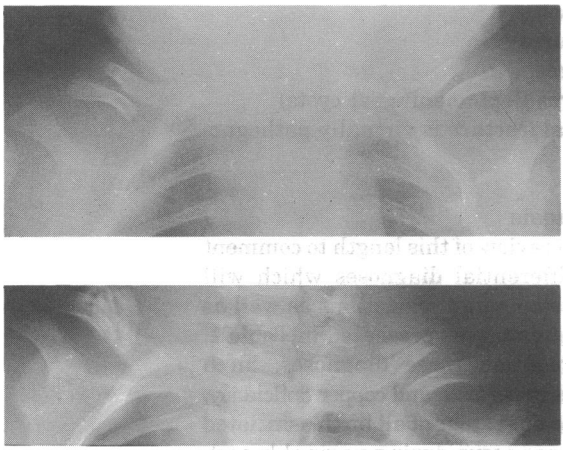

Figure 4. Birth injury or non-accidental injury? (top) At one month of age the defects in the midportions of both clavicles were thought to be ununited birth injuries or congenital pseudarthroses. (bottom) Ten days later there is callus around both clavicles indicative of recent trauma

or without dentinogenesis imperfecta should also not cause difficulty. Type IV is a heterogeneous group with mild to severe bone disease, normal sclerae and, in the majority, a positive family history. In the absence of a relevant family history what is the likelihood of a new mutation as the explanation for fractures? Taitz[23] showed that the incidence of type IV osteogenesis imperfecta with fractures under 1 year of age, with no family history, no wormian bones and no dentinogenesis imperfecta is 1 in 1 million to 1 in 3 million. Thus in a city of 500 000 people with 6000 births per annum the incidence would be one case every 100-300 years. The number of non-accidental injury cases with fractures would be expected to be 15 cases per year. Metaphyseal fractures do occur in osteogenesis imperfecta but only in the presence of obviously abnormal underlying bone disease[24].

Copper deficiency

Copper deficiency is a diagnosis much in vogue at the present and there has been much written in the non-medical press about a condition which could provide an explanation for 'temporary brittle bones'. Copper is necessary for the correct function of a number of enzymes, impairment of which explains the clinical features of copper deficiency. These include sideroblastic anaemia, neutropenia, abnormal skeletal radiology, psychomotor retardation and hypotonia[25]. Impaired lysyl oxidase activity, an enzyme which is concerned with the normal cross-linking of collagen in bone, results in abnormal formation. The skeletal manifestations occur late, some of the other features listed above being already evident. The earliest radiological manifestation is osteoporosis and this frequently becomes severe. In those children who have had their bone age estimated this has always been retarded and bone age retardation is already evident when osteoporosis is present. As the deficiency progresses the metaphysis becomes cup-shaped and frayed. Later metaphyseal sickle-shaped spurs appear which are really peripheral extensions of the zone of provisional calcification. These changes are distributed symmetrically throughout the skeleton, except for the proximal femur where its medial border is more affected than its lateral one, and are most easily seen at the sites of most active bone growth, ie the knees and wrists[26]. Fractures may occur through these sickle-shaped spurs. As well as sickle fractures other long bone fractures have been recorded. These have varied from multiple fractures over a number of years to the delayed healing of post-thoracotomy rib fractures. Fractures have not occurred in the presence of an otherwise normal skeleton. Copper deficiency is rare and only 16 cases have been complicated by fractures of any type (including sickle fractures). Only five of these 16 have been full term infants. Rib fractures have only occurred in preterm babies and no child has had a skull fracture due to copper deficiency.

Published reports indicate that one or more predisposing factors were present in every case. Because fetal copper stores accumulate rapidly in the third trimester, prematurity and low birth weight are the most frequent predisposing factors. Others have included total parenteral nutrition, feeding with copper deficient milk and malnutrition. Breast fed babies do not become deficient in copper.

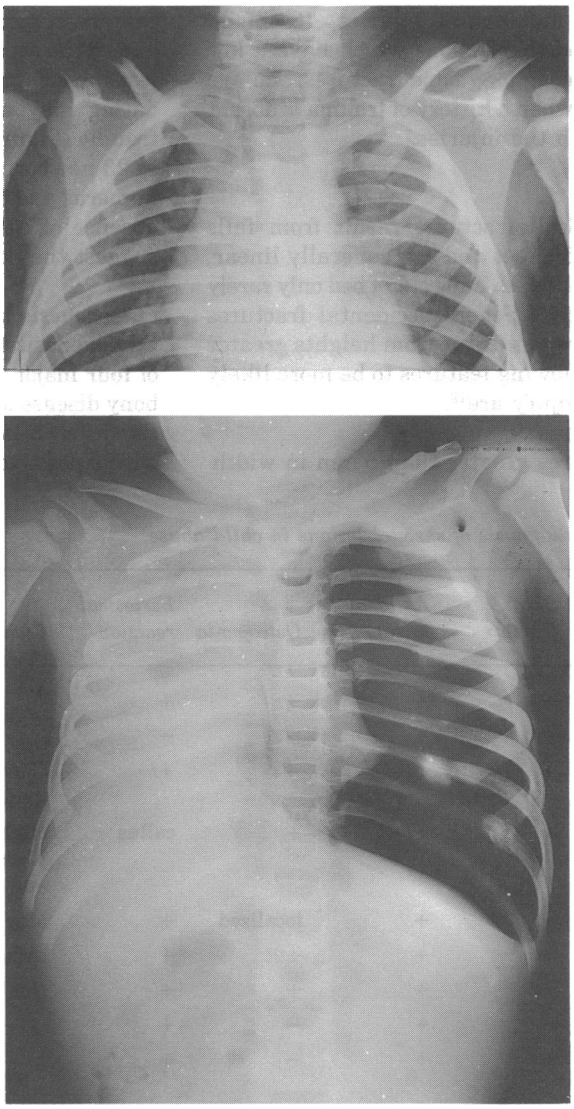

Figure 5. (top) At 9 months of age this child sustained fractures of the left clavicle and left 5th and 6th ribs. Following appropriate treatment he was discharged home. At 13 months he was readmitted, unconscious, to hospital. The chest radiograph (bottom) shows evidence of the previous fractures. There are more recent fractures of several other ribs and the left clavicle. There is a tension pneumothorax. Death occurred one hour after admission, the immediate cause of death being intra-abdominal haemorrhage due to laceration of the liver

Thus although we must consider copper deficiency as a cause of fractures in infants we can, with knowledge of the previously reported cases, comment on the likelihood of such a diagnosis even in the absence of plasma copper and caeruloplasmin estimations. It is unlikely:
(i) in a full term infant, under 6 months of age, who has been breast fed or has received a modern infant formula with a copper content of 40 μg/dl or more
(ii) in a preterm infant less than 2.5 months of age, because of fetal copper stores
(iii) in a term infant with rib fractures
(iv) in any child with a skull fracture
(v) in the absence of one of the predisposing factors mentioned above
(vi) in the absence of anaemia or neutropenia
(vii) without other radiological abnormalities (osteoporosis, metaphyseal changes and retarded bone age)
(viii) when recovery occurs without a change in diet or treatment with copper supplementation.

Conclusions

The radiologist has an important role in diagnosis, often being the first to suggest a diagnosis of abuse. He may suggest or exclude alternative diagnoses. It is often possible to determine a mechanism of injury and to date when that injury was sustained. There will always, of course, be the child with a totally inexplicable fracture or fractures. In the majority of cases the interests of the child are best served by returning it to the parents under appropriate supervision. This is the responsibility of other agencies but to send a child back to a place of danger may have disastrous consequences (Figure 5).

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(Accepted 6 July 1989)