Dating of fractures in infants

by Dr R Gallagher
Specialist registrar radiology
and Dr K Halliday
Consultant paediatric radiologist
email: kath.halliday@nuh.nhs.uk
Nottingham University Hospital, Nottingham

Introduction
Accurate radiological dating of fractures is frequently critical in cases of suspected non-accidental injury (NAI). The age of the fracture is important in assessing both the credibility of the history and the pool of possible perpetrators, and may be vital in deciding the future of the child and their family. Radiologists are frequently asked by police, social workers and lawyers to give as tight a time frame as possible for the occurrence of a fracture.

The majority of children suffering non-accidental fractures are younger than three years and fractures resulting from child abuse are significantly more common in children under 18 months of age than in older children. Accidental fractures in this age group are uncommon and the reporter frequently has little relevant experience to fall back on. In 2005 a review by the Welsh Child Protection Systematic Review Group highlighted the fact that there is very little published evidence to support professionals endeavouring to age fractures in children under five years.

DATING OF FRACTURES

By Dr R Gallagher
Specialist registrar radiology
and Dr K Halliday
Consultant paediatric radiologist
email: kath.halliday@nuh.nhs.uk
Nottingham University Hospital, Nottingham

Introduction
Accurate radiological dating of fractures is frequently critical in cases of suspected non-accidental injury (NAI). The age of the fracture is important in assessing both the credibility of the history and the pool of possible perpetrators, and may be vital in deciding the future of the child and their family. Radiologists are frequently asked by police, social workers and lawyers to give as tight a time frame as possible for the occurrence of a fracture.

The majority of children suffering non-accidental fractures are younger than three years and fractures resulting from child abuse are significantly more common in children under 18 months of age than in older children. Accidental fractures in this age group are uncommon and the reporter frequently has little relevant experience to fall back on. In 2005 a review by the Welsh Child Protection Systematic Review Group highlighted the fact that there is very little published evidence to support professionals endeavouring to age fractures in children under five years.

DATING OF FRACTURES

Histological stages of fracture healing

The stages of fracture healing are defined histologically by the formation of haematoma, “soft” or pro callus, mineralised “hard” callus and remodelling. Haemorrhage from the bone and surrounding soft tissues at the time of injury results in haematoma formation and an inflammatory response. As a result of this, a fibrin mesh is produced which seals off the site of injury and acts as a scaffold for bone healing. Osteoclastic cells, which resorb damaged, necrotic bone, and bone precursor (osteoprogenitor) cells, which initiate new bone production, are activated. By the end of the first week, a soft tissue callus composed of new blood vessels, fibrous tissue and cartilage develops. At this stage the predominantly uncalcified tissue anchors the fractured ends together but provides no structural rigidity. The protein scaffold for new bone is deposited subperiosteally and within the medullary cavity. As this new bone formation reaches the cartilage between the fractured ends, calcium uptake into the callus begins. The mineralised new bone forms a “hard” callus that bridges the fractured ends. Mineralisation progresses and eventually the bone becomes structurally rigid enough to allow weight bearing. As the callus matures and transmits weight-bearing forces, the portions that are not physically stressed are resorbed, and in this manner the callus is reduced in size.

Radiological signs of fracture healing

Since tissues of different radiographic density are produced during the course of fracture healing, certain stages may be demonstrated radiographically. However, there are only a few published studies that have investigated the reliability of these signs. Each of these studies set different inclusion criteria in terms of patient age, the bones involved and the types of fracture. Halliday et al looked at 37 long bone fractures in 31 patients aged 0-44 months. Islam et al studied forearm fractures in 141 patients aged 1-17 years. Yeo et al looked at femoral diaphysis fractures in 25 patients aged from birth to 14 years. Cumming studied fractures of the humerus, clavicle and femur in 23 neonates who sustained fractures at birth.

Many different radiographic signs associated with fracture healing are described in the literature, and different sets of criteria for fracture dating have been used in the published studies. The situation is further complicated by the fact that there is no universal definition of the terms used and there may be considerable inter-observer error in the interpretation of radiographic signs. The recent study by a group of Nottingham radiologists used the radiographic features described in ‘Diagnostic Imaging of Child Abuse,’ edited by Paul Kleinman, to evaluate fracture healing. These are: soft-tissue swelling; subperiosteal new bone formation; definition of a fracture line; presence or absence of callus; whether callus is well- or ill-defined; and the presence of endosteal callus. The reliability of these signs as markers for fracture dating is discussed below. Other signs that have been used in the assessment of fracture healing include fracture gap widening, callus density (compared to adjacent cortex), bridging of callus at the fracture site, and remodelling.

Soft tissue swelling

Haemorrhage and inflammation occurring at the time of trauma produces fluid around the fracture site. The normal soft tissue planes between fat and muscle become obliterated when surrounded by fluid. The length of time that the soft tissue swelling persists for will depend upon the severity of the fracture and whether it is appropriately immobilised. Interpretation of this sign is often hampered by poor quality radiographs and the presence of plaster casts, and the Nottingham study showed that there was some difference between observers in the identification of soft tissue swelling. What evidence there is suggests that soft tissue swelling takes several hours to develop, so it may not be present on initial radiographs and may persist for up to 10 days.

Subperiosteal new bone formation (SPNBF)

Localised subperiosteal haemorrhage occurs at the time of the fracture. However, elevated periosteum is not visible
radiographically until calcium accumulates in the subperiosteal haematoma. The Nottingham study found this to be the most reliable indicator of fracture healing with the least amount of interobserver error in its interpretation. In the study by Islam et al, periosteal reaction was not observed on any radiograph obtained before two weeks, however, only a small proportion of patients underwent radiography between seven and 14 days after injury, and most were in a cast. Periosteal reaction was evident in all patients four weeks after injury. The studies by Cumming and Halliday et al both found that SPNBF was invariably present by 11 days, the earliest it was seen was at seven days in Cumming’s study and at four days in the Nottingham study. (figure 1). It is often said that fractures heal faster in younger children but there is no published evidence to support this.

SPNBF is also seen in young babies as part of normal physiological bone growth. Physiological SPNBF occurs in infants between the ages of one and four months, and most commonly involves the femur or tibia. Physiological SPNBF is characteristically a smooth, regular linear density less than 2 mm thick and is usually bilateral. Pathological SPNBF is seen in infectious and metabolic disorders including rickets, osteomyelitis, congenital syphilis and scurvy.

Definition of a fracture line
Acute fractures have sharply defined margins. The fracture line becomes less well defined as the damaged, necrotic bone at the fractured edges is resorbed. Islam et al reported blunting of fracture margins on 60% of radiographs obtained one week post injury. Halliday et al found that it was a poor discriminator of fracture age and that there was a considerable amount of disagreement between observers.

Presence of endosteal callus
Endosteal callus is new bone formation at the fractured bone ends and is seen radiographically as an increase in density along the fracture line (figure 2). Islam et al report only 6% of fractures showed an increase in density at two weeks, but 85% did so at four to six weeks. Halliday et al observed the presence of endosteal callus as early as eight days, but reported only fair to moderate interobserver agreement.

Presence or absence of callus and well- or ill-defined callus
Yeo et al identified and assessed three stages of callus formation:

1. The earliest radiographically visible calcification.
2. The stage at which callus completely bridged the fracture site.
3. Mature, smooth callus that was homogenous in density but in which the fracture line was still visible.

These stages were demonstrated in 22 of the 25 patients studied and gave the mean number of days at which each stage was observed as: Stage 1 – 11.7; Stage 2 – 18.7; and Stage 3 – 55.3. The influence of the mechanism of injury, type of fracture or the initial angular site of the fracture in 13 of the 70 fractures initially detected.

Rib fractures may not be apparent radiographically until callus has formed and early radiographs may show no or only very subtle abnormalities. Rib fractures from abuse may occur at any location in the rib. Fractures at the costovertebral and costochondral junctions where fibrocartilaginous structures are involved can be particularly difficult to detect acutely. A study conducted in Nottingham has shown that follow-up chest radiographs at an interval of 10–21 days after the primary skeletal survey provide useful additional information regarding additional fractures and fracture dating.

The disc-like shape and lack of radiodensity of the distal fragments produced by metaphyseal fractures pose problems for their detection and dating. Due to the shape of the fragments the radiographic demonstration of these injuries is particularly dependant upon projection. The tangential projection demonstrates triangular “corner” fractures where a chunk of bone is pulled off the peripheral metaphyseal margin (figure 4a and b). When a crescentic fragment is pulled off the distal metaphysis it is best demonstrated in an angled projection, which produces a “bucket handle sign” (figure 5b). A subtle transverse radiolucency in the subphyseal region of the metaphysis may be the only radiographic sign of a metaphyseal fracture. During fracture healing, sclerosis along the fracture line is often indiscernible and there can be a paucity of SPNBF. Histological studies have shown that healing at this site occurs by extension of hypertrophic cartilage from the physis into the metaphysis. Kleinman et al showed that the extension of physeal lucency into the metaphysis on radiographs correlates with this histological finding. The most common pattern is a relatively focal radiolucent extension along the periphery of the physeal margin (figure 6). There are no published studies that assess the reliability of this sign as a marker of fracture dating.

Practical approach to assessment of fracture healing
Since so much importance is placed on the radiological evidence in cases of suspected abuse, it is vital that the quality of this evidence is optimised at each stage of the investigation. Radiographers and radiologists should be aware of the following:

• It is important that the skeletal survey is carried out to the highest possible technical standard in order to demonstrate subtle radiographic signs that may used to detect and date fractures, for example soft tissue swelling. Royal College of Radiologists Guidelines are available and should be followed.

• Oblique views of the ribs improve the sensitivity and specificity of the skeletal survey in detecting rib fractures with increased diagnostic accuracy of about 9%.

• Where there is a suspicion of a metaphyseal injury, supplementary coned views of the metaphysis in the angled and tangential AP and lateral projections are helpful.

• Images should always be reviewed by a radiologist or a senior radiographer with experience of NAI imaging.
before the patient leaves the department so that appropriate supplementary views and follow-up imaging can be arranged.

- Follow-up radiographs two weeks after the initial skeletal survey may be helpful in confirming injuries and may identify fractures not visible on the initial films, they may also provide useful dating information.\(^{12,18}\)

- Although radiographic signs of fracture healing are identifiable, their presentation can vary depending upon the site of the fracture. For example, metaphyseal fractures may result in no discernible fracture line and little SPNBF.

- SPNBF is the only feature of fracture healing that can be reliably assessed radiographically. Current evidence suggests that if there is no evidence of SPNBF on a radiograph the fracture must be less than 11 days old.\(^6\)

**Conclusion**

Radiological evidence is heavily relied upon by clinicians, police and lawyers in the investigation of child abuse cases. Several clearly identifiable radiographic signs that can be used to estimate the age of healing fractures have been described in the literature, and the available evidence suggests that SPNBF is the most reliable of these.\(^6\) However, there is currently insufficient published data to formulate an evidence-based guideline for fracture dating in children aged five years or less. This is of particular concern as it is this age group that is most at risk of non-accidental skeletal trauma.

**References**

FIGURE 4
Rib fractures appearing on delayed film.

FIGURE 4A
Initial film shows bilateral fractures of 2nd, 3rd and 4th ribs.

FIGURE 4B
Follow-up film taken 12 days later confirms bilateral 2nd, 3rd and 4th rib fractures, but also shows fractures of left 9th, 10th and 11th ribs, which were not visible on the initial radiographs.

FIGURE 5A
Metaphyseal corner fractures.

FIGURE 5B
Metaphyseal 'bucket handle' fracture.

FIGURE 6
Healing.