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The detection of significant fractures in suspected infant abuse

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ABSTRACT

Objective: Skeletal survey is a commonly used means of detecting fractures in infants, and is used as a screen in suspected cases of physical abuse. It is recognised that in live infants, a repeat survey some days after a suspected episode of injury will detect more fractures than one taken shortly after the suspected injury, indicating that the latter lacks sensitivity. In infants who die soon after a suspected episode of physical abuse, the managing clinicians do not have the option of a second survey; however there is the opportunity for the microscopic examination of bones removed at autopsy. Increasingly Osteoarticular Pathology at the Manchester University NHS Foundation Trust (MFT) is being sent samples of bones from infants suspected of inflicted injury for histological examination, both from bones with fractures detected at autopsy or skeletal survey and from posterior ribs and long bone metaphyses (sites of significance in assessing for abusive injury) when there is no evidence of fracture on skeletal survey or autopsy. Here we report the results of an audit of the anonymised data from a series of such cases, to establish the sensitivity of skeletal survey (SS) to detect fractures and to define the medico-legal value of submitting bones for histological examination.

Methods: This was an audit of skeletal injuries in 38 infants aged < 18 months presenting to MFT for specialist histopathological evaluation of suspected non-accidental fractures between January 2011 and June 2017. Histopathological examination was performed on all bones submitted and compared with contact radiography of isolated bones and post-mortem skeletal surveys undertaken by specialist paediatric or musculoskeletal radiologists for the presence of fracture.

Results: A total of 318 fractures were detected histologically; of these, 178 (56%) were of the ribs, 119 (37.5%) were of major limb long bones, 10 (3%) were of the skull, and 11 (3.5%) were recorded as 'other'. Excluding refractures, skeletal survey detected 54% of the fractures recorded histologically. No fractures were detected radiologically that were not seen histologically. Generally, for skeletal survey, detection rates improved with the age of the lesion, and rib fractures were more difficult to detect than long bone fractures. Ribs 5–8 were the most frequently fractured ribs, and metaphyses around the knee accounted for most metaphyseal limb long bone fractures undetected by SS.

Conclusion: In infants coming to post-mortem, histopathology is more sensitive than SS for the detection of clinically significant fractures. In children suspected of non-accidental injuries but with negative or equivocal SS, sampling of the anterior and posterior end of ribs 5–8 and the bones around the knee for histological examination could reveal clinically unsuspected fractures and significant evidence of physical abuse. 71% of infants showed evidence of old fractures typical of non-accidental injury.

1. Introduction

Since Caffey first established a relationship between unexplained subdural haematoma and long bone fractures in 1946,[1] studies examining links between skeletal injury and physical abuse in infants have grown in number. Most of these are radiological. Fractures are the second most common presentation of physical abuse, with classic metaphyseal lesion (CML) and posterior rib fractures being particularly specific.[2–16] The consequence of overlooking such injuries could prove fatal[4,5]; fractures indicative of inflicted injury that antedate death by days or weeks are, in our experience, often first recognised only after death.

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Imaging techniques are the mainstay of fracture recognition in live and dead infants. The skeletal survey (SS) is the first-line investigation for suspected physical abuse,[5,8] the Royal College of Radiologists recommends 22 different views[17] to adequately visualise the entire skeleton. For instance, SS identified 1029 fractures in 313 of 567 infants aged < 12 months.[9] 789 fractures (77%) were clinically unsuspected, thus highlighting the role of skeletal survey in detecting occult inflicted fractures, particularly ribs,[18] that would otherwise go undetected.

In addition to identifying fractures, SSs can provide information on the age of skeletal injuries and the presence of any underlying bone disease[17] which may prove particularly useful where an explanation provided by the care-giver does not match the type or extent of injuries sustained.[19]

CT scanning[7] has proven useful in confirming skeletal injuries otherwise subtle on skeletal survey in both living and dead children. High-detail CT scans can identify CMLs,[14] and create 3D reconstructions that effectively demonstrate the extent of an injury to a lay jury.[7] One drawback of CT scanning is the radiation dose[20–22]; potentially outweighing its value as a screening test in live infants.

MRI scanning has also been used to supplement SS. When used to assess non-cerebral injuries (including CMLs and rib fractures), whole-body MRI has a 'high specificity but low sensitivity' when compared to SS.[23] For instance when whole-body MRI was compared to SS in 16 infants, 5.4% of CMLs were identified by MRI vs 64.8% by SS alone.[23] MRI identified only 54% of rib fractures.

In live infants bone scintigraphy has a high sensitivity for radiographically subtle lesions, such as rib fractures, with 50% in one study being identified by bone scintigraphy alone.[24,25] One drawback is the low sensitivity of detection of CMLs because of high uptake of scintigraphic medium by normal growth plates.[24]

There is broad agreement that outside the skull, certain skeletal injuries carry a high likelihood of being abusive. The most significant in this respect are metaphyseal and posterior rib fractures[26] particularly in non-ambulatory infants.[3–5,7,10,12] Grasping by the chest, squeezing, violent shaking and pulling and twisting of the limbs are implicated in these injuries.[5,7,8] Caution is required in neonates as obstetric trauma, including traumatic vaginal births and uncomplicated Caesarean sections,[27–29] has been causally implicated in these types of fracture.

CMLs, particularly when acute, can be difficult to detect with conventional radiography.[5,7] One study reported 15 healing metaphyseal lesions visible on follow-up SS as 'indeterminate' initially.[4]

Whilst posterior rib fractures5–7,[9,11] are highly specific for non-accidental injury,[2,4–6,9–12] carrying a 95% positive predictive value for physical abuse in children aged < 3 years,[18] because of the anatomy, with bone and soft tissue overlay, and a frequent lack of displacement, they may be overlooked by conventional radiography, particularly if acute.[5,6,9,17,30] In life, follow-up SS increases detection rates. In one study,[30] 94% of fractures first diagnosed at follow-up were either metaphyseal or rib fractures, and in another,[9] 64% of 98 new definite fractures identified at follow-up in 41 infants were rib fractures.

In fatally abused infants follow-up SS is not possible[6]; necessitating a different approach for detecting skeletal injuries after death.

Skeletal survey, palpation at autopsy, and visualised peri-osseous bruising alert pathologists to the possibility of fractures. In addition, forensic and paediatric pathologists in the UK are increasingly taking key bones (e.g. posterior ribs) that might have occult fractures for histological examination by an experienced Osteoarticular Pathologist. Prior to histological analysis it is common practice for the laboratory dealing with the bone samples to undertake 'contact' (specimen) x-rays using a high dose, high resolution system. These are rarely, if ever, reported by radiologists, but guide experienced histopathologists in sample selection.

In one study comparing contact radiography (CR) with SS, fracture detection increased from 58% to 92%, the additional skeletal injuries including high-specificity type injuries, of metaphyses and posterior ribs.[4] Evidence indicates it may also improve fracture aging.[4,7,31,32]

Histology is regarded as the most accurate means of demonstrating and ageing fractures,[3,4,14,33] especially those that are radiographically subtle.[3,14,33] For instance, it is reported that: histology confirmed 6 CML identified as 'abnormal' on SS[3]; four from five rib fractures 'suspected', but not diagnosable, on SS[33] and metaphyseal fractures in two specimens that appeared normal radiographically.[3] However selecting tissue for histological examination is key, as it is not practical to sample the whole skeleton histologically. For this the histopathologist relies on the radiologist and autopsy pathologist to guide sampling.

There are no large studies that have systematically described the different fracture detection rates of post-mortem SS, CR and histopathology and related them to histological age of fracture, bone, and region of bone; and yet the evidence above suggests the right balance of these techniques could be extremely important in optimising the detection of abusive injuries. This is the rationale for our study.

2. Methods

This was a retrospective audit of anonymised data from all cases of suspected non-accidental injuries referred to the histology department of the Manchester Royal Infirmary for specialist histopathological evaluation of skeletal injuries between 2011 and June 2017 (226 cases). Inclusion criteria were:

- Child < 18 months old at the time of death.
- Recorded data from a post-mortem skeletal survey reported by a specialist paediatric or musculoskeletal radiologist.
- Archived contact radiographs of all the bones. Only cases with CR in 2 planes for all bones examined were included.

A total of 38 infants met these criteria. The median age was 12 weeks (range: 19 days–14 months).

Fractures detected for each of the 3 tests, SS, CR and histology, were tabulated and compared. The data for skeletal surveys was as reported by the specialist radiologists. Contact radiographs are used by specialist histopathologists to aid sampling for histological analysis. For this study however, in addition to being reviewed by AF and ER, all CR radiographs in which: no fracture could be seen; the appearances were felt to be equivocal; or where a fracture was seen histologically but not radiographically by the pathologists, were reviewed by a specialist consultant musculoskeletal radiologist (PK). All fractures identified on CR by AF, ER or PK were tabulated as positive. Histological recognition of fractures was made by AF, an osteoarticular pathologist specialising in the histological recognition and interpretation of fracture healing, in the biopsy diagnosis of paediatric metabolic bone disease, and 27 years medicolegal experience in recognising and aging fractures in infants.

Specimens of bone were received from Home Office and forensic pathologists from across the UK as samples of bone in formalin. A short clinical history and the results of SS were included in all cases used in this paper. Contact radiography was performed on a Faxitron [Faxitron Bioptics, LLC 3440 E Britannia Drive, Suite 150, Tucson, Arizona USA 85706]. Images were taken in 2 planes. Following this, bones were decalcified and then widely sampled to include known and suspected fracture sites from SS, autopsy findings, CR, and sites at which identifying a fracture might be of significance in assessing abusive injuries (mainly metaphyses and posterior elements of the ribs). The tissue was taken into paraffin using conventional methods and then sectioned at 4 μm. Serial sections were stained with haematoxylin and eosin (H&E) and Martius scarlet blue (MSB). Two sections were examined from most tissue blocks but equivocal microscopic findings always resulted in "deeper" sections being taken.

Fractures were aged histologically in a manner similar to that described by Klotzbach et al.[33] supplemented with our own data derived from previously published studies examining the in-situ molecular biology of fractures.[34–36] Briefly: