Child Protection Evidence
Systematic review on Fractures

Published: September 2020

While the format of each review has been revised to fit the style of the College and amalgamated into a comprehensive document, the content remains unchanged until reviewed and new evidence is identified and added to the evidence-base. Updated content will be indicated on individual review pages.

RCPCH
Royal College of Paediatrics and Child Health
Leading the way in Children's Health

Table of contents

Summary

Fractures have been recorded in as many as 55% of young children who have been physically abused,[1-3] 18% of whom have multiple fractures.[1] Fractures in physical child abuse denote severe assault and young children are at greatest risk of abusive fractures. Many abusive injuries can be clinically occult and investigative strategies are designed to maximise their early detection, potentially preventing escalation of physical abuse to more serious injury.

This systematic review has been updated and now evaluates the scientific literature published up until **March 2020** that compares abusive and non-abusive fractures in children. There are increasing numbers of high quality studies being published in this field, which continue to address the value of skeletal surveys in different populations and fracture patterns associated with abuse.

In the 2020 systematic review update, seven new studies have been included,[4-10] most adding to a growing body of literature about classic metaphyseal lesions (CMLs). This includes two studies reviewing the distinguishing features of abusive CMLs,[7,9] a study assessing subperiosteal new bone formation with distal tibial CMLs,[8] and another study on ultrasound findings in CMLs. [5] another reviewing the signs of acute and healing distal tibial CMLs.[6] We have also included a study on the yield of additional fractures identified with a skeletal survey in young children with a femoral fracture,[10] and a further study looked at avoiding skull radiographs in children with suspected inflicted injury who also underwent a head CT scan.[4]

The review aims to answer four clinical questions:

1. Which fractures are indicative of abuse?
2. What is the evidence for radiological dating of fractures in children?
3. What radiological investigations should be performed to identify fractures in suspected child abuse?
4. Does cardiopulmonary resuscitation cause rib fractures in children?

Evidence summary

- Abusive fractures are more common in children less than 18 months of age than in those older than 18 months
- Abused children were more likely to have multiple fractures than non-abused children
- Rib fractures in the absence of major trauma, birth injury or underlying bone disease have a high predictive value for abuse
- Multiple rib fractures are more commonly abusive than non-abusive
- Abusive femoral fractures are more likely to arise in children who are not yet walking
- Mid-shaft fractures are the most common femoral fractures in abuse and non-abuse (analysed for all age groups)

- Supra condylar humeral fractures in children are associated with accidental injury whilst the most common abusive humeral fractures in children aged less than five years are spiral or oblique
- Humeral fractures in those aged less than 18 months have a stronger association with abuse than humeral fractures in older children
- Linear fractures are the most common abusive and non-abusive skull fractures
- Metaphyseal fractures are more commonly described in physical child abuse than in non-abuse
- Metaphyseal fractures have been frequently described in fatal abuse
- Most children with classic metaphyseal lesions (CML) have other associated injuries which are often multiple
- Pelvic, hand, feet and sternal fractures occur in physical abuse and appropriate radiology is required for their detection
- The dating of fractures is an inexact science, the radiological features of bone healing represent a continuum, with considerable overlap in timescale
- The accuracy of radiological estimates of the time of injury are in terms of weeks rather than days
- Radiological investigations of suspected physical abuse include initial and follow up skeletal surveys with specific views to maximise detection of occult injuries particularly in young children
- Studies suggest that up to 12% of contacts under two years of age, of children who have been abused with serious injuries, may have a positive skeletal survey, with twins being a particularly high risk.

Background

This systematic review evaluates the scientific literature that compares abusive and non-abusive fractures in children published until March 2020 and reflects the findings of eligible studies. The review aims to answer four clinical questions:

1. Which fractures are indicative of abuse?
2. What is the evidence for radiological dating of fractures in children?
3. What radiological investigations should be performed to identify fractures in suspected child abuse?
4. Does cardiopulmonary resuscitation cause rib fractures in children?

Methodology

A literature search was performed using all OVID Medline databases for all original articles and conference abstracts published since 1950. Supplementary search techniques were used to

identify further relevant references. See Appendix 1 for full methodology, including search strategy and inclusion criteria.

Potentially relevant studies underwent full text screening and critical appraisal. To ensure consistency, ranking was used to indicate the level of confidence that abuse had taken place as well as for study types.

Findings of clinical question 1
Which fractures are indicative of abuse?

In this update we identified two new papers[7,9] adding to this clinical question, both studies reviewed the distinguishing features of abusive classic metaphyseal lesions (CML's).

Age

Fractures found in younger children are often due to abuse, and the included studies state that in children less than one year, 25-56% of all fractures were abusive.[11-14]

Abusive fractures are more prevalent in the youngest age groups; 85% of accidental fractures occurred in children older than five years whilst 80% of abusive fractures occurred in children younger than 18 months of age.[15] In children less than four years old, the mean age for accidental fractures was 22.1 months (95%CI 21.2, 24.02 months) while the mean age of abuse cases was 11.7 months (95%CI 10.6, 12.7 months), thus a significant difference between the age of accidental injuries and abuse was observed ($p<0.001$).[16] The greatest risk of abusive fractures was reported by Skellern *et al.* as being children less than four months of age ($p=0.0007$).[14]

Gender

Five studies assessed the difference between gender.[12-14,16,17] Abusive fractures were reported as more common in boys in one study ($p=0.024$);[17] however, no gender difference between abusive and non-abusive fractures was noted in children aged less than one year[12-14] or in children aged less than four years ($p=0.065$).[16]

Influence of ethnicity and socio-economic group

Two studies analysed ethnicity.[17,18] Leventhal *et al.*[17] found no difference by ethnicity or socio-economic grouping; however, in children less than three-years-old with fractures there was a greater proportion of abusive fractures in black children than white ($p\leq0.01$).[18]

Multiple fractures

Abused children were more likely to have multiple fractures than non-abused children ($p<0.001$);[15,17] however, one study found no difference.[12]

1.1 Rib fractures

In children less than four years of age, rib fractures were more commonly found in those abused than those accidentally injured.[16,19]

Children with rib fractures were significantly more likely to have been abused, and in those less than 18 months with rib fractures, the odds ratio (OR) for abuse was 23.7 (95%CI 9.5, 59.2, $p<0.001$) while in those aged over 18 months the OR was 9.1 (95%CI 3.3, 25, $p<0.001$).[16]

No study addressed disabled children or the influence of ethnicity and socio-economic group.

Meta-analysis

A meta-analysis was undertaken for children less than 48-months-old.[16,20-22] The four studies include children with confirmed or suspected abuse, but showed low heterogeneity ($I^2=0\%$). The positive predictive value (PPV) for rib fractures in relation to suspected or confirmed abuse is 66% (95% CI 42.5-89.7).

Number and location of abusive rib fractures

A study investigating fractures in young children found that rib fractures were the most strongly associated with abuse,[23] whilst another study found the most prevalent injuries in the child abuse group following non-bony head injury and skull fractures were rib fractures.[17]

Multiple rib fractures

Abused children had multiple rib fractures.[15,19-21,24-26] One study included a comparison with children with metabolic bone disease.[25] Flail chest due to multiple rib fractures in infant physical abuse is reported in one study[27] and another study reported that the risk of mortality increases with the number of ribs fractured.[23]

Location of fractures

Abusive rib fractures were recorded at any location on the rib and were either unilateral or bilateral.[15,20,21,24,28,29] Two studies found that anterior fractures were more common in abuse whilst lateral fractures were more common in non-abused children.[20,21] Posterior rib fractures were assessed in seven studies and stated that they were the predominant abusive

fracture.[20,22,26,30-33] Posterior and postero-lateral rib fractures were found to be equally common in abuse and metabolic bone disease.[25]

First rib fractures

Two studies were included that reported on first rib fractures.[22,34] Fractures were predominantly lateral, one posterior.[22,34] Five cases of abusive first rib fractures were reported in one study, four of which had no fracture to adjacent bones and four had associated neurological injury.[22]

1.2 Costochondral junction fractures

Anterior costochondral fractures are described in abuse,[28,34] they may be difficult to visualise radiographically and can occur with associated abdominal injuries.[28]

Intrathoracic injury in children with rib fractures

One study evaluated intrathoracic injuries in abused and non-abused children less than three years of age with rib fractures. Accidentally injured children had more intrathoracic injuries than abused.[19]

1.3 Femoral fractures

Meta-analysis

Two meta-analyses were conducted on children with femoral fractures aged up to 18 months with confirmed or suspected abuse[13,35-42] and children aged 12-48 months with confirmed or suspected abuse,[35,36,38,40-43] compared to non-abused children. For children aged up to 18 months there was low heterogeneity between studies (I^2=0%) and the positive predictive value (PPV) for suspected or confirmed abuse when a femoral fracture is present is 51.1% (95% CI 34.1-66.1). In children aged 12-48 months there was moderate heterogeneity present between studies (I^2=57.4%) and a far lower PPV of 11.7% (95% CI 6.1-17.3) for suspected or confirmed abuse. These findings are consistent with the observation that children who are not independently mobile are far less likely to sustain an accidental femoral fracture.[40]

Age

Femoral fractures in the abuse group occurred predominantly in children less than one year of age.[13-15,17,18,35,38,39,41-47] Abused children who were less than 18 months of age with a fracture were more likely to sustain a femoral fracture (17.5%, 66/377) than those aged 18 months or over (5.7%, 7/123). In contrast, accidentally injured children with a fracture were more likely to sustain a femoral fracture aged 18 months or over than below this age ($p<0.001$).[16] The odds ratio (OR) for

abuse in a child aged less than 18 months old with a femoral fracture was 1.8 (95%CI 1.2, 2.7, p=0.005), compared to 0.3 (95%CI 0.1, 0.7, p=0.003) in a child aged over 18 months.[16]

One study showed that a third of isolated femoral fractures in children less than three years of age were abusive.[45] The same study showed that a spiral fracture was the most common abusive fracture in children younger than 15 months (p=0.05); over this age, spiral fracture was not significantly associated with abuse.[45] However, there is some conflict as a different study reported no association between spiral fracture and abuse was confirmed with a population of children less than the age of three years.[48]

Another study looked at a wider age range (children aged up to three years) where there was no specific fracture type associated with abuse and found there was a highly significant association between femoral fracture in non-ambulant children and abuse.[39] A study of femoral fractures in children up to 48 months of age, found that the median age of abuse cases was lower (four months) versus accidental (26.2 months) (p<0.001).[36]

Fracture type

The most common fracture location in both abused and non-abused children was mid-shaft of the femur.[13,15,41,43-45,47-50] Proximal physeal injuries were described in abused children.[44,49,51,52]

Of 18 impacted transverse fractures of the distal femoral metadiaphysis in infants, 13 (72%) were non-abusive (from short falls) and five (28%) abused cases. The mean age did not differ significantly between the two groups (abuse: eight months vs non-abuse: 12 months). This was a highly selected case series ascertained through child protection specialists.[53]

A study of diaphyseal fractures found they were more common in accidental than abusive injury (p=0.007), however distal femoral fractures were more common in abused than accidentally injured children (p=0.01).[36]

Femoral shaft fractures

Transverse femoral fractures were more commonly associated with abuse than accidental injury.[48]

Femoral Metaphyseal fractures were recorded in a greater proportion of abusive femoral fractures than non-abusive fractures.[15,34,35,44,50]

One study reported 10/20 complete distal femoral metaphyseal fractures occurring in children aged less than one year were due to abuse[54] and accidental causes of metaphyseal fractures included birth injury, motor vehicle collision and falls.[54]

1.4 Humeral fractures

Meta-analysis

Two separate meta-analyses have been conducted, one for children up to 18 months of age[13,41,55-57] and one for 18-48 months.[41,55-57] There was low heterogeneity between the studies of children aged 0-18 months (I^2=0%). For children aged up to 18 months the positive predictive value (PPV) of a humeral fracture for confirmed or suspected abuse is 43.8% (95% CI 27.6-59.9). For children aged 18-48 months, the heterogeneity between studies was low (I^2=28.8%) and the PPV of a humeral fracture due to suspected or confirmed abuse was only 1.8% (95% CI 0-3.9).

The largest case-control study of humeral fractures in less than 48-month-olds highlighted that age less than 18 months, in conjunction with physical or radiology evidence of prior injury and suspicious history are significant indicators of an abusive aetiology.[55]

Age of children with humeral fractures

Several studies reported on the age of children with humeral fractures, with abusive humeral fractures occurring in 74/111 children under the age of one-year.[46]

Children less than 15-months-old, with humeral fractures, were more likely to have sustained an abusive humeral fracture (9/25, 36%) than those aged 15-36 months (1/99, 1%, $p<0.05$).[57] Humeral fractures in those aged less than 18 months were significantly more likely to be due to abuse than accidental injury ($p<0.001$); the odds ratio (OR) for abuse was 2.3 (95% CI 1.3, 4.1, $p=0.004$).[16] For a child older than 18 months with a humeral fracture the OR for abuse was 0.29 (95%CI 0.1, 0.7, $p=0.005$).[16] In a study of children under four-years with humeral fracture, a multivariate analysis was used to develop an algorithm to identify abuse.[55] Abused children tended to be younger than those who were accidentally injured ($p>0.001$).[55]

Fracture type

Four studies confirmed that spiral or oblique humeral fractures in children less than five years of age were strongly associated with abuse.[15,17,56,57] Humeral shaft fractures were more frequently due to abuse[55] and supracondylar fractures were overwhelmingly due to accidents.[15,55,57,58]

Fracture dislocation of the proximal or distal humeral epiphysis was described in abused and accidentally injured children aged up to seven years (majority under three years).[59-61] Epiphyseal humeral fractures are difficult to visualise but this may be enhanced using ultrasound or magnetic resonance imaging scanning.[59-61]

1.5 Skull fractures

Meta-analysis

A meta-analysis was conducted on studies that included children aged 0-48 months.[12,16,18,62,63]

There was low heterogeneity between these studies (I^2=0%) and the positive predictive value of a skull fracture for suspected or confirmed abuse was 20.1% (95% CI 13.3-26.9). Contrary to the other fractures analysed, age less than 18 months did not appear to be a key variable.[16] In one study, in children aged less than 18 months skull fractures were more common in the control subjects than those who were abused.[16]

Age of children with skull fractures

All studies included pre-school children, five only included children less than one year of age.[12-14,64,65] Skull fractures of either aetiology (abuse or accident) have an increased prevalence in younger infants.[12,13,16,18,62,64,65] In a study of children less than three years of age 80% (75/94) of accidental and 88% (23/26) of abusive skull fractures were in infants under one year of age.[17]

Skull fractures were more frequent in accidental trauma than abuse in those aged less than 18 months, ($p=0.002$) and for those older than 18 months ($p<0.001$).[16]

Fracture type

The most common abusive and non-abusive fractures were linear.[15,17,62,63] Meservy *et al*. studied 134 children aged less than two years old (motor vehicle accident excluded), 39 of whom were abused.[62] Multiple or bilateral fractures, or those that crossed suture lines, were more common in abused children ($p<0.05$).[62] No significant differences were recorded between the two aetiology groups with relation to nonparietal, depressed, diastatic ≥3mm or complex fractures.[62] In a series of alleged short distance fall victims, four children aged between two days and 18 months were found to have bilateral linear skull fractures.[66]

1.6 Metaphyseal fractures

Age

A study of 215 children aged less than three years old who were examined for a fracture described 13 abusive humeral fractures, including metaphyseal fractures.[17]

A study of 34 infants less than one year old with 55 fractures; 19 long bone fractures and five metaphyseal fractures were recorded.[12] Cause was accidental in 15 infants (44%) and

nonaccidental in 19 infants (56%), representing a greater incidence of accidental injury than previously indicated in this age group. However, there was no significant difference between the distribution of fractures between abuse and non-abuse.

The likelihood of classic metaphyseal lesions (CML) fracture in head injured infants aged less than one year of age was assessed in a study of 60 infants. There were 42 children deemed 'low risk' of abuse and 18 'high risk' (abuse rank two); 9/18 children in the high risk but no child with a 'low risk' had CMLs.[67] The CMLs involved all long bones but, more frequently, femur and tibia, 55% of CML were found around the knee.[34]

A newly included study of 20 infants with suspected abuse (mean age 2.6 months) showed that the distal tibial CML almost always involved the medial cortical margin and the fracture infrequently involved the lateral cortical margin.[9] The percentage point difference between fracture involvement in medial and lateral margins was statistically significant from zero ($p<0.001$). The distal tibial CML is most often encountered medially; lateral involvement is uncommon. This observation should help guide the radiologic diagnosis and could have implications for understanding the biomechanics of this distinctive injury.

A study of 67 children found lower extremity CMLs were far more frequent than upper extremity CMLs. The majority of single CMLs (n = 23) were in a lower extremity (78%, n = 67), primarily at the knee or ankle. Local signs of injury led to the diagnosis of 36% (n = 67) of the subjects.[7]

A study of 63 femoral fracture episodes in children aged less than four-years-old (once pathological fractures and MVC excluded) found 24 fractures were due to abuse/suspected abuse, four of which were distal metaphyseal chip fractures and a further five were distal metaphyseal fractures.[44] Of the 39 non-abusive fractures, five were distal metaphyseal fractures, one of which was a chip fracture.[44]

A study of 826 children with accidental fractures and 35 children less than five-years-old with abusive fractures reported that 17 metaphyseal corner fractures were noted amongst the abused children, all aged less than 18-months-old and that there were no metaphyseal fractures in the accident group.[15]

A study of infants aged less than one year showed the mean age of those with metaphyseal fractures was four months, 15/50 had bilateral symmetrical lower extremity metaphyseal fractures. There were 42/48 children with CML had positive skeletal survey for occult fractures and one nine-day old infant had CML as a consequence of birth.[34]

Femoral metaphyseal fractures are far more common amongst abused than non-abused infants.{Anderson, 1982 #35;Beals, 1983 #44}

A study that included 14 children with humeral fractures reported that 11 were abuse cases amongst which there were metaphyseal fractures but in none of the three accidental falls (all

were supracondylar).[41] Infants aged less than one year with CML were described and of the 119 children assessed for suspected maltreatment, 111 (93%) were rated 'highly likely' to be abused. The study found that the majority occurred in infants aged up to two months and decreased in frequency as age increased.[68] More than 95% of subjects with CMLs had at least one other injury.[68]

Fatally abused children with metaphyseal fractures

Five studies by Kleinman *et al.*[69-73] delineated the histologic/radiologic correlates of classical metaphyseal fractures in 31 fatally abused infants with skeletal injuries. Children ranged in age between three weeks and 10.5 months (mean age: three months). There were 165 fractures in the 31 children; 72 long bone fractures; 64 (89%) of which were classical metaphyseal lesions in 20 children. Metaphyseal fractures accounted for 39% of the total fractures and were found in 20/31 children. The 'commonest site' for CMLs was the tibia whilst metaphyseal fractures were commonly bilateral and symmetrical. Specimen radiography increased the yield of fractures noted on skeletal survey from 58% to 92%.[69-73]

Tibial and fibular fractures

Tibial and fibular fractures were attributed to abuse in 1/8 fractures in children less than three years,[18] when assessing abusive tibial fractures alone, 7/12 were metaphyseal.[15]

In assessing the age of children with fractures, one study noted 96% (23/24) of all tibial or fibular fractures were abusive in children less than 18 months.[37] Whilst another found that in children less than three-years-old, 14/35 tibial and fibular fractures were from abuse.[17] Worlock reported abusive tibial and fibular fractures in children less than 18 months of age but not in older toddlers.[15] Tibia and fibular fractures were more common in abuse than accidental injury ($p<0.001$) in children under four years old.[16] The OR for abuse in a child older than 18 months was 2.1 (95%CI 0.7, 6.2, $p=0.172$).[16] The odds ratio (OR) for abuse in a child aged less than 18 months with a tibial/fibular fracture was 12.8 (95% CI 5.1, 32.6, $p<0.001$).[16]

Radial and ulnar fractures

Children with injuries attributed to abuse were significantly younger than those with non-abusive injuries.[74] Most non-abusive fractures were greenstick, Worlock identified metaphyseal ulnar fractures in the abused group only.[15-18] Radial/ulnar fractures were more common in abused than control group children aged less than 18 months ($p=0.001$),[16] whilst in those less than four years of age with a radius/ulnar fracture, the OR for abuse was 5.8 (95%CI 2.4, 14.3, $p<0.001$).[16]

Forearm fractures in 135 children were studied and there were 11 cases attributed to abuse. These children were significantly younger than those with non-abusive injuries ($p<0.001$).[74] Buckle

fractures were the most common fracture type in both groups followed by transverse fractures. There were no significant differences in the distribution between the two groups. The study reported young age, additional injuries and an absent or inconsistent explanation should increase concern that the fracture was caused by child abuse.

*The criteria for the ranking of abuse was lowered for this section that relies largely on case studies of rarer fracture types, some of which have a lower abuse ranking.

1.7 Pelvic fractures

Nine included studies described pelvic fractures.[46,75-81] Most children with pelvic fractures had suffered from multiple additional injuries.[46,75-81] Two studies reported three infants. One child had up to 29 additional fractures recorded,[76,81] whilst another presented two case reports: one child had multiple burns and pelvic fractures; one was fatally abused due to associated intra-abdominal injuries.[80]

Five studies included children with pelvic fractures with associated suspected or confirmed sexual abuse. [75,77,78,80,82] In one study, a child was disabled and non-verbal.[77]

A report of fourteen cases of pubic radio-lucency are described, seven were cases of confirmed abuse, three had fractures of the superior pubic ramus, three had pelvic normal variants and one had indeterminant findings (all seven had multiple associated fractures including metaphyseal).[79]

A study described a four-month-old infant with leg pain and swelling had spinal fractures, comminuted fracture of distal left femoral metaphysis and a right ischial tuberosity fracture. These were not evident on the initial plain films but were seen on magnetic resonance imaging (MRI) and on the two-week follow-up skeletal survey.[76]

1.8 Fractures of the hands and feet

Seven studies described abusive fractures to hands and feet.[16,34,82-86] One comparative study found no significant difference in the rate of fractures to the hands and feet between abused and control children less than four years of age.[16]

Two cross-sectional studies showed that fractures to the hands and feet were present in 1.4% of all children less than ten years of age being evaluated for child abuse,[84] and in 5-5.5% of children less than two years old undergoing skeletal survey.[34,84] Abusive fractures to hands and feet were recorded in infants and toddlers; 47/56 children with abusive fractures to the hands and feet were aged less than two years.[34,82] The mean age of the children with abusive fractures to the hands was 14.1 months (range 5.6-22.4 months). The mean age of children with abusive fractures to the feet was 10 months (range 1.3-13.6 months).[84] One study showed the mean age of abusive fractures to the hands or feet was five months (range 1-10 months).[34] The mean number of hand

fractures per child was two (range 1-4), the mean number of fractures to the feet was 1.5 (range 1-3). The most common fractures were metacarpal or metatarsal.[84]

Another study described 22 fractures of the hands and feet in 11 abused infants,[85] Torus fractures predominated and 7/11 infants had additional fractures of the ipsilateral extremity.

A study of 16 infants with abusive fractures to hands or feet, metatarsals were the most common site of injury and transverse or buckle type fractures were present in 75%.[34] All infants with hand or feet fractures had additional fractures. There were two case reports included which described a six-month-old with fractures of second to fifth metatarsals bilaterally, and associated fractures of radius and ulna[83] and a ten-year-old with multiple bilateral phalangeal fractures of different ages thought to be secondary to hyper-extension.[86]

1.9 Mandibular fractures

Two included studies describe mandibular fractures.[87,88] One study describes a mandibular fracture after a direct blow in a six-month-old.[87] A second study addressed abusive mandibular fractures occurred in all age groups[88] and found that in contrast to other abusive fractures, mandibular fractures were not associated with other injuries.[88]

1.10 Sternal fractures

One included study[89] of 12 children (age range: 1.5–15.5 years) with sternal fracture, two were abused.[89] Both abusive cases were less than three years of age, one had associated long bone fractures.

1.11 Clavicular fractures

Three included studies described clavicular fractures in children aged up to five years.[15,16,34] In children with fractures, clavicular fractures were more common in abused children than those who were accidentally injured ($p<0.001$) for children less than 18 months and for those 18–48 months.[16] For a child aged less than four years with a clavicular fracture the odds ratio (OR) for abuse is 4.4 (95% CI 1.9, 10.2, $p=0.001$).[16] Clavicular fractures were identified in 18% of abused children less than 18 months versus 5% of those accidentally injured.[15] For those aged 18-60 months, 14% of the abused children versus 12% of the accidentally injured children had clavicular fractures.[15] One study noted that 4/24 abused infants with clavicular fractures had bilateral clavicular fractures 10/ 24 infants had further occult fractures on skeletal survey.[34]

1.12 Vertebral fractures

Fifteen included studies contain findings on vertebral fractures.[34,90-103] We conducted a spinal Injuries systematic review since injury to the spine can consist of both spinal fractures and injury to the spinal cord. Specific details relating to the studies of vertebral fractures can be found in the Spinal Injuries section.

1.13 Key evidence statements

- Abusive fractures are more common in children less than 18 months of age than in those older than 18 months
- Abused children were more likely to have multiple fractures than non-abused children
- Rib fractures in the absence of major trauma, birth injury or underlying bone disease have a high predictive value for abuse
- Multiple rib fractures are more commonly abusive than non-abusive
- Abusive femoral fractures are more likely to arise in children who are not yet walking
- Mid-shaft fractures are the most common femoral fractures in abuse and non-abuse (analysed for all age groups)
- Supra condylar humeral fractures in children are associated with accidental injury whilst the most common abusive humeral fractures in children aged less than five years are spiral or oblique
- Humeral fractures in those aged less than 18 months have a stronger association with abuse than humeral fractures in older children
- Linear fractures are the most common abusive and non-abusive skull fractures
- Metaphyseal fractures are more commonly described in physical child abuse than in non-abuse
- Metaphyseal fractures have been frequently described in fatal abuse
- Most children with classic metaphyseal lesions (CML) have other associated injuries which are often multiple
- Pelvic, hand, feet and sternal fractures occur in physical abuse and appropriate radiology is required for their detection

1.14 Limitations of review findings

- Considerable heterogeneity between studies
- Small number of comparative studies, in particular relating to less common fractures such as sternum, mandible, scapular, feet and hands

- Inadequate analysis of data by child's developmental stage, and a relative lack of data relating to non-mobile infants
- Few studies gave details of the number and type of co-existent fractures in individual children, which would have been of value to clinicians
- A lack of radiological detail is given in some of the studies particularly relating to metaphyseal fractures
- No data relating to disabled children.

Findings of clinical question 2

What is the evidence for radiological dating of fractures in children?

Nine studies were included of children aged up to 17-years-old.[6,8,104-110] For the 2020 update two new papers were identified.[6,8] Both new additions to the evidence base on fracture dating in children look at CMLs. One study assessed subperiosteal new bone formation with distal tibial CMLs[8] and another reviewed the signs of acute and healing distal tibial CMLs.[6] There were no studies addressing fracture dating in disabled children or the influence of ethnicity or socio-economic group.

Two studies found no correlation between the age and gender of the child and fracture dating[104,106] and another two studies ascertained children who had been abused where the authors felt they could identify the timing of the injury.[105,108] Halliday *et al.* concluded that if there is no subperiosteal new bone formation (SPNBF) on x-ray, then the fracture is likely to be less than 11 days old,[105] whilst Sanchez *et al.*, studying 16 infants, evaluated callus formation as an indicator of healing.[108]

Four studies defined different radiological criteria for fracture dating. The studies considered fractures of the immobilised forearm,[106] femoral region,[109] long bones[107] and clavicular fractures in the newborn.[109]

Three studies found hard callus and early remodelling is seen at eight weeks in most cases.[106,110] The peak period for a hard callus is at three weeks or greater and remodelling at five weeks or greater.[107] A study exploring the rate of radiological healing in newborn infants evaluated 131 infants with clavicular fractures aged 0-93 days and developed a timetable of healing according to standardised criteria.[109]

One recent study showed that in initial skeletal surveys, using only the AP radiograph, the prevalence of subperiosteal new bone formation with distal tibial CMLs is just 34%, but this figure rises to 71% with the addition of lateral and follow-up imaging.[8] The study states that it should be cautioned that even when skeletal surveys include initial AP, lateral and follow-up AP

radiographs of the tibia, nearly one third of distal tibial CMLs will fail to demonstrate subperiosteal new bone formation. The lack of subperiosteal new bone formation on a single point-in-time study should not be construed as evidence that a CML is acute.

Another study of 26 infants compared the appearances of tibial metaphyseal fractures on initial skeletal survey and follow up surveys performed 10-21 (mean 14.5) days later.[6] They record and describe stages of healing and conclude a thin bucket handle fracture is only seen acutely as none were present on the follow up films. They find rate of healing varies and 20% may heal completely in 2-3 weeks.

These new studies on radiographic signs of healing in distal tibial CMLs make an important initial contribution to the evidence in this area highlighting differences in dating of CMLs.

An early study by Cumming estimated the earliest calcification at the fracture site in 23 newborns, calcified periosteal reaction was noted as early as seven days.[104]

In one study levels of agreement between three radiologists regarding the timing of radiological features was only deemed 'moderate', apart from the recognition of periosteal reaction[105]. In another, levels of agreement between three radiologists were high amongst all radiographs, however the presence of a plaster cast limited interpretation for some images.[107]

Table 1. Summary of the dating characteristics identified

Radiologic feature	Cumming 1979[104] Peak (range)	Yeo 1994[110] Peak (range)	Islam 2000[106] Peak (range)	Halliday 2011[105]* Peak (range)	Prosser 2012[107] Peak (range)	Sanchez 2013[108]* Peak (range)	Walters 2014[109] Peak (range)	Fadell 2016[111] Peak (range)	Warner 2017[112] Peak (range)	Tsai 2019[8] Peak (range)	Karmazyn 2020[6] Peak (range)
Fracture gap widening	-	-	4-6 weeks 56% (2-8 weeks)	-	-	-	-	-	-	-	-
Periosteal reaction presence (Stage 1)	9-10 days (7-11 days)	1.6 weeks (1-3 weeks)	4-7 weeks 100% (2 weeks onwards)	(4-11 days)	15-35 days (5-96 days)	(1-3 weeks)	10 days (8-14 days)	Peak 1-11 days Peak 2 42 days (7 – 49)	Peak 9-49 Range 7-130		-
Marginal sclerosis	-	-	4-6 weeks 85% (2-11 weeks)	-	-		-	-	-		-
1st callus	-	-	4-7 weeks 100% (2 weeks onwards)	(4-11 days)	22-35 days (12-66 days)	(3-5 weeks)	Started at 10 days, peaked at 15 days	Peak 1 =11 Peak 2=61 Range 11-61	Peak 9-36 Range 9-130		-

Radiologic feature	Cumming 1979[104] Peak (range)	Yeo 1994[110] Peak (range)	Islam 2000[106] Peak (range)	Halliday 2011[105]* Peak (range)	Prosser 2012[107] Peak (range)	Sanchez 2013[108]* Peak (range)	Walters 2014[109] Peak (range)	Fadell 2016[111] Peak (range)	Warner 2017[112] Peak (range)	Tsai 2019[8] Peak (range)	Karmazyn 2020[6] Peak (range)
Callus density >cortex**	-	-	13 weeks 90% (4 weeks onwards)	**Did not assess, however = density noted (16-34 days)	≥ 22 days (19-96 days)	-	-	-	-	-	-
Bridging (Stage 2)	-	2.6 weeks (1.5-3.7 weeks)	13 weeks 50% (3 weeks onwards)	Earliest seen at 13 days, present on all films >20 days	≥ 36 days (19-300 days)	(7-9 weeks)	-	Peak 1 = 22 Peak 2 =63 Range=22-63	Peak 15-67 Range 15-130	-	-
Periosteal incorporation	-		14 weeks (7 weeks onwards)	-	-	-	-	-	-	-	-
Remodelling (Stage 3)	-	8 weeks (5-11 weeks)	9 weeks (4 weeks onwards)	-	≥ 36 days (45-421 days)	-	-	Peak 1=49 Peak 2 = 59 Range 35-151	Peak 51-247 Range 51-247	-	-
Subperiosteal new bone formation	-	-	-	-	-	-	-	-	-	Average time between initial and follow= 15.4 days Increase from 34% to 71% with follow-up AP plus initial lateral radiographs p<0.001	Five on follow-up that were new compared with the initial study

Radiologic feature	Cumming 1979[104] Peak (range)	Yeo 1994[110] Peak (range)	Islam 2000[106] Peak (range)	Halliday 2011[105]* Peak (range)	Prosser 2012[107] Peak (range)	Sanchez 2013[108]* Peak (range)	Walters 2014[109] Peak (range)	Fadell 2016[111] Peak (range)	Warner 2017[112] Peak (range)	Tsai 2019[8] Peak (range)	Karmazyn 2020[6] Peak (range)
Signs of acute vs healing fracture	-	-	-	-	-	-	-	-	-	Thin bucket handle (<1mm) sign = acute phase of injury, then thick bucket handle (1.7+/-0.5mm) followed by endochondral bone filling (1.9+/-0.6mm). Normalization of the metaphysis at 2-week follow-up was seen in one-fifth of cases.	-

- Data not reported/assessed * drawn from a population of children who were abused, with assumed date of injury. With thanks to Dr Kath Halliday for providing original data from her study[105]

2.1 Key evidence statements

- The dating of fractures is an inexact science, the radiological features of bone healing represent a continuum, with considerable overlap in timescale
- The accuracy of radiological estimates of the time of injury are in terms of weeks rather than days

2.2 Research implications

- Future studies could include fractures that are not routinely immobilised
- Future research should use previously defined features of radiological dating to enable comparisons between study populations
- Further studies establishing a timetable for healing for fractures in children less than three years of age would be of value.

2.3 Limitations of review findings

- Comparison between studies was hampered as:
    - Different bones were studied
    - There were variable time intervals between radiographs
    - Differing numbers of radiographs per fracture
- In many studies, fractures were immobilised with plaster, this may limit visualisation of features
- Although one study has included children whose fractures were not immobilised, these children had been abused and thus the precise time of the injury may be questionable
- A study has now been conducted determining the rate of healing for infant fractures this was necessarily based on clavicular fractures which may not heal at the same rate as long bones etc.
- No metaphyseal fractures were included in these studies and data cannot therefore be generalised to the healing of CMLs.

Findings of clinical question 3 What radiological investigations should be performed to identify fractures in suspected child abuse?

3.1 Skeletal surveys

Detection

Twelve studies including children aged up to 10 years were included.[1,4,5,10,113-120] In this update we identified three papers adding to this question.[4,5,10] One study reviewed the yield of additional fractures identified with a skeletal survey in young children with a femur fracture.[10] Another study assessed ultrasound findings in CML's[5] and a further study looked at avoiding skull radiographs in children with suspected inflicted injury who also underwent a head CT scan.[4]

Table 2: Details of included studies that evaluated follow up skeletal survey

Author, year, study design # children undergoing repeat imaging/total children	Imaging performed Time interval	Results of follow up SS	Comment
Harper *et al.*, 2013[116] **Cross sectional** **796/1038 (76.7%)**	20 centres included full SS according to AAP guidance 2009. At follow-up all centres excluded skull, 6 centres excluded spine, five excluded pelvis films Not available	124/796 (15.6%) had a new fracture, fractures included rib, long bone, CML, hands or feet, clavicle, vertebra and scapula. 18/252 (7.1%) of children with a normal initial SS had fractures on follow-up. 6.5% of subjects had fractures of hands and feet on follow-up and 1.6% vertebral fractures. No new fractures of the pelvis were identified. Concerning features on the initial SS were confirmed as normal in 55 subjects	Prospective study across 20 centres. Indications for SS not given. 24% of subjects did not return for follow-up imaging
Singh *et al.*, 2012[118] **Retrospective cohort** **169/1470**	Full SS including oblique views initially, omitted skull and spine for follow up imaging Mean 19 +/- 11 days	24/169 (14%) had previously unrecognised healing fractures on follow up 6/24 (25%) of these subjects had a negative initial SS. In eight cases findings on follow up influenced abuse diagnosis	Retrospective review from 2002-2009, 88% <one year. Significant increase in number of follow up SS 2005-2009. Except for two fractures that were present, but missed, on the initial SS, all of the fractures identified on the follow-up SS were rib or metaphyseal fractures of the extremities. Only 11% of

			initial cohort underwent repeat imaging. Noted new, and newly recognised, metacarpal fractures on follow up, argues against the proposal to omit hands/feet on follow up
Bennett *et al.*, 2011[114] **Case series** **47/47**	Initial and repeat were full SS according to American College of Radiology (ACR) standards, 19 images. Oblique views of ribs not routinely obtained. 9-56 days	All had normal initial SS, 4 (8.5%) had abnormal follow up SS. 3 rib fractures, 1 proximal humerus	Unusual inclusion criteria of only those with a completely negative SS, yet still showed additional forensically relevant fractures. No detail as to why these children underwent repeat imaging

Author, year, study design # children undergoing repeat imaging/total children	Imaging performed Time interval	Results of follow up SS	Comment
Karmazyn *et al.*, 2011[1] **Cross sectional** **930 children 109/116 equivocal fractures re-imaged**	Full SS (31 views), including oblique views initially. Repeat imaging only for equivocal findings N/A	Nine hundred thirty children (515 boys and 415 girls) were included. Fractures were detected in 317 children (34%), 166 (18%) had multiple fractures. Common sites for fractures were the long bones (21%), ribs (10%), skull (7%), and clavicle (2%). Ten children (1%) had fractures in the spine (n = 3), pelvis (n = 1), hands (n = 6), and feet (n = 2). All 10 children had other signs of physical abuse 29/116 (25%) definite fractures confirmed in previously equivocal findings	Retrospective study children <two years, 2003-2009 124/930 had new fractures on follow up. Main aim to propose reduced imaging for initial SS, propose excluding spine, pelvis, hands and feet, unless superficial injury to this area, as they accounted for 1% of fractures found. Cases described would suggest that some of these fractures were significant findings however
Sonik *et al.*, 2010[119] **Case series** **22/22**	Full SS, no oblique views ribs initially. 11/22 follow up full SS, 11 no repeat skull imaging 11-29 days (mean 16.7)	New fractures identified in 3/22 patients (13.6%), one in whom initial SS was normal	Retrospective study children <two years undergoing repeat SS, 2003-2007. No details as to why these children underwent repeat imaging. Propose omitting AP pelvis and lateral spine. No oblique views, small numbers with no power calculation to support recommendation
Anilkumar *et al.*, 2006[113] **Case series** **59/200**	Initial SS (including oblique views if age <one year), follow up chest x-ray +/- oblique views 10 days – 3 weeks	3/59 (5.1%) had additional rib fractures noted on follow up 2/59 (3.4%) had rib fractures identified for the first time Dating information was obtained in 3/59 patients (5.1%)	Retrospective study of children <two years, 1998-2003, routinely invited for follow up from 1/1/2000 Only 59/200 cases returned for follow up
Zimmerman *et al.*, 2005[120] **Prospective cohort** **48/74**	Initial and repeat were full SS, 19 images Skull excluded from repeat survey Mean 21.4 +/-9.7 days	22/48 children had additional information, 11 of whom had additional fractures identified. Additional fractures included rib, classic metaphyseal, clavicular, scapular, fibular and ulnar. In one child abuse was excluded by follow-up imaging	Prospective review between 1998 and 2000. Indications included all infants with suspected physical abuse who had multiple fractures, fractures of varying ages, fractures inconsistent with history, concern for abuse not diagnosed initially, abnormal initial SS. Only 48/74 (65%) of those called for follow-up attended

Author, year, study design # children undergoing repeat imaging/total children	Imaging performed Time interval	Results of follow up SS	Comment
Kleinman *et al.*, 1996[117] **Retrospective cohort** **23/181**	Initial and repeat were full SS Skull excluded from repeat survey, no obliques in first survey 14 days	13 (40.6%) children had 32 additional fractures identified. One initial SS was negative. Additional fractures included classic metaphyseal lesions, rib, spinal, pelvic and hand. Contributed to the dating of the injury for 13 of 70 fractures. One repeat SS confirmed original findings as a normal variant	Retrospective review between 1990 and 1995, indications for repeat SS included high suspicion of abuse, original imaging inconsistent with history
Hansen *et al.*, 2014[115] **Cross sectional** **534/1963**	Full ACR skeletal survey at baseline and follow-up compared to limited view follow-up (excluding spine, pelvis, and skull) 10–42 days	The limited view follow-up would have missed eight spinal fractures in five children not visible on the original skeletal survey. All of these infants had additional fractures. Two infants had spinal fractures visible on chest view, two had further spinal abnormalities on initial skeletal survey and one had no other indications of spinal fracture. No pelvic fractures were identified on the follow-up SS that were not present on the initial SS. Those with pelvic fractures had a median of 7.5 other fractures.	This study suggests that omitting pelvic images from the follow-up SS does not miss further fractures. Authors suggest omitting spinal views on the follow-up carries a low risk of missing significant spinal fractures

Key findings

- Whilst the reason for undertaking follow up SS varied between studies, and the combination of films included in initial and follow up SS varied; additional findings to the initial SS were reported in all included studies (Table 2), this was true when the initial SS was normal or abnormal. Follow up SS identified new fractures and clarified equivocal findings and radiological findings in children who had normal initial SS
- Additional fractures identified on follow up SS included rib, long bone, CML, hands or feet, clavicle, fibular and ulnar fractures, vertebra and scapula, but not pelvic fractures.

Which radiology views should be included in SS

Twenty studies were included with children aged up to 16 years, most of the children were less than two years of age.[1,26,60,75,77,78,81,83-85,91,93,96,101,121-126]

Benefit of oblique views of the chest

Three studies showed significant benefit of oblique views of the chest,[121,122,125] including a comparison of two view chest X-ray (anteroposterior and lateral) with a four view assessment

including two additional oblique views of the ribs in 73 children.[122] In this study, sensitivity improved by 17% (95% CI 2-36%, p=0.18) and specificity improved by 7% (95% CI 2-13%, p=0.004).[122] The average improvement for diagnostic accuracy between three radiologists was 9% (CI 5-16%, p=0.005).[122] Three children had rib fractures that were only seen on oblique films.[122] The addition of oblique views increased detection rate by 19%[125] in a study evaluating the benefit of oblique views in addition to a standard ACR skeletal survey in infants who all had at least one rib fracture.[125] The four-view chest series, posteroanterior, lateral, right oblique, and left oblique radiographs, adds information to that obtained from the two-view chest series and increases the accuracy of diagnosing rib fractures in cases of possible physical abuse. The additional rib fractures noted or excluded using the four-views were predominantly posterior and lateral.[121]

3.2 Skeletal survey (SS) versus radionuclide imaging (RNI)

Eighteen studies of children aged up to 16 years were included.[21,32,60,75,85,126-137] Eight studies compared the diagnostic yield in 509 children who had both investigations.[126,127,130,131,133-136] In the included studies RNI was performed between 24 to 96 hours of the SS, however the number of images included in SS varied. No study included oblique views of the ribs and all studies, except for Pickett *et al.*,[135] confirmed that using either investigation in isolation would miss some fractures.

Nine studies highlight additional findings on RNI not identified on SS.[21,32,60,75,85,128,129,132,137] Five cases had RNI findings confirmed on repeat plain films,[32,85,137] one of which describes costo-vertebral fractures seen on RNI but not on SS.[32] RNI was more sensitive, overall, at identifying bony abnormalities than SS[126,127,130,131,136] whilst two studies stated that SS had the greatest sensitivity.[133,135] SS identifies metaphyseal fractures and skull fractures significantly better than RNI,[133] however RNI had an increased sensitivity in detecting soft tissue trauma as well as bone trauma.[127]

Studies mostly found that neither SS or RNI is as good as the two investigations combined.[126,127,130,131,133,136] RNI predominately missed skull, metaphyseal and epiphyseal fractures whereas SS missed rib fractures.[60,126,130,131,133,136]

3.3 Identifying less common abusive fractures

Five studies questioned the value of screening for rarer fractures.[1,26,79,84,123] Children with these rarer (e.g. pelvis, hands and feet, sternum) fractures were reported to have either clinical findings or multiple additional fractures elsewhere.[1] This study included 11 additional views to those carried out during standard SS, limiting its applicability. In 530 screened children, no pelvic, one spinal and nine fractures were identified to the feet, the radiation dose of pelvic imaging was highlighted and omitting the pelvis was recommended.[123]

Of 365 children 5.5% had fractures to the spine, hands and feet. Of the 25 spinal fractures identified in ten children (from Hangmans fracture at C2 to sacral fractures), all but one had associated non-spinal injuries. Of these children, 1.4% of SS had hand fractures and 1.6% fractured feet.[84] Spinal fractures were also reported in 14/751 children with skeletal surveys and or neuroimaging, 22 spinal fractures were observed. Four children had co-existent injuries, 4/14 were aged two to four years and seven had multiple spinal fractures.[26]

Benefits of lateral views in addition to standard frontal views of long bones

Significantly more metaphyseal fractures were seen on combined frontal and lateral views ($p<0.01$) but there was no significant difference for diaphyseal fractures.[124] The levels of agreement between radiologists was found to improve with the addition of lateral views, especially in metaphyseal fractures. The study recommended the inclusion of coned metaphyseal views of knees and ankles within skeletal survey.

Which children with suspected abuse should be investigated for occult fractures?

Eighteen studies were included.[1,17,77,82,126,138-150]

Influence of ethnicity and socio-economic group

Ethnicity and socio-economic group have been reported to influence whether a child undergoes skeletal survey. African/American infants with unwitnessed head injury were more likely to have a SS than white infants (90.5% v 69.3%, $p=0.01$),[149] however non-white or Hispanic children or those without private insurance were more likely to undergo screening.[144] White children with private insurance were much less likely to have a SS than white children with no insurance/government insurance (50% v 88%, $p<0.001$).[149,150] The introduction of a screening guideline reduced the inequities in SS conducted in white versus African/American children (rates of SS in white children increased from 69.3% to 84.6%, ($p=0.05$) but stayed the same amongst African/American children).[144,149]

Influence of age on fracture detection

The diagnostic yield from SS correlates inversely with age and is significantly greater for children less than two years of age.[17,77,126,138,139,141,147,151] The rate of occult fractures detected in children aged less than two years in two large-scale studies was 10% – 13%.[1,141,152]

A higher diagnostic rate for SS was identified in children less than six months of age than in those aged two years and six months,[141] whilst two studies showed no difference in the yield of occult findings on SS in those aged less than one year and those aged one – two years.[142,147] Significantly

more rib fractures[143] and classical metaphyseal lesions[143,147] were found in children aged less than one year than those aged one to two years. A retrospective case series of skeletal survey found 14/17 (82%) of positive SS were in children less than one year of age,[139] 14/55 (25%) of children aged less than one year had positive SS.[139]

Screening siblings/household contacts

Siblings were assessed in three studies.[139,146,148] There were six skeletal surveys performed on siblings (less than three years old) of children with abuse, SS was positive in one sibling.[139] Skeletal survey was conducted in 134 household contacts aged less than two years, 16/134 had fractures, nine of whom were aged less than six months;[148] eight children had an isolated fracture and eight multiple fractures, none of which had clinical signs.[148] Fractures were found in 9/16 twins on their SS giving an odds ratio of 20.1 (95% CI 5.8-69.9) for identifying a fracture in a twin of an abused child.[148] Of 75 twin/triplet siblings screened, twins were more likely to have an occult fracture identified than non-twins.[146]

Indications for SS

Skeletal survey identified that 14% of children with abusive burns had occult fractures.[142,151] The mean age of children with positive SS and burns was significantly older than non-burns cases ($p=0.03$),[151] the fractures in children with burns included rib, CML, long bone, skull, and clavicular.[142] Positive SS findings were also seen in 29% of infants aged less than one year with an unwitnessed head injury warranting child protection investigations.[149] If the injury severity score was more than 15, cases were more likely to have positive findings than those with lower scores (OR 3.4, $p<0.01$).[149]

Abusive head trauma (AHT) was significantly associated with a positive SS, compared to children who underwent SS for other reasons ($p<0.00$).[141] Three children presenting with an isolated skull fracture and no other signs of abuse had a positive SS.[141] Skeletal survey was carried out in 86% of children aged less than 18 months presenting with an isolated skull fracture, of whom 6% had an additional fracture identified. Only one of nine with additional fractures was older than six months, eight of nine had a simple skull fracture.[145]

Further fractures were found in 12/201 (5.5%) children presenting with skull fracture in 201 children aged less than one year with a normal Glasgow Coma Scale (GCS).[140] A lower incidence of additional fractures was found in 141 infants aged less than one year presenting with a skull fracture (non-MVC) who underwent SS with only two additional fractures identified, each had risk factors for child abuse.[150] Additional fractures were lower limb metaphyseal fractures.[150]

Children presenting with apparent life threatening event (ALTE)/apnoea/seizures had a significantly higher rate of positive SS than those presenting for other reasons ($p=0.05$).[141]

What other imaging modalities may enhance the diagnosis of occult fractures?

Seventeen studies with children aged up to eight years were included.[29,60,61,79,146,153-164]

Computerised Tomography (CT)

Older studies suggested that Computerised tomography scan (CT) will miss skull fractures.[153,161,162] however, use of 3D reconstruction is valuable in interpreting skull fractures.[159]

CT of the head with 3D reconstruction was compared to skull radiographs in children with suspected abusive head trauma.[165] In this group of 177 children, who were aged under one year, skeletal surveys were carried out including two views, anteroposterior and lateral. Sixty-two (35%) had skull fractures detected by radiography whilst CT with 3-D reconstruction identified 67 (38%) skull fractures and was 97% sensitive and 94% specific for skull fracture. There was no significant difference between findings from plain radiographs and 3-D CT scans (p= 0.18). In this study CT with 3-D reconstruction was shown to be equivalent to skull radiographs in identifying skull fractures.

Another study assessed 104 eligible skeletal surveys and head CT examination pairs. Twenty-one had skull fractures. Head CT has high sensitivity and specificity for diagnosis of skull fracture and found to be more reliable than skull x-ray in assessment of skull fractures in infants and young children. Diagnostic accuracy was improved by using 3D reconstructions.[4]

Computerised tomography of chest may show rib fractures missed on two view chest radiography[164] or on four view chest radiographs.[160]

Magnetic Resonance Imaging (MRI)

MRI may be valuable additional investigations for physeal or epiphyseal injures[61] and may identify trauma where plain films are equivocal.[155]

Whole body MRI (WB-MRI) was compared to initial and repeat skeletal survey combined. WB-MRI had a high specificity (95%) but low sensitivity (40%) for detecting fractures and was poor at identifying rib and metaphyseal fractures in particular.[79]

Ultrasound (U/S)

Studies assessing the use of ultrasound have found they can show metaphyseal fractures around the knee[29,61,158] and also highlight periosteal haematoma of the tibia which was later confirmed as a fracture, and also a femoral fracture.[163] Ultrasound can be helpful in identifying distal humeral epiphysiolysis,[156] in the diagnosis of costo-chondral dislocation of the lower ribs[29,48] and if performed on the chest can show acute rib fractures not apparent on plain film, including

oblique views.[157] Ultrasound also confirmed presence of fracture in 33/39 CMLs across the tibia, femur, radius and fibula.[5]

Other imaging modalities

- The use of (^{18}F-NaF) positron emission tomography (PET) was compared to initial SS in 22 children (follow-up in 14) less than two years of age. PET versus SS had a sensitivity of 85% versus 72% for detecting all fractures, 92% versus 68% for thoracic fractures, and 67% versus 80% for detecting classic metaphyseal lesions.[166]
- PET identified three spinal fractures in one child missed on SS and confirmed on MRI.[166]
- Bone scintigraphy (BS) was evaluated in the diagnosis of non-accidental injury and was found to be similar to SS in 74% of cases.[167] In 4% (7/166) of the patients BS demonstrated a new finding and had a false-positive and false-negative rates of 2% and 13%, respectively. The two false-positive cases were because of a presumed infection of a clavicle and increased bony uptake. Of the 21 false negative cases, 16 had skull vault fractures, and five had metaphyseal fractures, which could be seen on film but not seen on BS. Routine use of BS as an adjunct to SS in the investigation of non-accidental injury aids confidence in diagnosis or identifies new findings in 12% of cases.

3.4 Key evidence statements

- Radiological investigations of suspected physical abuse include initial and follow up skeletal surveys with specific views to maximise detection of occult injuries particularly in young children
- Studies suggest that up to 12% of contacts under two years of age, of children who have been abused with serious injuries, may have a positive skeletal survey, with twins being a particularly high risk.

3.5 Research implications

Further research is needed in the following areas:

- To evaluate the diagnostic yield in household contacts of children with suspected abuse
- To assess the role of radiological screening of disabled children with suspected abuse.

3.6 Limitations of review findings

Which investigation has a higher yield, skeletal survey (SS) or radionuclide imaging (RNI)?

- Nine studies were published pre-1990; few studies published since 1998
- No study included oblique views of the ribs in the SS
- Rationales for choosing both investigations were not stated.

Does repeat SS enhance detection?

- There is evidence to support follow up SS which is now standard practice[168]
- Oblique views of ribs not included in early studies.

What views should be included in a SS?

- Older studies did not operate to current American College of Radiology/Royal College of Radiologists – Royal College of Paediatrics and Child Health national guidelines
- Decisions to include additional views (e.g. coned views) appear to be clinically determined, thus limiting their generalisability.

Which children with suspected abuse should be investigated for occult fractures?

- All studies were retrospective
- The methodology of SS varied between studies and the indications for requesting a SS were ill-defined in some studies
- It was not possible to define the diagnostic yield of SS for two/three-year-olds.

What other imaging modalities may enhance detection of occult fractures?

- Highly selected case series.

Findings of clinical question 4
Does cardiopulmonary resuscitation cause rib fractures in children?

Thirteen studies were included with children aged up to 18 years, with no new studies added in this update.[25,31,169-179] Data was not analysed by gender, disability, ethnicity or socio-economic group.

4.1 Cardiopulmonary resuscitation-related fractures

Rib fractures are a rare complication of cardiopulmonary resuscitation (CPR) in children, with the reported incidence of between 0-4.3% in 11 studies,[31,169-173,175-179] six of which showed no rib fractures.[31,170,173,175,177,178] One study of 80 children recorded an incidence of 18.7%.[172]

The fractures associated with CPR, where reported, were all multiple, anterior/anterolateral, unilateral or bilateral and there were no posterior rib fractures reported due to CPR. Two infants had rib fractures ascribed to CPR, one anterior and one postero-lateral following bimanual chest compression.[25] A rise in incidence of CPR related fractures was been noted and hypothesised that this was associated with the introduction of two-thumb rather than two-finger resuscitation.[176,180,181]

Details

Rib fractures were sought at post-mortem in ten studies. No authors referred to the use of specimen radiography.[169-174,176-179] Nine studies explored the prevalence of rib fractures following CPR.[31,169-173,175,177,178]

CPR related fractures have been reported. Three children, a two-month-old; a three-month-old who died of sudden infant death syndrome; a five-year-old who drowned, all were resuscitated by trained personnel and sustained fractures. One child, the three-month-old, was also resuscitated by untrained personnel for a total of 75 minutes. There was no concern about child abuse in any of these cases.[169,171] A further assessment of post-resuscitative clinical features found that 15/80 children aged 0-18 years sustained CPR induced rib fractures on early chest x-ray, in these cases abuse had been excluded, although admission was trauma-related.[172] A further included study found 24/546 SUDI cases sustained rib fractures, 15 were healing fractures, ten of which had features of abusive injury.[179] Of nine acute fractures, seven had no features of abusive injury and were thought to be CPR related. The fractures were multiple, anterolateral, and involved 3rd – 6th ribs; bilateral in one case.[179] Almost all (14/15) healing rib fractures were visible on post-mortem skeletal survey (SS), one case had only anantemortem chest radiographs.[179] Only 2/9 acute rib fractures were visible on post-mortem SS, found only by inspection of ribs following stripping of the pleura.[179]

In contrast, a larger study, of 382 children undergoing CPR, found no cases developed rib fractures, they all had a post-mortem examination including rib palpation and stripping of the parietal pleura.[173] Resuscitation of 153 children for 1 – 540 minutes resulted in no cases sustaining rib fractures.[177]

The location of fractures was described in a case series of five children sustaining rib fractures post-CPR noted that all children had by-stander CPR using one-handed and two-handed techniques, fractures found were anterolateral, 3rd–6th ribs, 2/5 bilateral.[174] A further 9/571 infants aged 0-6 months that exhibited rib fractures attributed to CPR lasting 21-260 minutes, fractures were all anterior to lateral. Almost three times as many fractures occurred between 2006-2008 versus 1997-2005.[176,180,181] It is hypothesised that these findings might correlate with the change in CPR technique as recommended by the International Liaison Committee on Resuscitation

(ILCOR), however no attempt was made to determine what method of CPR had been conducted.[176,180,181]

4.2 Research implications

- With the change in International Liaison Committee on Resuscitation (ILCOR) guidelines for resuscitation of infants recommending a two-thumb technique, further studies will be required to determine the incidence of rib fractures with this technique, using more sensitive radiological and autopsy techniques post-CPR, e.g. four view chest films/radionuclide imaging/specimen radiography.

4.3 Limitations of review findings

- The included studies were retrospective and included a wide age range of children, however the more recent studies have included infants less than one year old. The methodology of determining rib fractures was suboptimal in some studies where either early radiology or post-mortem without reflection of the pleura has been undertaken. The inclusion of trauma patients is problematic in determining the aetiology of the rib fractures.

Other useful resources

The review identified several interesting findings that were outside of the inclusion criteria, these are as follows:

Clinical question 1: Which fractures are indicative of abuse?

Rib fractures

- Post-mortem studies should include reflection of the pleura to ensure that all fractures are accurately identified.[182]

Imaging strategies

- Posterior rib fractures may not be seen on a skeletal survey but have been identified at post-mortem.[182]

Physiotherapy

- Rib fractures have been described as a consequence of chest physiotherapy for bronchiolitis in France.[183] The method of physiotherapy was not described and all children received this therapy unsupervised in their own homes.[183]
- However, a study of 647 children undergoing chest physiotherapy resulted in no rib fractures.[184]

Femoral fractures

- There has been a decrease in the incidence of femoral shaft fractures in children, reduction of 42% between 1987–2005.[185]
- The most common cause of femoral shaft fracture in children less than four years of age is a fall of less than one metre.[185]
- A fracture classification system to distinguish transverse, oblique or spiral fractures was developed and validated. There was moderate inter-observer reliability.[186]

Skull fractures

- Biparietal skull fractures might result from a single blow to the occiput, as described following accidental injury.[187]
- An influential study of severely abused children stated that depressed, diastatic, growing, and multiple fractures were more common in abuse than in non-abuse. The study included a considerable number of fatally abused children, and excluded unintentional fractures from motor vehicle injury and was not eligible for inclusion in this systematic review.[188]

Tibial fracture

- Undisplaced spiral fracture of the tibia without a concomitant fibular fracture is most likely to be an unintentional toddler fracture particularly if the child is a boy less than 2.5 years of age.[189]

Humeral fracture

- A case series of seven infants aged four to seven months with isolated humeral fractures where the explanation was when the infant rolled over. Skeletal surveys were negative, all cases arose as a consequence of court proceedings.[190]
- Radiological identification of distal humeral epiphyseal separation is aided by the use of ultrasound in young infants.[191]

Metaphyseal fractures

- A 1984 study reported that passive exercise physiotherapy administered, particularly to preterm infants, had caused metaphyseal fractures.[192]
- Metaphyseal fractures have been recorded in serial casting of clubfoot.[193]
- Birth trauma can cause metaphyseal fractures in breech delivery.[194]
- External cephalic version for breech presentation may result in CML.[195]
- CML occurring following birth was associated with pain expressed as irritability, lack of spontaneous movement of the affected leg and poor feeding in an infant.[195]
- A study of high resolution CT defines the precise fracture plane that occurs in metaphyseal fractures, contributing to an understanding of the biomechanics of these fractures.[196]

Post-mortem

- Post-mortem CT has a low sensitivity for rib fractures in comparison to autopsy.[197]
- Proposed autopsy techniques to maximise identification of fractures are described.[198]
- It is proposed that cone-beam CT performed during post-mortem may aid in the dating of fractures.[199]
- Vertebral clefts may be visible through the vertebral body and be confused with fractures. A post-mortem study discusses ten affected foetuses.[200]

Important clinical differentials

- Sternum ossification centres that projected over ribs on a chest film have been mistaken for fractures. Follow up imaging revealed real cause.[201]
- Diffuse cortical thickening on the medial aspect of the tibia, mimicking periosteal reaction may result from intraosseous needle insertion, but has been mistaken for abuse.[202]
- An overview of clinical variants that are important when reviewing skeletal surveys.[203]
- Heterotopic ossification from the ischium and sacrum to proximal femur posteriorly secondary to physical abuse.[204]
- Metaphyseal fragmentation may be noted in infants, simulating metaphyseal fractures.[205]
- It is important to distinguish suture variants within the occiput from fractures.[206]
- An unossified membranous strip within the parietal bone may be mistaken for skull fracture in infants.[207]
- Widespread medullary necrosis and periosteal reaction, with epiphyseal sparing, described as a complication of traumatic pancreatitis.[208]
- Useful information is described about the histopathology of vitamin D deficiency compared to NAI fractures.[209]

Biomechanics

- Descriptions of fractures determined by type and rates of stress and strain applied to a bone.[189,210-213]
- Reviews of biomechanics highlight numerous variables relating to childhood fractures.[189,210-213]
- Studies of falls down stairs highlighted that the peak age are children aged one year, sustaining predominantly minor injuries with 4/18 sustaining skull fracture and 10% with limb fractures.[214]

Consequences of abusive fractures

- Compartment syndrome may occur in the lower limbs as a consequence of abusive fractures.[215]

Presenting features

- 21% of children with abusive fractures were missed at initial presentation.[216]
- Boys with abusive extremity fractures attending non-pediatric emergency department or primary care were most commonly missed.[216]
- Delay (more than eight hours) in presentation with an extremity fracture was evaluated in 206 children.[217] Although the median time to presentation was one hour, 21% presented after eight hours, 15% showed no external sign of injury and 12% used the injured extremity normally. However, all children had at least one sign or symptom.[217]
- A study of the fracture pattern at diagnosis of 68 children with Osteogenesis Imperfecta (OI) showed that although rib fractures were identified in 21%, none of these occurred in infancy. All subjects with more than two fractures were diagnosed prenatally or in the immediate newborn period. 17 (25%) infants were diagnosed after one week of age but before 12 months of age. None of these infants had either rib fractures or more than one fracture at the time of diagnosis.[218]

Birth related fractures

- A study of birth related fractures, including metaphyseal, confirms that these fractures are painful and may be associated with tenderness and swelling.[219]
- Multiple rib fractures described in macrosomic infant with shoulder dystocia.[220,221]
- Posterior rib fractures described as birth injuries, some macrosomic[222,223] including those with shoulder dystocia.[220,221]
- Classic metaphyseal lesions of the femur have been noted after caesarian section. Two cases were breech presentation.[224]

- Femoral fractures are a rare birth injury (incidence 0.13/1000) as recorded in Ireland between 1996–1999. The typical fracture occurring was a spiral fracture of the proximal half of the femur which was held in an extended position. There were 5/7 affected infants that were delivered by caesarean section. In 6/7 cases, no evidence of femoral injury was noted on immediate post-natal examination.[225]
- Birth injury can cause depressed skull fractures.[226]
- Rib fractures have been identified in approximately 2% of ex pre-term infants (less than 37 weeks gestation).[227]

Age and likelihood of abuse

- Fracture requiring orthopaedic management was present in 28% of 11,554 inpatients with a diagnosis of child abuse. The relative risk for child abuse in children aged less than one year was 11.46; 3.07 for those aged one to two years.[228]
- The proportion of fractures rated as abusive in children aged less than three years attending a single centre fell by up to 50% over 24 years.[229]

Growth recovery lines

- Zapala *et al.* compared the likelihood of encountering growth recovery lines on skeletal surveys in 52 infants at low and 21 at high risk of abuse and suggested that abused infants are prone to a temporary disturbance in endochondral ossification as a result of episodic physiological stresses.[230]
- Prevalence of growth recovery lines was significantly different between groups, the low-risk group was 38% versus 71% in the high-risk group ($p<0.001$).[230]

Clinical question 2: What is the evidence for radiological dating of fractures in children?

- Repeat skeletal survey may aid in fracture dating.[117]
- Bone scans have no place in fracture dating as they become positive within seven hours and can remain positive for up to one year.[231]
- Study of animal models for dating rib fractures.[232]
- A small study of cone-beam CT on post-mortem specimens suggested that this may be an accurate estimate of the age of the fracture.[199]
- A study comparing whole body magnetic resonance imaging (WB-MRI) with skeletal survey noted that WB-MRI provided little information regarding fracture age.[233]

  Study of radiological features of healing accidental fractures – with very clear time frame (because all sustained at birth).[111]

Clinical question 3: What radiological investigations should be performed to identify fractures in suspected child abuse?

Practice guidelines

- American and British guidelines for practice have specific guidance on SS views to be taken.[168,234-236]
- What imaging is required[168]:
    - Imaging should always include a skeletal survey in children under two years old and skeletal survey and computed tomography head scan in children under one year old.
    - Skeletal surveys may occasional be indicated in older children; this should be considered on a case-by-case basis.
- Oblique views of the ribs are recommended when rib fractures are evident, and consideration should be given to including oblique views in the standard survey protocol.[234]
- Follow-up Skeletal Survey (SS) is recommended when there are abnormal or equivocal findings on the initial SS, or when abuse is suspected clinically.[234]
- Studies addressing concerns about radiation dosage.[237,238]
- Audit of UK SS three years after the British Society of Paediatric Radiology published their standards: revealed that only 15% included all appropriate views and technical quality has considerably improved (score 9.7/11).[239]
- Forty studies in the US were assessed for the performance of SS or Radionuclide Imaging of children with suspected physical abuse aged less than two years or infants less than on year with non-vehicle associated head injury or femoral fractures:[240]
    - 83% of children less than two years old underwent appropriate screening, 68% of those aged less than one with a head injury and 77% of those less than one with a femoral fracture. Influential variables for appropriate screening were injury severity and year of admission.[240]
- A helpful study in guiding day to day use of skeletal survey using various theoretical clinical scenarios.[241]
- Information on the radiation dose delivered by skeletal survey which is a common concern for parents/carers. The information is valuable to clinicians counselling families about skeletal survey.[242]
- Study relates to follow up skeletal survey recommendations and completion rates. Significant factors for new injury identification are stated. New fractures identified in 16%. Possibly warrants further evaluation/research to develop objective guidelines for recommendations for follow up SS.[243]

- Important conclusions relating to sentinel injuries and their investigation are presented.[244]
- 3D reconstructions of head CT are useful at evaluating possible skull fractures.[245]

Alternative imaging techniques

- Ultrasound (US) has been shown to be useful in detecting occult rib fractures in adults. These studies show an increased sensitivity of US over standard radiography, particularly in the cartilaginous portion of the rib.[246,247]
- Evaluation of separation of the distal humerus epiphysis is well defined by US, particularly in neonates where ossification is minimal.[248]
- The use of 18F-NaF positron emission tomography (PET) whole-body imaging has been shown to demonstrate additional subtle fractures including classic metaphyseal lesion of the humerus and iliac crest fractures not seen on initial SS.[166]
- Multi-planar computerised tomography scan (CT) and 3D image reconstructions may enhance the visualisation of rib fractures.[249] However, even these imaging modalities may miss rib fractures as detailed in post-mortem studies.[250,251]
- Post-mortem CT may be of value in detecting incomplete buckle rib fractures.[252]
- A study of 605 CT images of children aged 0-3 years highlighted that 53% had Wormian bones, the majority of which were multiple.[253]
- CT scan of chest has been shown to be more sensitive than the initial SS in demonstrating acute rib fractures.[254]

Other potential indications for imaging

- Multiple birth infants appear to be at higher risk of fractures or abdominal injuries than other siblings.[255]
- An exploration of 320 children less than two years of age presenting with a single extremity fracture, 37% of whom underwent neuroimaging, identified only five children (aged less than one year) with traumatic findings but none had clinically significant head injury.[256]
- In 146 infants less than six months of age presenting to child abuse physicians with an isolated bruise, 23.3% had occult fractures identified on skeletal survey.[257]

Clinical question 4: Does cardiopulmonary resuscitation cause rib fractures in children?

- Histological dating of fractures may be crucial to distinguish abusive from cardiopulmonary resuscitation (CPR) related fractures.[31,258,259]
- Posterior rib fractures in a child who has been resuscitated on a firm surface would appear inconsistent with the biomechanics of resuscitation.[260]

- One case study proposed that a 21-month-old with fatal head injuries sustained a posterior rib fracture as a consequence of CPR performed by trained personnel:[261]
    - However, this 21-month child had a co-existent unexplained pelvic fracture and absence of rib fracture prior to CPR was only determined by an abdominal computerised tomography scan.[261]
    - The paper itself contains much debate as to whether the case was abused or not and the reader cannot confidently conclude that this was a confirmed case of abuse.[261]
- CPR technique utilising a mannikin demonstrates that the majority of practitioners are likely to over-compress in the absence of real time feedback.[262]

References

1. Karmazyn B., Lewis M.E., Jennings S.G., *et al.* The prevalence of uncommon fractures on skeletal surveys performed to evaluate for suspected abuse in 930 children: should practice guidelines change? *AJR Am J Roentgenol* 2011; 197(1): W159-163. http://www.ncbi.nlm.nih.gov/pubmed/21700979.

2. Kogutt M.S., Swischuk L.E., Fagan C.J. Patterns of injury and significance of uncommon fractures in the battered child syndrome. *Am J Roentgenol Radium Ther Nucl Med* 1974; 121(1): 143-149. http://www.ncbi.nlm.nih.gov/pubmed/4833902.

3. Loder R.T., Bookout C. Fracture Patterns in Battered Children. *Journal of Orthopaedic Trauma* 1991; 5(4):428-433. http://journals.lww.com/jorthotrauma/Fulltext/1991/12000/Fracture_Patterns_in_Battered_Children_.7.aspx.

4. Martin A., Paddock M., Johns C.S., *et al.* Avoiding skull radiographs in infants with suspected inflicted injury who also undergo head CT: "a no-brainer?". *European Radiology*. https://link.springer.com/content/pdf/10.1007/s00330-019-06579-w.pdf.

5. Marine M.B., Hibbard R.A., Jennings S.G., *et al.* Ultrasound findings in classic metaphyseal lesions: emphasis on the metaphyseal bone collar and zone of provisional calcification. *Pediatric Radiology* 2019; 49(7): 913-921. https://link.springer.com/article/10.1007%2Fs00247-019-04373-w.

6. Karmazyn B., Marine M.B., Wanner M.R., *et al.* Establishing signs for acute and healing phases of distal tibial classic metaphyseal lesions. *Pediatric Radiology*. https://link.springer.com/article/10.1007%2Fs00247-020-04615-2.

7. Adamsbaum C., De Boissieu P., Teglas J.P., *et al.* Classic Metaphyseal Lesions among Victims of Abuse. *Journal of Pediatrics* 2019; 209: 154-+. https://www.jpeds.com/article/S0022-3476(19)30236-7/fulltext.

8. Tsai A., Connolly S.A., Ecklund K., *et al.* Subperiosteal new bone formation with the distal tibial classic metaphyseal lesion: prevalence on radiographic skeletal surveys. *Pediatr Radiol* 2019. https://link.springer.com/article/10.1007%2Fs00247-018-4329-z.

9. Tsai A., Johnston P.R., Perez-Rossello J.M., *et al.* The distal tibial classic metaphyseal lesion: medial versus lateral cortical injury. *Pediatric Radiology* 2018; 48(7): 973-978. https://link.springer.com/article/10.1007%2Fs00247-018-4103-2.

10. Cornell E.M., Powell E.C. Skeletal Survey Yield in Young Children with Femur Fractures. *Journal of Emergency Medicine* 2018; 55(6): 758-763. https://www.jem-journal.com/article/S0736-4679(18)30960-0/fulltext.

11. Hoskote A.U., Martin K., Hormbrey P., *et al.* Fractures in infants: one in four is non-accidental. *Child Abuse Review* 2003; 12(6): 384-391. http://onlinelibrary.wiley.com/doi/10.1002/car.806/abstract.

12. McClelland C.Q., Heiple K.G. Fractures in the first year of life. A diagnostic dilemma. *Am J Dis Child* 1982; 136(1): 26-29. http://www.ncbi.nlm.nih.gov/pubmed/7055105.

13. Rosenberg N., Bottenfield G. Fractures in infants: A sign of child abuse. *Annals of Emergency Medicine* 1982; 11(4): 178-180. http://www.sciencedirect.com/science/article/pii/S0196064482804939.

14. Skellern C.Y., Wood D.O., Murphy A., *et al.* Non-accidental fractures in infants: risk of further abuse. *J Paediatr Child Health* 2000; 36(6): 590-592. http://onlinelibrary.wiley.com/doi/10.1046/j.1440-1754.2000.00592.x/abstract.

15. Worlock P., Stower M., Barbor P. Patterns of fractures in accidental and non-accidental injury in children: a comparative study. *British Medical Journal (Clinical research ed.)* 1986; 293(6539): 100-102. http://www.bmj.com/content/bmj/293/6539/100.full.pdf.

16. Pandya N.K., Baldwin K., Wolfgruber H., *et al.* Child abuse and orthopaedic injury patterns: analysis at a level I pediatric trauma center. *J Pediatr Orthop* 2009; 29(6): 618-625. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-200909000-00017%2Froot%2Fv%2F2017-05-24T204004Z%2Fr%2Fapplication-pdf.

17. Leventhal J.M., Thomas S.A., Rosenfield N.S., *et al.* Fractures in young children. Distinguishing child abuse from unintentional injuries. *Am J Dis Child* 1993; 147(1): 87-92. http://www.ncbi.nlm.nih.gov/pubmed/8418609.

18. Kowal-Vern A., Paxton T.P., Ros S.P., *et al.* Fractures in the Under-3-Year-Old Age Cohort. *Clinical Pediatrics* 1992; 31(11): 653-659. http://journals.sagepub.com/doi/abs/10.1177/000992289203101103

19. Darling S.E., Done S.L., Friedman S.D., *et al.* Frequency of intrathoracic injuries in children younger than 3 years with rib fractures. *Pediatr Radiol* 2014; 44(10): 1230-1236. https://link.springer.com/article/10.1007%2Fs00247-014-2988-y.

20. Barsness K.A., Cha E.S., Bensard D.D., *et al.* The positive predictive value of rib fractures as an indicator of nonaccidental trauma in children. *J Trauma* 2003; 54(6): 1107-1110. http://www.ncbi.nlm.nih.gov/pubmed/12813330.

21. Cadzow S.P., Armstrong K.L. Rib fractures in infants: red alert! The clinical features, investigations and child protection outcomes. *J Paediatr Child Health* 2000; 36(4): 322-326. http://onlinelibrary.wiley.com/doi/10.1046/j.1440-1754.2000.00515.x/abstract.

22. Strouse P.J., Owings C.L. Fractures of the first rib in child abuse. *Radiology* 1995; 197(3): 763-765. http://pubs.rsna.org/doi/abs/10.1148/radiology.197.3.7480753.

23. Garcia V.F., Gotschall C.S., Eichelberger M.R., *et al.* Rib fractures in children: a marker of severe trauma. *J Trauma* 1990; 30(6): 695-700. http://www.ncbi.nlm.nih.gov/pubmed/2352299.

24. Schweich P., Fleisher G. Rib fractures in children. *Pediatr Emerg Care* 1985; 1(4): 187-189. http://www.ncbi.nlm.nih.gov/pubmed/3842163.

25. Cosway B., Mathura N., Mott A., *et al.* Occult Rib Fractures: Defining the Cause. *Child Abuse Review* 2015; 24(1): 6-15. http://onlinelibrary.wiley.com/doi/10.1002/car.2260/abstract.

26. Barber I., Perez-Rossello J.M., Wilson C.R., *et al.* Prevalence and relevance of pediatric spinal fractures in suspected child abuse. *Pediatr Radiol* 2013; 43(11): 1507-1515. https://link.springer.com/article/10.1007%2Fs00247-013-2726-x.

27. Gipson C.L., Tobias J.D. Flail chest in a neonate resulting from nonaccidental trauma. *South Med J* 2006; 99(5): 536-538. http://www.ncbi.nlm.nih.gov/pubmed/16711322.

28. Ng C.S., Hall C.M. Costochondral junction fractures and intra-abdominal trauma in non-accidental injury (child abuse). *Pediatr Radiol* 1998; 28(9): 671-676. https://link.springer.com/article/10.1007%2Fs002470050436.

29. Smeets A.J., Robben S.G.F., Meradji M. Sonographically detected costo-chondral dislocation in an abused child. *Pediatric Radiology* 1990; 20(7): 566-567. https://link.springer.com/article/10.1007%2FBF02011396.

30. Bulloch B., Schubert C.J., Brophy P.D., *et al.* Cause and Clinical Characteristics of Rib Fractures in Infants. *Pediatrics* 2000; 105(4): e48-e48. http://pediatrics.aappublications.org/content/pediatrics/105/4/e48.full.pdf.

31. Feldman K.W., Brewer D.K. Child abuse, cardiopulmonary resuscitation, and rib fractures. *Pediatrics* 1984; 73(3): 339-342. http://pediatrics.aappublications.org/content/73/3/339.long.

32. Smith F.W., Gilday D.L., Ash J.M., *et al.* Unsuspected costo-vertebral fractures demonstrated by bone scanning in the child abuse syndrome. *Pediatr Radiol* 1980; 10(2): 103-106. http://www.ncbi.nlm.nih.gov/pubmed/7454417.

33. Thomas P.S. Rib fractures in infancy. *Ann Radiol (Paris)* 1977; 20(1): 115-122. http://www.ncbi.nlm.nih.gov/pubmed/557946.

34. Barber I., Perez-Rossello J.M., Wilson C.R., *et al.* The yield of high-detail radiographic skeletal surveys in suspected infant abuse. *Pediatric Radiology* 2015; 45(1): 69-80. http://link.springer.com/article/10.1007%2Fs00247-014-3064-3

35. Anderson W.A. The significance of femoral fractures in children. *Annals of Emergency Medicine* 1982; 11(4): 174-177. http://www.sciencedirect.com/science/article/pii/S0196064482804927.

36. Baldwin K., Pandya N.K., Wolfgruber H., *et al.* Femur fractures in the pediatric population: abuse or accidental trauma? *Clin Orthop Relat Res* 2011; 469(3): 798-804. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3032851/pdf/11999_2010_Article_1339.pdf.

37. Coffey C., Haley K., Hayes J., *et al.* The risk of child abuse in infants and toddlers with lower extremity injuries. *Journal of Pediatric Surgery* 2005; 40(1): 120-123. http://www.sciencedirect.com/science/article/pii/S0022346804006062.

38. Gross R.H., Stranger M. Causative factors responsible for femoral fractures in infants and young children. *J Pediatr Orthop* 1983; 3(3): 341-343. http://www.ncbi.nlm.nih.gov/pubmed/6874931.

39. Hui C., Joughin E., Goldstein S., *et al.* Femoral fractures in children younger than three years: the role of nonaccidental injury. *J Pediatr Orthop* 2008; 28(3): 297-302. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-200804000-00004%2Froot%2Fv%2F2017-05-24T203952Z%2Fr%2Fapplication-pdf.

40. Schwend R.M., Werth C., Johnston A. Femur shaft fractures in toddlers and young children: rarely from child abuse. *J Pediatr Orthop* 2000; 20(4): 475-481. http://www.ncbi.nlm.nih.gov/pubmed/10912603.

41. Thomas S.A., Rosenfield N.S., Leventhal J.M., *et al.* Long-bone fractures in young children: distinguishing accidental injuries from child abuse. *Pediatrics* 1991; 88(3): 471-476. http://pediatrics.aappublications.org/content/88/3/471.long.

42. Wellington P., Bennet G.C. Fractures of the femur in childhood. *Injury* 1987; 18(2): 103-104. http://www.sciencedirect.com/science/article/pii/0020138387901835.

43. Blakemore L.C., Loder R.T., Hensinger R.N. Role of intentional abuse in children 1 to 5 years old with isolated femoral shaft fractures. *J Pediatr Orthop* 1996; 16(5): 585-588. http://www.ncbi.nlm.nih.gov/pubmed/8865041.

44. Beals R.K., Tufts E. Fractured femur in infancy: the role of child abuse. *J Pediatr Orthop* 1983; 3(5): 583-586. http://www.ncbi.nlm.nih.gov/pubmed/6655054.

45. Dalton H.J., Slovis T., Heifer R.E., *et al.* Undiagnosed abuse in children younger than 3 years with femoral fracture. *American Journal of Diseases of Children* 1990; 144(8): 875-878. http://jamanetwork.com/journals/jamapediatrics/article-abstract/515271.

46. Loder R.T., Feinberg J.R. Orthopaedic injuries in children with nonaccidental trauma: demographics and incidence from the 2000 kids' inpatient database. *J Pediatr Orthop* 2007; 27(4): 421-426. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-200706000-00012%2Froot%2Fv%2F2017-05-24T203945Z%2Fr%2Fapplication-pdf.

47. Scherl S.A., Miller L., Lively N., *et al.* Accidental and nonaccidental femur fractures in children. *Clin Orthop Relat Res* 2000; (376): 96-105. http://www.ncbi.nlm.nih.gov/pubmed/10906863.

48. Murphy R., Kelly D.M., Moisan A., *et al.* Transverse fractures of the femoral shaft are a better predictor of nonaccidental trauma in young children than spiral fractures are. *Journal of Bone & Joint Surgery, American Volume* 2015; 97(2): 106-111. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjbjs%2Fbeta%2F00004623-201501210-00003%2Froot%2Fv%2F2017-06-02T153049Z%2Fr%2Fapplication-pdf.

49. Ogden J.A., Lee K.E., Rudicel S.A., *et al.* Proximal femoral epiphysiolysis in the neonate. *J Pediatr Orthop* 1984; 4(3): 285-292. http://www.ncbi.nlm.nih.gov/pubmed/6736231.

50. Rex C., Kay P.R. Features of femoral fractures in nonaccidental injury. *J Pediatr Orthop* 2000; 20(3): 411-413. http://www.ncbi.nlm.nih.gov/pubmed/10823616.

51. Forlin E., Guille J.T., Kumar S.J., *et al.* Transepiphyseal fractures of the neck of the femur in very young children. *J Pediatr Orthop* 1992; 12(2): 164-168. http://www.ncbi.nlm.nih.gov/pubmed/1552017.

52. Jones J.C., Feldman K.W., Bruckner J.D. Child abuse in infants with proximal physeal injuries of the femur. *Pediatr Emerg Care* 2004; 20(3): 157-161. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-200403000-00002%2Froot%2Fv%2F2017-05-30T205351Z%2Fr%2Fapplication-pdf.

53. Haney S.B., Boos S.C., Kutz T.J., *et al.* Transverse fracture of the distal femoral metadiaphysis: a plausible accidental mechanism. *Pediatr Emerg Care* 2009; 25(12): 841-844. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-200912000-00008%2Froot%2Fv%2F2017-05-30T205529Z%2Fr%2Fapplication-pdf.

54. Arkader A., Friedman J.E., Warner W.C., Jr., *et al.* Complete distal femoral metaphyseal fractures: a harbinger of child abuse before walking age. *J Pediatr Orthop* 2007; 27(7): 751-753. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-200710000-00007%2Froot%2Fv%2F2017-05-24T203948Z%2Fr%2Fapplication-pdf.

55. Pandya N.K., Baldwin K.D., Wolfgruber H., *et al.* Humerus fractures in the pediatric population: an algorithm to identify abuse. *J Pediatr Orthop B* 2010; 19(6): 535-541. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpob%2Fbeta%2F01202412-201011000-00012%2Froot%2Fv%2F2017-05-24T203609Z%2Fr%2Fapplication-pdf.

56. Shaw B.A., Murphy K.M., Shaw A., *et al.* Humerus Shaft Fractures in Young Children: Accident or Abuse? *Journal of Pediatric Orthopaedics* 1997; 17(3): 293-297. http://journals.lww.com/pedorthopaedics/Fulltext/1997/05000/Humerus_Shaft_Fractures_in_Young_Children_.5.aspx.

57. Strait R.T., Siegel R.M., Shapiro R.A. Humeral fractures without obvious etiologies in children less than 3 years of age: when is it abuse? *Pediatrics* 1995; 96(4 Pt 1): 667-671. http://pediatrics.aappublications.org/content/96/4/667.long.

58. Farnsworth C.L., Silva P.D., Mubarak S.J. Etiology of supracondylar humerus fractures. *J Pediatr Orthop* 1998; 18(1): 38-42. http://www.ncbi.nlm.nih.gov/pubmed/9449099.

59. DeLee J.C., Wilkins K.E., Rogers L.F.*, et al.* Fracture-separation of the distal humeral epiphysis. *J Bone Joint Surg Am* 1980; 62(1): 46-51. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjcat%2Fbeta%2F00004728-200505000-00012%2Froot%2Fv%2F2017-05-23T195232Z%2Fr%2Fapplication-pdf.

60. Merten D.F., Kirks D.R., Ruderman R.J. Occult humeral epiphyseal fracture in battered infants. *Pediatr Radiol* 1981; 10(3): 151-154. http://www.ncbi.nlm.nih.gov/pubmed/7220130.

61. Nimkin K., Kleinman P.K., Teeger S.*, et al.* Distal humeral physeal injuries in child abuse: MR imaging and ultrasonography findings. *Pediatr Radiol* 1995; 25(7): 562-565. http://www.ncbi.nlm.nih.gov/pubmed/8545192.

62. Meservy C.J., Towbin R., McLaurin R.L.*, et al.* Radiographic characteristics of skull fractures resulting from child abuse. *AJR Am J Roentgenol* 1987; 149(1): 173-175. http://www.ncbi.nlm.nih.gov/pubmed/3495978.

63. Reece R.M., Sege R. Childhood head injuries: accidental or inflicted? *Arch Pediatr Adolesc Med* 2000; 154(1): 11-15. http://archpedi.jamanetwork.com/data/journals/peds/8508/poa8558.pdf.

64. Billmire M.E., Myers P.A. Serious Head Injury in Infants: Accident or Abuse? *Pediatrics* 1985; 75(2): 340-342. http://pediatrics.aappublications.org/content/75/2/340.long?sso=1&sso_redirect_count=1&nfstatus=401&nftoken=00000000-0000-0000-0000-000000000000&nfstatusdescription=ERROR%3a+No+local+token.

65. Stewart G., Meert K., Rosenberg N. Trauma in infants less than three months of age. *Pediatr Emerg Care* 1993; 9(4): 199-201. http://www.ncbi.nlm.nih.gov/pubmed/8043047.

66. Hiss J., Kahana T. The medicolegal implications of bilateral cranial fractures in infants. *J Trauma* 1995; 38(1): 32-34. http://www.ncbi.nlm.nih.gov/pubmed/7745653.

67. Kleinman P.K., Perez-Rossello J.M., Newton A.W.*, et al.* Prevalence of the classic metaphyseal lesion in infants at low versus high risk for abuse. *AJR Am J Roentgenol* 2011; 197(4): 1005-1008. http://www.ncbi.nlm.nih.gov/pubmed/21940592.

68. Thackeray J.D., Wannemacher J., Adler B.H.*, et al.* The classic metaphyseal lesion and traumatic injury. *Pediatric Radiology* 2016; 46(8): 1128-1133. http://link.springer.com/article/10.1007%2Fs00247-016-3568-0.

69. Kleinman P.K., Marks S.C., Jr. A regional approach to classic metaphyseal lesions in abused infants: the distal tibia. *AJR Am J Roentgenol* 1996; 166(5): 1207-1212. http://www.ncbi.nlm.nih.gov/pubmed/8615271.

70. Kleinman P.K., Marks S.C., Jr. A regional approach to the classic metaphyseal lesion in abused infants: the proximal humerus. *AJR Am J Roentgenol* 1996; 167(6): 1399-1403. http://www.ncbi.nlm.nih.gov/pubmed/8956566.

71. Kleinman P.K., Marks S.C., Jr. A regional approach to the classic metaphyseal lesion in abused infants: the proximal tibia. *AJR Am J Roentgenol* 1996; 166(2): 421-426. http://www.ncbi.nlm.nih.gov/pubmed/8553960.

72. Kleinman P.K., Marks S.C., Jr. A regional approach to the classic metaphyseal lesion in abused infants: the distal femur. *AJR Am J Roentgenol* 1998; 170(1): 43-47. http://www.ncbi.nlm.nih.gov/pubmed/9423596.

73. Kleinman P.K., Marks S.C., Jr., Richmond J.M.*, et al.* Inflicted skeletal injury: a postmortem radiologic-histopathologic study in 31 infants. *AJR Am J Roentgenol* 1995; 165(3): 647-650. http://www.ncbi.nlm.nih.gov/pubmed/7645487.

74. Ryznar E., Rosado N., Flaherty E.G. Understanding forearm fractures in young children: Abuse or not abuse? *Child Abuse and Neglect* 2015; 47: 132-139. http://www.sciencedirect.com/science/article/pii/S0145213415000538.

75. Ablin D.S., Greenspan A., Reinhart M.A. Pelvic injuries in child abuse. *Pediatr Radiol* 1992; 22(6): 454-457. http://www.ncbi.nlm.nih.gov/pubmed/1437374.

76. Bixby S.D., Wilson C.R., Barber I.*, et al.* Ischial apophyseal fracture in an abused infant. *Pediatr Radiol* 2014; 44(9): 1175-1178. https://link.springer.com/article/10.1007%2Fs00247-014-2960-x.

77. Ellerstein N.S., Norris K.J. Value of Radiologic Skeletal Survey in Assessment of Abused Children. *Pediatrics* 1984; 74(6): 1075-1078. http://pediatrics.aappublications.org/content/74/6/1075.long.

78. Johnson K., Chapman S., Hall C.M. Skeletal injuries associated with sexual abuse. *Pediatr Radiol* 2004; 34(8): 620-623. https://link.springer.com/article/10.1007%2Fs00247-004-1216-6.

79. Perez-Rossello J.M., Connolly S.A., Newton A.W.*, et al.* Pubic ramus radiolucencies in infants: the good, the bad, and the indeterminate. *AJR Am J Roentgenol* 2008; 190(6): 1481-1486. http://www.ncbi.nlm.nih.gov/pubmed/18492895.

80. Prendergast N.C., deRoux S.J., Adsay N.V. Non-accidental pediatric pelvic fracture: a case report. *Pediatric Radiology* 1998; 28(5): 344-346.https://link.springer.com/article/10.1007%2Fs002470050371.

81. Starling S.P., Heller R.M., Jenny C. Pelvic fractures in infants as a sign of physical abuse. *Child Abuse & Neglect* 2002; 26(5): 475-480. http://www.sciencedirect.com/science/article/pii/S014521340200323X.

82. Lindberg D.M., Harper N.S., Laskey A.L.*, et al.* Prevalence of abusive fractures of the hands, feet, spine, or pelvis on skeletal survey: perhaps "uncommon" is more common than suggested. *Pediatr Emerg Care* 2013; 29(1): 26-29. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-201301000-00006%2Froot%2Fv%2F2017-05-30T205621Z%2Fr%2Fapplication-pdf.

83. Jaffe A.C., Lasser D.H. Multiple Metatarsal Fractures in Child Abuse. *Pediatrics* 1977; 60(4): 642-643. http://www.ncbi.nlm.nih.gov/pubmed/263278.

84. Kleinman P.K., Morris N.B., Makris J.*, et al.* Yield of radiographic skeletal surveys for detection of hand, foot, and spine fractures in suspected child abuse. *AJR Am J Roentgenol* 2013; 200(3): 641-644. http://www.ncbi.nlm.nih.gov/pubmed/23436856.

85. Nimkin K., Spevak M.R., Kleinman P.K. Fractures of the hands and feet in child abuse: imaging and pathologic features. *Radiology* 1997; 203(1): 233-236. http://www.ncbi.nlm.nih.gov/pubmed/9122400.

86. Rao K.S., Hyde I. Digital lesions in non-accidental injuries in children. *Br J Radiol* 1984; 57(675): 259-260. http://www.ncbi.nlm.nih.gov/pubmed/6697090.

87. Schlievert R. Infant Mandibular Fractures: Are You Considering Child Abuse? *Pediatric Emergency Care* 2006; 22(3): 181-183. http://journals.lww.com/pec-online/Fulltext/2006/03000/Infant_Mandibular_Fractures__Are_You_Considering.11.aspx

88. Siegel M.B., Wetmore R.F., Potsic W.P.*, et al.* Mandibular fractures in the pediatric patient. *Archives of Otolaryngology–Head & Neck Surgery* 1991; 117(5): 533-536. http://jamanetwork.com/journals/jamaotolaryngology/article-abstract/619675.

89. Hechter S., Huyer D., Manson D. Sternal fractures as a manifestation of abusive injury in children. *Pediatr Radiol* 2002; 32(12): 902-906.

90. Bode K.S., Newton P.O. Pediatric nonaccidental trauma thoracolumbar fracture-dislocation: posterior spinal fusion with pedicle screw fixation in an 8-month-old boy. *Spine (Phila Pa 1976)* 2007; 32(14): E388-393. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fspne%2Fbeta%2F00007632-200706150-00023%2Froot%2Fv%2F2017-05-03T191153Z%2Fr%2Fapplication-pdf.

91. Carrion W.V., Dormans J.P., Drummond D.S.*, et al.* Circumferential growth plate fracture of the thoracolumbar spine from child abuse. *J Pediatr Orthop* 1996; 16(2): 210-214. http://www.ncbi.nlm.nih.gov/pubmed/8742287.

92. Cullen J.C. SPINAL LESIONS IN BATTERED BABIES. *Journal of Bone & Joint Surgery, British Volume* 1975; 57-B(3): 364-366. http://www.ncbi.nlm.nih.gov/pubmed/1158948.

93. Diamond P., Hansen C.M., Christofersen M.R. Child abuse presenting as a thoracolumbar spinal fracture dislocation: a case report. *Pediatr Emerg Care* 1994; 10(2): 83-86. http://www.ncbi.nlm.nih.gov/pubmed/8029116.

94. DICKSON R.A., LEATHERMAN K.D. Spinal Injuries in Child Abuse: Case Report. *Journal of Trauma and Acute Care Surgery* 1978; 18(12): 811-812. http://journals.lww.com/jtrauma/Fulltext/1978/12000/Spinal_Injuries_in_Child_Abuse__Case_Report_.5.aspx.

95. Feldman K.W., Avellino A.M., Sugar N.F.*, et al.* Cervical spinal cord injury in abused children. *Pediatr Emerg Care* 2008; 24(4): 222-227. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-200804000-00006%2Froot%2Fv%2F2017-05-30T205457Z%2Fr%2Fapplication-pdf.

96. Gabos P.G., Tuten H.R., Leet A.*, et al.* Fracture-Dislocation of the Lumbar Spine in an Abused Child. *Pediatrics* 1998; 101(3): 473-476. http://pediatrics.aappublications.org/content/pediatrics/101/3/473.full.pdf.

97. Gille P., Bonneville J., Francois J.*, et al.* Fracture des pédicules de l'axis chez un nourrisson battu (Fractures of axis pedicles in battered infant). *Chirurgie Pediatrique* 1980; 21(5): 343-538.

98. Kleinman P.K., Shelton Y.A. Hangman's fracture in an abused infant: imaging features. *Pediatr Radiol* 1997; 27(9): 776-777. https://link.springer.com/article/10.1007%2Fs002470050227.

99. Oral R., Rahhal R., Elshershari H.*, et al.* Intentional avulsion fracture of the second cervical vertebra in a hypotonic child. *Pediatr Emerg Care* 2006; 22(5): 352-354. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-200605000-00010%2Froot%2Fv%2F2017-05-30T205417Z%2Fr%2Fapplication-pdf.

100. Renard M., Tridon P., Kuhnast M.*, et al.* Three unusual cases of spinal cord injury in childhood. *Paraplegia* 1978; 16(1): 130-134. http://www.nature.com/sc/journal/v16/n1/pdf/sc197822a.pdf.

101. Rooks V.J., Sisler C., Burton B. Cervical spine injury in child abuse: report of two cases. *Pediatr Radiol* 1998; 28(3): 193-195. https://link.springer.com/article/10.1007%2Fs002470050330.

102. Sieradzki J.P., Sarwark J.F. Thoracolumbar Fracture-Dislocation in Child Abuse: Case Report, Closed Reduction Technique and Review of the Literature. *Pediatric Neurosurgery* 2008; 44(3): 253-257. http://www.karger.com/DOI/10.1159/000121475.

103. Tran B., Silvera M., Newton A.*, et al.* Inflicted T12 fracture-dislocation: CT/MRI correlation and mechanistic implications. *Pediatric Radiology* 2007; 37(11): 1171-1173. https://link.springer.com/article/10.1007%2Fs00247-007-0594-y.

104. Cumming W.A. Neonatal skeletal fractures. Birth trauma or child abuse? *J Can Assoc Radiol* 1979; 30(1): 30-33. http://www.ncbi.nlm.nih.gov/pubmed/429433.

105. Halliday K.E., Broderick N.J., Somers J.M.*, et al.* Dating fractures in infants. *Clinical Radiology* 2011; 66(11): 1049-1054. http://dx.doi.org/10.1016/j.crad.2011.06.001.

106. Islam O., Soboleski D., Symons S.*, et al.* Development and duration of radiographic signs of bone healing in children. *AJR Am J Roentgenol* 2000; 175(1): 75-78. http://www.ncbi.nlm.nih.gov/pubmed/10882250.

107. Prosser I., Lawson Z., Evans A.*, et al.* A timetable for the radiologic features of fracture healing in young children. *AJR Am J Roentgenol* 2012; 198(5): 1014-1020. http://www.ncbi.nlm.nih.gov/pubmed/22528890.

108. Sanchez T.R., Nguyen H., Palacios W.*, et al.* Retrospective evaluation and dating of non-accidental rib fractures in infants. *Clin Radiol* 2013; 68(8): e467-471. http://www.ncbi.nlm.nih.gov/pubmed/23622800.

109. Walters M.M., Forbes P.W., Buonomo C.*, et al.* Healing patterns of clavicular birth injuries as a guide to fracture dating in cases of possible infant abuse. *Pediatric Radiology* 2014; 44(10): 1224-1229. https://link.springer.com/article/10.1007%2Fs00247-014-2995-z.

110. Yeo L.I., Reed M.H. Staging of healing of femoral fractures in children. *Can Assoc Radiol J* 1994; 45(1): 16-19. http://www.ncbi.nlm.nih.gov/pubmed/8118709.

111. Fadell M., Miller A., Trefan L.*, et al.* Radiological features of healing in newborn clavicular fractures. *European Radiology* 2016; 27(5): 2180-2187. http://sfx.ucl.ac.uk/sfx_local?sid=OVID:embase&id=pmid:&id=doi:10.1007%2Fs00330-016-4569-y&issn=0938-7994&isbn=&volume=&issue=&spage=1&pages=1-8&date=2016&title=European+Radiology&atitle=Radiological+features+of+healing+in+newborn+clavicular+fractures&aulast=Fadell.

112. Warner C., Maguire S., Trefan L.*, et al.* A study of radiological features of healing in long bone fractures among infants less than a year. *Skeletal Radiology* 2017; 46(3): 333-341. http://link.springer.com/article/10.1007%2Fs00256-016-2563-8.

113. Anilkumar A., Fender L.J., Broderick N.J.*, et al.* The role of the follow-up chest radiograph in suspected non-accidental injury. *Pediatr Radiol* 2006; 36(3): 216-218. https://link.springer.com/article/10.1007%2Fs00247-005-0054-5.

114. Bennett B.L., Chua M.S., Care M.*, et al.* Retrospective review to determine the utility of follow-up skeletal surveys in child abuse evaluations when the initial skeletal survey is normal. *BMC Res Notes* 2011; 4: 354. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3213190/pdf/1756-0500-4-354.pdf.

115. Hansen K.K., Keeshin B.R., Flaherty E., *et al.* Sensitivity of the limited view follow-up skeletal survey. *Pediatrics* 2014; 134(2): 242-248. http://pediatrics.aappublications.org/content/pediatrics/134/2/242.full.pdf.

116. Harper N.S., Eddleman S., Lindberg D.M. The utility of follow-up skeletal surveys in child abuse. *Pediatrics* 2013; 131(3): e672-678. http://pediatrics.aappublications.org/content/pediatrics/131/3/e672.full.pdf.

117. Kleinman P.K., Nimkin K., Spevak M.R., *et al.* Follow-up skeletal surveys in suspected child abuse. *AJR Am J Roentgenol* 1996; 167(4): 893-896. http://www.ncbi.nlm.nih.gov/pubmed/8819377.

118. Singh R., Squires J., Fromkin J.B., *et al.* Assessing the use of follow-up skeletal surveys in children with suspected physical abuse. *J Trauma Acute Care Surg* 2012; 73(4): 972-976. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Ftjtacs%2Fbeta%2F01586154-201210000-00030%2Froot%2Fv%2F2017-05-26T191101Z%2Fr%2Fapplication-pdf.

119. Sonik A., Stein-Wexler R., Rogers K.K., *et al.* Follow-up skeletal surveys for suspected non-accidental trauma: can a more limited survey be performed without compromising diagnostic information? *Child Abuse Negl* 2010; 34(10): 804-806. http://www.ncbi.nlm.nih.gov/pubmed/20846722.

120. Zimmerman S., Makoroff K., Care M., *et al.* Utility of follow-up skeletal surveys in suspected child physical abuse evaluations. *Child Abuse Negl* 2005; 29(10): 1075-1083. http://www.ncbi.nlm.nih.gov/pubmed/16315349.

121. Hansen K.K., Prince J.S., Nixon G.W. Oblique chest views as a routine part of skeletal surveys performed for possible physical abuse--is this practice worthwhile? *Child Abuse Negl* 2008; 32(1): 155-159. http://www.ncbi.nlm.nih.gov/pubmed/18096227.

122. Ingram J.D., Connell J., Hay T.C., *et al.* Oblique radiographs of the chest in nonaccidental trauma. *Emergency Radiology* 2000; 7(1): 42-46. https://link.springer.com/article/10.1007%2Fs101400050009.

123. Jha P., Stein-Wexler R., Coulter K., *et al.* Optimizing bone surveys performed for suspected non-accidental trauma with attention to maximizing diagnostic yield while minimizing radiation exposure: utility of pelvic and lateral radiographs. *Pediatr Radiol* 2013; 43(6): 668-672. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4591047/pdf/nihms725802.pdf.

124. Karmazyn B., Duhn R.D., Jennings S.G., *et al.* Long bone fracture detection in suspected child abuse: contribution of lateral views. *Pediatr Radiol* 2012; 42(4): 463-469. https://link.springer.com/article/10.1007%2Fs00247-011-2248-3.

125. Marine M.B., Corea D., Steenburg S.D., *et al.* Is the new ACR-SPR practice guideline for addition of oblique views of the ribs to the skeletal survey for child abuse justified? *AJR Am J Roentgenol* 2014; 202(4): 868-871. http://www.ncbi.nlm.nih.gov/pubmed/24660718.

126. Merten D.F., Radkowski M.A., Leonidas J.C. The abused child: a radiological reappraisal. *Radiology* 1983; 146(2): 377-381. http://www.ncbi.nlm.nih.gov/pubmed/6849085.

127. Conway J.J., Collins M., Tanz R.R., *et al.* The role of bone scintigraphy in detecting child abuse. *Semin Nucl Med* 1993; 23(4): 321-333. http://www.ncbi.nlm.nih.gov/pubmed/8256139.

128. Curcoy Barcenilla A.I., Trenchs Sainz de la Maza V., Pou Fernandez J. [Utility of bone scintigraphy in the differential diagnosis of child maltreatment]. *An Pediatr (Barc)* 2006; 65(1): 83-84. http://www.ncbi.nlm.nih.gov/pubmed/16945295.

129. Frye T.R., Shores R.M., Slovis T.L., *et al.* Radiological case of the month. Child abuse. *Am J Dis Child* 1984; 138(3): 323-324. http://www.ncbi.nlm.nih.gov/pubmed/6702781.

130. Haase G.M., Ortiz V.N., Sfakianakis G.N., *et al.* The value of radionuclide bone scanning in the early recognition of deliberate child abuse. *J Trauma* 1980; 20(10): 873-875. http://www.ncbi.nlm.nih.gov/pubmed/7420497.

131. Jaudes P.K. Comparison of radiography and radionuclide bone scanning in the detection of child abuse. *Pediatrics* 1984; 73(2): 166-168. http://pediatrics.aappublications.org/content/73/2/166.long?sso=1&sso_redirect_count=1&nfstatus=401&nftoken=00000000-0000-0000-0000-000000000000&nfstatusdescription=ERROR%3a+No+local+token.

132. Kleinhans E., Kentrup H., Alzen G., *et al.* [A false negative bone scintigram in a biparietal skull fracture in a case of a Battered Child Syndrome]. *Nuklearmedizin* 1993; 32(4): 206-207. http://www.ncbi.nlm.nih.gov/pubmed/8372002.

133. Mandelstam S.A., Cook D., Fitzgerald M., *et al.* Complementary use of radiological skeletal survey and bone scintigraphy in detection of bony injuries in suspected child abuse. *Arch Dis Child* 2003; 88(5): 387-390; discussion 387-390. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1719552/pdf/v088p00387.pdf.

134. Olesen T., Egeblad M., Dige-Petersen H., *et al.* Somatic manifestations in children suspected of having been maltreated. *Acta Paediatr Scand* 1988; 77(1): 154-160. http://www.ncbi.nlm.nih.gov/pubmed/3369294.

135. Pickett W.J., Faleski E.J., Chacko A., *et al.* Comparison of radiographic and radionuclide skeletal surveys in battered children. *South Med J* 1983; 76(2): 207-212. http://www.ncbi.nlm.nih.gov/pubmed/6218618.

136. Sty J.R., Starshak R.J. The role of bone scintigraphy in the evaluation of the suspected abused child. *Radiology* 1983; 146(2): 369-375. http://www.ncbi.nlm.nih.gov/pubmed/6217487.

137. Williams G., Treves S.T. A second radiographic skeletal survey for child abuse triggered by bone scintigraphy found positive after the initial survey was called negative. *Clin Nucl Med* 2007; 32(1): 29-31. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fcnum%2Fbeta%2F00003072-200701000-00007%2Froot%2Fv%2F2017-05-23T190758Z%2Fr%2Fapplication-pdf.

138. Belfer R.A., Klein B.L., Orr L. Use of the skeletal survey in the evaluation of child maltreatment. *Am J Emerg Med* 2001; 19(2): 122-124. http://www.ncbi.nlm.nih.gov/pubmed/11239255.

139. Day F., Clegg S., McPhillips M., *et al.* A retrospective case series of skeletal surveys in children with suspected non-accidental injury. *J Clin Forensic Med* 2006; 13(2): 55-59. http://www.ncbi.nlm.nih.gov/pubmed/16464629.

140. Deye K.P., Berger R.P., Lindberg D.M. Occult abusive injuries in infants with apparently isolated skull fractures. *J Trauma Acute Care Surg* 2013; 74(6): 1553-1558. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Ftjtacs%2Fbeta%2F01586154-201306000-00027%2Froot%2Fv%2F2017-05-26T191120Z%2Fr%2Fapplication-pdf.

141. Duffy S.O., Squires J., Fromkin J.B., *et al.* Use of skeletal surveys to evaluate for physical abuse: analysis of 703 consecutive skeletal surveys. *Pediatrics* 2011; 127(1): e47-52. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4466842/pdf/zpee47.pdf.

142. Fagen K.E., Shalaby-Rana E., Jackson A.M. Frequency of skeletal injuries in children with inflicted burns. *Pediatric Radiology* 2015; 45(3): 396-401. https://link.springer.com/article/10.1007%2Fs00247-014-3163-1.

143. Hansen K.K., Campbell K.A. How useful are skeletal surveys in the second year of life? *Child Abuse Negl* 2009; 33(5): 278-281. http://www.ncbi.nlm.nih.gov/pubmed/19477006.

144. Higginbotham N., Lawson K.A., Gettig K.*, et al.* Utility of a child abuse screening guideline in an urban pediatric emergency department. *J Trauma Acute Care Surg* 2014; 76(3): 871-877. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Ftjtacs%2Fbeta%2F01586154-201403000-00045%2Froot%2Fv%2F2017-05-26T191138Z%2Fr%2Fapplication-pdf.

145. Laskey A.L., Stump T.E., Hicks R.A.*, et al.* Yield of skeletal surveys in children </= 18 months of age presenting with isolated skull fractures. *J Pediatr* 2013; 162(1): 86-89. http://www.ncbi.nlm.nih.gov/pubmed/22835884.

146. Lindberg D.M., Blood E.A., Campbell K.A.*, et al.* Predictors of screening and injury in contacts of physically abused children. *J Pediatr* 2013; 163(3): 730-735.e731-733. http://www.ncbi.nlm.nih.gov/pubmed/23566385.

147. Lindberg D.M., Berger R.P., Reynolds M.S.*, et al.* Yield of Skeletal Survey by Age in Children Referred to Abuse Specialists. *The Journal of Pediatrics* 2014; 164(6): 1268-1273.e1261. http://dx.doi.org/10.1016/j.jpeds.2014.01.068.

148. Lindberg D.M., Shapiro R.A., Laskey A.L.*, et al.* Prevalence of abusive injuries in siblings and household contacts of physically abused children. *Pediatrics* 2012; 130(2): 193-201. http://pediatrics.aappublications.org/content/pediatrics/130/2/193.full.pdf.

149. Rangel E.L., Cook B.S., Bennett B.L.*, et al.* Eliminating disparity in evaluation for abuse in infants with head injury: use of a screening guideline. *J Pediatr Surg* 2009; 44(6): 1229-1234; discussion 1234-1225. http://www.ncbi.nlm.nih.gov/pubmed/19524746.

150. Wood J.N., Christian C.W., Adams C.M.*, et al.* Skeletal surveys in infants with isolated skull fractures. *Pediatrics* 2009; 123(2): e247-252. http://pediatrics.aappublications.org/content/123/2/e247.long?sso=1&sso_redirect_count=1&nfstatus=401&nftoken=00000000-0000-0000-0000-000000000000&nfstatusdescription=ERROR%3a+No+local+token.

151. Hicks R.A., Stolfi A. Skeletal surveys in children with burns caused by child abuse. *Pediatr Emerg Care* 2007; 23(5): 308-313. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-200705000-00007%2Froot%2Fv%2F2017-05-30T205432Z%2Fr%2Fapplication-pdf.

152. Lindberg D.M., Berger R.P., Reynolds M.S.*, et al.* Yield of skeletal survey by age in children referred to abuse specialists. *J Pediatr* 2014; 164(6): 1268-1273 e1261.

153. Cohen R.A., Kaufman R.A., Myers P.A.*, et al.* Cranial computed tomography in the abused child with head injury. *AJR Am J Roentgenol* 1986; 146(1): 97-102. http://www.ncbi.nlm.nih.gov/pubmed/3510048.

154. Drubach L.A., Johnston P.R., Newton A.W.*, et al.* Skeletal trauma in child abuse: detection with 18F-NaF PET. *Radiology* 2010; 255(1): 173-181.

155. Eltermann T., Beer M., Girschick H.J. Magnetic resonance imaging in child abuse. *J Child Neurol* 2007; 22(2): 170-175. http://journals.sagepub.com/doi/abs/10.1177/0883073807300311?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed.

156. Hansen M., Weltzien A., Blum J.*, et al.* Complete distal humeral epiphyseal separation indicating a battered child syndrome: a case report. *Arch Orthop Trauma Surg* 2008; 128(9): 967-972. https://link.springer.com/article/10.1007%2Fs00402-007-0484-7.

157. Kelloff J., Hulett R., Spivey M. Acute rib fracture diagnosis in an infant by US: a matter of child protection. *Pediatr Radiol* 2009; 39(1): 70-72. https://link.springer.com/article/10.1007%2Fs00247-008-1011-x.

158. Markowitz R.I., Hubbard A.M., Harty M.P., *et al.* Sonography of the knee in normal and abused infants. *Pediatr Radiol* 1993; 23(4): 264-267. http://www.ncbi.nlm.nih.gov/pubmed/8414751.

159. Prabhu S.P., Newton A.W., Perez-Rossello J.M., *et al.* Three-dimensional skull models as a problem-solving tool in suspected child abuse. *Pediatr Radiol* 2013; 43(5): 575-581. https://link.springer.com/article/10.1007%2Fs00247-012-2546-4.

160. Sanchez T.R., Lee J.S., Coulter K.P., *et al.* CT of the chest in suspected child abuse using submillisievert radiation dose. *Pediatr Radiol* 2015; 45(7): 1072-1076. https://link.springer.com/article/10.1007%2Fs00247-014-3245-0.

161. Saulsbury F.T., Alford B.A. Intracranial bleeding from child abuse: the value of skull radiographs. *Pediatr Radiol* 1982; 12(4): 175-178. http://www.ncbi.nlm.nih.gov/pubmed/7133797.

162. Tsai F.Y., Zee C.S., Apthorp J.S., *et al.* Computed tomography in child abuse head trauma. *J Comput Tomogr* 1980; 4(4): 277-286. http://www.ncbi.nlm.nih.gov/pubmed/7471778.

163. Warkentine F.H., Horowitz R., Pierce M.C. The use of ultrasound to detect occult or unsuspected fractures in child abuse. *Pediatr Emerg Care* 2014; 30(1): 43-46. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-201401000-00011%2Froot%2Fv%2F2017-05-30T205638Z%2Fr%2Fapplication-pdf.

164. Wootton-Gorges S.L., Stein-Wexler R., Walton J.W., *et al.* Comparison of computed tomography and chest radiography in the detection of rib fractures in abused infants. *Child Abuse Negl* 2008; 32(6): 659-663. http://www.ncbi.nlm.nih.gov/pubmed/18562001.

165. Culotta P.A., Crowe J.E., Tran Q.A., *et al.* Performance of computed tomography of the head to evaluate for skull fractures in infants with suspected non-accidental trauma. *Pediatric Radiology* 2017; 47(1): 74-81. http://link.springer.com/article/10.1007%2Fs00247-016-3707-7.

166. Drubach L.A., Sapp M.V., Laffin S., *et al.* Fluorine-18 NaF PET imaging of child abuse. *Pediatr Radiol* 2008; 38(7): 776-779. https://link.springer.com/article/10.1007%2Fs00247-008-0885-y.

167. Bainbridge J.K., Huey B.M., Harrison S.K. Should bone scintigraphy be used as a routine adjunct to skeletal survey in the imaging of non-accidental injury? A 10 year review of reports in a single centre. *Clinical Radiology* 2015; 70(8): e83-e89. http://www.sciencedirect.com/science/article/pii/S0009926015001579.

168. Standards for Radiological Investigations of Suspected Non-accidental Injury. Joint document produced in collaboration with the Royal College of Paediatrics and Child Health. London: RCR;

169. Betz P., Liebhardt E. Rib fractures in children--resuscitation or child abuse? *Int J Legal Med* 1994; 106(4): 215-218. http://www.ncbi.nlm.nih.gov/pubmed/8038115.

170. Boz B., Erdur B., Acar K., *et al.* [Frequency of skeletal chest injuries associated with cardiopulmonary resuscitation: forensic autopsy]. *Ulus Travma Acil Cerrahi Derg* 2008; 14(3): 216-220. http://www.ncbi.nlm.nih.gov/pubmed/18781418.

171. Bush C.M., Jones J.S., Cohle S.D., *et al.* Pediatric injuries from cardiopulmonary resuscitation. *Ann Emerg Med* 1996; 28(1): 40-44. http://www.ncbi.nlm.nih.gov/pubmed/8669737.

172. Lin Y.R., Li C.J., Wu T.K., *et al.* Post-resuscitative clinical features in the first hour after achieving sustained ROSC predict the duration of survival in children with non-traumatic out-of-hospital cardiac arrest. *Resuscitation* 2010; 81(4): 410-417. http://www.ncbi.nlm.nih.gov/pubmed/20149514.

173. Matshes E.W., Lew E.O. Do resuscitation-related injuries kill infants and children? *Am J Forensic Med Pathol* 2010; 31(2): 178-185. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fajfm%2Fbeta%2F00000433-201006000-00016%2Froot%2Fv%2F2017-05-25T191735Z%2Fr%2Fapplication-pdf.

174. Matshes E.W., Lew E.O. Two-handed cardiopulmonary resuscitation can cause rib fractures in infants. *Am J Forensic Med Pathol* 2010; 31(4): 303-307. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fajfm%2Fbeta%2F00000433-201012000-00001%2Froot%2Fv%2F2017-05-25T191741Z%2Fr%2Fapplication-pdf.

175. Price E.A., Rush L.R., Perper J.A., *et al.* Cardiopulmonary resuscitation-related injuries and homicidal blunt abdominal trauma in children. *Am J Forensic Med Pathol* 2000; 21(4): 307-310. http://www.ncbi.nlm.nih.gov/pubmed/11111786.

176. Reyes J.A., Somers G.R., Taylor G.P., *et al.* Increased incidence of CPR-related rib fractures in infants--is it related to changes in CPR technique? *Resuscitation* 2011; 82(5): 545-548. http://www.ncbi.nlm.nih.gov/pubmed/21353734.

177. Ryan M.P., Young S.J., Wells D.L. Do resuscitation attempts in children who die, cause injury? *Emerg Med J* 2003; 20(1): 10-12. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1725991/pdf/v020p00010.pdf.

178. Spevak M.R., Kleinman P.K., Belanger P.L., *et al.* Cardiopulmonary resuscitation and rib fractures in infants. A postmortem radiologic-pathologic study. *Jama* 1994; 272(8): 617-618. http://jamanetwork.com/journals/jama/article-abstract/378357.

179. Weber M.A., Risdon R.A., Offiah A.C., *et al.* Rib fractures identified at post-mortem examination in sudden unexpected deaths in infancy (SUDI). *Forensic Sci Int* 2009; 189(1-3): 75-81. http://www.ncbi.nlm.nih.gov/pubmed/19477091.

180. Martin P.S., Jones M.D., Maguire S.A., *et al.* Increased incidence of CPR-related rib fractures in infants - Is it related to changes in CPR technique? *Resuscitation* 2012; 83(4): e109; author reply e111. http://www.ncbi.nlm.nih.gov/pubmed/22269097.

181. Reyes J.A., Somers G.R., Taylor G.P., *et al.* Response to Letter: Increased incidence of CPR-related rib fractures in infants – Is it related to changes in CPR technique? *Resuscitation* 2012; 83(4): e111. http://www.sciencedirect.com/science/article/pii/S0300957212000275.

182. Kleinman P.K., Marks S.C., Adams V.I., *et al.* Factors affecting visualization of posterior rib fractures in abused infants. *AJR Am J Roentgenol* 1988; 150(3): 635-638. http://www.ncbi.nlm.nih.gov/pubmed/3257621.

183. Chalumeau M., Foix-L'Helias L., Scheinmann P., *et al.* Rib fractures after chest physiotherapy for bronchiolitis or pneumonia in infants. *Pediatr Radiol* 2002; 32(9): 644-647. https://link.springer.com/article/10.1007%2Fs00247-002-0755-y.

184. Chapuis A., Maurric-Drouet A., Beauvois É. La kinésithérapie respiratoire ambulatoire du nourrisson est-elle pourvoyeuse de traumatisme thoracique ? *Kinésithérapie, la Revue* 2010; 10(108): 48-54. http://www.sciencedirect.com/science/article/pii/S1779012310749901.

185. Heideken J., Svensson T., Blomqvist P., *et al.* Incidence and trends in femur shaft fractures in Swedish children between 1987 and 2005. *J Pediatr Orthop* 2011; 31(5): 512-519. http://ssr-eus-go-

csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-201107000-00007%2Froot%2Fv%2F2017-05-24T204028Z%2Fr%2Fapplication-pdf.

186. Thompson N.B., Kelly D.M., Warner W.C.J., *et al.* Intraobserver and Interobserver Reliability and the Role of Fracture Morphology in Classifying Femoral Shaft Fractures in Young Children. *Journal of Pediatric Orthopaedics* 2014; 34(3): 352-358. http://mobile.journals.lww.com/pedorthopaedics/Fulltext/2014/04000/Intraobserver_and_Interobserver_Reliability_and.17.aspx

187. Arnholz D., Hymel K.P., Hay T.C., *et al.* Bilateral pediatric skull fractures: accident or abuse? *J Trauma* 1998; 45(1): 172-174. http://www.ncbi.nlm.nih.gov/pubmed/9680036.

188. Hobbs C.J. Skull fracture and the diagnosis of abuse. *Archives of Disease in Childhood* 1984; 59(3): 246-252. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1628552/

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1628552/pdf/archdisch00736-0062.pdf.

189. Pierce M.C., Bertocci G.E., Berger R., *et al.* Injury biomechanics for aiding in the diagnosis of abusive head trauma. *Neurosurgery Clinics* 2002; 13(2): 155-168. http://dx.doi.org/10.1016/S1042-3680(01)00006-7.

190. Somers J.M., Halliday K.E., Chapman S. Humeral fracture in non-ambulant infants-a possible accidental mechanism. *Pediatr Radiol* 2014; 44(10): 1219-1223. https://link.springer.com/article/10.1007%2Fs00247-014-2954-8.

191. Supakul N., Hicks R.A., Caltoum C.B., *et al.* Distal humeral epiphyseal separation in young children: an often-missed fracture-radiographic signs and ultrasound confirmatory diagnosis. *AJR Am J Roentgenol* 2015; 204(2): W192-198. http://www.ncbi.nlm.nih.gov/pubmed/25615780.

192. Helfer R.E., Scheurer S.L., Alexander R., *et al.* Trauma to the bones of small infants from passive exercise: A factor in the etiology of child abuse. *The Journal of Pediatrics* 1984; 104(1): 47-50. http://www.sciencedirect.com/science/article/pii/S0022347684805879.

193. Grayev A.M., Boal D.K., Wallach D.M., *et al.* Metaphyseal fractures mimicking abuse during treatment for clubfoot. *Pediatr Radiol* 2001; 31(8): 559-563. https://link.springer.com/article/10.1007%2Fs002470100497.

194. Altman D.H., Smith R.L. Unrecognized trauma in infants and children. *J Bone Joint Surg Am* 1960; 42-a: 407-413. http://www.ncbi.nlm.nih.gov/pubmed/13848782.

195. Lysack J.T., Soboleski D. Classic metaphyseal lesion following external cephalic version and cesarean section. *Pediatr Radiol* 2003; 33(6): 422-424. https://link.springer.com/article/10.1007%2Fs00247-003-0914-9.

196. Tsai A., McDonald A.G., Rosenberg A.E., *et al.* High-resolution CT with histopathological correlates of the classic metaphyseal lesion of infant abuse. *Pediatr Radiol* 2014; 44(2): 124-140. https://link.springer.com/article/10.1007%2Fs00247-013-2813-z.

197. Schulze C., Hoppe H., Schweitzer W., *et al.* Rib fractures at postmortem computed tomography (PMCT) validated against the autopsy. *Forensic Sci Int* 2013; 233(1-3): 90-98. http://www.ncbi.nlm.nih.gov/pubmed/24314506.

198. Love J.C., Sanchez L.A. Recognition of skeletal fractures in infants: an autopsy technique. *J Forensic Sci* 2009; 54(6): 1443-1446. http://onlinelibrary.wiley.com/doi/10.1111/j.1556-4029.2009.01148.x/abstract.

199. Cappella A., Amadasi A., Gaudio D., *et al.* The application of cone-beam CT in the aging of bone calluses: a new perspective? *Int J Legal Med* 2013; 127(6): 1139-1144. https://link.springer.com/article/10.1007%2Fs00414-013-0824-9.

200. Doberentz E., Madea B., Muller A.M. Coronal clefts in infants - rare differential diagnosis of traumatic injuries of vertebral bodies in battered children. *Leg Med (Tokyo)* 2014; 16(6): 333-336. http://www.ncbi.nlm.nih.gov/pubmed/25082734.

201. McAloon J., O'Neill C. Ossification centres, not rib fractures. *Archives of Disease in Childhood* 2011; 96(3): 284-284. http://adc.bmj.com/content/archdischild/96/3/284.full.pdf.

202. Harty M.P., Kao S.C. Intraosseous vascular access defect: fracture mimic in the skeletal survey for child abuse. *Pediatr Radiol* 2002; 32(3): 188-190. http://www.ncbi.nlm.nih.gov/pubmed/12164352.

203. Quigley A.J., Stafrace S. Skeletal survey normal variants, artefacts and commonly misinterpreted findings not to be confused with non-accidental injury. *Pediatr Radiol* 2014; 44(1): 82-93; quiz 79-81. https://link.springer.com/article/10.1007%2Fs00247-013-2802-2.

204. Sawyer J.R., Kapoor M., Gonzales M.H., *et al.* Heterotopic ossification of the hip after non-accidental injury in a child: case report. *J Pediatr Orthop* 2009; 29(8): 865-867. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-200912000-00007%2Froot%2Fv%2F2017-05-24T204005Z%2Fr%2Fapplication-pdf.

205. Kleinman P.K., Sarwar Z.U., Newton A.W., *et al.* Metaphyseal Fragmentation with Physiologic Bowing: A Finding Not to Be Confused with the Classic Metaphyseal Lesion. *American Journal of Roentgenology* 2009; 192(5): 1266-1268. http://dx.doi.org/10.2214/AJR.08.1619.

206. Choudhary A.K., Jha B., Boal D.K., *et al.* Occipital sutures and its variations: the value of 3D-CT and how to differentiate it from fractures using 3D-CT? *Surg Radiol Anat* 2010; 32(9): 807-816. https://link.springer.com/article/10.1007%2Fs00276-010-0633-5.

207. Saint-Martin P., Rérolle C., Alison D., *et al.* Unossified membranous strip of the parietal bone: A differential diagnosis of non-accidental head trauma in children–a case report. *La Revue de Médecine Légale* 2012; 3(1): 45-47. http://www.sciencedirect.com/science/article/pii/S1878652912000028.

208. Slovis T.L., Berdon W.E., Haller J.O., *et al.* Pancreatitis and the battered child syndrome. Report of 2 cases with skeletal involvement. *Am J Roentgenol Radium Ther Nucl Med* 1975; 125(2): 456-461. http://www.ncbi.nlm.nih.gov/pubmed/1200246.

209. Kepron C., Pollanen M.S. Rickets or abuse? A histologic comparison of rickets and child abuse-related fractures. *Forensic Science, Medicine & Pathology* 2015; 11(1): 78-87. http://sfx.ucl.ac.uk/sfx_local?sid=OVID:medline&id=pmid:25557084&id=doi:10.1007%2Fs12024-014-9639-3&issn=1547-769X&isbn=&volume=11&issue=1&spage=78&pages=78-87&date=2015&title=Forensic+Science%2C+Medicine+%26+Pathology&atitle=Rickets+or+abuse%3F+A+histologic+comparison+of+rickets+and+child+abuse-related+fractures.&aulast=Kepron.

210. Carter D.R., Spengler D.M. Mechanical properties and composition of cortical bone. *Clin Orthop Relat Res* 1978; (135): 192-217. http://www.ncbi.nlm.nih.gov/pubmed/361320.

211. Oehmichen M., Meissner C., Schmidt V., *et al.* Pontine axonal injury after brain trauma and nontraumatic hypoxic-ischemic brain damage. *Int J Legal Med* 1999; 112(4): 261-267. http://www.ncbi.nlm.nih.gov/pubmed/10433037.

212. Pierce M.C., Bertocci G. Injury biomechanics and child abuse. *Annu Rev Biomed Eng* 2008; 10: 85-106. http://www.annualreviews.org/doi/10.1146/annurev.bioeng.9.060906.151907.

213. Worn M.J., Jones M.D. Rib fractures in infancy: establishing the mechanisms of cause from the injuries--a literature review. *Med Sci Law* 2007; 47(3): 200-212. http://journals.sagepub.com/doi/abs/10.1258/rsmmsl.47.3.200?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed.

214. Docherty E., Hassan A., Burke D. Things that go bump … bump … bump: an analysis of injuries from falling down stairs in children based at Sheffield Children's Hospital. *Emergency Medicine Journal* 2010; 27(3): 207-208. http://emj.bmj.com/content/27/3/207.long.

215. Mooney J.F., 3rd, Cramer K.E. Lower extremity compartment syndrome in infants associated with child abuse: a report of two cases. *J Orthop Trauma* 2004; 18(5): 320-322. http://www.ncbi.nlm.nih.gov/pubmed/15105757.

216. Ravichandiran N., Schuh S., Bejuk M., *et al.* Delayed Identification of Pediatric Abuse-Related Fractures. *Pediatrics* 2010; 125(1): 60-66. http://pediatrics.aappublications.org/content/125/1/60.long.

217. Farrell C., Rubin D.M., Downes K., *et al.* Symptoms and time to medical care in children with accidental extremity fractures. *Pediatrics* 2012; 129(1): e128-133. http://pediatrics.aappublications.org/content/129/1/e128.long.

218. Greeley C.S., Donaruma-Kwoh M., Vettimattam M., *et al.* Fractures at diagnosis in infants and children with osteogenesis imperfecta. *J Pediatr Orthop* 2013; 33(1): 32-36. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-201301000-00007%2Froot%2Fv%2F2017-05-24T204044Z%2Fr%2Fapplication-pdf.

219. Snedecor S.T., Wilson H.B. Some obstetrical injuries to the long bones. *J Bone Joint Surg Am* 1949; 31a(2): 378-384. http://www.ncbi.nlm.nih.gov/pubmed/18116571.

220. Rajegowda BK, Chintalapalli P, Peralta D, *et al.* Unexpected detection of a newborn with multiple rib and clavicular fractures: birth injury? . *Neonatal Intensive Care* 2007; 20(1): 19-20.

221. van Rijn R.R., Bilo R.A., Robben S.G. Birth-related mid-posterior rib fractures in neonates: a report of three cases (and a possible fourth case) and a review of the literature. *Pediatr Radiol* 2009; 39(1): 30-34. https://link.springer.com/content/pdf/10.1007%2Fs00247-008-1035-2.pdf.

222. Barry P.W., Hocking M.D. Infant rib fracture--birth trauma or non-accidental injury. *Archives of Disease in Childhood* 1993; 68(2): 250. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1029248/

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1029248/pdf/archdisch00547-0094a.pdf.

223. Hartmann R.W., Jr. Radiological case of the month. Rib fractures produced by birth trauma. *Arch Pediatr Adolesc Med* 1997; 151(9): 947-948. http://jamanetwork.com/journals/jamapediatrics/article-abstract/518508.

224. O'Connell A., Donoghue V.B. Can classic metaphyseal lesions follow uncomplicated caesarean section? *Pediatr Radiol* 2007; 37(5): 488-491. https://link.springer.com/article/10.1007%2Fs00247-007-0445-x.

225. Morris S., Cassidy N., Stephens M., *et al.* Birth-associated femoral fractures: incidence and outcome. *J Pediatr Orthop* 2002; 22(1): 27-30. http://www.ncbi.nlm.nih.gov/pubmed/11744849.

226. Harwood-Nash D.C., Hendrick E.B., Hudson A.R. The significance of skull fractures in children. A study of 1,187 patients. *Radiology* 1971; 101(1): 151-156. http://www.ncbi.nlm.nih.gov/pubmed/5111967.

227. Lucas-Herald A., Butler S., Mactier H., *et al.* Prevalence and characteristics of rib fractures in ex-preterm infants. *Pediatrics* 2012; 130(6): 1116-1119. http://pediatrics.aappublications.org/content/pediatrics/130/6/1116.full.pdf.

228. Bullock D.P., Koval K.J., Moen K.Y., *et al.* Hospitalized cases of child abuse in America: who, what, when, and where. *J Pediatr Orthop* 2009; 29(3): 231-237. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fjpors%2Fbeta%2F01241398-200904000-00003%2Froot%2Fv%2F2017-05-24T204001Z%2Fr%2Fapplication-pdf.

229. Leventhal J.M., Larson I.A., Abdoo D., *et al.* Are abusive fractures in young children becoming less common? Changes over 24 years. *Child Abuse Negl* 2007; 31(3): 311-322. http://www.ncbi.nlm.nih.gov/pubmed/17383725.

230. Zapala M.A., Tsai A., Kleinman P.K. Growth recovery lines are more common in infants at high vs. low risk for abuse. *Pediatric Radiology* 2016; 46(9): 1275-1281.http://link.springer.com/article/10.1007%2Fs00247-016-3621-z.

231. Rosenthall L., Hill R.O., Chuang S. Observation of the use of 99mTc-phosphate imaging in peripheral bone trauma. *Radiology* 1976; 119(3): 637. http://www.ncbi.nlm.nih.gov/pubmed/935401.

232. Zumwalt R., Fanizza-Orphanos A. Dating of healing rib fractures in fatal child abuse. *Advanced Pathology* 1990; 3: 193-205.

233. Perez-Rossello J.M., Connolly S.A., Newton A.W., *et al.* Whole-body MRI in suspected infant abuse. *AJR Am J Roentgenol* 2010; 195(3): 744-750. http://www.ncbi.nlm.nih.gov/pubmed/20729455.

234. American Academy of Pediatrics, Di Pietro MA, Brody AS, *et al.* Diagnostic imaging of child abuse. *Pediatrics* 2009; 123(5): 1430-1435. http://pediatrics.aappublications.org/content/pediatrics/123/5/1430.full.pdf.

235. Practice Guideline for Skeletal Surveys in Children (PDF).

236. Non-accidental injury standard for skeletal surveys.

237. Bury R.F. The new ionising radiation regulations—will they make a difference? *Imaging* 2000; 12(4): 255-261. http://www.birpublications.org/doi/abs/10.1259/img.12.4.120255.

238. Berger R.P., Panigrahy A., Gottschalk S., *et al.* Effective Radiation Dose in a Skeletal Survey Performed for Suspected Child Abuse. *Journal of Pediatrics* 2016; 171: 310-312.http://ac.els-cdn.com/S0022347616000196/1-s2.0-S0022347616000196-main.pdf?_tid=aecd53e0-1f6f-11e7-af5d-00000aacb35e&acdnat=1491995199_ca5d6802d4abbed35254e72d2d51c86f.

239. Swinson S., Tapp M., Brindley R., *et al.* An audit of skeletal surveys for suspected non-accidental injury following publication of the British Society of Paediatric Radiology guidelines. *Clin Radiol* 2008; 63(6): 651-656. http://www.ncbi.nlm.nih.gov/pubmed/18455556.

240. Wood J.N., Feudtner C., Medina S.P., *et al.* Variation in occult injury screening for children with suspected abuse in selected US children's hospitals. *Pediatrics* 2012; 130(5): 853-860. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4074645/pdf/peds.2012-0244.pdf.

241. Wood J.N., Fakeye O., Mondestin V., *et al.* Development of hospital-based guidelines for skeletal survey in young children with bruises. *Pediatrics* 2015; 135(2): e312-320. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4306798/pdf/peds.2014-2169.pdf.

242. Wood J.N., French B., Song L., *et al.* Evaluation for Occult Fractures in Injured Children. *Pediatrics* 2015; 136(2): 232-240. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4516941/pdf/peds.2014-3977.pdf.

243. Harper N.S., Lewis T., Eddleman S., *et al.* Follow-up skeletal survey use by child abuse pediatricians. *Child Abuse & Neglect* 2016; 51: 336-342. http://sfx.ucl.ac.uk/sfx_local?sid=OVID:medline&id=pmid:26342432&id=doi:10.1016%2Fj.chiabu.2015.08.015&issn=0145-2134&isbn=&volume=51&issue=&spage=336&pages=336-42&date=2016&title=Child+Abuse+%26+Neglect&atitle=Follow-up+skeletal+survey+use+by+child+abuse+pediatricians.&aulast=Harper.

244. Lindberg D.M., Beaty B., Juarez-Colunga E., *et al.* Testing for abuse in children with sentinel injuries. *Pediatrics* 2015; 136(5): 831-838. http://pediatrics.aappublications.org/content/pediatrics/136/5/831.full.pdf.

245. Parisi M.T., Wiester R.T., Done S.L., *et al.* Three-dimensional computed tomography skull reconstructions as an aid to child abuse evaluations. *Pediatric Emergency Care* 2015; 31(11): 779-786.http://sfx.ucl.ac.uk/sfx_local?sid=OVID:embase&id=pmid:25198766&id=doi:10.1097%2FPEC.0000000000000199&issn=0749-5161&isbn=&volume=31&issue=11&spage=779&pages=779-786&date=2015&title=Pediatric+Emergency+Care&atitle=Three-dimensional+computed+tomography+skull+reconstructions+as+an+aid+to+child+abuse+evaluations&aulast=Parisi.

246. Kara M., Dikmen E., Erdal H.H., *et al.* Disclosure of unnoticed rib fractures with the use of ultrasonography in minor blunt chest trauma. *Eur J Cardiothorac Surg* 2003; 24(4): 608-613. http://www.ncbi.nlm.nih.gov/pubmed/14500082.

247. Mariacher-Gehler S., Michel B.A. Sonography: a simple way to visualize rib fractures. *AJR Am J Roentgenol* 1994; 163(5): 1268. http://www.ncbi.nlm.nih.gov/pubmed/7976923.

248. Fette A., Mayr J. Slipped distal humerus epiphysis in tiny infants easily detected and followed-up by ultrasound. *Ultraschall Med* 2012; 33(7): E361-363. https://www.thieme-connect.com/DOI/DOI?10.1055/s-0031-1281660.

249. Bixby S.D., Abo A., Kleinman P.K. High-impact trauma causing multiple posteromedial rib fractures in a child. *Pediatr Emerg Care* 2011; 27(3): 218-219. http://ssr-eus-go-csi.cloudapp.net/v1/assets?wkmrid=JOURNAL%2Fpemca%2Fbeta%2F00006565-201103000-00016%2Froot%2Fv%2F2017-05-30T205543Z%2Fr%2Fapplication-pdf.

250. Dedouit F., Mallinger B., Guilbeau-Frugier C., *et al.* Lethal visceral traumatic injuries secondary to child abuse: a case of practical application of autopsy, radiological and microscopic studies. *Forensic Sci Int* 2011; 206(1-3): e62-66. http://www.ncbi.nlm.nih.gov/pubmed/20875934.

251. Hong T.S., Reyes J.A., Moineddin R., *et al.* Value of postmortem thoracic CT over radiography in imaging of pediatric rib fractures. *Pediatr Radiol* 2011; 41(6): 736-748. https://link.springer.com/article/10.1007%2Fs00247-010-1953-7.

252. Yang K.M., Lynch M., O'Donnell C. "Buckle" rib fracture: an artifact following cardio-pulmonary resuscitation detected on postmortem CT. *Leg Med (Tokyo)* 2011; 13(5): 233-239. http://www.ncbi.nlm.nih.gov/pubmed/21795096.

253. Marti B., Sirinelli D., Maurin L., *et al.* Wormian bones in a general paediatric population. *Diagn Interv Imaging* 2013; 94(4): 428-432. http://www.ncbi.nlm.nih.gov/pubmed/23352712.

254. Sanchez T.R., Grasparil A.D., Chaudhari R., *et al.* Characteristics of Rib Fractures in Child Abuse-The Role of Low-Dose Chest Computed Tomography. *Pediatric Emergency Care.* 2016; 12. http://sfx.ucl.ac.uk/sfx_local?sid=OVID:embase&id=pmid:&id=doi:10.1097%2FPEC.0000000000000608&issn=0749-5161&isbn=&volume=&issue=&spage=no+pagination&pages=no+pagination&date=2016&title=Ped

iatric+Emergency+Care&atitle=Characteristics+of+Rib+Fractures+in+Child+Abuse-The+Role+of+Low-Dose+Chest+Computed+Tomography&aulast=Sanchez.

255. Lang C.A., Cox M.J., Flores G. Maltreatment in multiple-birth children. *Child Abuse Negl* 2013; 37(12): 1109-1113. http://www.ncbi.nlm.nih.gov/pubmed/23623445.

256. Wilson P.M., Chua M., Care M.*, et al.* Utility of head computed tomography in children with a single extremity fracture. *J Pediatr* 2014; 164(6): 1274-1279. http://www.ncbi.nlm.nih.gov/pubmed/24508443.

257. Harper N.S., Feldman K.W., Sugar N.F.*, et al.* Additional injuries in young infants with concern for abuse and apparently isolated bruises. *J Pediatr* 2014; 165(2): 383-388.e381. http://www.ncbi.nlm.nih.gov/pubmed/24840754.

258. Gunther W.M., Symes S.A., Berryman H.E. Characteristics of child abuse by anteroposterior manual compression versus cardiopulmonary resuscitation: case reports. *Am J Forensic Med Pathol* 2000; 21(1): 5-10. http://www.ncbi.nlm.nih.gov/pubmed/10739220.

259. Klotzbach H., Delling G., Richter E.*, et al.* Post-mortem diagnosis and age estimation of infants' fractures. *Int J Legal Med* 2003; 117(2): 82-89. http://www.ncbi.nlm.nih.gov/pubmed/12690504.

260. Kleinman P.K., Schlesinger A.E. Mechanical factors associated with posterior rib fractures: laboratory and case studies. *Pediatr Radiol* 1997; 27(1): 87-91. https://link.springer.com/article/10.1007%2Fs002470050073.

261. Plunkett J. Resuscitation injuries complicating the interpretation of premortem trauma and natural disease in children. *J Forensic Sci* 2006; 51(1): 127-130. http://onlinelibrary.wiley.com/doi/10.1111/j.1556-4029.2005.00027.x/abstract.

262. Martin P.S., Kemp A.M., Theobald P.S.*, et al.* Does a more "physiological" infant manikin design effect chest compression quality and create a potential for thoracic over-compression during simulated infant CPR? *Resuscitation* 2013; 84(5): 666-671. http://www.ncbi.nlm.nih.gov/pubmed/23123431.

263. Systematic Reviews: CRD's Guidance for Undertaking Reviews in Health Care. University of York; 2009.

264. Polgar A., Thomas S. Critical Evaluation of Published Research. In: 3rd edition ed. *Introduction to Research in the Health Sciences*. Melbourne: Churchill Livingstone; 1995. p.

265. A schema for evaluating evidence on public health interventions (version 4). Melbourne: National Public Health Partnership; 2002.

266. Weaver N., Williams J.L., Weightman A.L.*, et al.* Taking STOX: developing a cross disciplinary methodology for systematic reviews of research on the built environment and the health of the public. *Journal of Epidemiology and Community Health* 2002; 56(1): 48-55. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1732000/pdf/v056p00048.pdf.

267. Health Evidence Bulletins Wales: A systematic approach to identifying the evidence. Cardiff: Information Services UWCM; 2004.

268. Fleiss J.L. The statistical basis of meta-analysis. *Stat Methods Med Res* 1993; 2(2): 121-145. http://journals.sagepub.com/doi/abs/10.1177/096228029300200202?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed.

Appendix 1 – Methodology

We performed an all-language literature search of original articles, their references and conference abstracts published since 1950. The initial search strategy (it should be noted that Q4 required a separate search strategy) was developed across OVID Medline databases using keywords and Medical Subject Headings (MeSH headings) and was modified appropriately to search the remaining bibliographic databases. The search sensitivity was augmented by the use of a range of supplementary 'snowballing' techniques including consultation with subject experts and relevant organisations, and hand searching selected websites, non-indexed journals and the references of all full-text articles.

Standardised data extraction and critical appraisal forms were based on criteria defined by the National Health Service's Centre for Reviews and Dissemination.[263] We also used a selection of systematic review advisory articles to develop our critical appraisal forms.[79,264-267] Articles were independently reviewed by two reviewers. A third review was undertaken to resolve disagreement between the initial reviewers when determining either the evidence type of the article or whether the study met the inclusion criteria. Decisions related to inclusion and exclusion criteria were guided by Cardiff Child Protection Systematic Reviews, who laid out the basic parameters for selecting the studies.

Our panel of reviewers included paediatricians, paediatric radiologists, orthopedic surgeons, research officers, designated and named doctors and specialist nurses in child protection. All reviewers underwent standardised critical appraisal training, based on the CRD critical appraisal standards.[79]

Inclusion criteria

General criteria

Inclusion	Exclusion
Papers with all evidence types	Personal practice
English and non-English papers	Review papers
Papers from conferences – paediatric, radiology, orthopaedic	Management of fractures papers
Patients between 0-17 years of age	Papers where the population included adults and children
	Studies of non-abusive data only

Additional inclusion criteria specific review questions

1. Which fractures are indicative of abuse?

Inclusion	Exclusion
General inclusion criteria plus:	**General exclusion criteria plus:**
Comparative studies of children less than 17 years of age with fractures either abusive or non-abusive	Rank of abuse is 4 or 5 or mixed rank where relevant cases cannot be extracted
Non-comparative studies of other fracture types found in abuse where comparative data was unavailable	Studies addressing abusive/non-abusive fractures only
	Single case reports
	Studies of outcome or management of abusive fractures

2. What is the evidence for radiological dating of fractures in children?

Inclusion	Exclusion
General inclusion criteria plus:	**General exclusion criteria plus:**
Primary research addressing how you can date fractures radiologically in children up to 17 years of age	Underlying bone disease was present
	Criteria for dating was not detailed

3. What radiological investigations should be performed to identify fractures in suspected child abuse?

Inclusion	Exclusion
General inclusion criteria plus:	**General exclusion criteria plus:**
Children (0-17) who had radiological investigations to identify bone fractures in suspected child abuse	Studies where details on the yield from the investigations were not available
	Fatal abuse

4. Does cardiopulmonary resuscitation cause rib fractures in children?

Inclusion	Exclusion
General inclusion criteria plus:	**General exclusion criteria plus:**
External closed cardiopulmonary resuscitation (CPR)	Studies relating to complications or outcomes of CPR (other than rib fractures)
No underlying bone disease or child abuse as the cause of collapse	Inadequate quality of confirmation of fractures
Incidence of associated rib fractures was recorded	

Ranking of abuse

Distinguishing abuse from non-abuse is central to our review questions. As our reviews span more than 40 years, standards for defining abuse have changed markedly. We have devised the following ranking score where "1" indicates the highest level of confidence that abuse has taken place. These rankings are used throughout our systematic reviews (where appropriate).

Ranking	Criteria used to define abuse
1	Abuse confirmed at case conference or civil or criminal court proceedings or admitted by perpetrator
2	Abuse confirmed by stated criteria including multidisciplinary assessment
3	Abuse defined by stated criteria
4	Abuse stated but no supporting detail given
5	Suspected abuse

Ranking of evidence by study type

Ranking of evidence by study type	
T_1	Randomised controlled trial (RCT)
T_2	Controlled trial (CT)

T_3	Controlled before-and-after intervention study (CBA)
O_1	Cohort study/longitudinal study
O_2	Case-control study
O_3	Cross-sectional
O_4	Study using qualitative methods only
O_5	Case series
O_6	Case study
X	Formal consensus or other professional (expert) opinion (automatic exclusion)

Additional criteria for specific review questions

1. Which fractures are indicative of abuse?

As above.

2. What is the evidence for radiological dating of fractures in children?

Studies were graded for quality based upon study design, accurate documentation of time of injury and by standardised criteria for radiological dating.

3. What radiological investigations should be performed to identify fractures in suspected child abuse?

We also used the following ranking of skeletal survey (SS).

Ranking	Criteria used to define SS
1	SS to British Society of Paediatric Radiology/American College of Radiology standards, including oblique views of ribs
2	SS of all bones: axial/limbs/hands/feet/skull/pelvis/spine. Views taken specified
3	SS of skull/long bones/chest/pelvis. No mention of hands or feet
4	X-ray of skeleton including multiple bone radiology. No definition of what this included
5	Baby-gram

4. Does cardiopulmonary resuscitation cause rib fractures in children?

The authors were careful to give the cause of cardiorespiratory collapse and ranks 4/5 were excluded prior to abuse.

Definition of levels of evidence and grading practice recommendations

Practice recommendations.[263,266] This classification is based on the Bandolier system adapted to include the Centre for Reviews and Dissemination's guidance for undertaking reviews.[263]

Grade	Level	Type of evidence
A	Ia	Evidence obtained from a well-designed randomised controlled trial of appropriate size (T1)
B	Ib	Evidence obtained from a well-designed controlled trial without randomisation (T2, T3)
B	IIa	Evidence obtained from a well-designed controlled observational study e.g. cohort, case-control or cross-sectional studies. (Also include studies using purely qualitative methods) (O1, O2)
C	IIb	Evidence obtained from a well-designed uncontrolled observational study (O3, O4)
C	III	Evidence obtained from studies that are case study or case series (O5, O6)

Search strategy

Medline search strategy used for the 2017 fractures search questions 1-3:

1. Which fractures are indicative of abuse?

2. What is the evidence for radiological dating of fractures in children?

3. What radiological investigations should be performed to identify fractures in suspected child abuse?

1. Child abuse.mp. 2. child protection.mp. 3. (battered child or shaken baby or battered baby).mp. 4. 1 or 2 or 3 5. (child: or infant: or baby or toddler:).mp. 6. CHILD/ 7. CHILD, PRESCHOOL/ 8. 5 or 6 or 7 9. non-accidental injur:.mp. 10. (non-accidental trauma or nonaccidental trauma).mp.	23. pelvic fractur:.mp. 24. (spiral fractur: or transverse fractur:).mp. 25. metaphyseal fractur:.mp. 26. (corner fractur: or bucket handle fractur:).mp. 27. metaphyseal chip fractur:.mp. 28. classic metaphyseal lesion:.mp. 29. or/16-28 30. (investigat: adj3 fract:).mp. 31. (radiolog: adj3 fractur:).mp. 32. (roentgen: adj3 fract:).mp. 33. skeletal survey.mp.

11. (non-accidental: and injur:).mp. 12. soft tissue injur:.mp. 13. physical abuse.mp. 14. (or/9-13) and 8 15. 4 or 14 16. Fractures, Ununited/or Radius Fractures/or Fractures, Malunited/or Tibial Fractures/or Fractures, Bone/ or Rib Fractures/ or Femoral Neck Fractures/or Femoral Fractures/or Humeral Fractures/or Shoulder Fractures/or Fractures, Compression/or Fractures, Cartilage/or Hip Fractures/or Intra-Articular Fractures/or Fractures, Open/or Fractures, Closed/or Fractures, Comminuted/ 17. fractur:.mp. 18. Fractures, Bone/ 19. rib fractur:.mp. 20. (multiple skull fractur: or eggshell fractur: or skull fractur:).mp. 21. femoral fractur:.mp. 22. humeral fractur:.mp.	34. ((paediatric or pediatric) adj3 radiolog:).mp. 35. ((paediatric or pediatric) adj3 nuclear medicine).mp. 36. Tomography, X-Ray Computed/ 37. Scintigraphy.mp. 38. (bone scan or X rays).mp. 39. skeletal survey.mp. 40. isotope bone scan:.mp. 41. or/30-40 42. healing.mp. 43. (timing adj3 healing).mp. 44. (pattern: adj3 fractur:).mp. 45. ((dating or date) adj3 fractur:).mp. 46. (ag: adj3 fractur:).mp. 47. or/42-46 48. 41 or 47 49. 15 and 29 and 48 50. 8 and 29 and 47 51. 49 or 50 52. limit 51 to (humans and yr="2014 -Current") 53. limit 52 to humans

Medline search strategy used for the 2017 fractures search question 4: Does cardiopulmonary resuscitation cause rib fractures in children?

1 exp child/ 2 CHILD, PRESCHOOL/ 3 exp Infant, Newborn/ 4 (child* or babies or baby or toddler*).mp. 5 (infancy or infant* or neonat*).tw. 6 (pediatric* or paediatric*).tw. 7 or/1-6 8 metaphyseal fractur*.mp.	14 Wounds, Nonpenetrating/ 15 Thoracic Injuries/ 16 thoracic Injur*.tw. 17 ((rupture or trauma or injur*) adj3 (chest or lung or rib)).tw. 18 or/8-17 19 exp Cardiopulmonary Resuscitation/ 20 cardio-pulmonary resuscitation.mp. 21 CPR.mp.

9 rib fractur*.mp	22 cardiac massage.mp.
10 clavicle fractur*.mp.	23 heart massage.mp.
11 Rib Fractures/	24 or/19-23
12 Diaphragm/in [Injuries]	25 7 and 18 and 24
13 "Wounds and Injuries"/	26 limit 25 to yr="2014-Current"

Erratum

Please note that the **final search string** is missing from the search strategy published in the following publication

Kemp AM, Dunstan F, Harrison S, Morris S., Mann M, Rolfe K, Datta S, Thomas DP, Sibert JR, Maguire S. Patterns of skeletal fractures in child abuse: systematic review. British Medical Journal. 2008;337:a1518 [Pubmed]

The correct search strategy (at the time of publication of this paper) is found below:

1. Child abuse.mp.
2. child protection.mp.
3. (battered child or shaken baby or battered baby).mp.
4. 1 or 2 or 3
5. (child: or infant: or baby).mp.
6. non-accidental injur:.mp.
7. non-accidental trauma.mp.
8. (non-accidental: and injur:).mp.
9. soft tissue injur:.mp.
10. physical abuse.mp.
11. (or/6-10) and 5
12. 4 or 11
13. fractur:.mp.
14. 12 and 13
15. (investigat: adj3 fract:).mp.
16. (radiolog: adj3 fractur:).mp.
17. (roentgen: adj3 fract:).mp.
18. skeletal survey.mp.
19. bone scan:.mp.

20. Isotope Bone Scan:.mp.

21. Radionuclide.mp.

22. Scintigraphy.mp.

23. Tomography, X-Ray Computed/

24. ((paediatric or pediatric) adj3 radiolog:).mp.

25. ((paediatric or pediatric) adj3 nuclear medicine).mp.

26. or/15-25

27. (ageing adj3 fractur:).mp.

28. ((dating or date) adj3 fractur:).mp.

29. (pattern: adj3 fractur:).mp.

30. healing.mp.

31. or/27-30

32. 26 or 31

33. 14 and 32

Databases searched

Databases searched for both cardiopulmonary resuscitation and fractures review:

Databases	Time period searched
ASSIA (Applied Social Sciences Index and Abstracts)	1987 – 2020
Child Data	1958 – 2009†
CINAHL (*Cumulative Index to Nursing and Allied Health Literature)*	1982 – 2020
Cochrane Central Register of Controlled Trials (CENTRAL)	1996 – 2020
EMBASE	1980 – 2020
MEDLINE	1950 – 2020
MEDLINE In-Process and Other Non-Indexed Citations	1951 – 2020
Open SIGLE (System for Information on Grey Literature in Europe)	1980 – 2005*
Scopus	2009 – 2017
Social Care online (previously Caredata)	1970 – 2015
Trip Plus	1997 – 2005‡
Web of Knowledge – ISI Proceedings	1990 – 2020
Web of Knowledge – ISI Science Citation Index	1981 – 2020

Web of Knowledge – ISI Social Science Citation Index	2008 – 2020
* ceased indexing † institutional access terminated ‡ no yield so ceased searching	
Journals 'hand searched'	**Time period searched**
Child Abuse and Neglect	1977 – 2015
Child Abuse Review	1992 – 2015
Websites searched	**Date accessed**
The Alberta Research Centre for Health Evidence (ARCHE)	January 2015
Child Welfare Information Gateway (formerly National Clearinghouse on Child Abuse and Neglect)	January 2015

Pre-review screening and critical appraisal

Papers found in the database and hand searches underwent three rounds of screening before they were included in this update. The first round was a title screen where papers that obviously did not meet the inclusion criteria were excluded. The second was an abstract screen where papers that did not meet the inclusion criteria based on the information provided in the abstract were excluded. In this round the pre-review screening form was completed for each paper. These first two stages were carried out by systematic reviewer at the RCPCH and a clinical expert. Finally, a full text screen with a critical appraisal was carried out by members of the panel of expert reviewers. Critical appraisal forms were completed for each of the papers reviewed at this stage. Examples of the pre-review screening and critical appraisal forms used in previous reviews are available on request (evidence@rcpch.ac.uk).

Meta-analysis

We analysed data according to fracture sites. Where it was possible to obtain overall estimates of the probability of abuse for a particular fracture type from cross-sectional studies, we undertook a meta-analysis and presented the result as forest plots.

We pooled estimates from individual studies using the method of De Simonian and Laird, deriving a confidence interval for the pooled estimate and testing for heterogeneity between studies.[268] Given the varied nature of the studies, our work was inevitably a pooled estimate of different populations rather than a single one. Insufficient detail was shown in most papers to be able to analyse by age and so in the forest plots the studies were ranked in increasing order of mean age in the abused cases, as far as was possible. The results were generally summarised as the proportion of children with a given fracture type who are classed as abused – that is the

predictive value of the fracture type for identifying abuse. Proportions were compared between groups using the chi-square test or Fisher's exact test where that was appropriate.

Appendix 2 - Related publications

Publications arising from fractures review

- Prosser I, Maguire S, Harrison S, Mann M, Sibert J, Kemp A. Review. How old is this fracture? Radiological dating of fractures in children: a systematic review. American Journal of Roentgenology. 2005;184(4):1282-1286
- Maguire S, Mann M, John N, Ellaway B, Sibert JR, Kemp AM. Does cardiopulmonary resuscitation cause rib fractures in children? A systematic review. Child Abuse and Neglect. 2006;30(7):739-751
- Which radiological investigations should be performed to identify fractures in suspected child abuse? Clinical Radiology. 2006;61(9):723-736
- Kemp AM, Dunstan F, Harrison S, Morris S., Mann M, Rolfe K, Datta S, Thomas DP, Sibert JR, Maguire S. Patterns of skeletal fractures in child abuse: systematic review. British Medical Journal. 2008;337:a1518
- Kemp AM. Fractures in physical child abuse. Paediatrics and Child Health. 2008;18(12):550-553
- Maguire S, Cowley L, Mann M, Kemp A. What does the recent literature add to the identification and investigation of fractures in child abuse: an overview of review updates 2005 - 2013. Evidence Based Child Health: A Cochrane Review Journal. 2013;8(5):2044-2057.

Primary studies arising from fractures review

- Prosser I, Lawson Z, Evans A, Harrison S, Morris S, Maguire S, Kemp AM. A timetable for the radiologic features of fracture healing in young children. American Journal of Roentgenology. 2012;198(5):1014-1020
- Cosway B, Mathura N, Mott A, Bredow M, Fraser J, Rawlinson A, Wei C, Thyagarajan M, Harrison S, Kemp A. Occult rib fractures: Defining the cause. Child Abuse Review. 2013.

Appendix 3 – Flow of studies

2020 update