Child Protection Evidence
Systematic review on Fractures

Last updated: February 2015

The Royal College of Paediatrics and Child Health (RCPCH) is a registered charity in England and Wales (1057744) and in Scotland (SC038299)

Original reviews and content © Cardiff University, funded by NSPCC
Published by RCPCH July 2017

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.
# Table of contents

Summary ................................................................. 4  
Background ................................................................. 5  
Methodology ................................................................. 5  

Findings of clinical question 1 .................................................. 5  
1.1 Rib fractures ................................................................. 6  
1.2 Costochondral junction fractures ........................................... 7  
1.3 Femoral fractures ............................................................ 8  
1.4 Humeral fractures ........................................................... 9  
1.5 Skull fractures ............................................................... 10  
1.6 Metaphyseal fractures ....................................................... 11  
1.7 Pelvic fractures .............................................................. 13  
1.8 Fractures of the hands and feet ............................................. 14  
1.9 Mandibular fractures ......................................................... 14  
1.10 Sternal fractures ............................................................ 15  
1.11 Clavicular fractures ......................................................... 15  
1.12 Vertebral fractures ......................................................... 15  
1.13 Implications for practice .................................................... 15  
1.14 Limitations of review findings ............................................ 16  

Findings of clinical question 2 .............................................. 17  
2.1 Implications for practice ................................................... 19  
2.2 Research implications ....................................................... 19  
2.3 Limitations of review findings ............................................ 19  

Findings of clinical question 3 .............................................. 20  
3.1 Skeletal survey versus radionuclide imaging ......................... 20  
3.2 Skeletal surveys ............................................................ 21  
3.3 Less common abusive fractures ......................................... 25  
3.4 Occult fractures ............................................................ 26  
3.5 Implications for practice .................................................... 28  
3.6 Research implications ....................................................... 30  
3.7 Limitations of review findings ............................................ 30
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). Additional large scale studies have enabled a revised meta-analysis by age group which may be of value to practitioners in determining probability of abuse for a child presenting with unexplained fractures (4).

There are increasing numbers of high quality studies being published in this field. These continue to address the value of yield of skeletal surveys in different populations in addition to detailing specific fracture patterns associated with abuse. One new study addresses healing of fractures in very young infants addressing a previously ignored area, contributing to the timetable for the dating of fractures.

Fractures in physical child abuse denote severe assault and it is essential that they are identified if present. Changing guidelines with regard to cardiopulmonary resuscitation (CPR) in infants may have a bearing on the risk of rib fractures and recent studies have addressed this.

This systematic review evaluates the scientific literature on abusive and non-abusive fractures in children published up until February 2015 and reflects the findings of eligible studies. The review aims to answer four clinical questions:

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

Key findings:

- Fractures in children less than 18 months of age should be assessed for possible child abuse
- Multiple fractures are more suspicious of abuse
- The dating of fractures is an inexact science, the radiological features of bone healing represent a continuum, with considerable overlap
- Radiological estimates of time of injury are in terms of weeks rather than days. It is vital that all investigating agencies are aware of these broad time frames
- Either skeletal survey (SS) or radionuclide imaging (RNI) alone will miss occult fractures; optimal assessment should include both investigations
- If RNI is the first line of investigation, an additional skull X-ray must be performed and coned views of the metaphyses should be considered
- Recent studies suggest that up to 12% of household contacts aged less than two may have a positive SS with twins being a particularly high risk
Background

This systematic review evaluates the scientific literature on abusive and non-abusive fractures in children published until February 2015 and reflects the findings of eligible studies. The review aims to answer two clinical questions:

- Which fractures are indicative of abuse?
- What is the evidence for radiological dating of fractures in children?
- What radiological investigations should be performed to identify fractures in suspected child abuse?
- 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 and also for study types.

Findings of clinical question 1

Which fractures are indicative of abuse?

Age

- 85% of accidental fractures occurred in children over five years of age(5)
- 80% of abusive fractures, occurred in children under 18 months of age(5)
- Three studies examined children under one year of age: 67 abused, 115 non-abused(6-8)
- Overall, 25 – 56% of all fractures in children under one year of age were due to abuse(6-9)
- The highest incidence of abusive fractures was in children under four months of age (p=0.0007)(8)
- Abusive fractures were more common in children less than one year of age than in those older than two years(10)
• In a study of children under 4 years old, the mean age for accidental fractures was 22.1 months (95%CI 21.2, 24.02 months). The mean age of abuse cases was 11.7 months (95%CI 10.6, 12.7 months)(11)
• Children with abusive fractures were significantly younger (p<0.001)(11)

Gender
• One study showed that abusive fractures were more common in boys (p=0.024)(10)
• No gender difference was noted in children aged less than one year(6-8)
• No gender difference was found in children aged less than four years (p=0.065)(11)

Influence of ethnicity and socio-economic group
• Two studies analysed by ethnicity(10, 12)
• Black children were abused more than white (p<=0.01)(12)
• No difference in ethnicity was found(10)
• No significant differences by socio-economic grouping(10)

Multiple fractures
• Abused children were more likely to have multiple fractures than non-abused children (p<0.001)(5, 10)
• One study found no difference(6)

1.1 Rib fractures

Age range: 0-15 years
• In children less than four years of age rib fractures were more commonly found in those abused than those accidentally injured(11, 13)
• In those aged 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)(11)
• In those aged over 18 months with rib fractures the OR for abuse was 9.1 (95%CI 3.3, 25) (p<0.001)(11)
• Ten studies had a high abuse ranking of one or two(5, 11, 13-20)
• No study addressed disabled children
• No study addressed the influence of ethnicity and socio-economic group

Meta-analysis
• Of the studies included up to 2012, seven were suitable for meta-analysis(14-16, 21-24)
• However since 2013 we have restricted the meta-analysis to children less than 48 months of age(11, 14, 16, 23)
• These four studies include children with confirmed or suspected abuse but showed no heterogeneity ($I^2=0\%$)
• The positive predictive value for rib fractures in relation to suspected or confirmed abuse is 66% (95% confidence interval 42.5-89.7)
• The key new study was a very large-scale case-control study(11)

**Number and location of abusive rib fractures**

• In one study investigating fractures in young children, rib fractures were the most strongly associated with abuse(21)
• In another study, the most prevalent injuries in the child abuse group following non-bony head injury and skull fractures were rib fractures(10)

**Multiple rib fractures**

• Abused children had multiple rib fractures(5, 13, 14, 16, 17, 22, 25). This included a comparison with children with metabolic bone disease(17)
• Flail chest due to multiple rib fractures in infant physical abuse is reported in one study(18)
• One study reported that the risk of mortality increases with the number of ribs fractured(21)

**Location of fractures**

• Abusive rib fractures were recorded at any location on the rib and were unilateral or bilateral(5, 14, 16, 19, 22, 26)
• Anterior fractures were more common in abuse whilst lateral fractures were more common in non-abused children(14, 16)
• Seven studies stated that posterior rib fractures were the predominant abusive fracture, detailed breakdown was not given(14, 15, 20, 23-25, 27)
  o One study found posterior and postero-lateral rib fractures to be equally common in abuse and metabolic bone disease(17)

**First rib fractures**

Two studies (23, 28) report:

• Five cases of abusive first rib fractures were recorded(23)
• Predominantly lateral, one posterior.(23, 28) Four had no fracture to adjacent bones(23)
• Four had associated neurological injury(23)

**1.2 Costochondral junction fractures**

• Anterior costochondral fractures are described in abuse(26, 28)
• They may be difficult to visualise radiographically and can occur with associated abdominal injuries(26)
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(13)

1.3 Femoral fractures

Meta-analysis

- Of the studies included up to 2012, 13 were suitable for meta-analysis(7, 12, 29-39)
- Since 2013, the meta-analysis is sub-divided into children aged 0-18 months with confirmed or suspected abuse(7, 31-34, 37, 39-41) and children aged 12-48 months with confirmed or suspected abuse(31-34, 36, 39, 40)
- For children aged 0-18 months there was no 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% confidence interval 34.1-66.1)
- For 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% confidence interval 6.1-17.3)
- This is consistent with the observation that children who are not independently mobile are far less likely to sustain an accidental femoral fracture(31)

Age

- Femoral fractures in the abuse group occurred predominantly in children less than one year of age(5, 7, 8, 10, 12, 30, 32-36, 38, 39, 41, 42)
- Abused children less than 18 months of age (17.5%, 66/377) were more likely to sustain a femoral fracture than those aged 18 months or over (5.7%, 7/123). In contrast, accidentally injured children were more likely to sustain a femoral fracture aged 18 months old or over than below this age (p<0.001)(11)
- The odds ratio (OR) for abuse in a child aged less than 18 months with a femoral fracture was 1.8 (95%CI 1.2, 2.7) (p=0.005)(11)
- The OR for abuse in a child aged 18 months or over with a femoral fracture was 0.3 (95%CI 0.1, 0.7) (p=0.003)(11)
- A third of isolated femoral fractures in children less than three years of age were abusive(38)
- Spiral fracture was the most common abusive fracture in children under 15 months old (p=0.05); over this age spiral fracture was not significantly commoner in abused children(38)
- No specific fracture type in children aged 0 – 3 years was associated with abuse(41)
- There was a highly significant association between femoral fracture in non-ambulant children and abuse(31, 41)
• The median age of the abuse cases was lower (4 months) versus accidental (26.2 months) (p<0.001)(40)

Fracture type
• The commonest fracture location in both abused and non-abused children children was mid-shaft of the femur(5, 7, 30, 32, 35, 36, 38, 43-45)
• Proximal physeal injuries were noted in abused children(35, 44, 46, 47)
• Impacted transverse fractures of the distal femoral metadiaphysis were noted to be non-abusive in 13/22 (72%) cases versus five (28%) abused cases. The mean age did not differ between the two groups (abuse eight months, non-abuse 12 months). This was a highly selected case series ascertained through child protection specialists(48)
• Diaphyseal fractures were more common in accidental than abusive injury (p=0.007)(40)
• Distal femoral fractures were more common in abused than accidentally injured children (p=0.01)(40)

Femoral shaft fractures
• Transverse femoral fractures were more commonly associated with abuse than accidental injury(43)
• No association between spiral fracture and abuse was confirmed with this population of children aged less than three years(43)
• Metaphyseal fractures were recorded in more abusive femoral fractures than non-abusive fractures(5, 28, 34, 35, 45)
  o 10/20 complete distal femoral metaphyseal fractures occurring in children aged less than one year were due to abuse(49)
  o Accidental causes of metaphyseal fractures included birth injury, motor vehicle collision and falls(49)

1.4 Humeral fractures
• Out of 540 studies reviewed, 14 studies addressed humeral fractures(5, 7, 10-12, 32, 42, 50-56)

Meta-analysis
• Of the studies included up to 2012, four were suitable for meta-analysis(7, 12, 32, 56)
• Since 2013, two separate meta-analyses have been conducted, one for age 0-18 months(7, 32, 54-56) and one for 18-48 months(32, 54-56)
• There was no heterogeneity between the studies of children aged 0-18 months (I²=0%)
• For children aged 0-18 months with confirmed or suspected abuse the positive predictive value (PPV) of a humeral fracture is 43.8% (95% confidence interval 27.6-59.9)
• The largest case-control study addressing this highlighted that age less than 18 months, in conjunction with prior injury and suspicious history are significant indicators of an abusive aetiology
• 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% confidence interval 0-3.9)

**Age of children with humeral fractures**

• Children aged less than 15 months were more likely to sustain an abusive humeral fracture (9/25, 36%) than those aged 15-36 months (1/99, 1%) $p<0.05$ (56)
• 74/111 of abusive humeral fractures occurred in children under one year of age (42)
• 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% confidence interval (CI) 1.3, 4.1) $p=0.004$ (11)
• For a child aged more than 18 months with a humeral fracture the OR for abuse was 0.29 (95%CI 0.1, 0.7) $p=0.005$ (11)
• In a study of children aged less than four years with humeral fracture, a multivariate analysis was used to develop an algorithm to identify abuse (54)
  Abused children tended to be younger than those who were accidentally injured $p>0.001$ (54)

**Fracture type**

• Four studies confirmed that spiral or oblique humeral fractures in children less than five years of age were strongly associated with abuse (5, 10, 55, 56)
• Humeral shaft fractures were more frequently due to abuse (54)
• Supracondylar fractures were overwhelmingly due to accidents (5, 51, 54, 56)
• Fracture dislocation of the proximal or distal humeral epiphysis was described in abused and accidentally injured children (50, 52, 53):
  o **Age range**: from 0 - 7 years, the majority were under three years (50, 52, 53)
  o Epiphyseal humeral fractures are difficult to visualise (50, 52, 53)
  o Visualisation may be enhanced by the use of ultrasound or magnetic resonance imaging'scanning (50, 52, 53)

### 1.5 Skull fractures

**Meta-analysis**

• Of the studies included up to 2012, seven were suitable for meta-analysis (6, 7, 12, 57–60)
• Since 2013, the meta-analysis has been conducted on children aged 0-48 months (6, 11, 12, 58, 59)
• There was no 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\% confidence interval 13.3-26.9).

• Contrary to the other fractures analysed, age less than 18 months does not appear to be a key variable. In one study, in children aged less than 18 months skull fractures were more common in the control subjects than those who were abused.

**Age of children with skull fractures**

• All studies included pre-school children, five only included children less than one year of age (6–8, 57, 60).

• Skull fractures of either aetiology (abuse or accident) appear commoner in younger infants (6, 7, 11, 12, 57, 58, 60).

• In 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 (10).

• Skull fractures were more frequent in accidental trauma than abuse ($p=0.002$ in those aged less than 18 months, $p<0.001$ for those older than 18 months (11)).

**Fracture type**

• Meservy et al studied 134 children aged less than two years old (motor vehicle accident excluded), 39 of whom were abused (58).

• Multiple or bilateral fractures, or those that crossed suture lines, were more common in abused children, $p<0.05$ (58).

• No significant differences were recorded between the two aetiology groups with relation to nonparietal, depressed, diastatic $>/3$mm or complex fractures (58).

• The commonest abusive and non-abusive fractures were linear (5, 10, 58, 59).

• In a series of alleged short distance fall victims, four children aged between two days and 18 months exhibited bilateral linear skull fractures (61).

### 1.6 Metaphyseal fractures

**Age**

These studies all relate to live children (5, 6, 10, 28, 35, 62).

• A study of 215 children aged less than three years old described 13 abusive humeral fractures, including metaphyseal fractures (10).

• A study of 34 infants aged less than one year old (6):
  - 19 long bone fractures and five metaphyseal fractures were recorded.
No differentiation between abusive and non-abusive by fracture type is given in this study.

A study of 60 infants aged less than one year of age, 42 of whom were deemed ‘low risk’ of abuse and 18 ‘high risk’ (abuse rank two) determined that 9 / 18 children in the high risk but no child with a ‘low risk’ had classic metaphyseal lesions (CML): The CML involved all long bones but, more frequently, femur and tibia. 55% of CML were found around the knee.

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

A study of 826 children with accidental fractures and 35 children under five years old with abusive fractures: 17 metaphyseal corner fractures were noted among the abused children, all aged less than 18 months old. There were no metaphyseal fractures in the accident group.

A study of infants aged less than one year showed the mean age of those with metaphyseal fractures was 4 months: 15 out of 50 had bilateral symmetrical lower extremity metaphyseal fractures. 42 out of 48 children with CML had positive skeletal survey for occult fractures. One nine day old infant had CML as a consequence of birth.

Fatally abused children with metaphyseal fractures

Five studies by Kleinman et al(63-67) delineated the histologic / radiologic correlates of classical metaphyseal fractures in 31 fatally abused infants.

**Age range:** three weeks – 10.5 months (mean: three months)

There were 165 fractures in the 31 children; 72 long bone fractures; 64 (89%) were classical metaphyseal lesions in 20 children. The ‘commonest abusive fracture’ found was metaphyseal. The ‘commonest site’ was the tibia. The fractures were commonly bilateral and symmetrical.

Specimen radiography increased the yield of fractures noted on skeletal survey from 58% to 92%.
Tibial and fibular fractures

- One study noted 96% (23/24) of all tibial or fibular fractures were abusive in children under 18 months (37).
- In children less than three years old, 14 / 35 tibial and fibular fractures were from abuse (10).
- A small study identified abuse in 1 / 8 tibial and fibular fractures (12).
- Worlock reported abusive tibial and fibular fractures in children < 18 months of age but not in older toddlers (5).
- 7/12 abusive tibial fractures in infants were metaphyseal (5).
- Tibia and fibular fractures were commoner in abuse than accidental injury (p < 0.001) in children under four years old (11).
- The odds ratio (OR) for abuse in a child aged less than 18 months with a tibial / fibular fracture is 12.8 (95% confidence interval (CI) 5.1, 32.6) p < 0.001 (11).
- The OR for abuse in a child older than 18 months is 2.1 (95% CI 0.7, 6.2) p = 0.172 (11).

Radial and ulnar fractures

- The majority of non-abusive fractures were greenstick. Worlock identified metaphyseal ulnar fractures in the abused group only (5, 10-12).
- In children aged less than 18 months old radial/ulnar fractures were more common in the abused than the control group (p = 0.001) (11).
- In children less than four years of age with a radius / ulnar fracture, the OR for abuse is 5.8 (95% CI 2.4, 14.3) p < 0.001 (11).

1.7 Pelvic fractures

- The majority of children had suffered from multiple additional injuries (42, 68-74).
- Two studies reported three infants: one child had up to 29 additional fractures recorded (69, 74).
- One study reported two case reports: one child had multiple burns and pelvic fractures; one was fatally abused due to associated intra-abdominal injuries (73).
- Five studies included children with pelvic fractures with associated suspected or confirmed sexual abuse definite (68, 70, 71, 73, 75):
  - One of these children was disabled and non-verbal (70).
- 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) (72).
- 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 MRI and on the two week follow-up skeletal survey(69)

1.8 Fractures of the hands and feet

- 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(11)
- Two cross-sectional studies showed that fractures to the hands and feet were present in 1.4% in all children less than ten years being evaluated for child abuse(76), and in 5-5.5% of children less than two years undergoing skeletal survey(28, 76)
  - 47/56 children with fractures to the hands and feet were aged less than two years(28, 75)
  - The mean age of the children with fractures to the hands was 14.1 months, range 5.6-22.4 months. The mean age of children with fractures to the feet was 10 months, range 1.3-13.6 months(76)
  - One study showed the mean age of fractures to the hands or feet was 5 months (range 1-10 months)(28)
  - The mean number of hand fractures per child was 2, 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(76)
- 22 fractures of the hands and feet in 11 abused infants(77):
  - Torus fractures predominated
  - 7/11 infants had additional fractures of the ipsilateral extremity
- Among sixteen infants with fractures to hands or feet metatarsals were the most common site of injury and Transverse or buckle type fractures were present in 75%(28):
  - All infants with hand or feet fractures had additional fractures
- Two case reports:
  - Six month old with fractures of second to fifth metatarsals bilaterally, and associated fractures of radius and ulna(78)
  - A ten year old with multiple bilateral phalangeal fractures of different ages thought to be secondary to hyper-extension(79)

1.9 Mandibular fractures

- One study describes a mandibular fracture after a direct blow in a six month old(80)
- Abusive mandibular fractures occurred in all age groups(81)
- In contrast to other abusive fractures, mandibular fractures were not associated with other injuries(81)
1.10 Sternal fractures

- Data: 12 children; two abused
- Age range: 1.5 – 15.5 years
- Both abusive cases were less than three years old
- One had associated long bone fractures

1.11 Clavicular fractures

- Age range: 0 – 5 years
- 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(11)
- For a child aged less than four years with a clavicular fracture the odds ratio (OR) for abuse is 4.4 (95% confidence interval (CI) 1.9, 10.2) p=0.001(11)
- Clavicular fractures were identified in 18% of abused children less than 18 months versus 5% of those accidentally injured(5)
- For those aged 18 to 60 months, 14% of the abused children versus 12% of the accidentally injured children had clavicular fractures(5)
- One study noted that 4 of 23 abused infants had bilateral clavicular fractures due to abuse. 10 out of 23 infants had further occult fractures on skeletal survey(28)

1.12 Vertebral fractures

The following included studies contain findings on vertebral fractures(28, 82-95).

We conducted a Spinal Injuries systematic review that was jointly run between our Fractures and Neurological Injuries reviews, since injury to the spine can consist of both spinal fractures and injury to the spinal cord. Therefore, any specific details relating to the studies of vertebral fractures can be found in the Spinal Injuries section.

1.13 Implications for practice

- Fractures in children less than 18 months of age should be assessed for possible child abuse
- Multiple fractures are more suspicious of abuse

Rib fractures

- 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

**Femoral fractures**
• Femoral fractures in children less than 18 months of age are more likely to be due to abuse
• Significantly more abusive femoral fractures arise in children who are not yet walking
• Mid-shaft fracture is the commonest fracture in abuse and non-abuse (analysed for all age groups)

**Humeral fractures**
• The majority of accidental humeral fractures in children are supracondylar and the commonest abusive humeral fractures in children aged less than five years are spiral or oblique
• Humeral fractures in those aged less than 18 months has a stronger association with abuse than those in older children

**Skull fractures**
• Both abusive and non-abusive skull fractures are commoner in younger infants
• Linear fractures are the commonest abusive and non-abusive skull fracture

**Metaphyseal fractures**
• Metaphyseal fractures are more commonly described in physical child abuse than in non-abuse
• Classical metaphyseal lesions will only be found if rigorous radiological techniques are applied
• Metaphyseal fractures have been frequently described in fatal abuse

**Other fractures**
• Vertebral, pelvic, hands, feet and sternal fractures occur in physical abuse: appropriate radiology is required for detection
• Vertebral fractures may be unstable, early identification is important
• The presence of tibia/fibula fractures in a child aged less than 18 months is strongly associated with child abuse

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 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 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?

• **Age range**: 0-17 years Two studies found no correlation between the age of the child and fracture dating(96, 97)
• **Gender**: two studies found no correlation between gender and the dating of fractures(96, 97)
• No study addressed fracture dating in **disabled children**
• No study addressed the influence of **ethnicity and socio-economic group**
• Two studies ascertained children who had been abused, and the authors felt they could identify the timing of the injury(98, 99)
  o Halliday et al’s study 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(98)
  o Sanchez et al, studying 16 infants, evaluated callus formation as an indicator of healing(99)
• Three studies defined different **radiological criteria for fracture dating**, one on immobilised forearm(97), one on femoral fractures(100), and one on all long bones, predominantly upper limb(101)
• Three studies agreed that hard callus and early remodelling(99) is seen at eight weeks in the majority of cases(97, 102)
• One of the most recent studies demonstrated that the peak period for a hard callus is at 3 weeks or greater and remodelling at five weeks or greater(101)
• Cumming’s study estimated the earliest calcification at fracture site in 23 newborns, calcified periosteal reaction was noted as early as seven days(96)
• In one study levels of agreement between three radiologists regarding the timing of radiological features was only deemed ‘moderate’, apart from recognition of periosteal reaction(98)
• In another, levels of agreement between three radiologists were high amongst all radiographs, however the presence of a cast limited interpretation for some images(101)
A study exploring the rate of radiological healing in **newborn infants** evaluated 131 infants with clavicular fracture aged 0-93 days. A timetable of healing according to standardised criteria was developed.

### Summary of the dating characteristics identified

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture gap widening</td>
<td>4-6 weeks 56% (2-8 weeks)</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>4-6 weeks 56% (2-8 weeks)</td>
<td>Did not assess</td>
<td>Did not assess</td>
</tr>
<tr>
<td>Periosteal reaction presence (Stage 1)</td>
<td>9-10 days (7-11 days)</td>
<td>1.6 weeks (1-3 weeks)</td>
<td>4-7 weeks 100% (2 weeks onwards)</td>
<td>(4-11 days)</td>
<td>15-35 days (5-96 days)</td>
<td>(1-3 weeks)</td>
<td>10 days (8-14 days)</td>
</tr>
<tr>
<td>Marginal sclerosis</td>
<td>4-6 weeks 85% (2-11 weeks)</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>Did not assess</td>
</tr>
<tr>
<td>1st callus</td>
<td>4-7 weeks 100% (2 weeks onwards)</td>
<td>(4-11 days)</td>
<td>22-35 days (12-66 days)</td>
<td>(3-5 weeks)</td>
<td>Started at 10 days, peaked at 15 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Callus density &gt; cortex</td>
<td>13 weeks 90% (4 weeks onwards)</td>
<td>Did not assess, however = density noted (16-34 days)</td>
<td>≥ 22 days (19-96 days)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridging (Stage 2)</td>
<td>2.6 weeks (1.5-3.7 weeks)</td>
<td>13 weeks 50% (3 weeks onwards)</td>
<td>Earliest seen at 13 days, present on all films &gt; 20 days</td>
<td>≥ 36 days (19-300 days)</td>
<td>(7-9 weeks)</td>
<td>Did not assess</td>
<td></td>
</tr>
<tr>
<td>Periosteal incorporation</td>
<td>14 weeks (7 weeks onwards)</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td>Did not assess</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remodelling (Stage 3)</td>
<td>8 weeks (5-11 weeks)</td>
<td>9 weeks (4 weeks onwards)</td>
<td>Did not assess</td>
<td>≥ 36 days (45-421 days)</td>
<td>Did not assess</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 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(98)
2.1 Implications for practice

- The dating of fractures is an inexact science, the radiological features of bone healing represent a continuum, with considerable overlap
- Radiological estimates of time of injury are in terms of weeks rather than days. It is vital that all investigating agencies are aware of these broad time frames
- A broad timetable of fracture healing from children less than five years of age has been proposed but has not yet been validated
- Use of a standardised terminology with regard to the features of radiological fracture healing would be of benefit to all practitioners
- It has always been hypothesised that infants heal fractures quicker than older children. The first study of clavicular fracture healing in infants offers a timetable for dating such infant fractures

2.2 Research implications

- Future studies could possibly include fractures that are not routinely immobilised
- Future research should use previously defined features of radiological dating in order 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

- Different bones studied
- Variable time intervals between radiographs
- Differing numbers of radiographs per fracture
- In studies where fractures are 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
- Although 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.
Findings of clinical question 3
What radiological investigations should be performed to identify fractures in suspected child abuse?

3.1 Skeletal survey versus radionuclide imaging

Since 2007, no studies meeting our inclusion criteria have compared the value of Skeletal Survey versus Radionuclide Imaging

- Age range: 0 – 16 years
- Gender: data not analysed by gender
- No study addressed radiological investigations of disabled children
- No study addressed the influence of ethnicity and socio-economic group
- Details of included studies
- Total data: eight large studies compared the diagnostic yield in 509 children who had both investigations(103-110)
  - RNI was performed between 24 and 96 hours of the SS
  - The number of images included in SS varied between studies. The detail was poorly described. No study included oblique views of the ribs
  - All studies, with the exception of Pickett et al(109), confirmed that using either investigation in isolation would miss some fractures
- Nine small studies highlight additional findings on RNI not identified on SS(16, 20, 52, 68, 77, 111-114)
  - Five cases had RNI findings confirmed on repeat plain films(20, 77, 114)
  - Smith describes costo-vertebral fractures seen on RNI but NOT SS(20)
- Five studies showed that RNI was more sensitive, overall, at identifying bony abnormalities than SS(103-105, 107, 110)
- Two studies stated that SS had the greatest sensitivity(106, 109)
- RNI had a higher level of diagnostic significance over SS, excluding skull fractures(104, 110, 111, 113, 114)
- RNI was better at identifying individual fractures than SS(105, 107, 112)
- SS identifies metaphyseal fractures and skull fractures significantly better than RNI(106)
- No significant difference in the diagnostic specificity for rib fractures between either modality(106)
- Combining all other fracture types, RNI was better than SS(106)
- RNI had an increased sensitivity in detecting soft tissue as well as bone trauma(103)
- Neither SS or RNI is as good as the two investigations combined(103-107, 110)
• RNI predominately missed skull, metaphyseal and epiphyseal fractures whereas skeletal survey commonly missed rib fractures (52, 104-107, 110)

### 3.2 Skeletal surveys

#### Detection

- Of 540 studies reviewed, 12 studies addressed the issue (1, 114-124)
- **Gender:** data not analysed by gender
- **Age range:** 0 – 41 months, one study included children up to ten years (118)
- These studies did not address radiological investigations of **disabled children**
- **Influence of ethnicity and socio-economic group:** not addressed by these included studies

#### Details of included studies

<table>
<thead>
<tr>
<th>Author, year, study design</th>
<th>Number of children undergoing repeat imaging / total children</th>
<th>Imaging performed</th>
<th>Time interval</th>
<th>Results</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harper et al, 2013(119)</td>
<td>796/1038 (76.7%)</td>
<td>20 centres included full SS according to AAP guidance 2009. At follow-up all centres excluded skull, 6 centres excluded spine, five excluded pelvis</td>
<td>Not available</td>
<td>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. Concerning features were confirmed as normal in 55 subjects</td>
<td>Prospective study across 20 centres. Indications not given. 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. 24% of subjects did not return for follow-up imaging</td>
</tr>
<tr>
<td>Singh et al, 2012(122)</td>
<td>169/1470</td>
<td>Full SS including oblique views initially, omitted skull and spine for follow up imaging</td>
<td>Mean 19+/ - 11 days</td>
<td>24/169 (14%) had previously unrecognized healing fractures on follow up 6/24 (25%) of these subjects had a negative initial SS</td>
<td>Retrospective review from 2002-2009, 88% &lt; 1 year. Significant increase in number of follow up SS 2005-2009. 24/169 fractures identified on follow up SS. 2 fractures missed on initial SS. In 8 cases findings on follow up influenced abuse diagnosis, 6 negative</td>
</tr>
<tr>
<td>Study</td>
<td>Cases</td>
<td>Initial Imaging</td>
<td>Follow Up Imaging</td>
<td>Findings</td>
<td>Notes</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Bennett et al, 2011(116)</td>
<td>47/47</td>
<td>Initial and repeat were full SS according to ACR standards, 19 images. Oblique views of ribs not routinely obtained.</td>
<td>9-56 days</td>
<td>All had normal initial SS, 4 (8.5%) had abnormal follow up SS. 3 rib fractures, 1 proximal humerus</td>
<td>Initial SS. Only 11% of initial cohort underwent repeat imaging. Noted new, and newly recognized, metacarpal fractures on follow up, negating proposal to omit hands / feet on follow up</td>
</tr>
<tr>
<td>Karmazyn et al, 2011(1)</td>
<td>930 children</td>
<td>Full SS (31 views), including oblique views initially. Repeat imaging only for equivocal findings</td>
<td>N/A</td>
<td>29/116 (25%) definite fractures in previously equivocal findings</td>
<td>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</td>
</tr>
</tbody>
</table>
| Sonik et al, 2010(123)       | 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 < 2 years undergoing repeat SS, 2003-2007. No details as to why these children undergone repeat imaging. 3/22 new fractures, 1/6 initially normal fractures on repeat. Propose omitting AP pelvis and lateral spine. No oblique views, small numbers with no power calculation to
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Initial Imaging</th>
<th>Follow-Up Interval</th>
<th>Additional Fractures</th>
<th>Study Design</th>
<th>Supporting Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anilkumar et al, 2006(115)</td>
<td>59/200</td>
<td>Initial SS (including oblique views if age &lt; 1 year), follow up chest x-ray +/- oblique views</td>
<td>10 days - 3 weeks</td>
<td>3/59 (5.1%) had additional rib fractures noted on follow up</td>
<td>Case series</td>
<td>Retrospective study of children &lt; 2 years, 1998-2003, routinely invited for follow up from 1/1/2000 Only 59/200 cases returned for follow up</td>
</tr>
<tr>
<td>Zimmerman et al, 2005(124)</td>
<td>48/74</td>
<td>Initial and repeat were full SS, 19 images Skull excluded from repeat survey</td>
<td>Mean 21.4 +/- 9.7 days</td>
<td>22/48 children had additional information, 11 of whom had additional fractures identified. Additional fractures included rib, classic metaphyseal, clavicular, scapular, fibular and ulnar. One child in whom abuse was excluded by follow-up imaging</td>
<td>Prospective cohort</td>
<td>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</td>
</tr>
<tr>
<td>Kleinman et al, 1996(121)</td>
<td>23/181</td>
<td>Initial and repeat were full SS Skull excluded from repeat survey, no obliques in first survey</td>
<td>14 days</td>
<td>13 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 confirmed original findings for a normal variant</td>
<td>Retrospective cohort</td>
<td>Retrospective review between 1990 and 1995, indications for repeat SS included high suspicion of abuse, original imaging inconsistent with history</td>
</tr>
<tr>
<td>Hansen et al, 2014(117)</td>
<td>534/1963</td>
<td>Full ACR skeletal survey at baseline and follow-up compared to limited view follow-up</td>
<td>10 – 42 days</td>
<td>The limited view follow-up would have missed eight spinal fractures in five children not visible on the original skeletal survey. All of these</td>
<td>Cross sectional</td>
<td>This study would support the view that omitting pelvic images from the follow-up SS does not miss further fractures. Authors suggest omitting spinal views on the follow-up</td>
</tr>
</tbody>
</table>
(excluding spine, pelvis, and skull) 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.

• Williams describes a single case report of a six month old infant with an oblique fracture in the mid-diaphysis of the left femur. Bone scintigraphy indicated further fractures and repeat SS suggested a classic metaphyseal lesion on the right and left femur (114)
  o Kellof et al’s study described a single case, a child of nine weeks of age with rib fractures not detected on first SS with oblique views (120)
    Identified on ultrasound initially; bilateral rib fractures seen on repeat SS at 14 days
• Harlan et al was previously included but has been excluded as 97 out of 101 cases in the original study have been re-reported in Hansen (117)

Views

• Age range: 0 -16 years, the majority of the children less than two years of age (1, 76, 125, 126)
• Gender: data not analysed by gender
• No study addressed radiological investigations of disabled children
• No study addressed the influence of ethnicity and socio-economic group

Benefit of oblique views of the chest

• Three studies showed significant benefit of oblique views of the chest (127-129)
  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 (128)
• Sensitivity improved by 17% (95% confidence interval (CI) 2-36%), p=0.18(128)
• Specificity improved by 7% (95% CI 2-13%), p=0.004(128)
• The average improvement for diagnostic accuracy between three radiologists was 9% (CI 5-16%), p=0.005(128)
• Three children had rib fractures that were only seen on oblique films(128)
• The addition of oblique views increased detection rate by 19%(129)
• This study was evaluating the benefit of oblique views in addition to a standard ACR skeletal survey in infants who all had at least one rib fracture(129)
• The four view differed in the number of rib fractures detected in comparison to the two view (p=0.02)(127)
• The additional fractures noted/excluded were predominantly posterior and lateral(127)

3.3 Less common abusive fractures

• 16 studies recorded abusive fractures in less common sites and 15/16 stress the importance of specific radiological views:(1, 25, 52, 68, 70, 71, 74, 76-78, 83, 85, 88, 93, 107, 125):
  o Pelvic fractures are recorded in association with multiple injury or sexual abuse(1, 68, 70, 71, 74, 107)
  o Occult fractures of the hands and feet, predominantly torus fractures are described(1, 52, 77, 78)
  o Spinal fractures and fracture dislocations described, and may be occult even if unstable(1, 83, 85, 88, 93). One study noted only 1/530 children had compression fractures of the spine, presenting with paraplegia(125)
• Four studies questioned the value of screening for rarer fractures:
  o One study noted that all children with these rarer fractures had either clinical findings or multiple additional fractures elsewhere(1). This study included 11 additional views, limiting its applicability to those undergoing a standard SS
  o One study noted no pelvic, one spinal and nine fractures to the feet amongst 530 children screened. This study highlighted the radiation dose of pelvic imaging, and recommended omitting the pelvis(125)
  o One study noted 5.5% of 365 children had fractures to the spine, hands and feet. 25 spinal fractures were noted in ten children, from Hangmans fracture at C2 to sacral fractures, all but one had associated non-spinal injuries. 1.4% of SS had hand fractures and 1.6% fractured feet(76)
  o 14/751 children had spinal fractures. Four children had co-existent injuries. 4/14 were aged two to four years and seven had multiple spinal fractures(25)

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

One study described benefits of lateral views in addition to standards frontal views of long bones(126):
- Significantly more metaphyseal fractures were seen on combined frontal and lateral views ($p<0.01$)
- No significant difference for diaphyseal fractures
- Levels of agreement between radiologists improved the addition of lateral views, especially in metaphyseal fractures
- Recommendation of the inclusion of coned metaphyseal views of knees and ankles within skeletal survey

### 3.4 Occult fractures

#### Influence of ethnicity and socio-economic group
- African/American infants with unwitnessed head injury were more likely to have a SS than white infants (90.5% v 69.3%, $p=0.01$)(130). Non-white or hispanic children or those without private insurance were more likely to undergo screening(131, 132)
- White children with private insurance were much less likely to have a SS than white children with no insurance/government insurance (50% v 88%, $p<0.001$)(130, 133)
- 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 among African/American children)(130, 131)

#### Influence of age on fracture detection
- The diagnostic yield from SS correlates inversely with age and is significant for children under two years of age(10, 70, 107, 134-138)
- The rate of occult fractures detected in children aged less than two years in two large-scale studies was 10% – 13%(1, 136, 138)
- There is a higher diagnostic rate for SS in children under six months than in those aged two years and six months(136)
- 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(138, 139)
- Significantly more rib fractures(140) and classical metaphyseal lesions(138, 140) were found in children aged less than one year than those aged one – two years
- 14/17 (82%) of positive SS were in children less than one year of age(135)
- 14/55 (25%) of children aged less than one year had positive SS(135)
- Only 2/7 (29%) of children aged between one and two years had positive SS (personal correspondence)(135)

#### Screening siblings/household contacts
- Six skeletal surveys were performed on siblings (< three years old) of children with abuse. SS was positive in one sibling(135)
• 134 household contacts aged less than two years underwent a SS. 16/134 had fractures, 9 of whom were aged less than six months (141)
• Half of these children had an isolated fracture and half multiple fractures, none of which had clinical signs (141)
• 9/16 twins had fractures 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 (141). Of 75 twin triplet siblings screened, twins were more likely to have an occult fracture identified than non-twins (132)

**Indications for SS**

• 14% of children with abusive burns had occult fractures identified on SS (137, 139)
• Mean age of children with positive SS and burns was older than non-burns cases (p=0.03) (137)
• Fractures in children with burns included rib, CML, long bone, skull, and clavicular (139)
• 29% of infants aged less than one year with an unwitnessed head injury had positive findings on SS warranting child protection investigations (130)
• If the injury severity score was >15, cases were more likely to have positive findings than those with lower scores (OR 3.4, p<0.01) (130)
• Abusive head trauma (AHT) was significantly associated with a positive SS (P<0.00) (136)
• Three children presenting with an isolated skull fracture and no other signs of abuse had a positive SS (136)
• 86% of children aged less than 18 months presenting with an isolated skull fracture underwent SS, of whom 6% had an additional fracture identified. Only one of nine with additional fractures was aged more than 6 months, eight of nine had a simple skull fracture (142)
• Of 201 children less than one year of age presenting with skull fracture and a normal GCS, 12 had further fractures (5.5%) (143)
• 141 infants aged less than one year presenting with a skull fracture (non-MVC) underwent SS with only two identifying additional fractures. Each had risk factors for child abuse. Additional fractures were lower limb metaphyseal fractures (133)
• Children presenting with apparent life threatening event (ALTE) / apnoea had a higher rate of positive SS than those presenting for other reasons (p=0.05) (136)
• Children presenting with seizure had a higher rate of positive SS than those presenting for other reasons (p=0.02) (136)

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

• **Age range:** 0 – 8 years
• **Gender:** data not analysed by gender
• No study addressed radiological investigations of **disabled children**
• No study addressed the influence of **ethnicity and socio-economic group**

**Computerised Tomography (CT)**
• Older studies suggested that Computerised tomography scan (CT) will miss skull fractures(144-146). However, use of 3D reconstruction is a valuable asset in interpreting skull fractures(147)
• **CT of chest** may show rib fractures missed on two view chest radiography(148) or on four view chest radiographs(149)

**Magnetic Resonance Imaging (MRI)**
• MRI may be valuable additional investigations for physeal or epiphyseal injures(53)
• MRI may identify trauma where plain films are equivocal(150)
• **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. It was poor at identifying rib and metaphyseal fractures in particular(72)

**Ultrasound (U/S)**
• U/S may show metaphyseal fractures around the knee(19, 53, 151)
• U/S highlighted periosteal haematoma of the tibia, later confirmed as a fracture, and also a femoral fracture(152)
• U/S of the elbow may help to identify distal humeral epiphysiolysis(153)
• U/S may be useful in the diagnosis of costo-chondral dislocation of the lower ribs(19, 43)
• U/S of chest may show acute rib fractures not apparent on plain film, including oblique views(120)

**Other imaging modalities**
• Plain films may miss physeal or epiphyseal injuries of the humerus which may be seen on Radionuclide imaging(52) or MRI(120)
• The use of (**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(154)
• PET identified three spinal fractures in one child missed on SS and confirmed on MRI(154)

3.5 Implications for practice

*Which investigation has a higher yield, skeletal survey (SS) or radionuclide imaging (RNI)?*
• Either SS or RNI alone will miss occult fractures; optimal assessment should include both investigations
• If RNI is the first line of investigation, an additional skull X-ray must be performed and coned views of the metaphyses should be considered
• Confirmatory X-rays of abnormal areas on RNI should be performed
• If SS is the first line of investigation, oblique views of the chest should be included
• Consider repeat SS

Does repeat SS enhance detection?
• Repeat SS increases the diagnostic yield and clarifies tentative findings from the first SS
• Recent studies indicate that children with a negative first SS may have fractures on repeat SS that are of forensic importance
• Consideration could be given to omitting pelvic and/or additional spinal views on follow-up SS
• Repeat SS increases radiation dosage
• Issues of uncertain child protection status between SS

What views should be included in a SS?
• Radiological examination of the thorax should include oblique views
• Separate views of the pelvis with high-detailed imagery, paying particular attention to pubic rami
• High-detail, well-collimated posteroanterior views of hands and feet
• Anteroposterior and lateral views of the entire spine
• Consideration should be given to coned views around the knee to maximise detection of classic metaphyseal lesions

Which children with suspected abuse should be investigated for occult fractures?
• Recent studies suggest that up to 12% of household contacts aged less than two may have a positive SS with twins being a particularly high risk(141)
• Not enough detail was available to comment on the likely benefit of SS in sexual abuse, neglect or older disabled children
• Three studies described abusive fractures in older children, one who was disabled and two who had been physically and sexually abused(10, 134, 135)

What other imaging modalities may enhance detection of occult fractures?
• If a CT brain is being undertaken, 3D reconstruction may help in delineating skull fractures
• US is of value in identifying rib fractures in selected cases. CT may also identify rib fractures missed on four view plain films, however it has double the radiation dose of a full skeletal survey

3.6 Research implications

Further research is needed in the following areas:
• To determine the added value of a radionuclide imaging (RNI) in addition to a current standard (21 view) skeletal survey (SS)
• To determine the relative value of RNI versus repeat SS as a complimentary investigation to an initial SS
• To assess the role of radiological screening of disabled children with suspected abuse

3.7 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?

• Oblique views of ribs not included in early studies
• Further clarification as to which infants merit follow-up skeletal survey would be of value

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?**

- **Age range:** 0-18 years
- **Gender:** data not analysed by gender
- No study addressed CPR related rib fractures in disabled children
- Influence of ethnicity and socio-economic group: not addressed by these included studies

**4.1 Cardiopulmonary resuscitation-related fractures**

- Rib fractures are a rare complication of cardiopulmonary resuscitation (CPR) in children, with the reported incidence at 0-4.3% in ten (27, 155-163)/ 11 studies (27, 155-164), six of which showed no rib fractures (27, 156, 158, 159, 161, 162):
  - A single study recorded an incidence of 18.7% (164)
- Where details were given, the fractures associated with CPR were all multiple, anterior / anterolateral, unilateral or bilateral
- There were no posterior rib fractures due to CPR
- One study noted a rise in incidence and hypothesised that this was associated with the introduction of two-thumb rather than two-finger resuscitation (3, 160, 165, 166)
- One new study noted two infants with rib fractures ascribed to CPR, one anterior and one posterolateral following bimanual chest compression (17)

**Details**

- Rib fractures were sought at post-mortem in ten studies. No authors referred to the use of specimen radiography (155-158, 160-164, 167)
- Nine studies explored the prevalence of rib fractures following CPR (27, 155-159, 161, 162, 164):
  - These fractures occurred in the following children: a two month old; a three month old who died of sudden infant death syndrome; a five year old who drowned. Trained personnel resuscitated all three cases: 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 (155, 157)
15/80 children in Lin et al’s study of children aged 0-18 years sustained rib fractures on early chest x-ray but no details were available. Abuse had been excluded, although admission was trauma-related(164).

Of these nine studies, six did not record any children with CPR-related fractures(27, 156, 158, 159, 161, 162).

In a study of 382 children undergoing CPR, no cases developed rib fractures having had a post-mortem examination including rib palpation and stripping of the parietal pleura(158).

The children who did not sustain rib fractures were resuscitated for 1 - 540 minutes(161).

24/546 SUDI cases sustained rib fractures(163):

- 15 were healing fractures, 10 of which had features of abusive injury(163).
- Of nine acute fractures, seven had no features of abusive injury and were thought to be CPR related. These were multiple, anterolateral, and involving 3rd - 6th ribs; bilateral in one case(163).
- 14/15 healing rib fractures were visible on post-mortem skeletal survey (SS), one case had only antemortem chest radiographs(163).
- Only 2/9 acute rib fractures were visible on post-mortem SS, found only by inspection of ribs following stripping of the pleura(163).

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(167):

- The fractures found were anterolateral, 3 - 6 ribs, 2/5 bilateral(167).

9/571 infants aged 0-6 months exhibited rib fractures attributed to CPR, the duration of CPR was 21-260 minutes, fractures were all anterior to lateral. Almost three times as many fractures occurred between 2006-2008 versus 1997-2005(160, 165, 166).

This is hypothesized as correlating 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(160, 165, 166).

4.2 Research implications

- Prospective studies of children undergoing cardiopulmonary resuscitation (CPR) using more sensitive radiological and autopsy techniques post-CPR are needed e.g. four view chest films / radionuclide imaging / specimen radiography.

4.3 Implications for practice

- 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.
4.4 Limitations of review findings

- Retrospective studies
- Wide age range of children, however recent studies have included infants less than a year old
- Methodology of determining rib fractures is 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 a number of interesting findings that were outside of the inclusion criteria. These are as follows:

Clinical question 1

Rib fractures

- Post-mortem studies should include reflection of the pleura to ensure all fractures are accurately identified
- There is a need for a large scale study to determine the incidence of rib fractures following two-handed CPR

Imaging strategies

- Oblique views on chest X-ray of the ribs are significantly better at detecting posterior rib fractures(128)
- Posterior rib fractures may not be seen on a skeletal survey but identified at post-mortem(168)

Physiotherapy

- Rib fractures have been described as a consequence of chest physiotherapy for bronchiolitis in France(169), however a recent study of 647 children undergoing chest physiotherapy resulted in no rib fractures(170)
- The method of physiotherapy was not described and all children received this therapy unsupervised in their own homes(169)

Femoral fractures

- There is a decrease in the incidence of femoral shaft fractures in children, reduction of 42% between 1987 – 2005(171)
• The commonest cause of femoral fracture in children less than four years of age is a fall of less than one metre(171)
• A fracture classification system to distinguish transverse, oblique or spiral fractures was developed and validated. There was moderate inter-observer reliability(172)

**Skull fractures**
• Biparietal skull fractures might result from a single blow to the occiput, as described accidentally(173)
• 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 was not eligible for inclusion in this systematic review(174)

**Tibial fracture**
• Inadequate data on tibial fracture for meta-analysis(175)
• Undisplaced spiral fracture of the tibia without a concomitant fibular fracture is most likely to be a toddler fracture particularly if the child is a boy less than 2.5 years of age(175)

**Humeral fracture**
• A case series of seven infants aged 4-7 months with isolated humeral fractures postulated to occur when the infant rolled over. Skeletal surveys were negative, all cases arose as a consequence of court proceedings(176)
• Radiological identification of distal humeral epiphyseal separation is aided by the use of ultrasound in young infants(177)

**Metaphyseal fractures**
• Metaphyseal fractures may be missed if appropriate radiology is not employed(178, 179)
• Inappropriately administered physiotherapy, particularly to preterm infants, has caused metaphyseal fractures(180)
• Metaphyseal fractures are also recorded in serial casting of clubfoot(181)
• Birth trauma can cause metaphyseal fractures in breech delivery(182)
• External cephalic version for breech presentation may result in classic metaphyseal lesion (CML)(183)
• CML occurring following birth was associated with pain expressed in irritability, lack of spontaneous movement of the affected leg and poor feeding in an infant(183)
• A high resolution CT study defines the precise fracture plane that occurs in metaphyseal fractures, contributing to an understanding of the biomechanics of these fractures(184)
Post-mortem
- Post-mortem CT has a low sensitivity for rib fractures in comparison to autopsy(185)
- Proposed autopsy techniques to maximise identification of fractures(186)
- It is proposed that cone-beam CT performed during post-mortem may aid in the dating of fractures(187)
- Vertebral clefts may be visible through the vertebral body and be confused with fractures. A post-mortem study discusses ten affected fetus(188)

Important clinical differentials
- Sternum ossification centres projected over ribs on a chest film mistaken for fractures. Follow up revealed real cause(189)
- 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(190)
- An overview of clinical variants that are important on reviewing skeletal surveys(191)
- Heterotopic ossification from the ischium and sacrum to proximal femur posteriorly secondary to physical abuse(192)
- Metaphyseal fragmentation may be noted in infants, simulating metaphyseal fractures(193)
- It is important to distinguish normal suture variants within the occiput from fractures(194)
- An unossified membranous strip within the parietal bone may be mistaken for skull fracture in infants(195)
- Widespread medullary necrosis and periosteal reaction, with epiphyseal sparing, described as a complication of traumatic pancreatitis(196)

Biomechanics
- Fractures determined by type and rates of stress and strain applied to a bone(175, 197-200)
- Reviews of biomechanics highlight numerous variables relating to childhood fractures(175, 197-200)
- 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(201)

Consequences of abusive fractures
- Compartment syndrome may occur in the lower limbs as a consequence of abusive fractures(202)

Presenting features
- 21% of children with abusive fractures missed at initial presentation(203)
- Boys with extremity fractures attending non-pediatric emergency department or primary care most commonly missed(203)
• A survey of orthopaedic surgeons in Israel identified that only 35% had received training regarding child protection(204)
• Delay (more than 8 hours) in presentation with an extremity fracture was evaluated in 206 children(205)
• Although the median time to presentation was one hour, 21% presented after 8 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(205)
• A study of children with OI showed that although 21% sustained rib fractures, none of these occurred in infancy. All children with two or more fractures had previously been diagnosed with OI(206)

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(207)
• Multiple rib fractures described in macrosomic infant with shoulder dystocia(208, 209)
• Posterior rib fractures described as birth injuries, some macrosomic(210, 211) including those with shoulder dystocia(208, 209)
• Classic metaphyseal lesions of the femur have been noted after caesarian section. Two cases were breech presentation(212)
• 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. 5/7 affected infants were delivered by caesarean section. In 6/7 cases, no evidence of femoral injury was noted on immediate post-natal examination(213)
• Birth injury can cause depressed skull fractures(214)
• Rib fractures have been identified in approximately 2% of ex pre-term infants (less than 37 weeks gestation)(215)

Age and likelihood of abuse
• The relative risk for child abuse in children aged less than one year was 11.46; 3.07 for those aged 1-2 years(216)
• Abusive fractures more common in children less than 13 months of age(217)
• 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(218)
Clinical question 2

- The table in this oft-quoted source is derived from personal clinical experience of the authors, and has not been further validated by any primary research (219).
- No primary evidence was found to confirm faster fracture healing in infants (219).
- Repeat skeletal survey may aid in fracture dating (121).
- Bone scans have no place in fracture dating as they become positive within seven hours and can remain positive for up to one year (220).
- Study of animal models for dating rib fractures (221).
- 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 (187).
- A study comparing whole body magnetic resonance imaging (WB-MRI) with skeletal survey noted that WB-MRI provided little information regarding fracture age (222).

Clinical question 3

Practice guidelines

- American and British guidelines for practice; neither address the role of radionuclide imaging but have specific guidance on views to be taken (178, 179, 223, 224).
- Oblique views of the ribs are recommended when rib fractures are evident, and consideration should be given to including obliques in the standard survey protocol (223).
- Follow-up Skeletal Survey (SS) is recommended when there are abnormal or equivocal findings on the initial SS, or when abuse is suspected clinically (223).
- Addressing concerns about radiation dosage (225).
- Audit of UK SS three years after the British Society of Paediatric Radiology published their standards: only 15% included all appropriate views; technical quality considerably improved (score 9.7/11) (226).
- 40 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 one year with non-vehicle associated head injury or femoral fractures (227).
- 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 (227).

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 (228, 229).
• Evaluation of separation of the distal humerus epiphysis is well defined by US, particularly in neonates where ossification is minimal(230)
• The use of 18F-NaF positron emission tomography (PET) whole-body imaging is shown to demonstrate additional subtle fractures including classic metaphyseal lesion of the humerus and iliac crest fractures not seen on initial SS(154)
• **Multi-planar computerised tomography scan (CT)** and 3-dimensional (3D) image reconstructions may enhance the visualisation of rib fractures(231). However, even these imaging modalities may miss rib fractures as detailed in post-mortem studies(232, 233)
• **Post-mortem CT** may also be of value in detecting incomplete buckle rib fractures(234)
• 3D CT images of the skull may enhance the distinction between normal variants and fractures(194)
• A study of 605 CT images of children aged 0–3 years highlighted that 53% had Wormian bones, the majority of which were multiple(235)

**Other potential indications for imaging**

• Multiple birth infants appear to be at higher risk of fractures or abdominal injuries than other siblings(236)
• An exploration of children presenting with a single extremity fracture, 37% of whom underwent neuroimaging, identified only 5 children (aged less than one year) with intracranial injury(237)
• In 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(238)

**Clinical question 4**

• Histological dating of fractures may be crucial to distinguish abusive from cardiopulmonary resuscitation (CPR) related fractures(27, 239, 240)
• Posterior rib fractures in a child who has been resuscitated on a firm surface would appear inconsistent with the biomechanics of resuscitation (241)
• One publication proposed that a 21 month old with fatal head injuries sustained a posterior rib fracture as a consequence of CPR performed by trained personnel(242)
  • 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(242)
  • 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(242)
• CPR technique utilising a mannikin demonstrates that the majority of practitioners are likely to over-compress without real time feedback(243)
Related publications

Publications arising from fractures review


Kemp AM, Butler A, Morris S, Mann M, Kemp KW, Rolfe K, Sibert JR, Maguire S. Which radiological investigations should be performed to identify fractures in suspected child abuse? Clinical Radiology. 2006;61(9):723-736


Primary studies arising from fractures review


References


245. Critical Appraisal Skills Programme (CASP).


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(244). We also used a selection of systematic review advisory articles to develop our critical appraisal forms(245-249). 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(245), and this was supported by a dedicated electronic critical appraisal module.

Inclusion criteria

General criteria

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papers with all evidence types</td>
<td>Personal practice</td>
</tr>
<tr>
<td>English and non-English papers</td>
<td>Review papers</td>
</tr>
<tr>
<td>Papers from conferences – paediatric, radiology, orthopaedic</td>
<td>Management of fractures papers</td>
</tr>
<tr>
<td>Patients between 0-17 years of age</td>
<td>Papers where the population included adults and children</td>
</tr>
<tr>
<td></td>
<td>Studies of non-abusive data only</td>
</tr>
<tr>
<td></td>
<td>Methodologically flawed papers</td>
</tr>
</tbody>
</table>
# Additional criteria for specific review questions

## 1. Which fractures are indicative of abuse?

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

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

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>General inclusion criteria plus:</td>
<td>General exclusion criteria plus:</td>
</tr>
<tr>
<td>Primary research addressing how you can date fractures radiologically in</td>
<td>Underlying bone disease was present</td>
</tr>
<tr>
<td>children up to 17 years of age</td>
<td>Criteria for dating was not detailed</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>General inclusion criteria plus:</td>
<td>General exclusion criteria plus:</td>
</tr>
<tr>
<td>Children (0-17) who had radiological investigations to identify bone</td>
<td>Studies where details on the yield from the investigations were not</td>
</tr>
<tr>
<td>fractures in suspected child abuse</td>
<td>available</td>
</tr>
<tr>
<td></td>
<td>Fatal abuse</td>
</tr>
</tbody>
</table>
4. Does cardiopulmonary resuscitation cause rib fractures in children?

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

**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).

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

**Ranking of evidence by study type**

<table>
<thead>
<tr>
<th>Ranking of evidence by study type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$</td>
</tr>
<tr>
<td>$T_2$</td>
</tr>
<tr>
<td>$T_3$</td>
</tr>
<tr>
<td>$O_1$</td>
</tr>
</tbody>
</table>
O2 Case-control study
O3 Cross-sectional
O4 Study using qualitative methods only
O5 Case series
O6 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)

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

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(244, 248). This classification is based on the Bandolier system adapted to include the Centre for Reviews and Dissemination’s guidance for undertaking reviews(244).
<table>
<thead>
<tr>
<th>Grade</th>
<th>Level</th>
<th>Type of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Ia</td>
<td>Evidence obtained from a well designed randomised controlled trial of appropriate size (T1)</td>
</tr>
<tr>
<td>B</td>
<td>Ib</td>
<td>Evidence obtained from a well designed controlled trial without randomisation (T2, T3)</td>
</tr>
<tr>
<td>B</td>
<td>IIa</td>
<td>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)</td>
</tr>
<tr>
<td>C</td>
<td>IIb</td>
<td>Evidence obtained from a well designed uncontrolled observational study (O3, O4)</td>
</tr>
<tr>
<td>C</td>
<td>III</td>
<td>Evidence obtained from studies that are case study or case series (O5, O6)</td>
</tr>
</tbody>
</table>

**Search strategy**

Medline search strategy used for the 2015 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?

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.
11. (non-accidental: and injur:).mp.
12. soft tissue injur:.mp.
13. physical abuse.mp.
14. 16 or 17
15. or/16-28
16. 23. pelvic fractur:.mp.
17. 24. (spiral fractur: or transverse fractur:).mp.
18. 25. metaphyseal fractur:.mp.
19. 26. (corner fractur: or bucket handle fractur:).mp.
20. 27. metaphyseal chip fractur:.mp.
21. 28. classic metaphyseal lesion:.mp.
22. 29. or/16-28
30. (investigat: adj3 fract:).mp.
31. (radiolog: adj3 fractur:).mp.
32. (roentgen: adj3 fract:).mp.
33. skeletal survey.mp.
34. ((paediatric or pediatric) adj3 radiolog:).mp.
35. ((paediatric or pediatric) adj3 nuclear medicine).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 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.

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 2015 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.
9 rib fractur*.mp
10 clavicle fractur*.mp.
11 Rib Fractures/
12 Diaphragm/in [Injuries]
13 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.
22 cardiac massage.mp.
23 heart massage.mp.
24 or/19-23
Erratum

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


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

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:

<table>
<thead>
<tr>
<th>Databases</th>
<th>Time period searched</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASSIA (Applied Social Sciences Index and Abstracts)</td>
<td>1987 - 2015</td>
</tr>
<tr>
<td>Child Data</td>
<td>1958 - 2009†</td>
</tr>
<tr>
<td>CINAHL (Cumulative Index to Nursing and Allied Health Literature)</td>
<td>1982 - 2015</td>
</tr>
<tr>
<td>Cochrane Central Register of Controlled Trials (CENTRAL)</td>
<td>1996 - 2015</td>
</tr>
<tr>
<td>EMBASE</td>
<td>1980 - 2015</td>
</tr>
<tr>
<td>MEDLINE</td>
<td>1950 - 2015</td>
</tr>
<tr>
<td>MEDLINE In-Process and Other Non-Indexed Citations</td>
<td>1951 - 2015</td>
</tr>
<tr>
<td>Open SIGLE (System for Information on Grey Literature in Europe)</td>
<td>1980 - 2005*</td>
</tr>
<tr>
<td>Scopus</td>
<td>2009 - 2015</td>
</tr>
<tr>
<td>Social Care online (previously Caredata)</td>
<td>1970 - 2015</td>
</tr>
<tr>
<td>Trip Plus</td>
<td>1997 - 2005†</td>
</tr>
<tr>
<td>Web of Knowledge – ISI Proceedings</td>
<td>1990 - 2015</td>
</tr>
<tr>
<td>Web of Knowledge – ISI Science Citation Index</td>
<td>1981 - 2015</td>
</tr>
<tr>
<td>Web of Knowledge – ISI Social Science Citation Index</td>
<td>2008 - 2015</td>
</tr>
</tbody>
</table>
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 clinical experts. Finally a full text screen with a critical appraisal was carried out by members of the clinical expert sub-committee. 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 (clinical.standards@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(250). 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.