EVIDENCE-BASED CHILD HEALTH: A COCHRANE REVIEW JOURNAL
Evid.-Based Child Health **8**: 2044–2057 (2013)
Published online in Wiley Online Library (http://www.evidence-basedchildhealth.com). **DOI:** 10.1002/ebch.1941

Overview of Reviews

What does the recent literature add to the identification and investigation of fractures in child abuse: an overview of review updates 2005–2013

Sabine Maguire,[1] Laura Cowley,[1] Mala Mann[2] and Alison Kemp[1]
[1] *Early Years Research Programme, School of Medicine, Cardiff University, Cardiff, Wales, UK*
[2] *Support Unit for Research Evidence, Cardiff University, Cardiff, Wales, UK*

Evidence-Based Child Health: a Cochrane Review Journal is now indexed by MEDLINE (http://www.ncbi.nlm.nih.gov/pubmed) and Scopus (http://www.scopus.com)

Background: Fractures are a manifestation of physical abuse and common accidental injuries. Distinguishing which fractures are indicative of abuse and optimizing the identification of occult fractures are the challenges.

Objectives: To identify additional studies published since our original systematic reviews to address these two issues.

Methods: An all-language literature search of 14 databases was conducted for the years 2005–2013, using revised keywords. All studies underwent standardized critical appraisal by two independent reviewers, applying quality criteria relating to the confirmation of child abuse, exclusion of abuse and quality of skeletal survey conducted. A meta-analysis, stratified by age, was conducted to determine the predictive value for abuse of specific fractures by fitting a random effects model.

Results: Twenty-three studies addressed ‘radiological investigations’, and nine studies ‘fractures indicative of abuse’. Radiological studies reiterated that a single investigation (skeletal survey or radionuclide imaging) will miss some abusive fractures; in 8.4–37.6% of children, the repeat skeletal survey added new information that influenced the child protection procedures. Debate continues as to the optimal images to include in the repeat skeletal survey. A meta-analysis of femoral and humeral fractures by age highlighted that children younger than 18 months are significantly more likely to have sustained their fracture as a consequence of abuse, than those aged 1–4 years.

Authors’ Conclusions: Recent literature validates the original conclusions that repeat skeletal imaging adds important information on fractures. Comparative studies of femoral, humeral, rib and skull fractures enabled a meta-analysis by age, however further comparative studies are needed.

Keywords: fractures, child abuse, skeletal survey, repeat imaging, meta-analysis, oblique views

Background

The objective of this overview was to identify additional studies published since our original systematic reviews (1, 2) addressing two aspects of fractures in child abuse. Fractures have been reported in over a third of children younger than 2 years who have been physically abused, 18% of whom have multiple fractures (3). An abusive fracture in a young child denotes a severe assault; however up to 60% of boys and 40% of girls sustain accidental fractures by their 15th birthday. All children younger than 2 years presenting with suspected abuse should be screened for occult fractures, and the challenge is to determine the optimal radiological investigation strategy.

The two main questions reviewed in our original systematic reviews (SRs) were: Which radiological investigations should be performed to identify fractures in suspected child abuse? (1) Which fractures are indicative of abuse? (2) It is clear that fractures pose common dilemmas for practitioners, as they have consistently been the most frequently visited section of our SR website, www.core-info.cf.ac.uk.

*Correspondence to: Sabine Maguire, MBBCh, MRCPI, FRCPCH, Early Years Research Programme, School of Medicine, Cardiff University, 4th Floor, Neuadd Meirionnydd, Heath Park, Cardiff CF14 4YS, UK. E-mail: sabinemaguire@gmail.com

Since their original publication, each of these reviews has been updated annually, with a number of interesting developments. In this article, we detail our revised methodology and describe what the recent literature contributes.

Methods

The original reviews were conducted in accordance with a standard methodology for undertaking SRs (4). Prior to commencing, the principal investigator and the review team discussed the potential questions. The principal investigator and the information specialist met to look at possible terminology, search terms, dates, databases, key authors and key publications relating to the questions. Following this, the information specialist conducted a pilot search of relevant databases: MEDLINE, Embase, HealthSTAR and Cinahl. This generated over 1000 articles. The principal investigator then scanned these references for relevance to ensure that all relevant terms were captured and irrelevant search terms excluded from the search strategy. At this stage, the questions were refined and the final search strategy was developed in MEDLINE.

Search

A search strategy (Table A1) was developed to encompass the broad themes to identify the features that distinguish fractures resulting from abuse or non-abuse in children. In addition, the aim was to determine the optimal radiological investigations that should be carried out to detect fractures in children suspected of having been physically abused. The search strategy was developed using both text words and Medical Subject Headings, and consisted of the following search terms:

- terms related to child;
- child abuse and non-accidental injuries terminology;
- fractures terms;
- time factors;
- terms relating to radiological investigations.

The search strategy was adapted to search the rest of the databases. An all-language literature search was performed across 14 databases (Table A2), including grey literature databases and conference abstracts. The original date range spanned 1950–2005, while the updates covered the years 2005–2013. Textbooks were also searched.

Since the first fractures' publication in 2006, the search strategy has been modified owing to the improvement of the searching capabilities of the databases. With the expansion of biomedical literature, new databases were added to the search, while others were excluded because of a variety of reasons, such as not retrieving relevant studies or termination of institutional access to the database (Table A2). With further updates, our range of supplementary search techniques

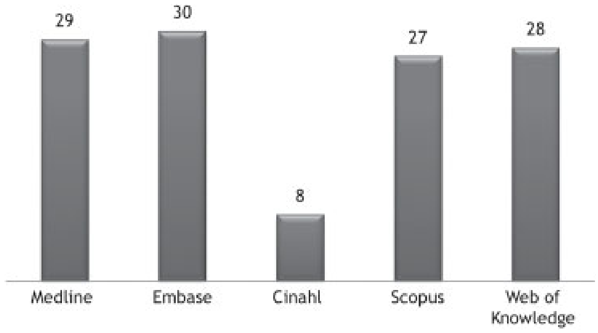

Figure 1. Number of included studies retrieved in each of the main databases.

expanded to increase the sensitivity of the search. This has included checking the references of reviewed articles, to see if they may be relevant to the review, liaising with experts and key authors and searching websites and relevant journal sites.

All newly included studies were retrieved from the bibliographic search. Figure 1 depicts the number of studies retrieved by each of the main databases; the majority of the 32 included studies were retrieved from MEDLINE and Embase. This is to be expected considering these databases cover the international literature in the fields of medicine, nursing, dentistry, biomedicine, pharmacology, allied health, health care systems and pre-clinical sciences. The eight studies yielded by Cinahl were also located in both MEDLINE and Embase. The study selection process is outlined in Figure 2.

Selection of studies

Two review authors independently assessed the potential relevance of all titles and abstracts identified from the database and the additional searches. Potentially relevant studies were obtained in full text and independently assessed for inclusion by two review authors, trained in critical appraisal and utilizing standardized critical appraisal methods, as below. Any disagreement was resolved by a third reviewer critically appraising the study, and consensus being reached.

Quality assessment and data extraction

While a classical SR includes only randomized clinical trials, clearly this is inappropriate with regard to studies addressing the distinction between abusive and non-abusive fractures. Thus, the two reviews included observational studies.

Critical appraisal forms (Appendix S1, supporting information) were developed by using questions which were adapted from validated sources (4–6). Two authors independently assessed the methodological quality of the studies to identify any potential sources of bias, and determined if any study should be omitted on the basis of study quality. Following quality assessment, data was extracted by the lead reviewer. Our review panel consisted of trained

DOI: 10.1002/ebch.1941

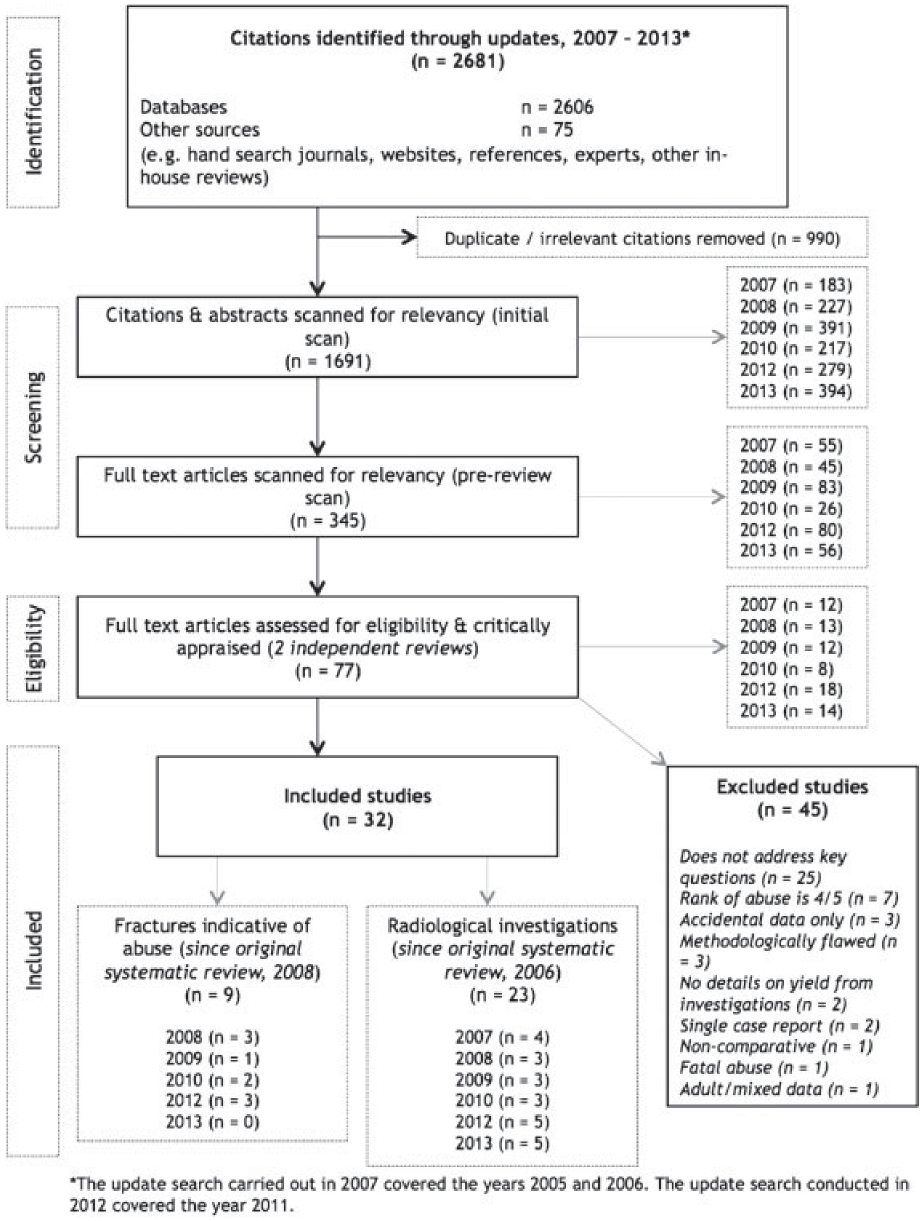

Figure 2. Study selection process.

reviewers, including paediatricians, paediatric radiologists, orthopaedic surgeons and specialist child abuse paediatric nurses.

One aspect that is always controversial when critically appraising the literature with regard to child abuse is the risk of circularity, that is, how do you know whether the injuries that are the subject of your review have not in fact been relied upon to conclude that the child was abused? Clearly, in this clinical field, there is no 'gold standard test' for the confirmation of abuse, and there is a very small minority of cases where the abuse has been independently witnessed to provide 'external confirmation'. To address this and minimize the risk that the authors might have based their decision regarding abuse solely on the injury in question, we have developed our own '*rank of abuse*' (Table 1). Essentially, the higher ranked studies included either a multidisciplinary assessment of the case, taking into account social and historical factors beyond the presenting injury, or a perpetrator admission or independently witnessed abuse, whereas lower ranked studies used explicit criteria or a clinical confirmation of abuse. We also developed our own ranking system for the *exclusion of abuse* in non-abused children, where explicit confirmation of the aetiology of injury is favoured (Table 1).

For the SR of radiological investigations (1), we ranked studies according to the quality of skeletal survey (SS) performed (Table 1), and initially accepted all rankings of SS. However, to ensure that we only include higher quality studies, we have since accepted studies ranked 1–3. With regard to the review of fractures indicative of abuse, we included comparative studies addressing long bone, skull and rib fractures in children younger than 18 years (2). Noncomparative studies were included for all other skeletal fractures

DOI: 10.1002/ebch.1941

Table 1. Inclusion/exclusion criteria and quality standards for confirmation of abuse, non-abuse and skeletal survey (SS) standard

Inclusion criteria
- Primary studies
- All languages
- Children aged 0–17 years

Fracture patterns only
- Comparative studies of children with fractures of the skull, femur, humerus, or rib
- Comparative and noncomparative studies of other abusive fracture types

Investigation for occult fractures only
- Children who had radiological investigations to identify bony fractures in suspected child abuse

Exclusion criteria
- Personal practice
- Review articles
- Management of fractures studies
- Studies where the population included adults and children and the child data could not be separated
- Studies of non-abusive data only
- Methodologically flawed papers

Fracture Patterns Only
- Rank of abuse is four or five or mixed rank where relevant cases cannot be extracted
- Studies of outcome or management of abusive fractures

Investigation for Occult Fractures Only
- Studies where details on the yield from the investigations were not available
- Ranking of skeletal survey is 4 or 5
- Fatal abuse

Ranking	Criteria used to define abuse
1	Abuse confirmed during case conference, family, civil or criminal court proceedings, admitted by perpetrator, independently witnessed or described by victim
2	Abuse confirmed by stated/referenced criteria including multidisciplinary assessment
3	Abuse defined by stated criteria
4	Abuse stated but no supporting detail given
5	Suspected abuse

Ranking	Exclusion of abuse in the non-abused group
1	Abuse actively excluded by stated criteria, witnessed traumatic cause or confirmed organic cause
2	Exclusion of abuse implicit in case definition used or stated criteria given
3	Aetiology of non-abuse group merely stated
4	Aetiology of comparison not stated

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

that as featured on our website (7); vertebral fractures were included in a separate SR of spinal injuries (8). For the original review, we accepted all ranks of abuse (2). However, following 2008, we raised the cut-off to ranks 1–3.

Results

Which radiological investigations should be performed to identify fractures in suspected child abuse?

This review used the search strategy outlined in Table A1, with inclusion criteria detailed in Table 1. The original review findings were published in 2006 (1). Having identified 1831 abstracts, 427 studies were reviewed and 34 included. The two main messages were that:

- Conducting a single investigation alone [SS or radionuclide imaging (RNI)] in suspected abuse would miss some occult fractures.
- A SS needed to be comprehensive, including views of the metaphyses and oblique views of the ribs to maximize the yield of occult fractures.

While these findings were accepted and incorporated into both the National Standards for Radiological Investigation of Suspected Abuse in the UK (9) and the American College of Radiology Appropriateness criteria (10) citing this SR, there was reluctance among clinicians to proceed to a second investigation. Since then, we have identified a further 77 studies potentially addressing this question, with 23 meeting our inclusion criteria (Fig. 2). The original review and national standards recommended that if an initial SS

DOI: 10.1002/ebch.1941

was negative, and clinical concerns remained, either a repeat SS (all views except skull X-ray) should be undertaken 11–14 days later, or a RNI should be undertaken shortly after the original SS, with further imaging of any identified 'hot spots'. This prompted a series of new studies addressing the 'added value' of a repeat SS (3, 11–15) as detailed in Table 2.

The main thrust of these new studies was to determine if a more limited SS could be performed on the second occasion (3, 11, 13–15) or whether the repeat SS influenced the decision regarding abuse.

The earliest of these (11) suggested that only a chest X-ray should be repeated; however only 59 of 200 children attended for repeat imaging, and as only a repeat chest X-ray was performed, they could not determine what additional information would have been gained from a full SS. Notwithstanding that, three of 59 children had additional rib fractures on follow-up, and two children had rib fractures identified for the first time, significantly influencing the diagnosis of abuse. They concluded that the repeat chest films provided clinically useful information in 12% of children, although only 30% attended for the follow-up imaging, suggesting that this may be an underestimate of the true yield (11).

Similarly, Harlan et al. reviewed 101 children who underwent a full repeat SS, in whom new information was provided in 37.6% of children, with 12% of those who had a normal SS, initially demonstrating fractures on follow-up (13). These authors concluded that the spine and pelvis could be omitted from follow-up, although no power calculation was conducted to determine if their study had sufficient sensitivity to determine the validity of this recommendation. Sonik et al. retrospectively reviewed 22 children undergoing initial and repeat SS (no details as to why these children underwent repeat imaging), and noted that three of 22 had new fractures identified (rib and extremities), while a further three indeterminate findings were clarified (14). On the basis of this small case series, they proposed that the pelvis, spine, hands and skull could be omitted from follow-up.

Singh et al. performed repeat SS on 11% of a total population of 1470 children undergoing SS, 14% of which were positive (16). Within these, eight cases had abuse confirmed as a consequence of the repeat SS, six of whom had a normal SS at presentation. Bennett et al. performed a repeat SS in all children with a normal initial SS, with all views bar oblique views of the ribs, of whom 4 out of 47 (8.5%) identified new fractures which affected the child protection decisions (15).

To date, no study has evaluated all children presenting with suspected abuse undergoing full initial SS, with oblique views of the ribs, and full repeat imaging (excluding skull) to determine the yield by presenting features, or adequately identify which images can be safely omitted on repeat.

While the initial review evaluated the benefit of RNI in addition to SS, only two single case studies addressed this subsequently (12, 17), noting that abnormalities on a RNI in the presence of normal SS were later confirmed as fractures on a repeat SS. Karmazyn et al. noted that 25% of children younger than 2 years undergoing further imaging (SS or RNI) had new findings (3).

Further studies have addressed which images should be included in a SS (3) and who should undergo imaging for occult fractures (18–22). Karmazyn et al. proposed that the spine, pelvis, hands and feet could be omitted from the SS, because of the relative infrequency of abusive fractures (1%) in their retrospective cross-sectional study and the suggestion that there were other indications of abuse in these cases (3). However, not all of the children had clinical signs or symptoms referable to these injuries, which would thus have been missed had imaging not been performed. It is also of note that their SS exceeds the 20 images normally recommended, by incorporating a further 11 images, thus its applicability to those undertaking a standard SS is unclear.

Most guidelines (9, 10) recommend SS for all children younger than 2 years with suspected physical abuse. Hansen and Campbell addressed the important question of the relative value of a SS in those aged 12–24 months, as many clinicians are reluctant to image these children (20). Our original review concluded that a SS was worthwhile in those aged over 1 year, with two authors addressing this; Merten showed a higher prevalence of occult fractures in those aged less than 1 year versus those aged 2–3 years ($p < 0.0005$) (23), whereas Belfer et al. showed no difference (24). Contrary to their own hypothesis, Hansen and Campbell found no significant difference in the prevalence of occult fractures amongst those aged 12–23 months (18.9%) and those aged 0–11 months (22.7%), (20) which concurs with Duffy et al. (25) and data obtained directly from the authors of another large-scale review (18). One study highlighted that introduction of a standard imaging guideline reduced racial disparities in those undergoing screening for occult fractures (26).

A further study addressed the value of imaging children presenting with an abusive burn (19), and noted that although only 58% of these children underwent a SS, the yield of occult fractures was 14%, and that the majority of these were 1–2 years of age. It is suggested by large retrospective case series that the highest yield of occult fractures is amongst those younger than 6 months (18, 25), and those presenting with abusive head trauma, acute life threatening events or seizure (25). One recent study (22) examined whether all children presenting with an 'isolated skull fracture' aged less than 18 months should undergo a SS. During the period 2004–2010 86% of eligible children underwent a SS. The authors excluded motor vehicle collision, shopping cart falls, penetrating injury, orbital rim fractures and those with any intracranial injury other than a small underlying extra-axial haemorrhage subjacent to the fracture site. While excluding

DOI: 10.1002/ebch.1941

Table 2. Studies addressing the value of repeat skeletal survey (SS) in children with suspected abuse, included since the original review, 2005–2013

Author, year, study design	Number of children undergoing repeat imaging total children	Imaging method	Imaging performed	Time interval	Results	Comment
Anilkumar et al., 2006, Case Series (11)	59/200	Film-screen and digital radiography	Initial SS (including oblique views if age <1 year), follow-up chest X-ray +/− oblique views	10 days–3 weeks	3/59 (5.1%) had additional rib fractures noted on follow-up 2/59 (3.4%) had rib fractures identified for the first time Dating information was obtained in 3/59 patients (5.1%)	Retrospective study of children <2 years, 1998–2003, routinely invited for follow-up from 1/1/2000 Only 59/200 cases returned for follow-up
Harlan et al., 2009, Case Series (13)	101/377	Computed radiography (both studies) 61 Digital radiography (both studies) 33 Both 7	Full SS (including oblique views) initially, with all views repeated except for skull	10–21 days	New information provided in 38 children (37.6%) 4/34 patients (12%) with normal initial SS had fractures diagnosed at follow up, involving rib, upper and lower limbs, feet, confirmation of previously indeterminate crush fracture to spine.	Retrospective study children <3 years, 2002–2007. Analysis conducted to determine if 'limited' follow-up could be performed. Only 185/377 underwent repeat SS (of whom 101 met inclusion criteria). 38/101 provided additional information. 4/34 with normal initial SS had fractures on follow-up. Propose 15/11/7/3 view reduced follow up—only 15 views would not miss any additional findings.
Sonik et al., 2010, Case Series (14)	22/22	Computed radiography	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 underwent 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 support recommendation.
Karmazyn et al., 2011, Cross-Sectional (3)	930 children 109/116 equivocal fractures re-imaged	Radiography alone 43 radionuclide imaging + radiography 35 Radionuclide imaging alone 25 Radiography + computerized tomography 4 Radionuclide imaging + computerized tomography 1 Computerized tomography alone 1 No details as to why differing modalities chosen, or extent of repeat radiography performed.	Full SS (31 views), including oblique views initially. Repeat imaging only for equivocal findings	N/A	29/116 (25%) definite fractures in previously equivocal findings	Retrospective study children <2 years, 2003–2009 124/930 had new fractures on follow-up. Main aim to propose reduced imaging for initial SS, propose excluding spine, pelvis, hands and feet, unless superficial injury to this area, as they accounted for 1% of fractures found. Cases described would suggest that some of these fractures were significant findings however.

DOI: 10.1002/ebch.1941

Table 2. Continued.

Author, year, study design	Number of children undergoing repeat imaging total children	Imaging method	Imaging performed	Time interval	Results	Comment
Singh et al., 2012, Retrospective Cohort (16)	169/1470	Radiography SS	Full SS including oblique views initially, omitted skull and spine for follow-up imaging	Mean 19+/− 11 days	24/169 (14%) had previously unrecognized healing fractures on follow-up 6/24 (25%) of these subjects had a negative initial SS	Retrospective review from 2002–2009, 88% < 1 year. Significant increase in number of follow-up SS 2005–2009. 24/169 fractures identified on follow-up SS. Two fractures missed on initial SS. In eight cases findings on follow-up influenced abuse diagnosis, six negative 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.
Bennett et al., 2011, Case Series (15)	47/47	Radiography SS	Initial and repeat were full SS according to American College of Radiology standards, 19 images. Oblique views of ribs not routinely obtained.	9–56 days	All had normal initial SS, four (8.5%) had abnormal follow-up SS. Three rib fractures, one proximal humerus.	Unusual inclusion criteria of only those with a completely negative SS, yet still showed additional forensically relevant fractures. No detail as to why these children underwent repeat imaging.

SS: skeletal survey.

DOI: 10.1002/ebch.1941

those who did not undergo a SS, they noted that 6% had occult fractures, the presence of 'red flags' did not appear to be a discriminator, and although the majority of those with occult fractures were younger than 6 months, this was representative of the total population. They concluded that a SS should be conducted either in all those aged less than 6 months, or those who are not independently mobile, who present with isolated skull fractures (22). However, no authors to date have conducted a prospective study of all children presenting with specific features (e.g. seizure, fracture) to determine the true predictive value of a SS in this instance; thus at this stage, the recommendation that all those with 'suspected physical abuse' younger than 2 years should be screened remains the best reflection of current evidence.

Our original review found insufficient evidence to determine whether siblings of those with confirmed abuse should undergo a SS. Since then, two authors have addressed this (18, 21), with slightly different results. Day et al. only screened six siblings, including two sets of twins, with one child (a twin) demonstrating occult fractures (18). Lindberg et al. (21) collated data on 134 'contacts' (i.e. children sharing the home with the abused child within the past month) younger than 2 years and undergoing a SS, 11.9% of which were positive for occult fractures. Notably 9 of 16 twins had a positive SS, suggesting that they may be at increased risk. These new findings would suggest where abused children have household 'contacts' less than 2 years old, particularly twins, that a SS should be considered.

Additional studies addressed specific imaging techniques, for example, the value of oblique views of the ribs (27), lateral views of the long bones (28) or additional modalities, such as computerized tomography of chest (29), 3D computerized tomography of skull (30), ultrasound (31, 32) and whole body magnetic resonance imaging (33, 34). These are detailed in Table S1. Our original review concluded that oblique views of the ribs did contribute to the detection of occult rib fractures, and they have subsequently been added to the UK and US national recommendations. Hansen and colleagues (27) specifically addressed this question, and noted that additional fractures were visualized by the four views (posterior anterior, lateral, right and left oblique) in 12 of 22 cases. Amongst these cases, 19 additional fractures were seen on the four-view, and six rib fractures were excluded, thus they concluded the overall accuracy was improved by use of the four-view rather than two-view chest series. Given the extremely high specificity of rib fractures for physical abuse and the lack of bruising present in the majority of cases, this is an important addition to the diagnostic yield.

Which fractures are indicative of abuse?

The original review findings related to this question were published in 2008 (2). Having identified 2014 abstracts, 439 studies were reviewed and 32 included, of which 26 were eligible for meta-analysis. The findings detailed the probability that certain fractures were abusive, with rib fractures having the highest probability. Multiple fractures are more common in abuse than non-abusive injury, supracondylar humeral fractures are usually accidental, and a femoral fracture in a pre-mobile child has a high probability of an abusive origin. In the original review (2), meta-analyses of the descriptive data utilizing a random effects model to account for heterogeneity were performed using positive predictive values (PPVs) of femoral, humeral, skull and rib fractures for abuse as the measure of effect (Table 3). However we were unable to stratify the analyses by the age of the children, as that varied considerably across studies. Included studies derived the probability of abuse in children with specific fracture types and we could not derive odds ratios (ORs) or sensitivity analyses for diagnostic test accuracy. Since then, we have identified a further 65 studies potentially addressing this question, with nine meeting our inclusion criteria (Fig. 2).

Pandya et al. (35) have addressed both deficiencies in a study of children younger than 48 months. The study included 500 child-abuse cases (337 <18 months, 123 >18 months) from a level 1 paediatric trauma centre. Abuse was confirmed at multi-agency child abuse team assessments from 1998 to 2007. The 985 controls (425 < 18 months, 560 > 18 months) were children who presented to the emergency department or were admitted to hospital with trauma and were identified from the general trauma database 2000–2003 at the same unit.

The study confirmed previous findings that victims of abuse with fractures were significantly younger than controls (11.7 vs. 22.1 months). For children younger than 18 months, the age- and sex-adjusted odds of rib and limb fractures for abuse were significantly higher than in controls. In children aged 18–48 months, the odds of a rib fracture remained higher for abuse, while the odds for humerus and femoral fractures were in favour of the controls, and tibial and/or fibular fractures were not significant indicators of either (Table 4). In addition, the study offers the first opportunity to compare the prevalence of clavicular, radius and ulnar fractures in abuse and in controls.

Pandya et al. (35) is the largest and probably one of the most comprehensive studies to be published to date. Data were recorded independently and abuse defined prospectively; cases and controls were taken from the same unit, albeit over slightly different time periods. There was no detail of mechanism of injury available. The study was sufficiently powered to show significant differences in the commonest fracture types but under-powered with respect to the less-common fracture types (e.g. hands, feet). No detail is given as to the level of radiological investigation between the two groups. This was likely to have been more thorough for the abuse group who would have a SS performed as a matter of routine and the detail of

DOI: 10.1002/ebch.1941

Table 3. Results of meta-analysis of fracture types with positive predictive value for abuse: original data and new age stratified analysis*

Original analysis (All ages) (2)		Updated analysis			
Bone fracture/studies	**Positive predictive value for abuse (95% CI)**	**Bone fracture/studies**	**Age range**	**Positive predictive value for suspected or confirmed abuse (95% CI)**	**Measure of heterogeneity**
Femur/13 studies (confirmed abuse, excluding motor vehicle collision, violent trauma)	27.7% (CI 15.1–43.7)	Femur/nine studies (confirmed or suspected): (36, 38, 53–59)	0–18 months	50.1% (CI 34.1–66.1)	$I^2 = 0\%$
Femur/13 studies (confirmed or suspected abuse, excluding motor vehicle collision, violent trauma)	42.7% (CI 32.4–53.7)	Femur/eight studies (confirmed or suspected abuse): (36, 38, 43, 54, 55, 57–59)	12–48 months	11.7% (CI 6.1–17.3)	$I^2 = 57.4\%$
Humerus/four studies (confirmed abuse)	47.6% (CI 5.6–93.8)	Humerus/five studies (confirmed or suspected abuse): (37, 40, 56, 58, 60)	0–18 months	43.8% (CI 27.6–59.9)	$I^2 = 0\%$
Humerus/four studies (confirmed or suspected abuse)	53.9% (CI 19.7–88.2)	Humerus/four studies (confirmed or suspected abuse): (37, 40, 58, 60)	18–48 months	1.8% (CI –0–3.9)	$I^2 = 28.8\%$
Rib/seven studies (confirmed abuse, excluding motor vehicle collision)	70.9% (CI 41.8–91.3)	Rib fractures/four studies (confirmed or suspected abuse): (35, 61–63)	0–48 months	66% (CI 42. 5–89.7)	$I^2 = 0\%$
Skull/seven studies (confirmed or suspected abuse)	30.1% (CI 18.9–45.7)	Skull fractures/four studies (confirmed or suspected abuse): (35, 64–66)	0–48 months	20.1% (CI 13.3–26.9)	$I^2 = 0\%$

I^2: index describing the percentage of total variation across studies due to heterogeneity.
*For studies by Pandya (35, 37) and Baldwin (38) data were collected for abused children and controls from the same unit but for different time periods (abuse 1998–2007; controls 2000–2003), an assumption was made that the 3-year data set for controls would be representative of the 9 years over which abuse data were collected. Thus, the control data were scaled up by a factor of three to estimate positive predictive value of fracture type for abuse.

Table 4. Odds ratio (OR with 95% confidence intervals) for abuse versus non-abuse in children aged less than 18 months of age and children 18–48 months, derived from Pandya et al. 35, 37

Fracture	<18 months of age OR for abuse (95% CI)	18–48 months OR for abuse (95% CI)
Ribs	23.7 (CI 9.5–59.2)	9.1 (CI 3.3–25.0)
Tibia/fibula	12.8 (CI 5.1–32.6)	2.1 (CI 0.7–6.2)
Humerus	2.3 (CI 1.3–4.1)	0.29 (CI 0.1–0.7)
Femur fracture	1.8 (CI 1.2–2.7)	0.3 (CI 0.01–0.7)

Age- and sex-adjusted OR using binary logistic regression.

fracture type was not available. Although the abuse cases were diagnosed at hospital discharge by the child abuse team, the final substantiation decision of the area child protection team is not known.

Updated meta-analysis

The data from Hui et al. (36), Pandya (35, 37) and Baldwin (38) were added to the previous data with the aim of completing meta-analyses focused more clearly around distinct age ranges. We were able to complete a meta-analysis for children younger than 18 months and for children 1–5 years of age for humeral and femoral fractures, based on two separate data sets. For skull and rib fractures we restricted the studies in the meta-analysis to those that included children younger than 4 years (Table 3).

We used PPVs as a measure of effect with 95% confidence intervals (CIs). We pooled data using a random effects model to allow for both intra- and inter-study variances and to give a more conservative estimate of the effect. The level of heterogeneity was expressed using the I^2 index which describes the percentage of total variation across studies that is not due to chance but rather a result of heterogeneity, where I^2 of 25%, 50% and 75% represented low, moderate and high levels of heterogeneity respectively (39). MIX: meta-analysis version 2.0 for Windows software was used to present data in forest plots for each outcome, showing the calculated PPV with 95% CI (available on request).

The meta-analysis confirms that the probability that a humeral or femoral fracture is abusive in origin is significantly greater for a child younger than 18 months than for one between 12 and 48 months of age. While it was not possible to calculate overall probabilities of abuse for infants and older children for rib and skull fractures, the revised PPV for abuse from the meta-analyses for specific age groups of 0–4 year olds was within the same range as the original meta-analysis (2).

Fracture site for femoral and humeral fractures

In 2010 and 2011, based on their recognition of the significant association between long bone fractures

DOI: 10.1002/ebch.1941

and abuse in children younger than 18 months, Pandya et al. published two further studies (37, 38) on the same dataset.

The case–control analysis of humeral fractures (37) included 39 humeral fractures in 36 abuse cases and 95 children with an accidental humeral fracture. The study showed that 83.3% of proximal humeral fractures and 86.7% of humeral shaft fractures were associated with abuse. When compared with shaft fractures, a distal humeral fracture was significantly more likely to be associated with accidental injury, a factor previously identified by Strait et al. (40) and Farnsworth et al. (41).

Baldwin et al. (38) applied the same process to 70 children with an abusive femoral fracture and 139 children with accidental femoral fractures. Children with accidental trauma were more likely to have a diaphyseal fracture [OR for abuse 0.4 (CI 0.2–0.8)], a finding consistent with the study by Beals et al. (42) but not supported by Blakemore (43) or the more recent study by Hui (36) who noted no relationship. Baldwin (38) proposed that abuse cases were more likely to sustain a distal femoral fracture [OR 2.3 (1.2–4.4)] but there was no difference in proximal fracture between the two groups.

Two studies explored the hypothesis that complete transverse metaphyseal fractures of the distal femur were strong indicators of abuse in children of pre-walking stage. Arkader et al. (44) identified 20 children less than 1 year of age (mean age 6 months 10 days, range 5 days–12 months), after Suspected Child Abuse and Neglect assessment of those with a doubtful description of injury, 10 (50%) were deemed definite abuse, abuse was suspected in a further five and there were five cases of confirmed accident (three fall from furniture, lap and swing, a motor vehicle accident and a birth injury).

Haney et al. (45) followed this study with a case series of transverse impact fractures of the entire lower femoral meta-diaphysis derived from an international group of child protection specialists. The study included 18 children, 13 cases (72%) were deemed probable non-abuse and five were probable abuse (28%). For the 16 children less than a year of age, 11 (69%) were not abused and five (31%) were probable abuse. The data collection methodology and security of diagnosis of these two studies vary considerably. The latter has the potential to suffer from recall and referral bias by child protection physicians. There was however no significant difference between the PPV for abuse between the two studies 31% (14.2–55.6%) versus 50% (29.9–70.1%) ($p = 0.12$) in children less than a year of age with a complete transverse distal meta-diaphyseal femoral fracture; however, the studies are small with wide confidence intervals. Thus, abuse should form part of the differential diagnosis for this fracture. Haney (45) describes the mechanism of injury in accidental cases where two children were dropped and landed on the knee or prone.

Metaphyseal fractures

The original SR identified a paucity of comparative studies of the classical metaphyseal lesion (CML) (2). Kleinman, who had published several case series of abusive metaphyseal fractures (46–49) undertook a retrospective review of case notes and compared the prevalence of classical metaphyseal fractures in the SS of children with high and low risk of abuse over a 10-year time period (50); see Table S2. There were no CML fractures in the low-risk group (mean age 4.4 months), yet 9 of 18 (50%) of the high-risk group (mean age 4.6 months) had 18 CMLs. The difference was highly significant ($p = 0.001$, Fisher's exact test). The most common locations for the CMLs were distal femoral and proximal tibial lesions. Although restricted to a comparison of children with abusive and non-abusive head trauma, this is a useful comparative study.

Other skeletal fractures

A large-scale noncomparative study of abusive fractures confirmed the higher prevalence of abusive fractures in younger children, and reiterated that multiple fractures were common (51).

Perez-Rosello et al. (52) described the challenges of differentiating inflicted fractures from developmental variants of the superior pubic ramus in infants, highlighting that the best indication of a fracture is an oblique fracture line, extensive callus, displacement of osseous fragments with evidence of additional injuries around the pelvis. They suggest that a smooth margined, vertical lucency with no other indicators of trauma should not be interpreted as a fracture.

Conclusions

The identification of occult fractures in children who have been abused and distinguishing which fractures are indicative of abuse remains one of the most common dilemmas that paediatricians and radiologists face when assessing children with suspected abuse. The original review findings with regard to radiological investigations to be undertaken in children with suspected abuse clearly concluded that a single investigation (i.e. SS or RNI) would miss some fractures, yet routine practice at the time was to conduct a single investigation. In the intervening years, a further 23 studies have been included, of which six addressed this question. Although the indications for performing repeat imaging (11–14 days later) varied, and both the quality and images included in the original SS and the repeat SS also varied, the overall conclusion is clear—additional imaging will reveal fractures which were not identified initially (in 8.4–37.6% of children), and which have the potential to influence the child protection decisions. The challenge now is to define precisely which images should be incorporated into the repeat SS, and which children should undergo

DOI: 10.1002/ebch.1941

such imaging. At this time, it would appear that those for whom it is deemed relevant should have a full repeat SS (omitting skull) and including oblique views of the ribs. There has been little additional literature regarding the ‘added value’ of a RNI conducted at the time of the original SS, although what little there is would support its use in selected cases. Further useful information has been published with regard to additional imaging strategies, the role of SS in children with burns and in siblings.

While we were delighted that there was sufficient high quality studies to enable a meta-analysis to be performed for certain fracture types (femoral, humeral, rib and skull) within the original review of fractures indicative of abuse, we were frustrated that the data were not explicit with regard to age. Thus, we were unable to conduct separate meta-analyses by age for these fractures. We are very pleased that since the original review, nine studies have been published, two of which (35, 36) are of sufficient quality to enable a novel meta-analysis by age to be conducted for two fracture types (femoral and humeral). This has emphasized the significantly higher probability of abuse when an infant younger than 18 months presents with a femoral fracture versus a child aged 12–48 months (PPV 52.6%, 95% CI 34.6–70.5 vs. PPV 13.5%, 95% CI 7.3–19.6). Likewise, a humeral fracture is far more likely to be abusive in origin in a child younger than 18 months versus 12–48 months (PPV 55.4%, 95% CI 39.2–71.6 vs. PPV 3.3%, 95% CI 1.3–7.8). While there was insufficient data to conduct an age-sensitive meta-analysis for other fractures, the excellent study by Pandya et al. (35) does make a significant contribution to the literature on this topic. Pandya *et al.* (35) is one of the few published studies to explore tibial and fibular fractures in abuse and suggests that in the children younger than 18 months, the odds of a tibial/fibular fracture arising from abuse is even higher than for femoral or humeral fractures. While this finding was supported by Coffey et al. (53) in the original review that identified 96% (23/24) of tibial fractures, there are still insufficient studies to populate a meta-analysis of this fracture type. One of the frustrations of the original review was the lack of comparative data relating to CMLs, precluding a meta-analysis. Kleinman et al. have attempted to address this gap (46–50), and have demonstrated a highly significant association between the presence of CML in children presenting with head trauma who have been abused, versus those who have not ($p = 0.001$).

Overall, the additional 32 studies included since the original reviews have added considerable depth to the literature in this important area. It is to be hoped that further high-quality comparative studies of other fractures, particularly rib, skull, forearm and lower leg, will be conducted, with data presented in different age groups to inform this important area of clinical practice. Further details of all included studies, including those related to the dating of fractures, can be found on our website www.core-info.cf.ac.uk

Acknowledgements

We are grateful to the NSPCC for the funding of this work, to our panel of reviewers, and to Laura Wain for editorial assistance.

Declaration of interest

The authors have no financial or competing interests with regard to this work. The authors do not receive any financial assistance beyond that provided by the charity, NSPCC, for undertaking this work.

Supporting information

Additional supporting information may be found in the online version of this article.

Appendix S1. CAF: Child protection fractures study—COFS update 2013.
Table S1. Studies addressing the radiological investigation of suspected abuse included since original review (2005–2013).
Table S2. Included studies for fractures indicative of abuse 2005–2013.

References

1. Kemp AM, Butler A, Morris S, Mann M, Kemp KW, Rolfe K, *et al.* Which radiological investigations should be performed to identify fractures in suspected child abuse? *Clin Radiol* 2006; **61**: 723–736.
2. Kemp AM, Dunstan F, Harrison S, Morris S, Mann M, Rolfe K, *et al.* Patterns of skeletal fractures in child abuse: systematic review. *Br Med J* 2008; **337**: a1518.
3. Karmazyn B, Lewis ME, Jennings SG, Hibbard RA, Hicks RA. The prevalence of uncommon fractures on skeletal surveys performed to evaluate for suspected abuse in 930 children: Should practice guidelines change? *Am J Roentgenol* 2011; **197**: W159–W163.
4. NHS Centre for Reviews and Dissemination. Undertaking systematic reviews of research on effectiveness. *CRD's Guidance for those Carrying Out or Commissioning Reviews CRD Report No. 4*, 2nd edn. University of York; 2001.
5. Critical Appraisal Skills Programme. xxxx. Available at: http://www.casp-uk.net/ [accessed on 7 June 2013].
6. Polgar A, Thomas SA. *Critical Evaluation of Published Research. Introduction to Research in the Health Sciences*, 3rd edn. Melbourne: Churchill Livingstone; 1995.
7. Cardiff Child Protection Systematic Reviews (CORE INFO). Which fractures are indicative of abuse? 2013. Available at: http://www.core-info.cardiff.ac.uk/reviews/fractures/which-fractures-are-indicative-of-abuse [accessed on 24 May 2013].
8. Kemp AM, Joshi AH, Mann M, Tempest V, Liu A, Holden S, *et al.* What are the clinical and radiological characteristics of spinal injuries from physical abuse: a systematic review. *Arch Dis Child* 2010; **95**: 355–360.
9. Royal College of Radiologists, Royal College of Paediatrics and Child Health. *Standards for Radiological Investigations of Suspected Non-Accidental Injury*. London, UK: RCR, RCPCH; 2008. Available at: http://www.rcr.ac.uk/docs/radiology/pdf/RCPCH_RCR_final.pdf [accessed on 24 May 2013].
10. American College of Radiology. ACR Appropriateness Criteria®: suspected physical abuse — child. 2012. Available at: http://www.acr.org/~/media/ACR/Documents/AppCriteria/Diagnostic/SuspectedPhysicalAbuseChild.pdf [accessed on 24 May 2013].
11. Anilkumar A, Fender LJ, Broderick NJ, Somers JM, Halliday KE. The role of the follow-up chest radiograph in suspected non-accidental injury. *Pediatr Radiol* 2006; **36**: 216–218.

DOI: 10.1002/ebch.1941

12. Williams G, Treves ST. A second radiographic skeletal survey for child abuse triggered by bone scintigraphy found positive after the initial survey was called negative. *Clin Nucl Med* 2007; **32**: 29–31.
13. Harlan SR, Nixon GW, Campbell KA, Hansen K, Prince JS. Follow-up skeletal surveys for nonaccidental trauma: Can a more limited survey be performed? *Pediatr Radiol* 2009; **39**: 962–968.
14. Sonik A, Stein-Wexler R, Rogers KK, Coulter KP, Wootton-Gorges SL. Follow-up skeletal surveys for suspected non-accidental trauma: Can a more limited survey be performed without compromising diagnostic information? *Child Abuse Negl* 2010; **34**: 804–806.
15. Bennett BL, Chua MS, Care M, Kachelmeyer A, Mahabee-Gittens M. Retrospective review to determine the utility of follow-up skeletal surveys in child abuse evaluations when the initial skeletal survey is normal. *BMC Res Notes* 2011; **4**: 354.
16. Singh R, Squires J, Fromkin JB, Berger RP. Assessing the use of follow-up skeletal surveys in children with suspected physical abuse. *J Trauma Acute Care Surg* 2012; **73**: 972–976.
17. Curcoy Barcenilla AI, Trenchs Sainz De La Maza V, Pou Fernández J. Utility of bone scintigraphy in the differential diagnosis of child maltreatment [Spanish]. *An Pediatr* 2006; **65**: 83–84.
18. Day F, Clegg S, McPhillips M, Mok J. A retrospective case series of skeletal surveys in children with suspected non-accidental injury. *J Clin Forensic Med* 2006; **13**: 55–59.
19. Hicks RA, Stolfi A. Skeletal surveys in children with burns caused by child abuse. *Pediatr Emerg Care* 2007; **23**: 308–313.
20. Hansen KK, Campbell KA. How useful are skeletal surveys in the second year of life? *Child Abuse Negl* 2009; **33**: 278–281.
21. Lindberg DM, Shapiro RA, Laskey AL, Pallin DJ, Blood EA, Berger RP. Prevalence of abusive injuries in siblings and household contacts of physically abused children. *Pediatrics* 2012; **130**: 193–201.
22. Laskey AL, Stump TE, Hicks RA, Smith JL. Yield of skeletal surveys in children ≤18 months of age presenting with isolated skull fractures. *J Pediatr* 2013; **162**: 86–89.
23. Merten DF, Radlowski MA, Leonidas JC. The abused child: a radiological reappraisal. *Radiology* 1983; **146**: 377–381.
24. Belfer RA, Klein BL, Orr L. Use of the skeletal survey in the evaluation of child maltreatment. *Am J Emerg Med* 2001; **19**: 122–124.
25. Duffy SO, Squires J, Fromkin JB, Berger RP. Use of skeletal surveys to evaluate for physical abuse: analysis of 703 consecutive skeletal surveys. *Pediatrics* 2011; **127**: e47–e52.
26. Rangel EL, Cook BS, Bennett BL, Shebesta K, Ying J, Falcone RA. Eliminating disparity in evaluation for abuse in infants with head injury: use of a screening guideline. *J Pediatr Surg* 2009; **44**: 1229–1235.
27. Hansen KK, Prince JS, Nixon GW. Oblique chest views as a routine part of skeletal surveys performed for possible physical abuse-Is this practice worthwhile? *Child Abuse Negl* 2008; **32**: 155–159.
28. Karmazyn B, Duhn RD, Jennings SG, Matthew RW, Tahir B, Hibbard R, *et al.* Long bone fracture detection in suspected child abuse: contribution of lateral views. *Pediatr Radiol* 2012; **42**: 463–469.
29. Wootton-Gorges SL, Stein-Wexler R, Walton JW, Rosas AJ, Coulter KP, Rogers KK. Comparison of computed tomography and chest radiography in the detection of rib fractures in abused infants. *Child Abuse Negl* 2008; **32**: 659–663.
30. Prabhu SP, Newton AW, Perez-Rossello JM, Kleinman PK. Three-dimensional skull models as a problem-solving tool in suspected child abuse. *Pediatr Radiol* 2013; **43(5)**: 575–581.
31. Kelloff J, Hulett R, Spivey M. Acute rib fracture diagnosis in an infant by US: a matter of child protection. *Pediatr Radiol* 2009; **39**: 70–72.
32. Hansen M, Weltzien A, Blum J, Botterill NJ, Rommens PM. Complete distal humeral epiphyseal separation indicating a battered child syndrome: a case report. *Arch Orthop Trauma Surg* 2008; **128**: 967–972.
33. Eltermann T, Beer M, Girschick HJ. Magnetic resonance imaging in child abuse. *J Child Neurol* 2007; **22**: 170–175.
34. Perez-Rossello JM, Connolly SA, Newton AW, Zou KH, Kleinman PK. Whole-body MRI in suspected infant abuse. *Am J Roentgenol* 2010; **195**: 744–750.
35. Pandya NK, Baldwin K, Wolfgruber H, Christian CW, Drummond DS, Hosalkar HS. Child abuse and orthopaedic injury patterns: analysis at a level I pediatric trauma center. *J Pediatr Orthop* 2009; **29**: 618–625.
36. Hui C, Joughin E, Goldstein S, Cooper N, Harder J, Kiefer G, *et al.* Femoral fractures in children younger than three years: The role of nonaccidental injury. *J Pediatr Orthop* 2008; **28**: 297–302.
37. Pandya NK, Baldwin KD, Wolfgruber H, Drummond DS, Hosalkar HS. Humerus fractures in the pediatric population: an algorithm to identify abuse. *J Pediatr Orthop B* 2010; **19**: 535–541.
38. Baldwin K, Pandya NK, Wolfgruber H, Drummond DS, Hosalkar HS. Femur fractures in the pediatric population: abuse or accidental trauma? *Clin Orthop Relat Res* 2011; **469**: 798–804.
39. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials* 1986; **7**: 177–188.
40. Strait RT, Seigel RM, Shapiro RA. Humeral fractures without obvious etiologies in children less than 3 years of age: when is it abuse? *Pediatrics* 1995; **96**: 667–671.
41. Farnsworth CL, Silva PD, Mubarak SJ. Etiology of supracondylar humerus fractures. *J Pediatr Orthop* 1998; **18**: 38–42.
42. Beals RK, Tufts E. Fractured femur in infancy: the role of child abuse. *J Pediatr Orthop* 1983; **3**: 583–586.
43. Blakemore LC, Loder RT, Hensinger RN. Role of intentional abuse in children 1 to 5 years old with isolated femoral shaft fractures. *J Pediatr Orthop* 1996; **16**: 585–588.
44. Arkader A, Friedman JE, Warner WC, Wells L. Complete distal femoral metaphyseal fractures: a harbinger of child abuse before walking age. *J Pediatr Orthop* 2007; **27**: 751–753.
45. Haney SB, Boos SC, Kutz TJ, Starling SP. Transverse fracture of the distal femoral metadiaphysis: a plausible accidental mechanism. *Pediatr Emerg Care* 2009; **25**: 841–844.
46. Kleinman PK, Marks SC Jr. A regional approach to the classic metaphyseal lesion in abused infants: the proximal humerus. *Am J Roentgenol* 1996; **167**: 1399–1403.
47. Kleinman PK, Marks SC Jr. A regional approach to classic metaphyseal lesions in abused infants: the distal tibia. *Am J Roentgenol* 1996; **166**: 1207–1212.
48. Kleinman PK, Marks SC Jr. A regional approach to the classic metaphyseal lesion in abused infants: the proximal tibia. *Am J Roentgenol* 1996; **166**: 421–426.
49. Kleinman PK, Marks SC Jr. A regional approach to the classic metaphyseal lesion in abused infants: the distal femur. *Am J Roentgenol* 1998; **170**: 43–47.
50. Kleinman PK, Perez-Rossello JM, Newton AW, Feldman HA, Kleinman PL. Prevalence of the classic metaphyseal lesion in infants at low versus high risk for abuse. *Am J Roentgenol* 2011; **197**: 1005–1008.
51. Loder RT, Feinberg JR. Orthopaedic injuries in children with nonaccidental trauma: demographics and incidence from the 2000 kids' inpatient database. *J Pediatr Orthop* 2007; **27**: 421–426.
52. Perez-Rossello JM, Connolly SA, Newton AW, Thomason M, Jenny C, Sugar NF, *et al.* Pubic ramus radiolucencies in infants: the good, the bad, and the indeterminate. *Am J Roentgenol* 2008; **190**: 1481–1486.
53. Coffey C, Haley K, Hayes J, Groner JI. The risk of child abuse in infants and toddlers with lower extremity injuries. *J Pediatr Surg* 2005; **40**: 120–123.
54. Anderson WA. The significance of femoral fractures in children. *Ann Emerg Med* 1982; **11**: 174–177.
55. Gross RH, Stranger M. Causative factors responsible for femoral fractures in infants & young children. *J Pediatr Orthop* 1983; **3**: 341–343.
56. Rosenberg N, Bottenfield G. Fractures in infants: a sign of child abuse. *Ann Emerg Med* 1982; **11**: 178–180.
57. Schwend RM, Werth C, Johnston A. Femur shaft fractures in toddlers and young children: rarely from child abuse. *J Pediatr Orthop* 2000; **20**: 475–481.

58. Thomas SA, Rosenfield NS, Leventhal JM, Markovitz RI. Long bone fractures in young children: distinguishing accidental injuries from child abuse. *Pediatrics* 1991; **88**: 471–476.
59. Wellington P, Bennet GC. Fractures of the femur in childhood. *Injury* 1987; **18**: 103–104.
60. Shaw BA, Murphy KM, Shaw A, Oppenheim WL, Myracle MR. Humerus shaft fractures in young children:accident or abuse? *J Pediatr Orthop* 1997; **17**: 293–297.
61. Barsness KA, Cha ES, Bensard DD, Calkins CM, Partrick DA, Karrer FM, *et al.* The positive predictive value of rib fractures as an indicator of nonaccidental trauma in children. *J Trauma* 2003; **54**: 1107–1110.
62. Cadzow SP, Armstrong KL. Rib fractures in infants: Red alert! The clinical features, investigations and child protection outcomes. *J Paediatr Child Health* 2000; **36**: 322–326.
63. Strouse PJ, Owings CL. Fractures of the first rib in child abuse. *Radiology* 1995; **197**: 763–765.
64. Kowal-Vern A, Paxton TP, Ros SP, Lietz H, Fitzgerald M, Gamelli RL. Fractures in the under 3 yr old age cohort. *Clin Pediatr* 1992; **31**: 653–659.
65. Meservy CJ, Towbin R, McLaurin RL, Myers PA, Ball W. Radiographic characteristics of skull fractures resulting from child abuse. *Am J Roentgenol* 1987; **149**: 173–175.
66. Reece RM, Sege R. Childhood head injuries: accidental or inflicted? *Arch Pediatr Adolesc Med* 2000; **154**: 11–15.

Appendix

Table AI. Search strategy

Original search strategy—OVID MEDLINE 1950—October 2005

1. Child abuse.mp.
2. child protection.mp.
3. (battered child or shaken baby or battered baby).mp.
4. 1 or 2 or 3
5. child/
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. 13. fractur:.mp.
14. rib fractur:.mp.
15. skull fractur:.mp.
16. femoral fractur:.mp.
17. humeral fractur:.mp.
18. pelvic fractur:.mp.
19. spiral fractur:.mp.
20. metaphyseal fractur:.mp.
21. (corner fractur: or bucket handle fractur:).mp.
22. metaphyseal chip fractur:.mp.
23. classic metaphyseal lesion:.mp.
24. or/13-23
25. (investigat: adj3 fract:).mp.
26. (radiolog: adj3 fractur:).mp.
27. (roentgen: adj3 fract:).mp.
28. skeletal survey.mp.
29. bone scan.mp.
30. Isotope Bone Scan:.mp.
31. Radionuclide.mp.
32. Scintigraphy.mp.
33. ((paediatric or pediatric) adj3 radiolog:).mp.
34. ((paediatric or pediatric) adj3 nuclear medicine).mp.
35. (ag: adj3 fractur:).mp.
36. ((dating or date) adj3 fractur:).mp.
37. (pattern: adj3 fractur:).mp.
38. (heal: adj3 fractur:).mp.
39. (timing adj3 healing).mp.
40. or/25-39
41. 12 and 24
42. 12 and 24 and 40
43. 41 or 42

Update search strategy - OVID Medline 2013 Update 8 January 2013

1. Child abuse.mp.
2. child protection.mp.
3. (battered child or shaken baby or battered baby).mp.
4. 1 or 2 or 3
5. (child: or infant: or baby or toddler:).mp.
6. CHILD/
7. CHILD, PRESCHOOL/
8. 5 or 6 or 7
9. non-accidental injur:.mp.
10. non-accidental trauma.mp.
11. (non-accidental: and injur:).mp.
12. soft tissue injur:.mp.
13. physical abuse.mp.
14. (or/9-13) and 8
15. 4 or 14
16. Fractures, Ununited/ or Radius Fractures/ or Fractures, Malunited/ or Tibial Fractures/ or Fractures, Bone/ or Rib Fractures/ or Femoral Neck Fractures/ or Femoral Fractures/ or Humeral Fractures/ or Shoulder Fractures/ or Fractures, Compression/ or Fractures, Cartilage/ or Hip Fractures/ or Intra-Articular Fractures/ or Fractures, Open/ or Fractures, Closed/ or Fractures, Comminuted/
17. fractur:.mp.
18. Fractures, Bone/
19. rib fractur:.mp.
20. (multiple skull fractur: or eggshell fractur: or skull fractur:).mp.
21. femoral fractur:.mp.
22. humeral fractur:.mp.
23. pelvic fractur:.mp.
24. (spiral fractur: or transverse fractur:).mp.
25. metaphyseal fractur:.mp.
26. (corner fractur: or bucket handle fractur:).mp.
27. metaphyseal chip fractur:.mp.
28. classic metaphyseal lesion:.mp.
29. or/16-28
30. (investigat: adj3 fract:).mp.
31. (radiolog: adj3 fractur:).mp.
32. (roentgen: adj3 fract:).mp.
33. skeletal survey.mp.
34. ((paediatric or pediatric) adj3 radiolog:).mp.
35. ((paediatric or pediatric) adj3 nuclear medicine).mp.
36. Tomography, X-Ray Computed/
37. Scintigraphy.mp.
38. (bone scan or X rays).mp.
39. skeletal survey.mp.
40. isotope bone scan:.mp.
41. or/30-40
42. healing.mp.
43. (timing adj3 healing).mp.
44. (pattern: adj3 fractur:).mp.
45. ((dating or date) adj3 fractur:).mp.
46. (ag: adj3 fractur:).mp.
47. or/42-46
48. 41 or 47
49. 15 and 29
50. 47 and 49
51. Limit 50 to yr = "2012—Current"

DOI: 10.1002/ebch.1941

Table A2. Information sources

Databases—Original search	**Time period searched**
All EBM Reviews (Cochrane DSR, ACP Journal Club, DARE, CCTR, CMR, HTA, NHSEED) via Ovid	1966–2005
ASSIA (Applied Social Sciences Index and Abstracts) via CSA Illumina	1987–2005
Caredata	1970–2005
Child Data via National Children's Bureau	1996–2005
CINAHL (Cumulative Index to Nursing and Allied Health Literature) via Ovid	1982–2005
EMBASE via Ovid	1980–2005
MEDLINE via Ovid	1950–2005
Pre-MEDLINE via Ovid	2005
SIGLE (System for Information on Grey Literature in Europe)	1980–2005
Trip Plus	1997–2005
Web of Knowledge—ISI Proceedings	1990–2005
Web of Knowledge—ISI Science Citation Index	1981–2005
Databases—Update search	
ASSIA (Applied Social Sciences Index and Abstracts)	1987–2013
Child Data via National Children's Bureau	1996–2009†
CINAHL (Cumulative Index to Nursing and Allied Health Literature) via EBSCO	1982–2013
Cochrane Central Register of Controlled Trials	1996–2013
EMBASE via Ovid	1980–2013
HMIC (Health Management Information Consortium) via Ovid	1979–2013
MEDLINE via Ovid	1950–2013
MEDLINE In-Process and Other Non-Indexed Citations via Ovid	1950–2013
Open SIGLE (System for Information on Grey Literature in Europe)	1980–2005*
Scopus	2009–2013
Social Care online (previously Caredata)	1970–2013
Web of Knowledge—ISI Proceedings	1990–2013
Web of Knowledge—ISI Science Citation Index	1981–2013
Web of Knowledge—ISI Social Science Citation Index	2008–2013
Journals 'hand searched'	
Child Abuse and Neglect	1977–2013
Child Abuse Review	1992–2013
Websites searched	**Date accessed**
The Alberta Research Centre for Health Evidence (ARCHE)	January 2013
Child Welfare Information Gateway (formerly National Clearinghouse on Child Abuse and Neglect)	January 2013
Google Scholar	January 2013

ISI: Institute for Scientific Information.
*Stands for ceased indexing.
†Stands for institutional access terminated.

If you would like to make a comment on the above article, you are invited to submit a letter to the Editor by email (child@ualberta.ca). Selected letters may be edited and published in future issues of the journal.

DOI: 10.1002/ebch.1941