Multicentre study of physical abuse and limb fractures in young children in the East Anglia Region, UK

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ABSTRACT

Objective To determine if the detection of physical abuse in young children with fractures is of uniform high standard in the East Anglia Region of the UK, and whether we can identify areas for improvement in our detection of high-risk groups.

Design Multicentre retrospective 4-year study.

Setting 7 hospitals across the East Anglia Region of Britain (East Anglia Paediatric Physical Abuse and Fractures study).

Participants Age groups and fractures indicated as being at higher risk for physical abuse (all children under 12 months of age, and fractures of humerus and femur in children under 36 months of age).

Outcome measures Our criterion for physical abuse was the decision of a multiagency child protection case conference (CPCC).

Results Probability of CPCC decision of physical abuse was highest in infants, ranging from 50% of fractures sustained in the first month of life (excluding obstetric injuries) to 10% at 12 months of age. Only 46%–86% of infants (under 12 months) with a fracture were assessed by a paediatrician for physical abuse after their fracture. Significant variation in the use of skeletal surveys and in CPCC decision of physical abuse was noted in children attending different hospitals.

Conclusions It is a concern that significant variation between hospitals was found in the investigation and detection of physical abuse as confirmed by CPCC decisions. To minimise failure to detect true cases of physical abuse, we recommend that all high-risk children should be assessed by a paediatrician prior to discharge from the emergency department. Our proposed criteria for assessment (where we found probability of CPCC decision of physical abuse was at least 10%) are any child under the age of 12 months with any fracture, under 18 months of age with femur fracture and under 24 months with humeral shaft fracture (not supracondylar).

What is already known on this topic?

- Fractures in children under 12 months of age are more likely to be due to physical abuse than in older children.
- Fractures of the humeral shaft and femur in very young children are disproportionately associated with physical abuse compared with other bones in the limbs.

What this study adds?

- The likelihood of a multiagency decision of physical abuse as a cause of limb fracture in young children in East Anglia varies significantly between hospitals.
- We highlight that a large proportion of higher risk children are not currently being assessed by paediatricians.
- We propose age guidelines for children with fractures who should be assessed by paediatricians, due to their higher risk of being from physical abuse.

INTRODUCTION

Physical abuse of children by adults, also known as inflicted injury or non-accidental trauma, can lead to fractures and other serious injuries.[1–5] Since most children at higher risk of fractures due to physical abuse have little or no language abilities, it remains a great challenge for clinicians to differentiate fractures that occur accidentally from those deliberately caused by abusive carers.[6–9] Attempts have been made to establish which factors in the history, examination, imaging and age of the child give the best indication as to whether a fracture was accidental or a result of physical abuse.[10–14] Studies have been published using data from individual hospitals across the world, but the significant majority come from the USA.[15] It has been noted that findings vary quite widely between centres,[4 16 17] suggesting that detection of physical abuse varies in incidence between geographic areas. While it can take place in any family, it occurs more frequently in areas with social challenges, with complex interplay between social deprivation, income inequality, mental health problems, alcohol and substance misuse and domestic abuse.[18–20]

Even the gold standard criterion for identifying physical abuse remains problematic. The decision of a multiagency child protection case conference (CPCC) and the decision of family courts are both considered to be the highest rank indicators of

physical abuse.[4] While all cases reaching court will have a CPCC decision of abuse, not all cases regarded as abuse by the CPCC will reach the court due to the social context of the abuse event. Therefore, data from CPCCs will give larger numbers regarded as physical abuse than is the case for court decisions of physical abuse. The decision of family courts will be an opinion based on the balance of probability, with a minority meeting a threshold of 'beyond reasonable doubt' in the criminal courts.[21] Opinion may differ between child protection specialists as to which would be the better criterion to use in research, but we have used the decision of the CPCC as the inclusion criterion for this study.

Research into physical abuse is particularly challenging as a circular argument of logic is present. Without an accurate objective diagnostic tool for identifying physical abuse, we rely on a CPCC decision as our best clear criterion. However, CPCC decisions are based on the advice of expert witnesses, who base their interpretation on past research. This past research is based on previous decisions made by CPCCs and courts. Therefore, this circular argument could result in a persistent and unidentified error in the whole process of identifying physical abuse in young children.

To compensate for the variation in data between centres, meta-analysis has created larger data sets.[4 22 23] Kemp *et al*'s[4] publication was a particularly important meta-analysis, as it gave for the first time an estimate of the relative risk of different fractures in different age groups being due to physical abuse. Such an approach has indicated that the highest risk groups for physical abuse are children under 12 months of age with any fracture, while humerus and femur fractures also have an increased association with physical abuse in young children over the age of 12 months.[4] However, meta-analyses face a number of challenges, since most source studies use different methodologies and do not include their raw data, which greatly limits statistical comparison between centres. Some studies use CPCC and court decisions as their endpoint, but more use the opinion of the hospital child protection team as their endpoint, which is a less stringent criterion. Therefore, multicentre studies with consistent methodology have been called for as urgently needed.[15]

Here we present the first ever multicentre study in the UK where we attempt to investigate the process of detecting physical abuse in children with fractures in the limbs and spine. All the major hospitals in one region have worked together to provide data using identical methodology. This enables us to detect potential variations in the process of assessment and identification of fractures due to physical abuse. Such a study should be more representative of the population of the UK, and of the clinical practice of those healthcare professionals assessing children in the UK, than past studies based in the USA. This would provide the kind of high-quality data that might enable improvements to national guidelines for paediatricians when undertaking their physical abuse assessments,[24] making sure they focus their expertise on those children whose fractures have a higher statistical chance of being associated with physical abuse.

METHODS

The hospitals involved in this study were Peterborough City Hospital (who led the study), Addenbrooke's Hospital (Cambridge), Norfolk and Norwich Hospital (Norwich), The West Suffolk Hospital (Bury St Edmunds), Bedford Hospital, The Ipswich Hospital and Northampton General Hospital. The hospitals at Cambridge and Norwich are teaching hospitals with medical schools, while the other hospitals vary from large to small district general hospitals. All have 24-hour emergency departments, paediatric wards, on-site paediatricians, child protection teams and between one and four specialist paediatric orthopaedic surgeons. The data from each hospital have been kept anonymised when presented in this paper (ie, not numbered in the order given above). This is to ensure that no hospital is perceived to be 'better' or 'worse' at identifying physical abuse. Our aim is to provide data that allows all hospitals to improve their ability to detect physical abuse, in a constructive and non-judgemental way.

The study covered injuries in young children from 1 January 2009 to 31 December 2012 (4 years). These dates were chosen as it gave sufficient time for the influential conclusions of the Kemp *et al's* publication[4] in the *BMJ* to become well known to clinicians treating children with fractures.

Clinicians from each hospital worked with their respective audit departments to identify those children that previous meta-analysis research suggests were at highest risk of physical abuse. Our inclusion criteria were all children under 12 months of age who sustained a fracture to limb or spine, and all children under the age of 3 years who sustained a fracture to any part of the femur, or to the shaft or proximal part of the humerus (ie, excluding supracondylar fractures). Supracondylar fractures were excluded from our study as they are a common fracture in walking age young children when a fall occurs.[25] As hospital coding may not always be accurate, the emergency department and inpatient notes and X-rays of every case were consulted by paediatric orthopaedic surgeons to ensure a fracture was present, the child was of the correct age and the bones involved were eligible for inclusion in the study. Children with fractures of the skull and ribs alone were not included in the study.

Working with the paediatricians and child protection team at each hospital, it was determined if the child was referred to a paediatrician for an assessment of whether physical abuse had taken place, if a skeletal survey had been requested, if the child had been referred to social services and the outcome of any multiagency CPCCs that resulted from the incident. CPCC outcomes were ascertained for every patient through the treating hospital's Safeguarding Children teams, who sought feedback from Children's Social Care about the CPCC judgement. These outcomes were classified in a binary fashion; either the child was determined to have been physically abused, or the CPCC made a different finding.

Statistical analysis

Comparison between categorical variables was performed using Pearson's X^2 test. The effect of various covariates on the probability of a high-risk fracture case being a physical abuse was computed using multivariate logistic regression. Statistical significance for all statistical calculations was defined as $p<0.05$. Statistical analysis was performed using the R programming language (V.3.2.5, Vienna, Austria).

Ethics

The NHS Health Research Authority has approved this study (IRAS project ID 251113, REC reference 19/HRA/0292). All the data were anonymised, and the work fulfils the requirements for a hospital quality and service improvement exercise.

RESULTS

Hospital variation in investigation of physical abuse

We looked at hospital variations of the proportion of young children with fractures in the high-risk groups being reviewed by a paediatrician, and the proportion of reviewed cases sent for

Table 1 Breakdown of investigations in the seven hospitals

Hospital ID	1	2	3	4	5	6	7	Overall
Fracture cases	49	11	35	35	74	41	44	289
Paediatric review Infants (0–12 months)	13 (46%)	4 (80%)	10 (77%)	16 (67%)	27 (71%)	12 (50%)	17 (86%)	99 (65%)
Paediatric review All high-risk cases (%)	26 (53)	7 (64)	18 (51)	23 (66)	40 (54)	20 (49)	33 (75)	167 (58)
Skeletal survey (%)	11 (22)	6 (55)	5 (14)	3 (9)	8 (11)	1 (2)	12 (27)	46 (16)

a skeletal survey. The breakdown of investigations by hospital is shown in table 1. No statistically significant variation was detected between hospitals in terms of proportion reviewed by a paediatrician, but significant variation was found for the use of skeletal survey between hospitals (X^2 tests performed, p values are 0.2 and <0.001, respectively).

Decision of a CPCC that fractures were due to physical abuse

The total number of babies born at the seven hospitals over the 4-year period from January 2009 to December 2012 was 120 612. This allowed us to determine the total number of children at risk of a fracture due to physical abuse in the hospital catchment area. The number of children with a fracture in our high-risk groups (infants, femur and humerus fractures) was 282. The total number of children where a CPCC decided that physical abuse had taken place to cause that fracture was 29. The raw data for each child has not been given in order to maintain their anonymity. Likelihood of a CPCC decision of physical abuse being associated with a fracture was calculated from the mean number of babies born per year at each hospital. The likelihood that a fracture in children aged 0–364 days would lead to a CPCC decision of physical abuse was 0.21/1000 of the total at-risk population. The likelihood of such a CPCC decision of physical abuse in cases of fracture of the femur or humerus (excluding supracondylar) in children under the age of 3 years was much lower at 0.03/1000 and 0.025/1000, respectively (table 2, figure 1).

Variation in identification of physical abuse between hospitals

We then looked at the variation of the proportion of cases resulting in a CPCC decision of physical abuse across the seven hospitals under study, while controlling for the age of the patients. We ran a logistic regression with age and hospital as predictors. The estimated probability of a CPCC decision of abuse in a child at age 1 year with a fracture is shown in figure 2 for each of the seven hospitals. We remark that under the model assumptions, the relative frequency of discovering physical abuse between hospitals for all other ages stays the same. An analysis of deviance X^2 test was carried out and a statistically significant hospital variation was observed ($p<0.01$). It should be noted that in one hospital there were no cases of physical abuse in any child with a fracture in limbs or spine confirmed by a CPCC decision during the 4-year study period. Kendall's rank correlation test showed that hospitals more likely to employ skeletal surveys were also hospitals with a higher likelihood of deciding a fracture was due to physical abuse (Kendall's tau=0.567, $p<0.0001$).

Effect of age on physical abuse

In figure 3 we plot all cases examined in this study by age of the patient and the case outcome (cases with CPCC decision of physical abuse are on the top row and negative cases are on the bottom row). More positive cases are seen in the younger children groups. We fit a logistic regression to explain the age dependency of the probability of physical abuse. We also fit logistic regressions individually for infant physical abuse (figure 3A), humerus (figure 3B) and femur (figure 3C). The red curves show estimated probability of physical abuse and blue dashed curves represent 95% pointwise confidence bands. The estimated decrease in log odds of physical abuse for every 1 year increase in age is summarised in table 3. As an example, the odds that a femoral fracture in a 12-month-old child is a result of physical abuse is estimated to be five times that of the corresponding odds of a 24-month-old child. In terms of overall probability, in the first month of life the probability of a suspicious case being physical abuse is about 50%, but it decreases with the age of the infant and is about 20% when a child has reached 6 months of age.

Most frequent sites of injury in infants

In the infant group (below 12 months), the most common locations for limb fractures were the femur, tibia/fibula, radius/ulna, humerus and clavicle (table 4). Injuries ranged from one fracture to six fractures in the same infant (one case had fractures to a femur, bilateral tibias, radius, humerus and clavicle). Extremity injuries of the hand and feet in this age group were rare. Fractures of the humerus were the most likely to be associated with a CPCC decision of physical abuse (31% physical abuse, 69% accidental). However, most other long bone fractures were associated with a CPCC decision of physical abuse in just 15%–21% of cases.

DISCUSSION

This is the first ever multicentre study of hospitals covering an entire region of the UK, using the same data collection method, to assess the process of detecting limb and spine fractures due to physical abuse in young children. We have used an endpoint

Table 2 Likelihood that any child of relevant age living in the study catchment area will sustain a fracture that will lead to a child protection case conference decision of physical abuse (PA) (in ‰) by hospital (numbered 1–7)

Hospital ID	1	2	3	4	5	6	7	Overall
Femoral PA (0–36 months)	0.056	0.030	0.022	0.018	0.042	0	0.029	0.030
Humeral PA (0–36 months)	0.037	0	0.066	0	0.014	0	0.043	0.025
All PA (0–12 months)	0.28	0.091	0.26	0.11	0.25	0	0.30	0.21

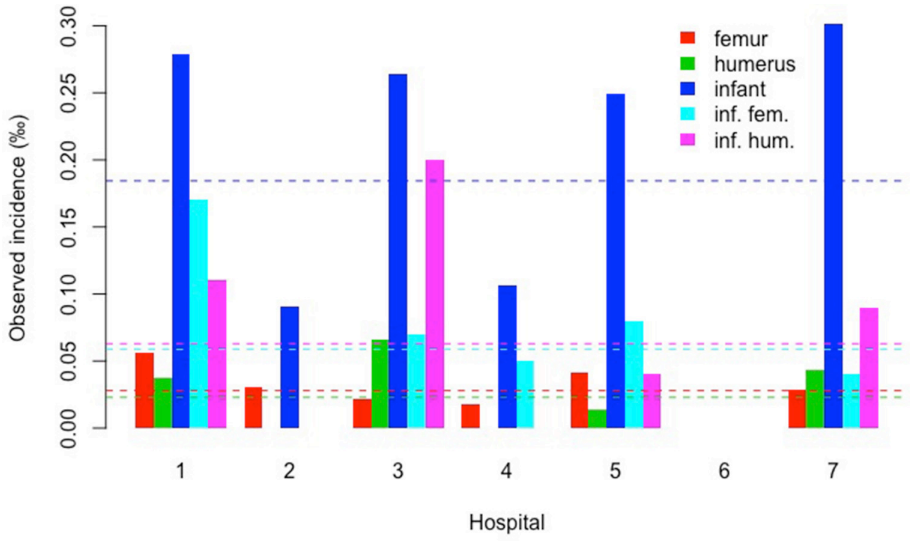

Figure 1 Incidence of child protection case conference (CPCC) decision of fracture due to physical abuse in the seven hospitals in East Anglia. Data given for femur (red) and humerus (green) fractures in children aged less than 3 years, any limb or spine fracture in an infant (dark blue) and femur (pale blue) and humerus (pink) fractures in an infant. The overall likelihood of CPCC decision of abuse in the region for each fracture group is indicated by the dashed line of the same colour.

of multiagency CPCC decision of physical abuse, which past research has suggested should be regarded as a top rank criterion.[4] In consequence, this study provides the most reliable data available to us to look at variation in assessment of higher risk groups between hospitals.

This research highlights significant variation in the likelihood of a CPCC decision of physical abuse across the region, and we found this difference to be statistically significant. While a component of this may be due to true variation in incidence from differences in social deprivation across the region, it should be noted that the catchment area of every hospital in the study includes areas with significant social deprivation.[26] Therefore, we believe that this difference in physical abuse detection rate between hospitals also indicates variation in its detection by healthcare professionals and social services. Past research in the USA has demonstrated considerable variation among clinicians regarding how to investigate physical abuse, the requesting of skeletal surveys and interpretation of fracture imaging.[27–29] This was also found in our study, with significant variation between hospitals in the likelihood that a skeletal survey would be requested. While we did find correlation at different hospitals between likelihood of requesting a skeletal survey and likelihood that a fracture would be regarded as abuse, we think it might be premature to conclude that it was the lack of skeletal surveys that led to decisions of physical abuse at some hospitals being rare. For instance, hospital 2, which had both high skeletal survey percentage and higher than average proportion of fractures regarded as due to physical abuse, actually had no positive skeletal survey results among the six cases imaged. In other words, positive skeletal surveys did not appear to be the driving factor in deciding physical abuse in these cases. It seems more likely that the higher skeletal survey rate in some hospitals was a result of a higher level of suspicion of physical abuse by the managing paediatricians when investigating fractures in young children. Therefore, variation in level of suspicion by paediatricians may be the key factor contributing to variation in the probability that an injured child will be regarded as having suffered from physical abuse.

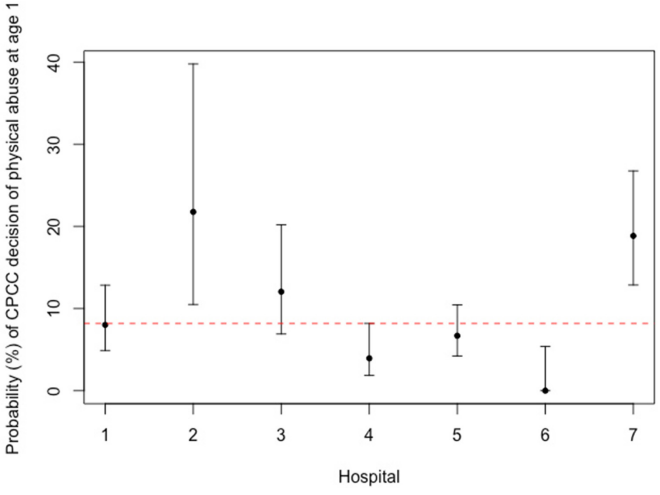

Figure 2 Variation among hospitals of the estimated probability of child protection case conference (CPCC) decision of physical abuse at age 1 year given the presence of a fracture. The red dashed line indicates the average probability in the East Anglia Region.

Most of the previous work on fractures in young children due to physical abuse has been done in the USA, so the research presented here allows comparison with the UK. In table 5, we compare the East Anglia data with the CIs calculated from the meta-analysis study by Maguire *et al*.[22] For humeral fractures in children aged under 18 months, the upper and lower figures for our 95% CIs were lower than those of Maguire *et al*, but they nevertheless overlap. However, our CIs for femoral fractures in children aged 0–18 months were considerably lower and did not overlap at all with the data from Maguire *et al*. We suspect a component of this difference may be differing thresholds for determining physical abuse used in some North American studies and our study. However, further explanations may include that (A) physical abuse may be more common in the USA than in the UK, (B) potential differences in the likelihood of clinicians in the USA and UK to decide whether physical abuse had occurred, or (C) publication bias in studies where those with low incidence of

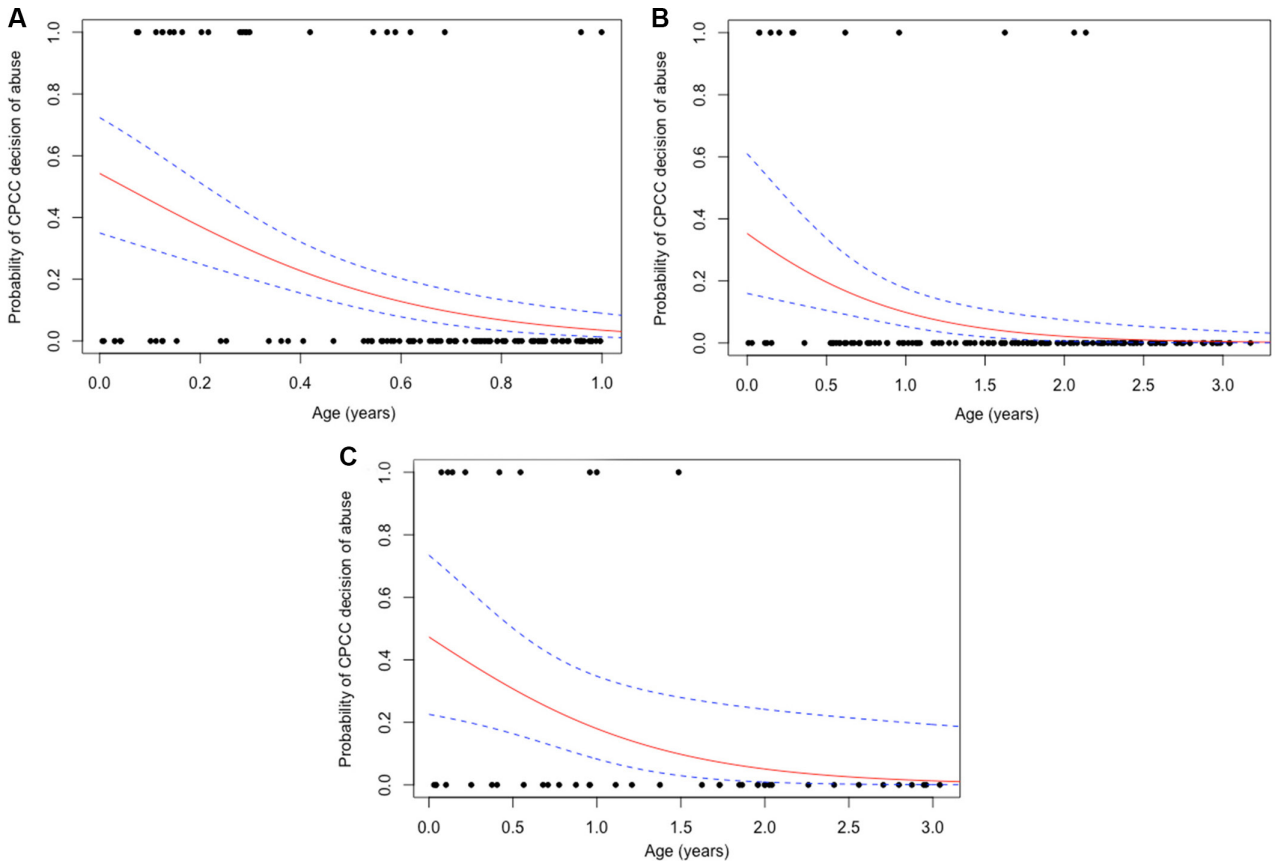

Figure 3 Relationship between age and probability of child protection case conference (CPCC) decision of physical abuse after coming to hospital for suspicious injuries. Black dots are the reported cases. Top row are CPCC decision of physical abuse cases, and bottom row are the negative cases (either no CPCC case, or decision of no abuse at CPCC). The red curve is the estimated relationship between child's age and probability of physical abuse. Blue dashed curves form a pointwise 95% confidence band of the red curve. (A) CPCC decision of physical abuse in infant <12 months. (B) CPCC decision of abuse for humeral fracture <3 years. (C) CPCC decision of abuse for femur fracture <3 years.

physical abuse are not submitted for (or accepted for) publication while those with high prevalence are published.

We have determined the proportion of high-risk fractures that are currently being assessed by paediatricians in hospitals in East Anglia. For infants with fractures this ranged from 46% to 86%, while for all the patients meeting the inclusion criteria for this study this ranged from 49% to 75%. We would recommend that 100% of young children with a fracture in any group believed to be high risk are assessed by a paediatrician to consider whether physical abuse has taken place. From the findings of this study, we propose that injuries with a probability of 10% or higher that a CPCC decision of physical abuse would occur would be a reasonable threshold for assessment by paediatrics. Based on our data, this would mean that all infants under 12 months of age with any fracture should be assessed by paediatrics, as would children of up to 18 months of age with a femur fracture, and up to 24 months with a humerus shaft fracture (not supracondylar). This would pick up virtually all the cases identified in this study, and these ranges give easy-to-remember age bands that healthcare professionals can use in clinical practice. Such a proposal would not be an onerous increase in workload. In most hospitals, on average less than one child per week per hospital would require assessment. Other children should also be assessed if

Table 3 Coefficient estimates of the logistic regression for age effect

Type of physical abuse	Estimated age effect*	CI	P value
All fractures (0–12 months)	0.031	(0.014 to 0.067)	<0.0001
Femoral (0–36 months)	0.20	(0.12 to 0.33)	0.001
Humeral (0–36 months)	0.24	(0.13 to 0.45)	0.02

*OR for every 1 year increment in age.

Table 4 Distribution of fractures in infants (less than 12 months), with proportion of each fracture that led to a child protection case conference (CPCC) decision of physical abuse. Number of infants=25, number of fractures=31

Bone injured	No CPCC decision of physical abuse	CPCC decision of physical abuse
Femur	34	9 (21%)
Tibia/fibula	27	6 (18%)
Radius/ulna	25	5 (17%)
Humerus	18	8 (31%)
Clavicle	17	3 (15%)
Hand	5	0
Foot	1	0
Vertebra	1	0
Total fractures	128	31

Fractures of adjacent bones due to the same injury (eg, radius/ulna, tibia/fibula) are counted as one. Multiple fractures in different limbs in the same infant, so from different injuries, are counted separately.

Table 5 CIs for probabilities (%) of different groups at high risk of physical abuse

High-risk group	Maguire *et al* [22] meta-analysis abuse 95% CI	East Anglia abuse 95% CI
All fractures in infants (child aged 0–12 months)	Not given	10.9 to 23.3
Humeral fractures (child aged 0–18 months)	27.6 to 59.9	16.5 to 54.0
Femoral fractures (child aged 0–18 months)	34.1 to 66.1	6.1 to 25.4

there are specific causes for concern in addition to their fracture type and age group.[24]

We have found that in infants there was a broad range of skeletal involvement in those associated with a CPCC decision of physical abuse. The fractured bone most likely to result in a CPCC decision of physical abuse was the humerus, as 30% of humeral fractures in infants resulted in such a CPCC decision. Fractures of the forearm, clavicle, femur and tibia in infants were associated with a CPCC decision of physical abuse in 15%–21%. The younger the infant, the higher the probability that a fracture would lead to a CPCC decision of abuse. However, it should be noted that there is no bone, and no age group, when a CPCC decision of physical abuse is more probable than an interpretation of accidental cause. It is always statistically more likely that a particular fracture will be considered by a CPCC to be accidental rather than due to physical abuse.

Our study area includes regions of marked social deprivation as well as affluent areas for every hospital that contributed data.[26] We had hoped to assess whether CPCC decision of physical abuse might vary with levels of deprivation in the region, but were unable to do so as hospital catchment areas are different from the local authority boundaries for which such deprivation data are collected.[26]

The limitations of the study include the lack of a perfect diagnostic criterion for physical abuse (currently the best being the opinion of a multiagency CPCC), the fact that incidence of CPCC decision of abuse does not necessarily equate to the true incidence of physical abuse, the retrospective nature of the study (although virtually all past research of physical abuse and fractures has been retrospective), the limited power of the study (being regional and not national in scale) and that the East Anglia Region does not include any of the largest cities in the UK (which might give different results).

Correction notice This paper has been corrected since it was published Online First. In the second section of the results (Decision of a CPCC that fractures were due to physical abuse), in the sentence 'The likelihood that a fracture in children aged 0-364 days would lead to a CPCC decision of physical abuse was 0.83/1000 of the total at-risk population', the fraction should read '0.21/1000'. Similarly, in the sentence 'The likelihood of such a CPCC decision of physical abuse in cases of fracture of the femur or humerus (excluding supracondylar) in children under the age of 3 years was much lower at 0.12/1000 and 0.10/1000 respectively', the fractions should read '0.03/1000 and 0.025/1000 respectively'.

Contributors PDM instigated the study, designed the study, obtained HRA approval, recruited the hospitals to join the study, collated the data and wrote the paper. RB contributed to the study design and towards writing the paper. TW, RDS and RJS performed the statistical analysis. All other authors collected data from their hospitals and commented on the paper.

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Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement In order to ensure patient anonymity, the journal editors have requested that we do not include our raw data in this publication, even in an anonymised form.

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