European Journal of Radiology 83 (2014) 584–588

Contents lists available at ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Abusive head trauma: Differentiation between impact and non-impact cases based on neuroimaging findings and skeletal surveys

T. Sieswerda-Hoogendoorn[a,b,*], S.G.F. Robben[c,1], W.A. Karst[d,2], F.M. Moesker[e,3], W.M. van Aalderen[f,4], J.S. Laméris[g,4], R.R. van Rijn[a,b,4]

[a] Department of Forensic Medicine, Netherlands Forensic Institute, The Hague, The Netherlands
[b] Department of Radiology, Academic Medical Center/Emma Children's Hospital, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands
[c] Maastricht University Medical Center, P.O. Box 5800, 6202 AZ Maastricht, The Netherlands
[d] Department of Forensic Medicine, Netherlands Forensic Institute, P.O. Box 24044, 2490 AA The Hague, The Netherlands
[e] Faculty of Medicine, Academic Medical Center, Amsterdam, The Netherlands
[f] Department of Paediatrics, Academic Medical Center/Emma Children's Hospital, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands
[g] Department of Radiology, Academic Medical Center, Meibergdreef 9, 1105 AZ Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 3 October 2013
Received in revised form
22 November 2013
Accepted 26 November 2013

Keywords:
Abusive head trauma
Child abuse
Head injury, closed
Haematoma, subdural
Forensic medicine

ABSTRACT

Objectives: To determine whether imaging findings can be used to differentiate between impact and non-impact head trauma in a group of fatal and non-fatal abusive head trauma (AHT) victims.
Methods: We included all AHT cases in the Netherlands in the period 2005–2012 for which a forensic report was written for a court of law, and for which imaging was available for reassessment. Neuroradiological and musculoskeletal findings were scored by an experienced paediatric radiologist.
Results: We identified 124 AHT cases; data for 104 cases (84%) were available for radiological reassessment. The AHT victims with a skull fracture had fewer hypoxic ischaemic injuries than AHT victims without a skull fracture ($p = 0.03$), but the relative difference was small (33% vs. 57%). There were no significant differences in neuroradiological and musculoskeletal findings between impact and non-impact head trauma cases if the distinction between impact and non-impact head trauma was based on visible head injuries, as determined by clinical examination, as well as on the presence of skull fractures.
Conclusions: Neuroradiological and skeletal findings cannot discriminate between impact and non-impact head trauma in abusive head trauma victims.

1. Introduction

1.1. Background

Abusive head trauma (AHT) is defined by the American Academy of Pediatrics as an inflicted injury to the head and its contents, including those injuries caused by both shaking and blunt impact [1]. Imaging plays an important role in establishing the diagnosis of AHT. In the absence of any other plausible explanation, the diagnosis in most cases is based on clinical and radiological findings associated with abuse [2–4]. The radiological findings are both intracranial findings on CT or MRI and fractures found with conventional radiographs. Furthermore, retinal haemorrhages can be diagnostic of AHT [5] and bruises on the body have been found in 35% of the cases [6].

Neuroradiological findings associated with AHT have recently been described in two systematic reviews that compared AHT and non-AHT patients [4,7]. The study by Kemp et al. analyzed 21 studies, focusing specifically on neuro-imaging. They found subdural haematomas (SDHs) (OR 8.2), multiple SDHs (OR 6), SDHs over the convexity (OR 4.9), interhemispheric SDHs (OR 9.5), posterior fossa SDH (OR 2.5), hypoxic-ischaemic injury (OR 3.7) and cerebral oedema (OR 2.2) to be significantly associated with AHT [4]. The systematic review by Piteau et al. looked for a wider range of radiological findings. They describe 24 studies, of which 17 are

* Corresponding author at: Department of Forensic Medicine, Netherlands Forensic Institute, The Hague, The Netherlands. Tel.: +31 20 5669111.
E-mail addresses: t.sieswerda@amc.nl (T. Sieswerda-Hoogendoorn), s.robben@maastrichtuniversity.nl (S.G.F. Robben), w.karst@nfi.minvenj.nl (W.A. Karst), f.moesker@erasmusmc.nl (F.M. Moesker), w.m.vanaalderen@amc.nl (W.M. van Aalderen), j.s.lameris@amc.nl (J.S. Laméris), r.r.vanrijn@amc.nl (R.R. van Rijn).
[1] Tel.: +31 43 3876910.
[2] Tel.: +31 70 8886666.
[3] Current address: Erasmus University, Dr. Molewaterplein 50, 3000 CA Rotterdam, The Netherlands. Tel.: +31 622722682.
[4] Tel.: +31 20 5669111.

0720-048X/$ – see front matter
http://dx.doi.org/10.1016/j.ejrad.2013.11.015

also described by Kemp et al. They found SDHs (OR 8.9), cerebral ischaemia (OR 4.8) and cerebral oedema (OR 2.2) to be associated with AHT. However, these reviews do not evaluate the difference between impact and non-impact AHT.

Skeletal survey reveals new information in 11% of all children evaluated for possible physical abuse [8]. In the same study, however, children evaluated for possible AHT had positive skeletal surveys in 23% of the cases. In other studies, the number of positive skeletal surveys in AHT victims ranges between 9 and 50%, depending on inclusion criteria, e.g. whether the skeletal surveys are obtained during life or post-mortem [9,10].

1.2. Objectives

Although it is widely recognized that AHT can be caused by either shaking or impact head trauma or a combination of both, in the individual patient the cause of the injury is often unknown without a confessing perpetrator [11]. Unfortunately, there is no tool yet for such differentiation. If we would be able to differentiate between non-impact and impact head trauma, we would overcome the need for confession or a witnessed assault. Knowing what happens exactly at the moment a caregiver severely harms a child can help to both improve the treatment for the perpetrator as the development of prevention projects. Furthermore it can help in formulating a charge against the accused. As imaging findings are the cornerstone for the diagnosis of AHT, we tried to determine whether imaging findings can be used to differentiate between non-impact (shaking) and impact head trauma.

We conducted a retrospective cohort study in which we describe the neuroradiological findings associated with AHT [4,7] and the number and type of fractures in AHT victims in the Netherlands. The aim of this study is to investigate whether there is a difference in imaging findings between children with and without impact head trauma, defined as the presence of skull fractures or visible head injury upon clinical examination.

2. Materials and methods

We performed a retrospective file review of all AHT cases for which the Dutch courts of law requested forensic medical expertise in the period 1-1-2005–31-12-2012. We used 3 inclusion criteria: (1) a diagnosis of AHT confirmed by a forensic physician, (2) children's age under 5 years and (3) imaging available for reappraisal by a paediatric radiologist with experience in child abuse (RR or SR). Forensic paediatric medical expertise in the Netherlands is only available in two centres: the Forensic Medical Child Abuse Centre (FMCAC, Utrecht) and the Netherlands Forensic Institute (NFI, The Hague). Both Institutes provide forensic reports for courts, performed by a physician specialized in forensic paediatrics. A forensic physician evaluates the complete set of medical data (records of the medical evaluation in the clinical setting, past medical care and autopsy reports) and police files, from a forensic point of view. As the verdict of a judge, besides the forensic report, is based on non-scientific information as well, a diagnosis of AHT established by a forensic physician is considered to be the most objective and best reference standard for AHT in the Netherlands. Past medical care consists of contacts with the general practitioner, the primary health care system and hospitals. Police files consist of interrogations of suspects and witnesses, transcripts of wire-taps and all other forensic information collected by the police.

We collected variables describing demographic characteristics, mechanism of injury, outcome and type of imaging performed. The independent variable, mechanism of injury, was defined as evidence for impact head trauma in 2 different ways: (1) a skull fracture was present, and (2) other (non-radiological) signs of blunt force trauma to the head were documented, e.g. bruising or swelling of the soft tissue of the head. The last category also includes children with a skull fracture. This way of classification does not rule out that children who underwent impact trauma but did not sustain a skull fracture or other signs of blunt-impact trauma to the head were classified as no evidence for impact trauma. A detailed list of dependent variables, intracranial injuries, was collected, based on 2 recent systematic reviews describing imaging findings associated with AHT (Table 1). Variables collected for the skeletal survey were whether the skeletal survey was performed according to the American College of Radiology (ACR) or the Royal College of Radiologists (RCR) guidelines, and the number and type of fractures including the number of classic metaphyseal lesions (CMLs).

We included CT and MRI images obtained when the children were alive because several neuroradiological features will change after demise. Post-mortem skeletal surveys were included. A bilateral SDH over the convexity was classified as 1 SDH. Focal parenchymal injury was defined as intraparenchymal haemorrhage or brain contusion. Closed head injury was defined as any intracranial injury without skull fracture. Only fractures of which the radiologist was certain they were present were included. Findings considered to be 'suggestive of' fractures were omitted, unless they were proven to be a real fracture during follow-up skeletal survey or autopsy. All images were reassessed by a paediatric radiologist (either RR or SR) with extensive experience with paediatric forensic cases. All studies were available in an electronic form.

This study was not subject to medical ethical review, as it is a retrospective study and according to Dutch law no Institutional Review Board approval is required for retrospective studies in which patients are described anonymously and do not have to change their behaviour in any way [12].

Data were analyzed using IBM SPSS Statistics 19 for Windows. Continuous data were expressed as means and standard deviations or medians and inter-quartile ranges (IQR) when non-normally distributed, demonstrated with a Kolmogorov–Smirnov test. Differences between groups were tested with Chi square for dichotomous data, Mann–Whitney *U* test for numeric data because of non-normal distribution, Pearson's Chi square for nominal data and Fisher's exact test for nominal data when the expected values in any of the cells of a contingency table was below 5.

3. Results

In the period 2005–2012, 124 reports diagnosing AHT had been written for the law courts. In 104 of these cases (84%) radiological information was available for reassessment. There were 73 boys (70%) and 31 girls (30%), median age at admission was 91 days (range 8 days–3 years 7 months). Ninety-nine of the 104 children (95%) had intracranial injury, 34/104 had one or more skull fractures (33%) and 43/104 (41%) had one or more fractures elsewhere. Twenty-seven of the 104 children (26%) died, 11/104 (11%) had a good outcome, 34/104 (33%) were disabled and for 32/104 (31%) no prognosis could be given based on medical information in the forensic report.

3.1. Neuroimaging

In 99/104 children (95%) neuro-imaging available for reassessment (CT and/or MRI) had been performed while they were alive. In 83/99 children (84%) at least one CT was performed; in 47 children 1 CT was performed, in 19 children 2 CTs, in 10 children 3 CTs, in 5 children 4 CTs, in 1 child 6 CTs and in 1 child 8 CTs. In 53/83 children (64%) the first CT was made on the day of admission. In 2 children, the CT was made 8 and 9 days respectively before admission, and the diagnosis of AHT was established retrospectively. In the other

Table 1
Intracranial injuries in children with and without a skull fracture and children with and without signs of impact head trauma.

Variable, *n* group	Descriptive	All, 99	Skull fracture, 30	No skull fracture, 69	*p*	Signs of impact head trauma, 54	No signs of impact head trauma, 45	*p*
SDH[a] (including hygroma)	*n*/*n* group (%)	86/99 (87)	23/30 (77)	63/69 (91)	0.06[f]	45/54 (83)	41/45 (91)	0.3
Number of SDHs[a]	Median (IQR)	2 (1–3)	2 (0.8–3)	2 (1–3)	0.3	2 (1–3)	2 (1.5–3)	0.3
Multiple SDHs[a]	*n* (%)	66/99 (67)	18/30 (60)	48/69 (70)	0.4	32/54 (59)	34/45 (76)	0.09
Bilateral SDHs[a]	*n* (%)	56/99 (57)	15/30 (50)	41/69 (59)	0.4	26/54 (48)	30/45 (67)	0.06
SDH[a] convexity	*n* (%)	75/99 (76)	20/30 (67)	55/69 (80)	0.2	37/54 (69)	38/45 (84)	0.07
SDH[a] interhemispheric	*n* (%)	56/99 (57)	15/30 (50)	41/69 (59)	0.4	32/54 (59)	23/45 (53)	0.6
SDH[a] posterior fossa/infratentorial	*n* (%)	11/99 (11)	2/30 (7)	9/69 (13)	0.5[f]	3/54 (6)	8/45 (18)	0.05
SAH[b]	*n* (%)	30/99 (30)	10/30 (33)	20/69 (29)	0.7	19/54 (35)	11/45 (24)	0.3
EDH[c]	*n* (%)	1/99 (1)	1/30 (3)	0/69 (0)	0.3[f]	1/54 (2)	0/45 (0)	1.0[f]
Number of EDHs[c]	Median (IQR)	0 (0–0)	0 (0–0)	0 (0–0)	0.1	0 (0–0)	0 (0–0)	0.4
Number of extra-axial haemorrhages	Median (IQR)	2 (1–3)	2 (0.8–3)	2 (2–3)	0.6	2 (1–3)	2 (2–3)	0.7
Hypoxic ischaemic injury/cerebral ischaemia	*n* (%)	49/99 (50)	10/30 (33)	39/69 (57)	0.03	25/54 (46)	24/45 (53)	0.5
Cerebral oedema	*n* (%)	77/99 (78)	23/30 (77)	54/69 (78)	0.9	41/54 (76)	36/45 (80)	0.6
Focal parenchymal injury[d]	*n* (%)	13/99 (13)	7/30 (23)	6/69 (9)	0.06[f]	9/54 (17)	4/45 (9)	0.3
Diffuse axonal injury	*n* (%)	9/99 (9)	2/30 (7)	7/69 (10)	0.7[f]	4/54 (7)	5/45 (11)	0.7[f]
Closed head injury[e]	*n* (%)	67/99 (68)	–	–		–	–	–

[a] Subdural haematoma.
[b] Subarachnoid haematoma.
[c] Epidural haematoma.
[d] Intraparenchymal haemorrhage or brain contusion.
[e] Intracranial injury without skull fracture.
[f] Nominal data are tested with Pearson's Chi square. If the expected values in any of the cells of a contingency table was below 5, a Fisher's exact test was used. These outcomes are marked.

children, the range of days on which the first CT was performed was 1–25 days. In 71/99 children (72%), at least one MRI was performed; in 52 children, 1 MRI was performed, in 10 children 2 MRIs, in 7 children 3 MRIs, in 2 children 5 MRIs. In 9/71 children (13%), the first MRI was made on the day of admission; in 20/71 children (28%) the MRI was performed on the next day. In the other children, the range of days on which the first MRI was performed was 2–49 days.

3.2. Intracranial injuries

Intracranial injuries described in the 99 included cases in which neuro-imaging was available are presented in Table 1. In the group with skull fractures, the number of patients with hypoxic ischaemic injury was significantly lower (33% vs. 57%, OR 0.39, 95%CI 0.16–0.94, $p = 0.034$). If the distinction between impact and non-impact head trauma cases was based on skull fracture and/or other signs of blunt force trauma to the head, no significant differences in any of the variables were found.

3.3. Skeletal survey

In 98 children (94%), a skeletal survey was performed and available for reassessment. Fifty-five skeletal surveys (56%) were performed according to international guidelines; in 43 cases (44%), one or more images were missing.

3.4. Fractures

Fifty-six children (57%) had one or more fractures, 42 children (43%) had no fractures. In total, 254 fractures were identified with skeletal surveys. The median number of fractures for the whole group was 1 (IQR 0–3), with a maximum of 28 fractures. The median number of fractures for the children with at least one fracture was 3 (IQR 1–5.8). The number and distribution of the fractures in these 56 children is provided in Fig. 1.

Of all children who had a skeletal survey ($n = 98$), there was no significant difference in the number of co-existing fractures elsewhere in the skeleton between children with ($n = 30$) and without ($n = 68$) a skull fracture ($p = 0.8$). In all children who had a skeletal survey with at least 1 non-skull fracture ($n = 36$), there was no significant difference in number of co-existing fractures elsewhere in the skeleton between children with and without a skull fracture ($p = 0.8$). There was no significant difference in the *number of CMLs* between children with and without a skull fracture, neither for the whole group of children who had a skeletal survey ($p = 0.9$) nor for the children with at least one co-existing fracture elsewhere in the skeleton ($p = 0.8$). In children in whom fractures elsewhere in the skeleton were present, there was no significant difference in the *distribution* of co-existing fractures between children with and without a skull fracture ($p = 0.6$).

Of all children who had a skeletal survey ($n = 98$), there was no significant difference in the number of co-existing fractures elsewhere in the skeleton between children with ($n = 54$) and without

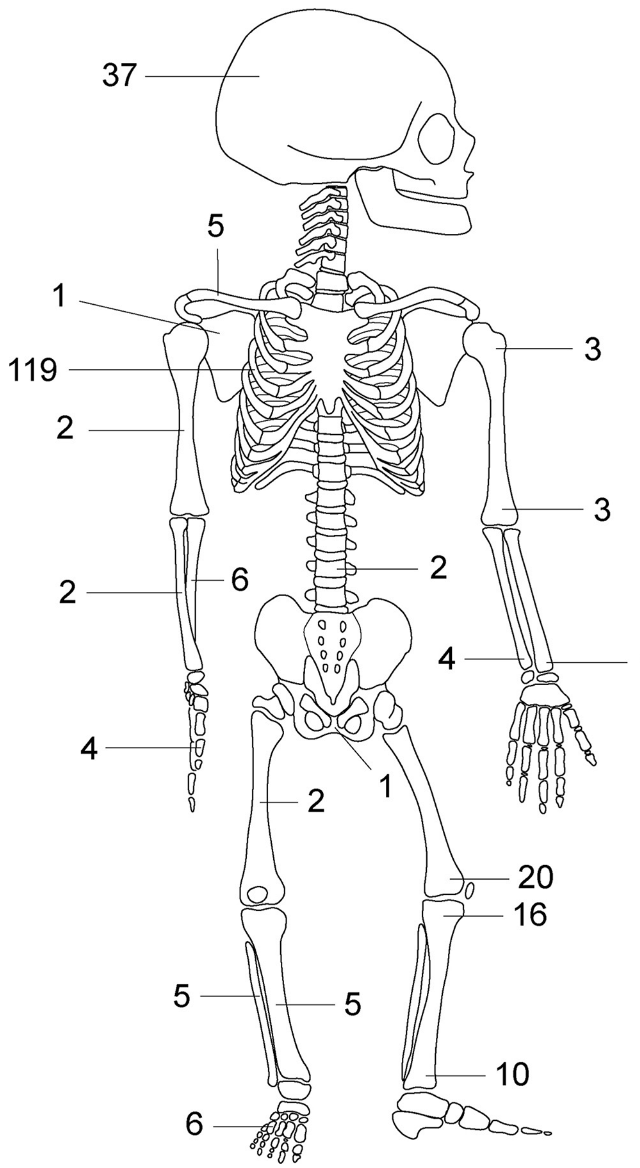

Fig. 1. Distribution of 254 fractures in 56 AHT cases. Numbers shown are the total number of fractures of both the left and right side, the sides on which the numbers are displayed are randomly chosen.

($n = 44$) signs of an impact head trauma ($p = 0.7$). In all children who had a skeletal survey with at least 1 non-skull fracture ($n = 36$), there was no significant difference in the number of co-existing fractures elsewhere in the skeleton between children with and without signs of an impact head trauma ($p = 0.9$). There was no significant difference in the *number of CMLs* between children with and without signs of an impact head trauma, neither for the whole group of children who had a skeletal survey ($p = 0.9$) nor for the children with at least one co-existing fracture elsewhere in the skeleton ($p = 0.5$). In children in whom fractures elsewhere in the skeleton were present, there was no significant difference in the *distribution* of co-existing fractures between children with and without signs of impact head trauma ($p = 0.5$).

4. Discussion

To the best of our knowledge, this is the first study to investigate the difference in radiological features, both in neuroimaging and conventional radiographs, between impact and non-impact AHT cases. Differences in neuroimaging between AHT and accidental head injury have been described in several recent articles [4,7]. SDHs in particular, including their number and location, proved to be associated with AHT. In our study, except for hypoxic–schaemic injury, neither SDH appearance nor other brain injuries reported to be characteristic for AHT are different between impact and non-impact head trauma cases. If the distinction between impact and non-impact head trauma is solely based on the presence or the absence of skull fractures, we found that only hypoxic-ischaemic injury was seen significantly more frequently on neuroimaging in patients without skull fractures. Although significant, the relative difference in the proportions between the two groups is small and cannot be used to discriminate between impact and non-impact head trauma in clinical practice. The difference disappears when the definition of impact head trauma is extended to other external injuries of the head as well. An explanation might be that impact forces causing a fracture are partially absorbed by the skull (resulting in a fracture), leaving less kinetic energy to damage the brain.

There was no difference in the number and location of co-existing fractures in the skeleton between impact and non-impact head trauma cases and this can therefore not be used to differentiate between the different forms of violence.

An explanation for the homogeneity among impact and non-impact head trauma cases is the possibility of infliction of both forms of violence (shaking and impact head trauma) in the majority of the cases. As AHT has for a long time been, and in many court proceedings still is, called 'shaken baby syndrome', it is possible that doctors and police officers question suspects mostly about shaking. Furthermore, it is possible that shaking is regarded to be less violent and therefore more easily confessed to, compared to impact violence e.g. hitting, kicking or throwing. It might be possible that in many cases the violence starts with shaking, as described by Adamsbaum [11], and ends with a final impact head trauma. If this is the case, for many AHT victims both forms of violence are applied and our distinction, based on the presence of a skull fracture or visible injury, might not correctly identify all impact head trauma cases.

4.1. Strengths and limitations

We describe a relatively large group of AHT cases, in which all diagnoses are confirmed by an independent forensic physician who does not have a personal relationship with the parents. This is therefore a homogenous group with a high certainty of abuse. As this is a retrospective study of all cases in the Netherlands, radiological data were obtained from different hospitals using different protocols. Therefore, and because imaging is performed based on clinical characteristics, there was low uniformity in the number of CT and MRI scans and adherence to skeletal survey protocols. This could have resulted in certain neuroradiological features or fractures being underestimated. For example, diffuse axonal injury is best detected by means of susceptibility weighted imaging sequences [13], but this is not a routine sequence in daily clinical practice in the Netherlands and it could therefore be under detected in this study. However, this problem would probably cause an underestimation of all parameters described and would not cause a biased underestimation in any of the subgroups. Therefore we think the results describing the differences between impact and non impact head trauma are generalizable to other populations as well. Another limitation of this study is the fact that we do not know the exact trauma mechanism, including intensity and frequency. We classified our groups on the presence of skull fractures or other external head injuries. However, we do not know how well this correlates with the true cause of the injury.

5. Conclusion

In patients with AHT, skull fractures and traumatic soft tissue changes of the skin of the head are indicative (or direct proof) of impact head trauma. We found that other neuroradiological and skeletal imaging findings are not of additional value in discriminating between impact and non impact head injury as these differences were non-existent or too small for a radiological distinction. The question about the origin of the injury in AHT can therefore at the present time not be answered by the radiologist. The low uniformity in type of imaging performed in this retrospective series, underlines the need for evidence-based imaging guidelines in (suspected) AHT.

Prior publication

We have described the number of families with multiple incidents of abuse for a part of the children described in this study in an article published in *Acta Paediatrica*. The study in *Acta Paediatrica* concerns the period 2005–2010 and describes 89 patients, this study concerns 2005–2012 and describes 124 patients. The study in *Acta Paediatrica* deals with social paediatric aspects exclusively, while this study submitted to *European Radiology* describes radiological aspects.

Conflicts of interest

The authors have no conflicts of interest or financial relationships relevant to this article to disclose.

Financial support

TS, WK and RR are paid employees from the Netherlands Forensic Institute. SR is a paid employee from the Maastricht University Medical Centre. FM was a medical student at the time of the data collection. WA is a paid employees by the Emma's Children Hospital. JL is a paid employee by the Academic Medical Hospital Amsterdam. The employers did not have any influence on design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript.

Acknowledgements

The authors would like to thank R.A.C. Bilo and L.L.B.M. van Duurling for providing information on missing data. Furthermore we would like to thank E. Sneekes for her assistance with the data collection.

References

[1] Christian CW, Block R. Abusive head trauma in infants and children. Pediatrics 2009;123:1409–11.
[2] Hettler J, Greenes DS. Can the initial history predict whether a child with a head injury has been abused? Pediatrics 2003;111:602–7.
[3] Kemp AM, Rajaram S, Mann M, et al. What neuroimaging should be performed in children in whom inflicted brain injury (iBI) is suspected? A systematic review. Clin Radiol 2009;64:473–83.
[4] Kemp AM, Jaspan T, Griffiths J, et al. Neuroimaging: what neuroradiological features distinguish abusive from non-abusive head trauma? A systematic review. Arch Dis Child 2011;96:1103–12.
[5] Maguire SA, Watts PO, Shaw AD, et al. Retinal haemorrhages and related findings in abusive and non-abusive head trauma: a systematic review. Eye (Lond) 2013;27:28–36.
[6] Fanconi M, Lips U. Shaken baby syndrome in Switzerland: results of a prospective follow-up study, 2002–2007. Eur J Pediatr 2010;169:1023–8.
[7] Piteau SJ, Ward MG, Barrowman NJ, Plint AC. Clinical and radiographic characteristics associated with abusive and nonabusive head trauma: a systematic review. Pediatrics 2012;130:315–23.
[8] 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:e47–52.
[9] Hughes-Roberts Y, Arthurs OJ, Moss H, Set PA. Post-mortem skeletal surveys in suspected non-accidental injury. Clin Radiol 2012;67:868–76.
[10] 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. AJR Am J Roentgenol 2011;197:1005–8.
[11] Adamsbaum C, Grabar S, Mejean N, Rey-Salmon C. Abusive head trauma: judicial admissions highlight violent and repetitive shaking. Pediatrics 2010;126:546–55.
[12] Central Committee on Research involving Human Subjects. Does your study have to be reviewed? The Hague, 2013. http://ccmo-online.nl/main.asp. Last accessed August 2013.
[13] Colbert CA, Holshouser BA, Aaen GS, et al. Value of cerebral microhemorrhages detected with susceptibility-weighted MR Imaging for prediction of long-term outcome in children with nonaccidental trauma. Radiology 2010;256:898–905.