Clinical and Radiographic Characteristics Associated With Abusive and Nonabusive Head Trauma: A Systematic Review

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KEY WORDS

abusive head trauma, head injury, children, abuse, systematic review

ABBREVIATIONS

AHT—abusive head trauma
CI—confidence interval
nAHT—nonabusive head trauma
OR—odds ratio

Drs Piteau and Plint conceived and designed the study; Drs Piteau and Ward screened literature search results and identified articles for retrieval, reviewed full papers for inclusion, and extracted data for meta-analysis; Dr Barrowman analyzed the data; and all authors interpreted the data, critically revised the draft, and gave final approval of the version to be published. Dr Piteau is the guarantor for the study.

www.pediatrics.org/cgi/doi/10.1542/peds.2011-1545

doi:10.1542/peds.2011-1545

Accepted for publication Apr 9, 2012

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PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: *The authors have indicated they have no financial relationships relevant to this article to disclose.*

FUNDING: No external funding.

COMPANION PAPER: A companion to this article can be found on page 347, and online at www.pediatrics.org/cgi/doi/10.1542/peds.2012-1442.

abstract

BACKGROUND AND OBJECTIVE: To systematically review the literature to determine which clinical and radiographic characteristics are associated with abusive head trauma (AHT) and nonabusive head trauma (nAHT) in children.

METHODS: We searched MEDLINE, EMBASE, PubMed, conference proceedings, and reference lists to identify relevant studies. Two reviewers independently selected studies that compared clinical and/or radiographic characteristics including historical features, physical exam and imaging findings, and presenting signs or symptoms in hospitalized children ≤6 years old with AHT and nAHT.

RESULTS: Twenty-four studies were included. Meta-analysis was complicated by inconsistencies in the reporting of characteristics and high statistical heterogeneity. Notwithstanding these limitations, there were 19 clinical and radiographic variables that could be meta-analyzed and odds ratios were determined for each variable. In examining only studies deemed to be high quality, we found that subdural hemorrhage(s), cerebral ischemia, retinal hemorrhage(s), skull fracture(s) plus intracranial injury, metaphyseal fracture(s), long bone fracture(s), rib fracture(s), seizure(s), apnea, and no adequate history given were significantly associated with AHT. Epidural hemorrhage(s), scalp swelling, and isolated skull fracture(s) were significantly associated with nAHT. Subarachnoid hemorrhage(s), diffuse axonal injury, cerebral edema, head and neck bruising, any bruising, and vomiting were not significantly associated with either type of trauma.

CONCLUSIONS: Clinical and radiographic characteristics associated with AHT and nAHT were identified, despite limitations in the literature. This systematic review also highlights the need for consistent criteria in identifying and reporting clinical and radiographic characteristics associated with AHT and nAHT. *Pediatrics* 2012;130:315–323

Abusive head trauma (AHT) is the most common cause of traumatic death in children younger than 1 year[1] and is the most common cause of death due to child abuse.[1] Survivors of AHT are left with significant morbidity, with 45% having permanent neurologic sequelae compared with 5% of nonabuse cases.[2]

While the annual incidence of AHT is estimated at ∼24 to 34 per 100 000 children younger than 1 year,[3–5] this is likely an underestimate because many cases are not brought to medical attention and others are not recognized as abuse. AHT in children can be difficult to diagnose because the symptoms are nonspecific, the history is often inaccurate, and the victim is often preverbal. In 1 study, physicians missed the diagnosis on initial presentation in one-third of cases and this resulted in repeated trauma, increased morbidity, and death.[6] As there is no gold standard diagnostic test for child abuse, the diagnosis relies on clinical and radiographic features as well as supporting social and child welfare information. AHT may be recognized in part by historical features (eg, no history of trauma, a low-impact trauma history, a changing or inconsistent history, or a history incompatible with the injuries or incompatible with the child's developmental stage), certain types of intracranial injuries (eg, diffuse subdural hemorrhages), and associated injuries (eg, retinal hemorrhages, metaphyseal fractures, and patterned bruising).[6–12]

We planned a systematic review to summarize the best available evidence comparing the clinical and radiographic characteristics of AHT and nonabusive head trauma (nAHT) in hospitalized children. By identifying these features we hope to help front-line clinicians in the difficult task of distinguishing between AHT and nAHT trauma. Such information may improve outcomes for the victims of abuse and their siblings through the early identification of child abuse.

METHODS

We followed a protocol for this review, in which all eligibility criteria, outcomes, and analyses were specified a priori (available from authors on request).

Search Strategy

The main search strategy (Supplemental Information 1) was developed by an experienced librarian and included MEDLINE (1950 to November, week 2, 2010) and EMBASE (1980 to week 45, 2010); both searches were executed through the Ovid interface. Other search strategies included searches of relevant conference proceedings (American Academy of Pediatrics, Canadian Pediatric Society, Pediatric Academic Societies, Society for Academic Emergency Medicine, Canadian Association of Emergency Physicians, American College of Emergency Physicians) for 1999–2009, contact with the primary author of relevant studies, and review of the reference lists of included studies and relevant reviews. There was no restriction on year, language, or publication status. Studies identified as eligible were used as seed articles for a PubMed-related article search conducted on November 18, 2010 (Supplemental Information 1). The first 50 related articles (ranked by relevance) not previously identified by the subject search were retained and screened.

Study Selection

Studies were included if they compared historical features, physical examination or imaging findings, or presenting signs or symptoms of AHT and nAHT in hospitalized children ≤6 years old. Head trauma was defined as skull fracture on computed tomography, MRI, or plain radiography or at least 1 of the following on computed tomography or MRI: subdural hemorrhage, epidural hemorrhage, subarachnoid hemorrhage, intraparenchymal hemorrhage, brain contusion, diffuse axonal injury, cerebral edema, and hydrocephalus. Exclusion criteria included duplicate publications, review articles, opinion pieces, consensus statements, studies evaluating abusive injury exclusive of head trauma, noncomparative studies evaluating AHT, studies evaluating nonhospitalized children, studies examining only clinical outcomes, management or postmortem investigations, or studies judged to be methodologically weak owing to significant bias. Studies were judged to have significant bias if the same variables were applied in both the diagnosis and the characterization of abuse; for example, the pattern of head trauma was the primary factor used to define abuse and then was analyzed as a variable of abuse.

Two reviewers (S.J.P. and M.G.K.W.) independently reviewed the titles and abstracts generated by the search to identify potentially relevant articles. The 2 reviewers then independently assessed the full article by using a standardized form with eligibility criteria established a priori. Disagreements were resolved by consensus or by a third reviewer (A.C.P.) as necessary. The third reviewer (A.C.P.) additionally reviewed the eligibility of all studies deemed eligible by both reviewers (S.J.P. and M.G.K.W.), and disagreements were resolved by consensus. Authors were asked for clarification when it was unclear whether all children in the study met our definition of head trauma.

Assessment of Methodological Quality

Two independent reviewers (S.J.P. and M.G.K.W.) assessed study quality and disagreements were resolved by consensus or by the third reviewer (A.C.P.). Reviewers were not blinded to author or other publication details. Study quality was assessed according to the ability to accurately categorize the etiology of head trauma as abusive or nonabusive based on a priori criteria. In the absence of a gold standard diagnostic test for child abuse, the quality of the a priori criteria was assessed based on its ability to be free of bias and circular logic to arrive at a diagnosis of child abuse. Specifically, we applied the previously published 5-point scale, "ranking criteria for the definition of abuse," to categorize studies as high (score of 1 or 2) or low quality (score of 3–5) (Table 1).[7,13–17]

Data Extraction

Two reviewers (S.J.P. and M.G.K.W.) independently extracted data to a standardized form and entered it into Microsoft Excel (Microsoft Corp, Redmond, WA). Only consensus data were used in the review. Extracted data included: (1) characteristics of the study (design, year of publication, etc), (2) description of study populations (age, number of participants, etc), (3) standards used to determine abusive and nonabusive nature of injury, (4) type of head trauma (subdural hemorrhage, epidural hemorrhage, subarachnoid hemorrhage, intraparenchymal hemorrhage, skull fracture plus intracranial injury, isolated skull fracture, cerebral ischemia, cerebral edema, and diffuse axonal injury), and (5) other clinical variables. Other clinical variables included historical features (no adequate history, history of low-impact trauma, inconsistent history, the injury was blamed on home resuscitative efforts or on siblings, or delay in seeking care after an injury), presenting signs and symptoms (seizures at or within 24 hours of presentation, vomiting, apnea at presentation, lethargy, abnormal neurologic status such as cranial nerve palsy or paresis), other physical findings (such as scalp swelling, retinal hemorrhage(s), rib fracture(s), long bone fracture(s), metaphyseal fracture(s), any bruising, head and neck bruising, other organ injury, cardio-respiratory compromise, and Glasgow Coma Scale score on admission), and operative interventions. Where studies included a category of head trauma of indeterminate etiology, these cases were excluded. Where studies included children with injuries that did not meet our definition of head trauma along with those that did meet our definition, we extracted data for eligible children only, and if data could not be extracted for only these children, the study was excluded.

TABLE 1 Ranking of Criteria Used to Define Abuse[17]

Ranking	Criteria Used to Define Abuse
1	Abuse confirmed at case conference or civil, family, or criminal court proceedings or admitted by perpetrator
2	Abuse confirmed by stated criteria including multidisciplinary assessment
3	Diagnosis of abuse defined by stated criteria
4	Abuse stated as occurring, but no supporting detail given as to how it was determined
5	Abuse stated simply as "suspected"; no details on whether it was confirmed

Data Analysis

Data were expressed as pooled odds ratios (ORs) with 95% confidence intervals (CIs). For ORs >1, the variable is associated with AHT and for ORs <1, the variable is associated with nAHT. Data were pooled by using the Dersimonian-Laird random effect method by using the empirical OR with inverse variance weighting except when at least 1 cell in a 2×2 table was 0, in which case 0.5 was added to all the cells in the table before computing the empirical OR and variance. Heterogeneity was examined by using the I^2 statistic. Significance was determined by a P value $<.05$. Analyses were conducted by using custom programs written by using R version 2.10.[18]

Due to the inconsistency in the specific clinical and radiographic variables reported between studies and in the manner of reporting these variables between studies, we limited our meta-analysis to 19 variables.[19] These variables were chosen because they were considered clinically relevant, were reported in at least 2 studies, and could be dichotomized into present and absent. These variables were subdural hemorrhage(s), epidural hemorrhage(s), subarachnoid hemorrhage(s), retinal hemorrhage(s), skull fracture(s) co-occurring with intracranial injuries, isolated skull fracture(s), cerebral ischemia, cerebral edema, diffuse axonal injury, scalp swelling (defined as either soft tissue swelling or subgaleal hematoma), metaphyseal fracture(s), long bone fracture(s), rib fracture(s), any bruising, head and neck bruising (distinguished from other signs of external head trauma), apnea at presentation, seizure(s) at presentation or within 24 hours of presentation, vomiting, and no adequate history (such as no history of trauma).

Clinical and radiographic variables were analyzed in 2 separate groups: (1) all studies that reported a given variable and (2) high-quality studies only (rank 1 or 2). Given that the most common age group affected by abuse is children <3 years old, we had a priori planned a subgroup analysis by age (children ≤ 3 and ≥ 3 years of age). This analysis was, however, not possible given the manner in which data were presented within included studies. When possible, the mean age of children in the 2 cohorts was compared. A Wilcoxon signed rank test tested the hypothesis that the abused children were younger than those not abused, accounting for the pairing within studies of children identified as abused and not abused. We expanded our a priori analysis plan by examining this hypothesis for studies that included only children up to 24 and 36 months old, respectively.

During data extraction, it became clear that studies could be grouped into 3 categories by the manner in which they reported clinical and radiographic characteristics, and this resulted in the need to expand our a priori analysis plan to consider missing data. For example, in reporting retinal hemorrhages, some studies clearly stated that all children in each cohort had fundoscopic exams,[15,20,21] some studies reported this variable for only the subset of children in each cohort who had fundoscopic exams,[10,22–24] while others (mainly retrospective cohort studies) reported the number of retinal hemmorhages as if all children in each cohort had a fundoscopic exam, but in detailed review, it was clear that this was highly unlikely.[2,11,24–28] We determined that of the 19 variables reported in this review, retinal hemorrhages and rib, long bone, and metaphyseal fractures were most likely to be affected by informative missing data,[29] and these variables required a sensitivity analysis. These variables were chosen as specific investigations (skeletal survey or bone scan) or a specialized physical exam skill (fundoscopic examination) would be needed to rule out these findings and that these investigations and exams were much more likely to be completed for children in whom abusive trauma was suspected. For the sensitivity analysis, we considered all studies, as well as high-quality studies alone, and examined (1) those studies in which all children had the relevant investigation or examination and (2) those studies in which either all children had the relevant investigation or examination done and/or studies in which the proportion of the children having the investigation or examination done was clearly stated. We chose not to impute missing values (eg, we did not assume that unexamined children in the nonabuse cohort had the finding typically associated with abuse) given that in many of the retrospective studies we could not determine how many children had the investigation or examination done.

RESULTS

Description of Studies

Figure 1 shows the flow of studies through the selection process. Five hundred ninety-six studies were identified; 85 were deemed possibly relevant on screening and full text publications were obtained, and of these, 24 met inclusion criteria (Fig 1).[2,8–12,15–21,26–28,30–38] Two included studies[37,38] were identified by reviewing reference lists of relevant reviews.[17] One study[2] appeared to report data for 40 children that were also included in a second[35] publication; only variables with no overlap were included. Table 2 describes the included studies. Twenty-one studies were deemed high quality (rank 1 or 2), and 3 studies were deemed low quality (rank 3, 4, or 5).

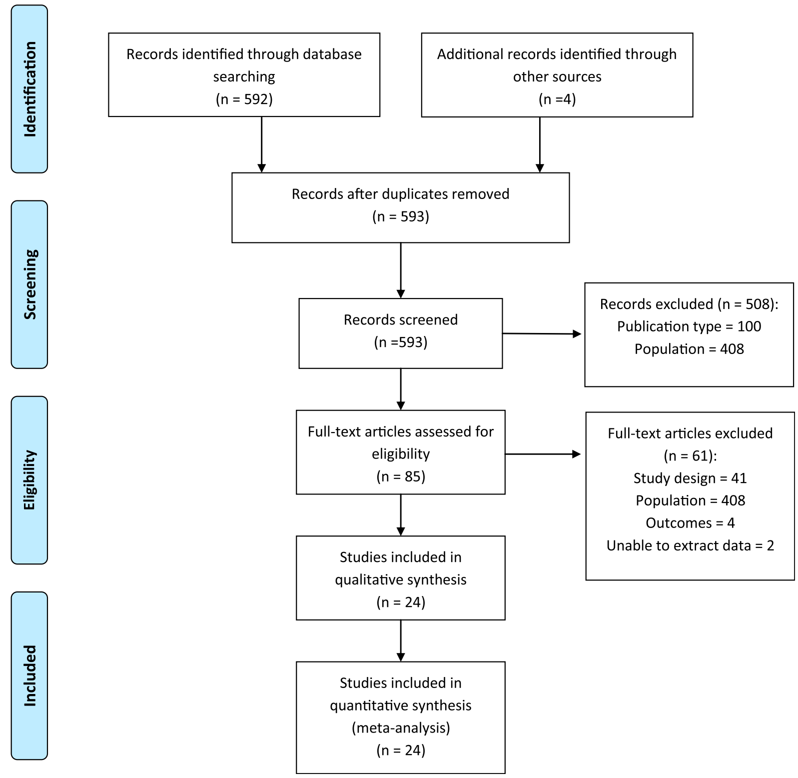

FIGURE 1
Study flow.

Clinical and Radiographic Variables

There was a wide range of clinical content in the included studies with 82 variables reported overall. Studies reported 1 to 35 variables, with a mean of 15 variables. Subdural hemorrhage was the most commonly reported variable, being reported in 15 studies. The following characteristics were reported in at least 10 studies: retinal hemorrhages, subarachnoid hemorrhage, epidural hemorrhage, seizure, and the injury mechanisms of motor vehicle accidents, falls, and admitted/witnessed assault.

Inconsistency in the definition and reporting of clinical and radiographic variables as well as high statistical heterogeneity presented challenges to meta-analysis. For example, subdural hemorrhage was reported as total, unilateral, bilateral, mixed density, interhemispheric, or subdural hemorrhage plus other injuries.[2,8–12,15,21–23,25–28,31–35,37,38] Skull fracture was reported as simple, complex, multiple, bilateral, depressed, nonparietal, diastatic fractures >3 mm, or fractures crossing suture lines.[8,9,11,12,15,22,24–26,28,31–38] By selecting variables that were clinically relevant, reported in at least 2 studies, and that could be dichotomized into present or absent, we were able to individually meta-analyze 19 clinical and radiographic variables. Table 3 provides a summary of the results of the meta-analysis for each

TABLE 2 Characteristics of Included Studies (*N* = 24)

First Author	Year of Publication	Country	Age, mo	Sample Size[a]	Type of Study	Study Quality Rank
Bechtel[9]	2004	US	0–24	82	Prospective	1 and 2
Billmire[24]	1985	US	0–12	70	Retrospective	1 and 2
Datta[35]	2005	UK	0–24	52	Retrospective	1 and 2
Duhaime[12]	1992	US	0–24	68	Prospective	1 and 2
Ettaro[25]	2004	US	0–36	377	Retrospective	1 and 2
Ewing-Cobbs[2]	1998	US	0–72	40	Prospective	1 and 2
Ewing-Cobbs[35]	2000	US	0–72	60	Prospective	1 and 2
Feldman[22]	2001	US	0–36	54	Prospective	1 and 2
Hettler[10]	2003	US	0–36	163	Retrospective	1 and 2
Hobbs[36]	1984	UK	0–24	89	Retrospective	1 and 2
Hoskote[37]	2002	UK	0–24	16	Retrospective	4
Hymel[8]	2007	US	0–36	41	Prospective	1 and 3
Ichord[31]	2007	US	0–36	52	Prospective	1 and 2
Keenan[26]	2004	US	0–24	152	Prospective	1 or 2
Kelly[28]	2004	New Zealand	0–24	64	Retrospective	4
McKinney[30]	2008	US	0–36	32	Retrospective	1 and 2
Myhre[32]	2007	Norway	0–36	52	Retrospective	2
Reece[11]	2000	US	0–36	179	Retrospective	1 and 2
Ruppel[38]	2001	US	0–72	13	Prospective	5
Shugerman[27]	1996	US	0–36	87	Retrospective	2
Tzioumi[23]	1998	Australia	0–24	36	Retrospective	1 and 2
Vavilala[33]	2007	US	0–60	10	Prospective	1 and 2
Vinchon[21]	2005	France	0–24	150	Prospective	1 and 2
Vinchon[15]	2009	France	0–24	84	Prospective	1

High-quality studies = 1–2; low-quality studies = 3–5 as based on the criteria used to determine the etiology of head injury.
[a] Sample size reported is that of children in each included study that met our definition of head trauma and for whom data relevant to the review could be extracted. The Duhaime,[12] McKinney,[32] Reece,[11] and Billmire[26] studies included children who did not meet our definition of head trauma and the sample size reported is for only those children that meet our definition.

individual characteristic, and Supplemental Information 2 shows forest plots for these characteristics. The degree of statistical heterogeneity varied markedly between the variables and ranged from low to high (Table 3). Of note, a high OR does not directly correlate with a high positive predictive value for a given feature since this depends on the prevalence of abuse in the individual studies.

Variables Associated With AHT

When examining all studies, subdural hemorrhage(s), cerebral ischemia, cerebral edema, retinal hemorrhage(s), skull fracture(s) co-occurring with intracranial injury, metaphyseal fracture(s), long bone fractures(s), rib fracture(s), any bruising, seizure(s) at or within 24 hours of presentation, apnea at presentation, and no adequate history were individually significantly associated with AHT (Table 3). Including only high-quality studies, cerebral edema and any bruising were no longer significantly associated with AHT.

Variables Associated With nAHT

When examining all studies, epidural hemorrhage(s), isolated skull fracture (s), scalp swelling, and head and neck bruising were significantly associated with nAHT (Table 3). When analysis was limited to high-quality studies, head and neck bruising was no longer significantly associated with nAHT.

Variables Not Significantly Associated With AHT or nAHT

When examining all studies and only high-quality studies, subarachnoid hemorrhage(s), diffuse axonal injury, and vomiting were not significantly associated with AHT or nAHT. Head and neck bruising, any bruising, and cerebral edema were not significantly associated with AHT or nAHT in only high-quality studies.

Sensitivity Analysis

We performed a sensitivity analysis for 4 variables: retinal hemorrhages and long bone, metaphyseal, and rib fractures (Supplemental Information 3 and 4). While retinal hemorrhages remained significantly associated with AHT, long bone and rib fractures did not, and there were no studies examining metaphyseal fractures to include in the analysis. The small number of studies also limited the analyses for rib and long bone fractures.

Age

Fourteen studies contributed data to the age analysis. Seven studies did not report the mean age of the individual cohorts,[12,25,26,30,32,34,36] 3 studies reported the mean age for both cohorts but we extracted data only for children meeting our eligibility criteria and we could not extract the corresponding age data,[11,12,24] and 1 article reported mean age[35] but this overlapped with data reported in another article.[2] In all except 1 study,[8] the mean age of children identified as abused was lower than the mean age of children identified as not abused ($P < .0004$). The range of mean ages reported was 2.1 to 22 months in the abuse cohort and 5.64 to 43 months in the nonabuse cohort. Among the abuse cohort, the mean age was <12 months in 12 (86%) studies and <6 months in 6 (43%) studies. Among the nonabuse cohort, the mean age was <12 months in 7 (50%) studies and <6 months in 1 (7%) study. When the analysis was restricted to the 11 studies that include children <36 months old and to the 6 studies that include children <24 months old, the mean age of the children identified as abused remained lower than the mean age of children identified as not abused ($P = .003$ and $P = .03$, respectively).

DISCUSSION

Principal Findings of the Review

Distinguishing between AHT and nAHT can be challenging. Negative consequences

TABLE 3 Clinical and Radiographic Characteristics Associated With ABT and nABT

Characteristic	No. of Studies	OR (95% CI); OR >1 Favors Abuse; OR <1 Favors Nonabuse	I^2, %	*P*
Subdural hemorrhage(s)				
All studies	15	8.92 (6.77–11.74)	0	<.001
High-quality studies	14	8.90 (6.75–11.73)	0	<.001
Epidural hemorrhage(s)				
All studies	10	0.15 (0.08–0.29)	0	<.001
High-quality studies	9	0.13 (0.06–0.26)	0	<.001
Subarachnoid hemorrhage(s)				
All studies	13	1.42 (0.67–3.0)	76	.36
High-quality studies	11	1.31 (0.58–3.0)	80	.52
Cerebral edema				
All studies	9	2.17 (1.06–4.45)	54	.03
High-quality studies	7	2.05 (0.82–5.10)	65	.12
Cerebral ischemia				
High-quality studies	4	4.79 (1.84–2.46)	29	.001
Diffuse axonal injury				
All studies	6	1.47 (0.26–8.32)	61	.66
High-quality studies	4	0.83 (0.06–2.46)	72	.89
Skull fracture(s) + intracranial injury				
High-quality studies	4	7.76 (1.06–57.08)	88	.04
Isolated skull fracture(s)				
High-quality studies	2	0.01 (0.003–0.04)	0	<.001
Long bone fracture(s)				
All studies	8	4.234 (2.50–7.19)	0	<.001
High-quality studies	6	4.344 (2.52–7.49)	0	<.001
Metaphyseal fracture(s)				
All studies	2	11.76 (2.18–63.41)	0	.004
High-quality studies	1	1 5.06 (1.93–117.72)	Single estimate	<.001
Rib fracture(s)				
All studies	7	8.89 (4.04–7.19)	1	<.001
High-quality studies	6	9.84 (4.42–21.90)	0	<.001
Retinal hemorrhage(s)				
All studies	14	27.12 (15.70–46.84)	24	<.001
High-quality studies	12	28.24 (15.37–51.90)	35	<.001
Any bruising				
All studies	5	4.77 (1.62–14.05)	15	.005
High-quality studies	3	5.35 (0.91–31.41)	0	.06
Head and neck bruising				
All studies	3	0.42 (0.19–0.94)	26	.03
High-quality	2	0.65 (0.27–1.57)	0	.34
Scalp swelling				
High-quality studies	7	0.12 (0.05–0.32)	65	<.001
Apnea				
All studies	4	5.31 (2.34–12.05)	0	<.001
High-quality studies	3	4.89 (2.08–11.49)	0	<.001
Seizure(s)				
All studies	10	7.25 (3.04–17.27)	77	<.001
High-quality studies	9	11.24 (7.30–17.29)	0	<.001
Vomiting				
High-quality studies	3	0.89 (0.02–4.88)	83	.89
No adequate history				
All studies	9	46.94 (12.91–170.63)	69	<.001
High-quality studies	8	52.72 (12.79–217.33)	72	<.001

including re-injury and death have been shown to occur when the diagnosis has been missed.[6] There can also be negative consequences to the child and family with an incorrect diagnosis of abusive injury. For these reasons, accurate diagnoses must be made. From our systematic review we were able to highlight some clinical and radiographic characteristics associated with AHT and nAHT in children.

We found that each of subdural hemorrhage(s), cerebral ischemia, skull fracture(s) in conjunction with intracranial injury, retinal hemorrhage(s), long bone fracture(s), rib fracture(s), metaphyseal fracture(s), seizure(s) at presentation or within 24 hours, apnea at presentation, and no adequate history were individually significantly associated with AHT when only high-quality studies were meta-analyzed. Epidural hemorrhage(s), scalp swelling, and isolated skull fracture(s) were each significantly associated with nAHT when high-quality studies were meta-analyzed. Although we recognize that patterns of injuries are of key importance in making a diagnosis of abuse or nonabuse, limitations in the data, as well as the manner in which it was presented, prevented us from examining whether variables were associated with abuse when found in combination.

Comparison With Other Studies

In 1962, Kempe described "battered child syndrome" as the combination of subdural hemorrhage, skeletal injuries, and bruises.[39] Since then, many studies have supported the association of subdural hemorrhage with child abuse,[6,40,41] the association of epidural hemorrhage with nAHT, and the association of subarachnoid hemorrhage with both mechanisms of injury.[2,27,35] Our study provides evidence that a younger age is associated with AHT, and this may support the hypothesized temporal association between AHT and crying patterns in infants within the first 3 months of life.[42] This finding may also reflect the physiologic and anatomic differences in younger children that may alter the susceptibility to head injury with a given mechanism or force.[43–45]

Maguire et al[13] recently published a systematic review addressing a similar question as our review. Similar to our study, they found that apnea, retinal hemorrhage, rib fractures, long bone fractures, skull fractures associated with intracranial injury, and seizures were associated with abuse.[13] The review also found head and neck bruising was associated with nAHT. Some important differences exist, however, between these 2 reviews, including the definition of head trauma, articles included, characteristics analyzed, statistical methodology, and data representation. Specifically, our review included examination of historical features and the type of intracranial injury. We believe that the type of intracranial injury associated with injury mechanism is critical, as these may be the initial data available to front-line clinicians who must make a preliminary determination around injury mechanism. We included only studies of admitted patients to focus on more seriously injured patients, and we limited our study population to a younger age to focus on the primary age group at risk for AHT. We included more studies in our systematic review, although 3 studies in Maguire et al's 2009 review did not meet our inclusion criteria. We also chose to examine statistical heterogeneity between studies and to examine all studies, as well as only high-quality studies, to address the robustness of our data. Interestingly, when low-quality studies were excluded from analysis, only 3 variables were no longer significantly associated with either AHT or nAHT suggesting our conclusions are fairly robust. We dealt with informative missing data in a different manner. The Maguire et al 2009 review imputed informative missing data when only a proportion of the children in each cohort had the investigations. We chose not to use this approach for our sensitivity analysis since we could not determine the proportion of children in each cohort that had the given investigation or exam performed. The small number of studies accurately reporting missing data limited our sensitivity analysis.

Two other reviews of characteristics associated with AHT and nAHT have been recently published. One, by Kemp et al, reviewed neuroradiologic features in 21 studies of children hospitalized with head trauma. This study's finding that subdural hemorrhage and hypoxic ischemic injury were significantly associated with AHT[46] was in agreement with our results. The authors also found that cerebral edema was associated with AHT. The second study, a patient-level meta-analysis from 6 cohort studies, examined the positive predictive values of a combination of 6 clinical features (head and neck bruising, rib fracture, skull fractures, long bone fractures, retinal hemorrhage, seizures, and apnea) in conjunction with intracranial injury.[47] It reported that any combination of $\geq$3 features yielded a positive predictive value for AHT of 85%. Given the limitations of the articles included in our review, an analysis of combined features was not possible in our study.

Limitations of the Review

The meta-analysis for this review was made difficult by inconsistencies in the criteria used to determine the etiology for head trauma, inconsistencies in defining and reporting clinical and radiographic variables, and a moderate to high degree of statistical heterogeneity between studies. As there are no standardized criteria for the definition of abuse, most authors developed their own criteria, and many of these are fraught with circular reasoning. The diagnosis of AHT relies on historical features, clinical findings, and radiologic interpretations, and it is these same criteria that are used to categorize head trauma as abusive or nonabusive. We attempted to address this limitation by using a published scale to rank the quality of the criteria used for defining abuse[7,13,16,17] and examined our results for all eligible studies, as well as for those using high-quality criteria. However, for features that have been traditionally associated with abuse (such as subdural hemorrhage and retinal hemorrhage), this ranking scale does not compensate well for circularity and thus our results must be interpreted cautiously.

Significant variability in the definition and description of clinical and radiographic variables in the included studies made meta-analysis difficult. This variability highlights the need for the standardization of definitions and descriptions of characteristics to accurately compare data between studies or combine data for meta-analysis. Ultimately, such standardization could advance the development of accurate diagnostic criteria for AHT. The high degree of heterogeneity among studies may reflect this lack of standardization, somewhat weakening the clinical interpretability of the review findings.

All studies included in this review were, as expected, observational studies. Selection, informational, and confounding bias are limitations to these studies. The retrospective studies were limited with respect to reporting missing data. Many studies reported data around characteristics (eg, retinal hemorrhages) as if all children in both cohorts had undergone the necessary investigation or examination (eg, fundoscopy) to look for the characteristic in question; however, a detailed review of the data revealed this to be unlikely. While we performed a sensitivity analysis to examine this issue, our results need to be interpreted cautiously. The retrospective studies in this review were also limited by recall bias; for example, the low-quality studies relied on medical record coding for the diagnosis of abuse, without reviewing supporting detail as to how abuse was determined. By limiting the review to studies of admitted children, only serious head injuries would have been included, but children who died before presentation would have been excluded. As well, children with less severe abusive injuries may be less likely to be brought to the hospital after an abusive event. Thus, a selection bias may occur for children with more severe injuries and symptoms in the abusive cohort being brought to the hospital compared with those in the nonabusive cohort.

CONCLUSIONS

Clinical and radiographic variables associated with AHT and nAHT in children were identified, despite important limitations in the existing literature. This systematic review highlights the need for consistent criteria in identifying and reporting the historical, physical, and radiographic variables associated with abusive and nonabusive head injuries. A future multicenter prospective trial evaluating AHT and nAHT by using standard criteria for both the categorization of etiology and for the examination and reporting of characteristics of head trauma would allow for more definitive findings.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the following individuals for their contributions to this project: Margaret Sampson, MLIS, PhD, AHIP (search services), and Erin Crouchman, MSc (article retrieval).

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FEEDING FRENZY: *We often think of the ecosystem from the bottom up: single-celled organisms capture energy from the sun and are at the bottom of the food chain. Larger animals feed on smaller ones culminating with the top predator that is preyed upon by no other species. We all know that if the algae were to die, the entire food chain would collapse. However, what happens if the predators, or those near the top of the food chain, disappear? Now, more data suggest the critical role that top predators play in managing food chains and ecosystems. As reported in* The New York Times *(Environment: June 12, 2012), salt marshes across Cape Cod are disintegrating. The reason for their destruction is that the Sesarma crab population has exploded. Juvenile and adult crabs are eaten by many different animals, but the key predators of the inch-long Sesarma crab are blue crabs, striped bass, and cod. The problem is that in areas where there is a lot of recreational fishing and shellfishing, the populations of these predators have been decimated. With fewer predators, the Sesarma crab population has increased dramatically. As the Sesarma crabs eat marsh grasses, vast areas of the salt marshes have become denuded of grass that is essential for the development of fish nurseries, filtering water, and prevention of erosion. Hence, the loss of the marsh grass has many detrimental effects. All ecosystems require balance. Removing either the foundation or the top predator from a food chain has profound untoward effects. At least there is something we can do for the salt marshes in Cape Cod: release any fish caught in these areas.*

Noted by WVR, MD