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ORIGINAL ARTICLE

Occult head injury is common in children with concern for physical abuse

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Abstract

Background Studies evaluating small patient cohorts have found a high, but variable, rate of occult head injury in children <2 years old with concern for physical abuse. The American College of Radiology (ACR) recommends clinicians have a low threshold to obtain neuroimaging in these patients.

Objectives Our aim was to determine the prevalence of occult head injury in a large patient cohort with suspected physical abuse using similar selection criteria from previous studies. Additionally, we evaluated proposed risk factors for associations with occult head injury.

Materials and methods This was a retrospective, secondary analysis of data collected by an observational study of 20 U.S. child abuse teams that evaluated children who underwent subspecialty evaluation for concern of abuse. We evaluated children <2 years old and excluded those with abnormal mental status, bulging fontanelle, seizure, respiratory arrest, underlying neurological condition, focal neurological deficit or scalp injury.

Results One thousand one hundred forty-three subjects met inclusion criteria and 62.5% (714) underwent neuroimaging with either head computed tomography or magnetic resonance imaging. We found an occult head injury prevalence of 19.7% (141). Subjects with emesis (odds ratio [OR] 3.5, 95% confidence interval [CI] 1.8–6.8), macrocephaly (OR 8.5, 95% CI 3.7–20.2), and loss of consciousness (OR 5.1, 95% CI 1.2–22.9) had higher odds of occult head injury.

Conclusion Our results show a high prevalence of occult head injury in patients <2 years old with suspected physical abuse. Our data support the ACR recommendation that clinicians should have a low threshold to perform neuroimaging in patients <2 years of age.

Keywords Abusive head trauma · Children · Computed tomography · Magnetic resonance imaging · Neuroimaging · Non-accidental trauma

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Introduction

In children with concern for physical abuse, testing for additional occult, traumatic injuries is often undertaken because the identification of these injuries can affect the perceived likelihood of abuse or determine the timing of injury [1]. Unfortunately, exam findings for abusive head trauma (AHT) are often difficult to recognize or occult, with one study estimating that 31.2% of AHT is missed [2, 3]. Recognizing occult AHT in cases of abuse is of particular importance because AHT is the leading cause of death among physically abused infants [4].

Multiple small studies have suggested relatively high rates of occult head injury in children <2 years old with concern for physical abuse, prompting the American College of Radiology (ACR) to advocate for a low threshold to perform neuroimaging in these patients, even in the absence of neurological symptoms [5–8]. The study by Rubin et al. [5] found a 37.3% rate of occult head injury in children <2 years old admitted for suspicion of physical abuse and a similar study by Laskey et al. [6] found a 29% rate of occult head injury. Still, some authors contend that the rate of occult AHT in children with suspected abuse is much lower, with the recent study by Wilson et al. [9] showing patients with isolated extremity fractures and an otherwise normal skeletal survey had a rate of AHT of only 4.3%. The estimates within these small samples had important variation, and even among child abuse physicians, neuroimaging is often omitted when it is recommended [10]. Moreover, testing is omitted more frequently and with higher variability by non-child abuse physicians [11, 12].

With increased recognition of the dangers of avoidable radiation exposure, the authors have anecdotally encountered resistance to obtain neuroimaging in well-appearing infants, sometimes based on the Pediatric Emergency Care Applied Research Network (PECARN) decision rule. This well-validated decision rule was developed to assess the risk of clinically significant traumatic brain injury (TBI) in the setting of accidental trauma and is not recommended for use in children with concern for abuse [13–16].

In the setting of non-accidental trauma, clinical prediction rules have been developed to help clinicians decide which children should undergo further evaluation for abuse. The Pittsburgh Infant Brain Injury Score (PIBIS) is a clinical prediction rule that has been validated for evaluating AHT in children without a history of trauma, and the body region- and age-based bruising decision rule TEN-4 (torso, ear and neck; 4 years old and younger) helps clinicians identify which children should undergo evaluation for abuse based upon bruising distribution [17, 18].

Knowing the rate of occult AHT can help clinicians balance the risks of missed AHT with the risks of radiation exposure, which have been shown to increase lifetime cancer risk [19–21]. With previous studies showing varying rates of occult head injury in cases of abuse, the aim of our study was to provide a more precise estimate of occult AHT in children <2 years old by evaluating a large patient cohort using similar selection criteria from previous studies. In addition, we evaluated for associations with occult AHT by examining the prevalence of suggested risk factors in our cohort with occult AHT.

Materials and methods

This was a retrospectively designed, secondary analysis of data from the Examining Siblings to Recognize Abuse (ExSTRA) research network with detailed methods previously described [22]. Briefly, the ExSTRA research network was a prospective, observational study of 20 U.S. child abuse teams that included children <10 years of age who underwent subspecialty evaluation for concern of physical abuse between January 15, 2010, and April 30, 2011. All U.S. centers utilized pediatric child abuse teams and all centers are listed in the acknowledgments. Although the primary analysis of the ExSTRA network involved household contacts such as siblings or children who shared a daycare with the index child, the present analysis includes data only from index children. All testing for index children was undertaken at the discretion of the clinical team and our cohort consisted of inpatients, outpatients and emergency department patients. All participating centers and the data coordinating center obtained approval for the parent study with waiver of informed consent from their local institutional review board. This secondary analysis of de-identified data was determined to be exempt from review by the Colorado Multi-Institutional Review Board.

For this secondary analysis, we used several steps to identify subjects from the ExSTRA cohort whose head injuries might be considered occult. First, we used structured data to exclude subjects with: age >24 months, abnormal mental status, and/or a bulging fontanel. Age was precisely defined (e.g., subjects who had passed their 6-month birthday [even by an hour or a day] were analyzed in the 6- to <12-months group while those who had not were analyzed in the 0 to <6-months group).

Unstructured data, such as free text, were then reviewed by a single reviewer (M.B., with 7 years' experience) who was masked to neuroimaging results, and applied the exclusion criteria used by Rubin et al. (scalp injury, seizures, respiratory arrest, underlying neurological condition or focal neurological deficit) [5]. Subjects with reported bruising were excluded if unstructured data did not specify location since these injuries may have been to the scalp. Also, children who were coded as having normal mental status using structured data were excluded if unstructured data suggested altered mental status (e.g., sleepiness, lethargy). Children without structured data for mental status were excluded unless unstructured data specifically implied normal mental status (e.g., normal exam) or reported specific exam findings (e.g., bruise to thigh, leg swelling) and did not mention abnormal mental status. Ten percent of subjects were reviewed by an additional masked reviewer (D.M.L., with 21 years' experience) to assess inter-rater reliability.

The remaining subjects formed the main cohort for our analysis and were evaluated for the risk factors identified by Rubin et al. (age <6 months, facial bruising, rib fracture(s), or multiple fractures) [5]. We also evaluated our cohort for elements of the PECARN decision rule, including loss of consciousness, severe mechanism of injury and abnormal behavior [13]. We were unable to apply all criteria of the PECARN decision rule due to the clinical setting and exclusion of subjects with altered mental status, scalp injuries and palpable skull fractures. The PIBIS clinical prediction rule was not evaluated because the ExSTRA data did not contain all necessary data (head circumference percentile or hemoglobin). Unstructured data were evaluated for emesis, macrocephaly and known, but not palpable, skull fractures.

Neuroimaging was considered positive for occult head injury if it was the first to identify a traumatic finding and the injury was not previously identified by other testing. Neuroimaging was also considered positive if it raised concern for an injury ultimately confirmed by other testing. Descriptive statistics were used to describe rates of occult injuries, and the kappa statistic was used to measure inter-rater reliability for coding of unstructured data.

Results

As shown in Figure 1, 1,255 of 2,890 subjects in the ExSTRA cohort were excluded based upon structured data that showed a bulging fontanel (n=68), age >24 months (n=915), or altered mental status (n=413). The number of excluded subjects equals more than 1,255 because participants could have more than one exclusion criterion. Review of unstructured data identified an additional 492 participants who were excluded by altered mental status, bulging fontanel, incomplete data or for signs of AHT using exclusion criteria based on the study by Rubin et al. [5]. The decision to exclude patients based on unstructured data showed very good inter-rater reliability, with a kappa of 0.85 [23]. Of the 492 patients who were excluded by these criteria, 91.1% (448) received neuroimaging and head injury was identified in 64.5% (289).

The remaining 1,143 participants form the main cohort for this analysis. A total of 62.5% (714) of patients received neuroimaging. This included 80% (571) of patients receiving computed tomography (CT) alone, 6% (41) receiving magnetic resonance imaging (MRI) alone and 14% (100) receiving both a CT and MRI. Two subjects included in our study did not have a neuroimaging modality listed.

Demographics of the study cohort and those receiving neuroimaging are shown in Table 1. The mean age was 8.2 months and, as with previous abuse studies, there was a slight male predominance in our cohort [24]. Imaging was obtained at a higher rate for younger subjects with 82.4% of subjects <6 months old undergoing imaging. The prevalence of occult injury for each age group is listed in Table 2.

Of the 714 patients who were imaged, 19.7% (141) were found to have an occult head injury on either CT or MRI. This included 16% (114) of patients with an intracranial injury, 5.0% (36) with a skull fracture and 1.3% (9) with both a skull fracture and intracranial injury. Of the 100 patients that received both CT and MRI, there were 5 cases where MRI diagnosed head trauma that was not evident on CT; these

Fig. 1 Subject flow diagram

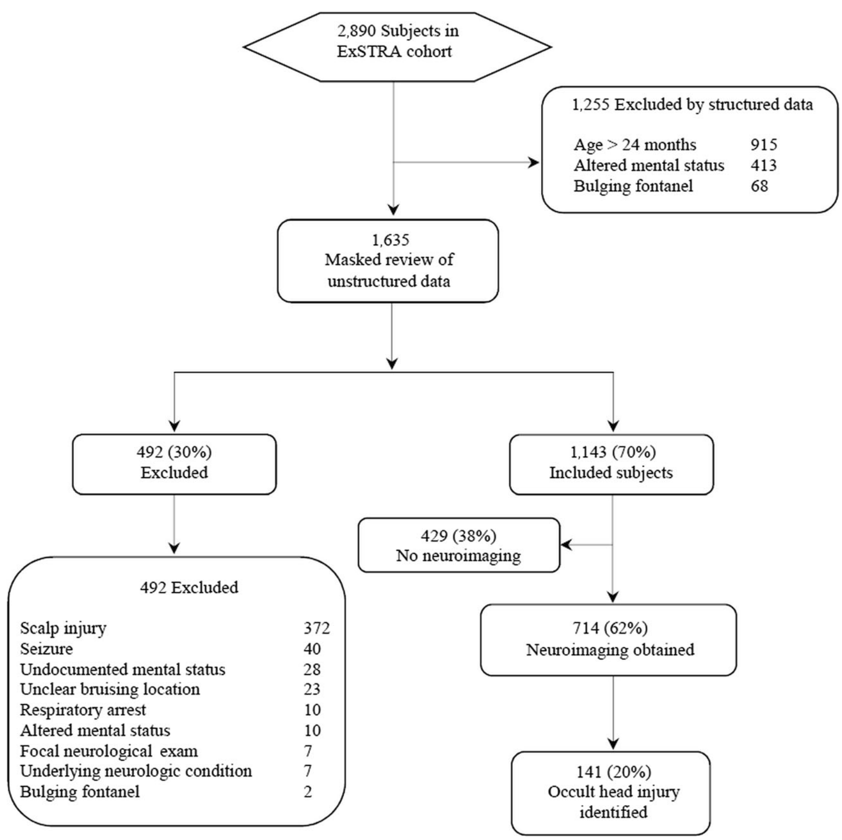

Table 1 Demographics of study cohort

Characteristic	All subjects (1,143) *n* (%)	Imaged subjects (714) *n* (%)
Age		
0 to <6 months	550 (48.1)	453 (63.4)
6 to <12 months	273 (23.9)	169 (23.7)
12 to <18 months	177 (15.5)	53 (7.4)
18 to <24 months	143 (12.5)	39 (5.4)
Male	649 (56.8)	417 (58.4)
Non-cranial injuries		
Rib fracture	155 (13.6)	138 (19.3)
Facial injury	296 (25.9)	204 (28.6)
Multiple fractures	254 (22.2)	207 (29)
Burns	112 (9.8)	31 (4.3)
Intra-abdominal/thoracic injury	21 (1.8)	18 (2.5)
Other risk factors		
Loss of consciousness	10 (0.9)	9 (1.3)
Macrocephaly	29 (2.5)	29 (4.1)
Emesis	48 (4.2)	43 (6.0)
ICU admission	40 (3.5)	35 (4.9)

findings included ischemia, subdural hematoma or intraparenchymal hemorrhage. In addition, there were 11 cases where MRI reportedly helped characterize extra-axial hemorrhages or demonstrated ischemia in addition to hemorrhage identified on CT. Descriptions of head injuries detected by neuroimaging are listed in Table 3.

Table 4 lists the proportion of subjects who were imaged and who had injuries identified according to proposed risk factors or decision rules. Among the 714 imaged patients, 81.2% (580) had at least one high-risk criterion proposed by Rubin et al. [5] and 16.7% (119) had at least one PECARN criterion.

Discussion

Occult AHT is common in children who undergo subspecialty evaluation for physical abuse. In this study, we report the prevalence of occult head injury in a population with concern for abuse.

Our occult AHT prevalence includes only imaged patients since the true rate of occult injury in those subjects not receiving neuroimaging cannot be discerned. If we presume negative neuroimaging for all subjects who did not undergo neuroimaging, the prevalence of occult head injury is still relatively high at 12.3%.

We assessed high-risk criteria suggested by Rubin et al. [5] to evaluate for associations with occult head trauma. Approximately 74% of subjects with at least one high-risk criterion were imaged. Subjects with rib fractures had the highest rate of neuroimaging at 89%. We found no statistically significant difference in occult AHT in imaged subjects having one suggested high-risk characteristic relative to those without an identified risk factor. Despite this, the prevalence of occult injury was still high with each criterion demonstrating an occult head injury at least 16% of the time. Our evaluation of these high-risk criteria should be interpreted cautiously in light of our decision to analyze only those subjects who underwent neuroimaging. Because we cannot estimate the prevalence of occult

Table 2 Age groups of imaged subjects with occult AHT

Age (months)	Total subjects *n* (%)	Neuroimaging obtained *n* (%)	Occult AHT *n* (%)
0 to <6	550 (48.1)	453 (82.4)	93 (20.5)
6 to <12	273 (23.9)	169 (61.9)	31 (18.3)
12 to <18	177 (15.5)	53 (29.9)	12 (22.6)
18 to <24	143 (12.5)	39 (27.3)	5 (12.8)
Total	1,143 (100)	714 (62.5)	141 (19.7)

Occult injury percentage based upon imaged patients only

AHT abusive head trauma

Table 3 Occult head injuries detected by neuroimaging

	Subjects *n* (%)
Subjects with occult head injury	141 (19.7)
Intracranial injury	114 (16)
Subdural hematoma	82 (11.5)
Subarachnoid hemorrhage	30 (4.2)
Intraparenchymal hemorrhage/contusion	7 (1)
Infarct	3 (0.4)
Epidural hematoma	2 (0.3)
Skull fracture	36 (5)
Skull fracture and intracranial injury	9 (1.3)
Forehead swelling not detected on exam	1 (0.1)

Occult injury percentage based upon total number of imaged patients

injuries in children who did not have imaging, our results are affected both by the underlying risk of injury and the clinical team's decision to obtain imaging. The prevalence of occult head injuries in children with risk factors identified by Rubin is almost certainly affected by the high rate of imaging in this group due to the incorporation of these criteria into professional guidelines [5, 8].

We excluded children who were not imaged from our odds ratio (OR) calculations. We found no significant difference in the prevalence of occult head injury between different age groups, including younger subjects 0 to <6 months of age. However, similar to our analysis of Rubin's suggested high-risk criteria, these findings are likely biased by higher imaging rates in younger subjects.

Subjects with a history of emesis, macrocephaly or loss of consciousness had significantly higher associations with AHT. We included subjects with these signs and symptoms in our cohort since we modeled our exclusion criteria after previous studies evaluating for occult head trauma, on which ACR imaging recommendations are based [5, 6, 8]. While it could be argued that these symptoms are overt, and not occult signs of head injury, this is not how they are perceived clinically. Most infants with emesis do not receive a head CT, and the same is true for macrocephaly, particularly in the absence of a report of significant head trauma. Nevertheless, we calculated the rate of occult AHT in our cohort excluding those with emesis, loss of consciousness or macrocephaly and still found a high prevalence of occult head injury of 15.8%.

In the general population of the pediatric emergency department, the PECARN decision rule has been used to identify children at very low risk for clinically important TBI who could forego head CT and is not recommended in cases with concern for physical abuse [16]. Its inclusion criteria require a child to present within 24 h of injury and time of injury can be difficult to determine in cases of abuse. Further, it was derived to identify clinically important TBI, where some abusive head injuries are forensically if not clinically important [16, 25]. Nevertheless, we sought to determine whether components of the PECARN decision rule might identify children with occult AHT. For children <2 years of age, the PECARN decision rule suggests that CT can be avoided in children with: normal mental status, no non-frontal scalp hematoma, no loss of consciousness or loss of consciousness <5 s, no severe mechanism of injury, no palpable skull fracture and normal behavior per their parent. Our cohort excluded children with altered mental status or any scalp injury, including a palpable skull fracture. We reviewed data to identify children within our cohort who had abnormal behavior, a reported severe mechanism of injury or any reported loss of consciousness. Meeting one

Table 4 Evaluation of high-risk criteria

	Met criteria (*n*)	*n* (%) imaged	*n* (%) with occult AHT	OR (95% CI)
At least 1 Rubin criterion	784	580 (74.0)	114 (19.7)	1.0 (0.6–1.6)
<6 months	550	453 (82.4)	93 (20.5)	1.1 (0.8–1.7)
Face injury	296	204 (68.9)	42 (20.6)	1.1 (0.7–1.6)
Rib fracture	155	138 (89.0)	23 (16.7)	0.8 (0.5–1.3)
Multiple fractures	254	207 (81.5)	35 (16.9)	0.8 (0.5–1.2)
*At least 1 PECARN criterion	140	119 (85.0)	42 (35.3)	**2.7 (1.7–4.3)**
Emesis	48	43 (89.6)	19 (44.2)	**3.5 (1.8–6.8)**
Macrocephaly	29	29 (100)	19 (65.5)	**8.5 (3.7–20.2)**
Loss of consciousness	10	9 (90.0)	5 (55.6)	**5.1 (1.2–22.9)**

Abusive head trauma percentages are taken from the population of children who had imaging. Bold values are statistically significant

AHT abusive head trauma, *CI* confidence interval, *OR* odds ratio

*PECARN (Pediatric Emergency Care Applied Research Network) criteria include abnormal behavior, loss of consciousness and severe mechanism of injury. Subjects with scalp injuries, palpable skull fractures and altered mental status were excluded from our cohort

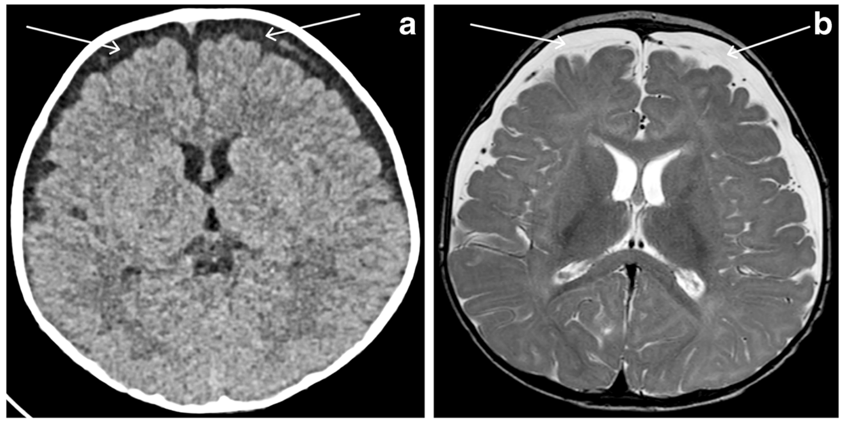

Fig. 2 A well-appearing 5-month-old boy male with normal neurological exam and no reported history of trauma. Concern for abuse arose based upon facial bruising. CT (**a**) and T2-weighted MR (**b**) images show small bilateral subdural hemorrhages (*arrows*)

of these criteria had an OR of 2.7 (95% CI 1.7–4.3), significantly increasing the likelihood of AHT. However, as the PECARN network has noted, the negative predictive value in this setting (83%) does not meet the extremely high standard set by the PECARN group. This is of particular importance in a child with concern for abuse, since these occult findings may be associated with forensic significance (e.g., a young child with an isolated injury and a history of a minor trauma may not be reported to Child Protective Services or have secondary prevention, but the identification of occult TBI may lead providers to doubt the offered history or trigger protective interventions). For example, a 5-month-old child presented to our institution with fever and upper respiratory infection symptoms and no reported history of trauma. A neurological exam was normal but concern for abuse arose based on facial bruising. Neuroimaging was ultimately obtained and demonstrated thin bilateral subdural hemorrhages that prompted further intervention (Fig. 2).

Strengths of our study include a large population, with prospective data collection from a geographically diverse group of U.S. centers, and a high rate of neuroimaging. Limitations include a retrospective study design, a significant fraction of children without imaging, and unclear clinical or forensic significance of the injuries identified. Additionally, we are unable to determine whether neuroimaging was obtained before or after suspicious findings were discovered. It is possible that macrocephaly or emesis were more likely to be noted or documented only when AHT was identified. It is unclear whether neuroimaging was obtained before or after child abuse physician consultation and the data set did not include the treating team's stated reasons for obtaining imaging. If child abuse physician consults were obtained because of the positive imaging, this would have artificially increased the perceived yield of imaging in identifying occult trauma. Our prevalence of occult head injury may differ from hospitals that do not employ child abuse teams. Missing data are a limitation of this secondary analysis. Approximately 14% of subjects did not have mental status coded in structured data. Our approach of reviewing unstructured data and excluding those without documentation of normal mental status may have excluded some children with normal mental status who were at lower risk for occult injury. If we preferentially excluded these subjects, our estimate of occult head injury would be artificially inflated.

Conclusion

In this study, we evaluated occult head trauma in patients <2 years old with suspected abuse. Our cohort consisted of children with similar inclusion and exclusion criteria utilized in previous studies and we found a high prevalence of occult head injury in patients <2 years of age with suspected physical abuse. Macrocephaly, emesis and loss of consciousness were found to have a strong association of occult head injury. Occult AHT is common among abused children and our data support the ACR recommendation that clinicians should have a low threshold to perform neuroimaging in patients <2 years of age with suspected abuse.

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Compliance with ethical standards

Conflicts of interest Dr. Lindberg has received payment for expert witness record review and testimony related to children with concern for physical abuse. None of the other authors has potential conflicts of interest.

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