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YIELD OF NEUROIMAGING IN INFANT PHYSICAL ABUSE EVALUATIONS: DO INFANT AGE AND INJURY TYPE MATTER?

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☐ **Abstract—Background: Neuroimaging can be an important part of the medical workup for children with suspected physical abuse, but there are not specific guidelines on which children should undergo neuroimaging. Objective: We sought to evaluate the yield of neuroimaging in children <12 months of age who are undergoing physical abuse evaluations and to determine how the yield varied by age, injuries, and social risk factors. Methods: This was a retrospective observational study of infants who presented to an urban children's hospital between September 2007 and October 2012, were evaluated by the hospital's child abuse team, and who received skeletal surveys and underwent neuroimaging for suspected physical abuse. Infants who were diagnosed with head trauma before the abuse evaluation were excluded. Logistic regression was used to investigate the relationship between neuroimaging yield and patient age, presenting injury, and social features. Results: Head injuries were identified in 14 of 170 infants (8.2%). The yield was similar in children <6 months of age and children ≥6 months of age (7.5% and 9.4%, respectively; $p = 0.674$). Infants with bruises and cases involving a delay in seeking care or cases with previous Child Protective Services involvement were more likely to have injuries identified on neuroimaging. Infants with current or past neurologic signs/symptoms were also more likely to have head injuries on neuroimaging (5/17, 29%), although most infants with abnormal neuroimaging findings did not have neurologic signs/symptoms (9/14, 64%). Conclusions: We found that while certain features were associated with abnormal findings on neuroimaging, infant age (<6 months vs. 6-12 months) was not.** © **2019 Elsevier Inc. All rights reserved.**

☐ **Keywords—child abuse; craniocerebral trauma; tomography; magnetic resonance imaging; computed tomography**

INTRODUCTION

Physical abuse is a significant cause of morbidity and mortality in infants. Physical abuse can result in skeletal and head injuries that may not be clinically obvious, and therefore the medical evaluation of infants where there is concern for physical abuse involves screening for occult injury (1,2). While the American Academy of Pediatrics and the American College of Radiology recommend skeletal surveys for children <2 years of age with suspected physical abuse, there are not clear neuroimaging recommendations (3). Radiation and sedation concerns lead some physicians to only order neuroimaging on younger infants or on infants with certain injuries.

We are unaware of any studies comparing the yield of neuroimaging in infants <6 months of age with those 6 to 12 months of age (4–7). This uncertainty presents a gap in clinical knowledge and practice. Additional data on the injury patterns or risk factors associated with positive

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neuroimaging screening could also help guide clinicians who are assessing infants for possible physical abuse.

Our objective was to evaluate the yield of neuroimaging studies in children <1 year of age who were undergoing physical abuse evaluations (for reasons other than head trauma) and to determine how the yield varied by infant age, injuries, and risk factors.

METHODS

Overview

This retrospective medical record review was conducted at a large urban children's hospital after approval from the institutional review board. The hospital's child abuse team includes child abuse pediatricians and social workers, and according to institutional guidelines the team evaluates all infants with fractures or head injuries and all nonambulatory infants with bruises, burns, or oral injuries. Most physical abuse evaluations are initiated during the initial emergency department presentation. The team is also consulted for other concerns of abuse or neglect. The team collaborates in making a medical diagnosis of abuse, accident, medical condition (not trauma), or indeterminate.

Study Subjects

The study included infants <12 months of age evaluated at this institution between September 1, 2007 and October 1, 2012. Children <12 months were studied because screening neuroimaging is less commonly ordered in older children (5). Other inclusion criteria included a child abuse team consultation for physical abuse concerns other than head trauma, as well as completed skeletal survey and head computed tomography (CT) or brain magnetic resonance imaging (MRI) scans. Head trauma was defined as scalp swelling, skull fracture, or intracranial injury. During the study period, neuroimaging at this institution was often part of the workup for occult injury among children <12 months of age who were suspected victims of physical abuse, although practices varied. Children who did not undergo head imaging in the form of CT or MRI scan were excluded. Children with head trauma diagnosed before the child abuse consultation were excluded. Patients with signs and symptoms that could possibly be neurologic in nature were not excluded, because some of these findings (such as vomiting or "spitting up more") are often not specific and may not prompt clinicians to order neuroimaging. Subjects were identified via the child abuse team database and social work database, which track all cases of suspected physical abuse at this institution.

Neuroimaging

The type of neuroimaging performed (CT, MRI, or both CT and MRI) and results were extracted from radiology reports. Positive neuroimaging was defined as any finding consistent with trauma as defined above. Any additional neuroimaging performed to confirm or clarify abnormal or equivocal findings on a CT scan of the head was also documented.

Measures

Clinical and demographic characteristics were abstracted from the medical record. Presenting injuries or complaints, trauma histories, physical examination findings, and skeletal imaging findings were documented. One chief complaint was "concern for abuse by history"; this group included siblings of abused children or cases where abuse of the infant was reportedly witnessed. Children without past or present abnormal neurologic signs and symptoms were also analyzed separately. Abnormal neurologic signs and symptoms were defined as seizure, respiratory arrest, vomiting, abnormal mental status, or abnormal neurologic examination. It was noted whether a report was made to state Child Protective Services (CPS) for the concern for physical abuse. Four risk factors for maltreatment were documented: no history to account for the injury, changing history of injury, previous CPS involvement (either per caregiver report or discovered during the investigation), and a delay in seeking care. The determination of delay in seeking care was made by the reviewing child abuse pediatrician and was decided by consensus of the second child abuse pediatrician when the determination was unclear. The final determination (abuse, not abuse, or indeterminate) made by the child abuse pediatrician who consulted on the child was also recorded.

Statistical Analysis

Descriptive statistics were used to characterize the study population, the neuroimaging performed, and neuroimaging results. The nonparametric Wilcoxon rank sum test for age and chi-square or Fisher exact tests for categorical variables were used. The unadjusted association between all potential risk factors and neuroimaging yield was evaluated using bivariate logistic regression modeling. To account for hypothesized age differences between the samples, we also assessed the age-adjusted association between all risk factors and yield using multivariable logistic regression modeling. A 2-sided p value $\leq .05$ was considered statistically significant.

RESULTS

During the study period, 205 patients underwent a child abuse team consultation and skeletal survey. There were 35 patients who did not undergo neuroimaging and were excluded, giving a final sample size of 170 infants. The median age of the patients was 4.7 months; more than half were <6 months of age. Other key demographic factors, the patients' presenting injuries, and neurologic signs and symptoms are detailed in Table 1. The most common presenting injuries were extremity fractures other than classic metaphyseal lesions (CMLs) and bruises. Most of the infants (90%) did not have current or past signs or symptoms that could be associated with neurologic issues. Of those who did, vomiting was the most common (12/170, 7.1%).

Of the 170 infants, 14 (8.2%) had positive (abnormal) neuroimaging findings. Eight infants had subdural hemorrhages, and subpial hemorrhage was noted in 1 infant. Five had skull fractures, 1 of which was not noted on skeletal survey. Given the retrospective study design, however, we cannot determine whether CT images of the head or results aided the radiologists in interpreting the plain skull films.

The yield of neuroimaging did not vary by age in our sample (Table 2). The yield of neuroimaging in infants <6 months of age was 8 of 106 (7.5%) and the yield among infants ≥6 months of age was 6 of 64 (9.4%). This difference was not statistically significant ($p = 0.674$). The variables that were significantly associated with positive neuroimaging results based on p values and confidence intervals were bruising, delay in care, and previous CPS involvement. A history of current or past vomiting was also associated with positive findings on neuroimaging, while other neurologic signs and symptoms were not. We did not find an association between race, gender, and insurance with neuroimaging yield.

Of the 14 infants with positive neuroimaging, 5 had past or present symptoms that could have been related to the neurologic system. Importantly, 2 of these infants had pre-existing medical conditions that could account for the symptoms, and the other 3 had symptoms that were nonspecific. One infant had a report of past and current vomiting, but had a complicated medical history including operatively treated necrotizing enterocolitis. Another infant had a medical history significant for hypoxic ischemic encephalopathy and had had abnormal neurologic examinations and seizures since birth. The remaining 3 infants had reported vomiting or "spitting up more" at the time of presentation. A subgroup analysis of patients without current or past neurologic signs/symptoms (n = 152) was conducted. In this subgroup, 9 infants (5.9%) had positive neuroimaging, and there were no differences between patients with positive and negative neuroimaging findings based on age, other demographic characteristics, injury type, or risk factors.

Table 1. Sample Characteristics

Characteristic	Median (IQR) or n (%) N = 170
Age (months), continuous	4.7 (2.7–7.5)
Age, categorical	
<6 months	106 (62.4)
≥6 months	64 (37.6)
Male	93 (54.7)
Race/ethnicity	
Hispanic	60 (35.3)
White	45 (26.5)
African American	45 (26.5)
Other	15 (8.8)
Missing data	5 (2.9)
Insurance	
Public	129 (75.9)
Private	41 (24.1)
Presenting injuries*	
Extremity fracture (not CML)	89 (52.4)
Bruise	53 (31.2)
Concern for abuse by history	25 (14.7)
CML	20 (11.8)
Rib fracture	16 (9.4)
Burn	5 (2.9)
Oral injury	6 (3.5)
Pulmonary hemorrhage	2 (1.2)
Any neurologic sign/symptom	17 (10.0)
≥1 risk factor†	117 (68.8)

CML = classic metaphyseal fracture; IQR = interquartile range.
* The number of injuries is greater than the total N of 170 because some patients had multiple injuries. The percentage reflects the percentage of patients in the study sample with the specified injury; therefore, the sum is >100%.
† Risk factor defined as no history to account for the injury, changing history of injury, previous Child Protective Services involvement, or a delay in seeking care.

A description of patients with positive neuroimaging (based on final neuroimaging results) is detailed in Table 3. Of the 14 patients with positive neuroimaging results, the child abuse pediatrician determination was "abuse" in 11 and "indeterminate" in 3 patients. All cases were reported to state CPS. Surprisingly, neuroimaging results likely changed the determination of abuse in only 1 case (subject 14), who was a sibling of an abused child. In this case, neuroimaging findings led to the child abuse pediatrician determination of "indeterminate" (rather than no signs of abuse) because the caregivers provided a potentially plausible trauma history well into the investigation.

DISCUSSION

Overall, the yield of positive findings on screening neuroimaging of infants with suspected physical abuse in our study was 8.2%. Infants <6 months of age were no more likely to have positive neuroimaging than patients

Table 2. Unadjusted and Age-Adjusted Associations Between Risk Factors, Clinical Findings, and Neuroimaging Yield (N = 170)

	Median (IQR)/n (%)		Unadjusted		Age-adjusted	
	Negative	Positive				
Clinical Characteristic	n = 156 (91.8)	n = 14 (8.2)	OR (95% CI)	*p*	OR (95% CI)	*p*
Age (months), continuous	4.8 (2.7–7.5)	4.7 (3.1–7.4)	1.04 (0.86–1.25)	0.7025		
Risk factor						
Delay in care	14 (8.97)	4 (28.57)	3.86 (1.07–13.92)	0.0393	4.06 (1.1–14.92)	0.0350
Previous CPS involvement	22 (14.1)	5 (35.71)	3.38 (1.04–11.04)	0.0433	3.48 (1.06–11.44)	0.0401
No history	80 (51.28)	7 (50)	0.95 (0.32–2.84)	0.9268	0.97 (0.32–2.9)	0.9516
Changing history	24 (15.38)	1 (7.14)	0.42 (0.05–3.39)	0.4177	0.43 (0.05–3.48)	0.4308
Neurologic sign or symptom						
Vomiting	8 (5.13)	4 (28.57)	7.4 (1.9–28.84)	0.0039	7.42 (1.85–29.68)	0.0046
Seizure/abnormal movement	1 (0.64)	1 (7.14)	11.92 (0.7–201.84)	0.0860	12 (0.71–203.81)	0.0854
Abnormal examination	5 (3.21)	1 (7.14)	2.32 (0.25–21.4)	0.4567	2.48 (0.26–23.39)	0.4265
Altered mental status	4 (2.56)	1 (7.14)	2.92 (0.3–28.11)	0.3530	3.08 (0.32–30.11)	0.3328
Apnea/arrest	2 (1.28)	0 (0)				
Presenting injuries or concerns						
CML	18 (11.54)	2 (14.29)	1.28 (0.26–6.18)	0.7602	1.39 (0.28–6.99)	0.6922
Rib fracture	14 (8.97)	2 (14.29)	1.69 (0.34–8.33)	0.5187	1.97 (0.36–10.71)	0.4311
Extremity fracture (not CML)	84 (53.85)	5 (35.71)	0.48 (0.15–1.49)	0.2012	0.46 (0.15–1.46)	0.1874
Any fracture	100 (64.10)	7 (50.00)	0.56 (0.19–1.68)	0.30	0.57 (0.19–1.70)	0.5589
Bruise	45 (28.85)	8 (57.14)	3.29 (1.08–10.02)	0.0361	3.29 (1.08–10.01)	0.0364
Concern for abuse by history	22 (14.10)	3 (21.43)	1.66 (0.43–6.43)	0.4625	1.63 (0.42–6.34)	0.4840
Burn	4 (2.56)	1 (7.14)	2.92 (0.3–28.11)	0.3530	3.02 (0.31–29.26)	0.3403
Oral injury	6 (3.85)	0 (0)				
Pulmonary hemorrhage	2 (1.28)	0 (0)				

CI = confidence interval; CML = classic metaphyseal fracture; CPS = child protective services; IQR = interquartile range; OR = odds ratio.

6 to 12 months of age. Rates of positive neuroimaging differ between our sample and those of previous studies, which may be related to differences in the study populations. Rubin et al. studied children <2 years of age with high-risk criteria (multiple fractures, rib fractures, facial injury, or age <6 months) and found a higher rate of positive neuroimaging (37%) (4). Laskey et al. included older children as well, evaluating 38 children <48 months of age who had head imaging as part of a physical abuse workup (5). The overall positive neuroimaging rate was 29%, with children <12 months of age being more likely to have intracranial injury. Unlike our study, Laskey et al. did not exclude patients who presented with skull fractures (5). Harper et al studied young infants (<6 months of age) who presented with apparently isolated bruising and found that 27.4% had positive neuroimaging, which is consistent with our own higher rate of positive imaging in infants with bruising (6). Some studies have found lower rates of positive neuroimaging than our study. Wilson evaluated children <2 years of age with a single extremity fracture and found a lower prevalence of occult head injuries (4.3%) (8). Shaikh included children <2 years of age who were admitted for child abuse evaluations and found that 5% had evidence of occult head injury on CT, though they did not include any children with current or past neurologic abnormalities (9).

It is notable that the rate of positive neuroimaging resembles rates of positive skeletal surveys performed in similar populations, and the American Academy of Pediatrics recommends skeletal surveys in these cases. Duffy et al. found that skeletal surveys were positive in 13.1% of infants who were undergoing an evaluation for child physical abuse, while Lindberg found a positive rate of 25.7% in a similar population (10,11). Laskey et al. found that the yield of skeletal surveys was 9% for children <6 months of age with skull fractures (12).

The presence of neurologic symptoms has sometimes been used to guide neuroimaging. While we found a higher neuroimaging yield in children with neurologic signs or symptoms, it is important to note that most of the infants with positive neuroimaging results did not have these findings. It is also of note that vomiting (or "spitting up more"), a symptom that is not specific to head trauma, was the most common symptom documented in children classified as having neurologic symptoms. In addition, 2 of the 5 infants with positive neuroimaging had neurologic signs or symptoms that could be attributed to their pre-existing medical conditions rather than trauma. While it is possible that not all neurologic findings were identified in this retrospective study, social workers and child abuse pediatricians routinely ask questions about such symptoms at our institution. Our findings therefore support the consideration of screening infants with neuroimaging even in the absence of neurologic signs and symptoms.

Table 3. Patients with Abnormal Neuroimaging

Patient No.	Age (Months)	History/Chief Complaint	Skin Abnormalities	Skeletal Survey Findings	Neuroimaging Findings	Red Flags	Final CAP Determination
1	2	Hospital follow-up visit, PMD noted facial bruising and weight loss, vomiting	Diffuse face and ear bruising	4 rib fractures	CT: bilateral SDH MRI: same	No history, changing history, and previous CPS involvement	Abuse
2	2	Parent almost dropped baby, caught by arm; crying since	None	Spiral humerus fracture	CT: questionable punctate hemorrhages MRI: focal subpial hemorrhage	None	Indeterminate
3	2	Right thigh bump and crying	None	Acute oblique femur and clavicle fracture, healing humerus fracture, 4 healing rib fractures	CT: bilateral and interhemispheric SDH MRI: same	No history, previous CPS involvement, delay in seeking care	Abuse
4	3	Mother witnessed father smothering patient	5 face bruises, chest bruise	None	CT: questionable SDH MRI: SDH	Previous CPS involvement	Abuse
5	3	Decreased left arm movement	2 trunk bruises, linear foot bruises	Parietal skull fracture, scapula fracture, 4 CMLs	CT: confirmed parietal skull fracture	No history	Abuse
6	4	Leg pain after fall with adult	None	Bilateral skull fractures, oblique femur fracture, femur CML	CT: confirmed bilateral skull fractures MRI: normal	None	Abuse
7	4	Fussy, concern for constipation	Cheek bruise, hand print bruise on chest	None	CT: questionable SDH MRI: SDH	No history	Abuse
8	4	Bed fall, leg swelling	None	Bilateral parietal skull fractures, transverse femur fracture	CT: confirmed bilateral skull fractures	Delay in seeking care	Abuse
9	6	Vomiting for 3 days	Bite mark on cheek, 2 abdominal bruises	None	CT: possible SDH MRI: bilateral SDH	Previous CPS involvement	Abuse
10	6	Face bruising; parent stated he struck the infant	Diffuse face bruising, subconjunctival hemorrhage, groin/leg abrasions	None	CT: suspected SDH MRI: bilateral SDH	Delay in seeking care	Abuse
11	7	Infant with HIE/cerebral atrophy; elbow swelling	None	Distal radius fracture; radius/ulna dislocation	CT: Bilateral SDH and severe atrophy	No history, delay in seeking care	Abuse
12	8	Infant on antiplatelet medications; face bruising and acute vomiting	4 face bruises	None	CT: bilateral SDH MRI: same	No history	Indeterminate
13	9	Marks on legs	Arm bruise, foot bruise, 6 circular leg lesions with linear marks in them	Frontal skull fracture	CT: confirmed frontal skull fracture MRI: normal	None	Abuse
14	10	Sibling of child with abusive head trauma	None	None	CT: occipital fracture MRI: normal	CPS history	Indeterminate

CAP = child abuse pediatrician; CML = classic metaphyseal fracture; CPS = Child Protective Services; CT = computed tomography; HIE = hypoxic ischemic encephalopathy; MRI = magnetic resonance imaging; PMD = primary medical doctor.

The fact that we found no significant difference in the yield of neuroimaging in infants <6 months of age vs. those >6 months of age is somewhat surprising. This must be interpreted in the context of a single-center study as well as a possible selection bias since more young infants underwent neuroimaging in our study population, but our results call into question the practice of obtaining neuroimaging only on young infants. Also surprising was the finding that infants with bruising were more likely to have positive neuroimaging findings, but those with other injuries were not. Specific features of the bruises may have played a role. All of the children with bruising who had positive neuroimaging findings had multiple bruises, often in locations that previous studies have found to be strongly associated with abuse (13–16). In addition, 6 of the patients with positive neuroimaging findings had facial skin injuries, which should increase clinician concern for other head injuries. In our study, infants with injuries known to have high specificity for abuse, including CMLs and rib fractures, did not have a higher yield on neuroimaging, which could be attributable to the small number of patients in these categories.

Our study found that in almost all cases, the neuroimaging did not change the child abuse pediatrician's determination of abuse. In the single case where the determination did change (from "not abuse" to "indeterminate"), it is unlikely that this change impacted the child's placement or safety because the infant's sibling had clear findings of abuse and the child was already in an out-of-home placement. Even though in this case the child's safety was not impacted, in other cases it may be. Abused children are sometimes returned to injurious environments when alternate theories for injuries are proposed and accepted in child protection court proceedings. The discovery of cranial injuries, particularly when injuries suggest multiple episodes of abuse, may highlight the extent of the maltreatment and prevent future harm to the child. In addition, while the infants with cranial injuries in our study did not require neurosurgical intervention, in some cases this may be necessary. The identification of head injuries is also important to alert caregivers and medical providers of the potential need for developmental services for the child in the future in order to maximize their school success and overall function.

Limitations

There are limitations to this study. Not all children who were evaluated by the child abuse team and who underwent a skeletal survey received neuroimaging; older infants and those without risk factors were less likely to undergo neuroimaging ($p < 0.05$). Infants with extremity fractures (that were not CMLs) were also less likely to undergo neuroimaging ($p < 0.05$) while those with CMLs and bruises were more likely to undergo neuroimaging ($p < 0.05$). There was no significant difference between imaging rates according to race, gender, and insurance status. When a sensitivity analysis was performed, inputting negative neuroimaging results for those that did not have neuroimaging done, the prevalence of positive neuroimaging was 6.8% (14/205). Another possible limitation of our retrospective design is that the determination of delay in seeking care and whether the discovery of occult head trauma changed the determination of abuse was based on our judgment. No accepted standard for delay in seeking care in children with injuries or illnesses exists, and because the severity of trauma symptoms can vary widely, determining a delay in seeking care using a discrete time cutoff is not reasonable. Because of this, injury information, the severity of reported or expected symptoms, and the time until medical care was sought were all considered in determining whether an unreasonable delay in seeking care was present. Another limitation to this study was the relatively small number of children with positive neuroimaging findings. This may have hindered the ability to detect differences between infants with positive and negative studies. This retrospective study was done at a single institution; a prospective, multicenter study would be helpful in further delineating the optimal use of neuroimaging screening in infants.

CONCLUSIONS

In conclusion, neuroimaging can be useful in infants with suspected physical abuse. Our study does not support focusing neuroimaging screening on infants <6 months of age, as the yield in this age group did not differ from infants 6 to 12 months of age. Infants with bruises (particularly facial bruises and multiple bruises) and some social risk factors may warrant particular consideration for neuroimaging screening.

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ARTICLE SUMMARY

1. Why is this topic important?

There is variability in how clinicians screen infants with suspected physical abuse for head trauma. There are no clear guidelines, and few studies have evaluated the yield of neuroimaging in this population.

2. What does this study attempt to show?

This study shows which clinical features are associated with positive neuroimaging in infants with suspected physical abuse.

3. What are the key findings?

The yield of neuroimaging was not related to infant age. Bruising and delay in seeking care were features associated with abnormal neuroimaging findings. While positive neuroimaging was more common in infants with past or present neurologic signs or symptoms, most infants with positive neuroimaging did not have documentation of these signs or symptoms.

4. How is patient care impacted?

These findings suggest that age <6 months and the presence of neurologic signs or symptoms are not optimal criteria for determining the need for screening neuroimaging.