Enlarged subarachnoid spaces and intracranial hemorrhage in children with accidental head trauma

Amanda K. Fingarson, DO,¹ Maura E. Ryan, MD,² Suzanne G. McLone, MPH,³
Corey Bregman, MD,² and Emalee G. Flaherty, MD¹

Departments of ¹Pediatrics, Division of Child Abuse Pediatrics, and ²Medical Imaging, Division of Neuroradiology; and ³Stanley Manne Children's Research Institute, Ann and Robert H. Lurie Children's Hospital of Chicago, Illinois

OBJECTIVE Benign external hydrocephalus (BEH) is an enlargement of the subarachnoid spaces (SASs) that can be seen in young children. It is controversial whether children with BEH are predisposed to developing subdural hemorrhage (SDH) with or without trauma. This issue is clinically relevant as a finding of unexplained SDH raises concerns about child abuse and often prompts child protection and law enforcement investigations.

METHODS This retrospective study included children (1–24 months of age) who underwent head CT scanning after an accidental fall of less than 6 feet. Head CT scans were reviewed, cranial findings were documented, and the SAS was measured and qualitatively evaluated. Enlarged SAS was defined as an extraaxial space (EAS) greater than 4 mm on CT scans. Clinical measurements of head circumference (HC) were noted, and the head circumference percentile was calculated. The relationship between enlarged SAS and HC percentile, and enlarged SAS and intracranial hemorrhage (ICH), were investigated using bivariate analysis.

RESULTS Of the 110 children included in this sample, 23 had EASs greater than 4 mm. The mean patient age was 6.8 months (median 6.0 months). Thirty-four patients (30.9%) had ICHs, including subarachnoid/subpial (6.2%), subdural (6.2%), epidural (5.0%), and unspecified extraaxial hemorrhage (16.5%). Enlarged SAS was positively associated with subarachnoid/subpial hemorrhage; there was no association between enlarged SASs and either SDH or epidural hemorrhage. A larger SAS was positively associated with larger HC percentile; however, HC percentile was not independently associated with ICH.

CONCLUSIONS Enlarged SAS was not associated with SDH, but was associated with other ICHs. The authors' findings do not support the theory that BEH predisposes children to SDH with minor accidental trauma.

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KEY WORDS intracranial hemorrhage; enlarged subarachnoid spaces; benign external hydrocephalus; trauma

BENIGN external hydrocephalus (BEH) is an enlargement of the subarachnoid space (SAS) that is seen in some young children. It is frequently associated with macrocephaly and is typically characterized by a period of rapidly increasing head circumference (HC) in infancy that resolves by 2 years of age.^{8,15,28} This condition is known by multiple terms, including benign extraaxial fluid, benign subdural collections of infancy, benign enlargement of the SASs, and benign extracerebral fluid collections in infancy. There are no established criteria for

diagnosis, although several studies have used extraaxial space (EAS) measurements greater than 4 mm on head CT scans to identify BEH.^{2,6,11,13,19} It is unclear whether young children with enlarged SASs are at risk for the development of subdural hemorrhage (SDH) with minor trauma or no trauma. Some case series and a mathematical model by Papasian and Frim have concluded that children with enlarged SASs are at increased risk of SDH due to stretched bridging veins.^{3,7,10,13,16,18,21} However, a finite element model by Raul et al. concluded the opposite: that increased cere-

ABBREVIATIONS BEH = benign external hydrocephalus; CPS = child protective services; EAH (NOS) = extraaxial hemorrhage (not otherwise specified); EAS = extraaxial space; EDH = epidural hemorrhage; HC = head circumference; ICH = intracranial hemorrhage; SAH = subarachnoid hemorrhage; SAS = subarachnoid space; SDH = subdural hemorrhage; SPH = subpial hemorrhage.

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bral spinal fluid in the SASs creates a damping effect and protects against intracranial hemorrhage (ICH).²⁰ Studies that have looked at larger groups of children with enlarged SASs have concluded that subdural collections are infrequently found.^{4,12,24}

This issue becomes important when evaluating children for possible maltreatment. Subdural hemorrhages are sometimes found on head CT or brain MR images of infants who present for evaluation for macrocephaly or for another cause. Given that physical abuse is considered to be the most common cause of SDH in this age group, this finding presents clinicians with a diagnostic challenge.^{1,17,23,25} Clinicians must determine whether the collections represent hemorrhage from a remote inflicted injury (where the other signs of injury, such as fractures, bruises, or retinal hemorrhages, may have resolved) or an underlying condition that predisposed the patient to SDH in the absence of either inflicted or significant trauma.

This study aims to determine whether children with enlarged SASs, measured quantitatively by CT scans as EAS greater than 4 mm and assessed qualitatively, are more likely to develop SDH or other ICH after minor accidental head trauma, i.e., falls from less than 6 feet. In addition, we assessed agreement between quantitative measurements of SAS size and the neuroradiologists' qualitative assessment of SAS enlargement. The systematic measurements of SAS sizes in infants and young children collected during this study will assist us in evaluating imaging standards for diagnosing BEH.

Methods

Study Participants

Study participants included children 1–24 months of age who presented to a large Midwestern pediatric hospital with reported accidental falls from less than 6 feet and underwent head CT scanning between June 1, 2006, and June 30, 2012. Study participants were identified using the hospital's child abuse team's database. Additional cases were identified through a search of the hospital's electronic medical records (Epic) using the following ICD-9-CM diagnosis codes: 782.2, 784.2, 800–804, 850–854, 873, 900, 910, 920, 925, 959.01, and 959.09. The following E codes were also searched for via Epic: E880–E886 and E888. Institutional review board approval was obtained for this study.

Children were excluded if the neuroradiologists (M.E.R. and C.B.) determined that the image quality was insufficient due to motion, artifact, slice selection, or angulation that precluded accurate measurement of EAS. Infants younger than 1 month of age were excluded because birth trauma could have contributed to any intracranial findings. Children were also excluded if no approximate time or date of trauma was known or documented, or if more than one trauma history was provided. Children with radiographic concern for prior injury or an underlying neurological diagnosis were excluded. Finally, if the hospital's child abuse team suspected the child was a victim of abuse or neglect, the case was excluded because the caregivers may have provided inaccurate information about the time and nature of the trauma.

Children were included in the study if they were transferred from an outside hospital that referred to state child protective services (CPS), but our hospital's child abuse team concluded they did not suspect the injury was caused by abuse or neglect. These children were included because some hospitals have protocols stating that they must report all infant head trauma to CPS regardless of their suspicion for abuse. Per our institution's protocol, the hospital's multidisciplinary child abuse team of child abuse pediatricians and social workers is consulted on all head injuries in children younger than 2 years of age, head injuries at any age that have been reported to CPS, and any time clinicians have concern for maltreatment. The team's social workers conduct detailed psychosocial assessments on these cases and document detailed information about the reported trauma history. This multidisciplinary team guides decisions about reporting to state CPS.

Data Abstraction

Clinical information was reviewed by a board-certified child abuse pediatrician (A.K.F.). Information obtained included the child's age, gestational age at birth, trauma history details, clinical symptoms, physical examination findings, and duration of time from trauma to examination/imaging. If clinical HC measurements and the patient's weight were obtained within a 2-week period of the head CT, those measurements were recorded. The fall height was estimated using the following guidelines: falls from the child's height, couches, standard chairs, and standard beds were estimated to be less than 3 feet; falls from caregivers' arms, high chairs, cribs, tall beds, tables, and countertops were estimated to be 3–6 feet.

Evaluation of Images

Head CT images were reviewed by one of 2 board-certified neuroradiologists (M.E.R. or C.B.). Questionable findings were decided by consensus. Information regarding skull fractures and parenchymal injury was recorded. Intracranial hemorrhage (ICH) was categorized as epidural hemorrhage (EDH), subdural hemorrhage (SDH), subarachnoid/subpial hemorrhage (SAH/SPH), or extraaxial hemorrhage (not otherwise specified) (EAH [NOS]). The unspecified EAH category was used when hemorrhages were too small to accurately distinguish between SDH and EDH. The 2 neuroradiologists, who were blinded to each other's judgment, also qualitatively classified the subarachnoid spaces by the degree of enlargement (none, borderline, mild, moderate, or severe).

Head size was calculated from CT using equations described in previous publications. HC was estimated by measuring the anteroposterior and transverse dimensions on axial head CT scans at the level of the basal ganglia, and area was approximated by using an ellipse equation: $\text{Area} = \pi \times (\text{transverse}/2) \times (\text{anteroposterior}/2)$.⁵

Subarachnoid space (estimated by EAS size) is defined as the greatest distance from the gyral surface to the inner calvarial cortex. EAS was measured on axial CT scans at the level of the lateral ventricle and averaged between the left and right sides (Fig. 1).⁹

Head CT scans obtained at outside hospitals in chil-

FIG. 1. Estimation of SAS from the measurement of EAS on axial CT scans. EAS size is measured as the greatest distance from the frontal gyral surface to the inner calvarial cortex (black lines).

dren who were transferred to our institution were included if the studies were loaded into our hospital's picture archiving and communication system, and if the neuroradiologist determined that the imaging was of sufficient quality for interpretation.

Statistical Analysis

Analyses were performed using the SPSS software package (version 22.0, IBM); p values < 0.05 were considered statistically significant. Standard statistical methods were used to summarize the data: frequencies and percentages for nominally scaled variables, and means and standard deviations for continuously scaled variables. Statistical differences between groups were calculated using the Student t -test for continuous measurements and Fisher's exact test for categorical variables. Statistical correlations between continuous measurements were calculated using Pearson's r . An interrater reliability analysis using the kappa statistic was performed to determine consistency among raters.

Results

Of the 136 patients identified who had undergone head CT scanning for a fall, 4 were excluded due to excessive fall distance (> 6 feet), 4 were excluded for unexplained bruises possibly caused by abuse, 4 were excluded for unclear timing or mechanism of injury, and 14 were excluded due to neuroradiology limitations.

Our final cohort included 110 children, with a mean age of 6.8 months (median age 6.0 months; Table 1). The population was predominantly white and Hispanic (42.7%

TABLE 1. Study population characteristics for 110 children with accidental head trauma

Characteristic	Value*
Mean age in mos ($\pm$ SD)	6.8 $\pm$ 4.65
Sex	
Male	56 (50.9)
Female	54 (49.1)
Race/ethnicity	
White/Caucasian	47 (42.7)
Hispanic/Latino	41 (37.3)
Asian	5 (4.5)
Black	3 (2.7)
Other/unknown/declined	14 (12.7)
Insurance (n = 109)	
Private	63 (57.8)
Public	46 (42.2)
Gestational age at birth (n = 87)	
Term	74 (85.1)
Preterm	13 (14.9)
Mean EAS measurement in mm ($\pm$ SD)	2.9 $\pm$ 1.71
> 4 mm	23 (20.9)
EAS qualitative assessment	
No enlargement	70 (63.6)
Borderline enlargement	20 (18.2)
Mild enlargement	13 (11.8)
Moderate enlargement	7 (6.4)
Severe enlargement	0 (0)
Intracranial injuries	
Fracture	85 (77.3)
ICH	34 (30.9)
SAH/SPH (n = 81)†	5 (6.2)
SDH (n = 81)‡	5 (6.2)
EAH (NOS) (n = 91)§	15 (16.5)
EDH (n = 80)¶	4 (5.0)
Multiple ICHs (n = 81)**	5 (6.2)

* Values are presented as the number of patients (%) unless otherwise indicated. Percentages may not add up to 100% due to rounding.

†, ‡, §, ¶, ** Categories are mutually exclusive.

and 37.3%, respectively). Males and females were equally represented (50.9% and 49.1%, respectively). Most of the children in the study were born at term. Of the 82 children with gestational age documented in the medical record, only 14.9% were born before 37 weeks' gestation. The average age of the premature subjects (n = 13) was 34.3 weeks. Only 1 child was born prior to 32 weeks' gestation. More than half of the patients were privately insured. Of the 110 eligible children, 34 (30.9%) had ICH. ICH types included about equal numbers of SAH/SPH, SDH, and EDH. Almost half (15) had EAH (NOS) (16.5%), and 5 children (6.2%) had more than 1 type of ICH. Skull fractures were very common in our sample (85/110, 77.3%; Table 1).

The overall mean EAS measurement was 2.9 mm (me-

dian 2.6 mm; Table 1). Twenty-three participants in the sample (20.9%) had an EAS size greater than 4 mm. The qualitative assessment determined that most of the sample (70/110) did not have any enlargement of the EAS (63.6%), while 20 (18.2%) had borderline enlargement, 13 (11.8%) had mild enlargement, and 7 (6.4%) had moderate enlargement. No children had severe enlargement (Table 1). There was no association between age and EAS size. There was a positive, significant association between preterm birth and enlarged EAS in the sample—31% of preterm births had enlarged EAS versus 15% who were not preterm births.

EAS qualitative estimates made by 2 neuroradiologists (EAS₁ and EAS₂) were positively correlated with the EAS quantitative measurements. The interrater reliability for the 2 neuroradiologists was found to be $\kappa = 0.46$ ($p < 0.001$), which indicates moderate agreement.

Thirty-seven children in the sample (33.6%) had an HC measurement documented. The mean HC percentile was 53rd percentile and the median was 63rd percentile. This was similar to the weight percentiles (mean 54th and median 57th percentiles) in our population. There was poor agreement between clinically measured and radiographically calculated head circumferences, so only clinically measured HCs were used.

The mean EAS was significantly larger in those with SAH/SPH (5.4 mm vs 2.6 mm, $p < 0.001$) and those with multiple hemorrhages (4.1 mm vs 2.6 mm, $p < 0.05$). The mean EAS was also significantly higher in those with ICH overall (all ICH types combined [3.6 mm vs 2.6 mm, $p < 0.05$]). There was no association between increased EAS and SDH, EAH (NOS), or EDH (Table 2). There was no difference in the rate of ICH in children who fell less than 3 feet versus 3–6 feet. Although the number of patients became very small, fall height also did not change the outcomes. Both SAH/SPH and multiple hemorrhages remained associated with enlarged EAS. Increased EAS was positively associated with larger clinically measured HC percentile ($r = 0.44$, $p < 0.01$). However, clinically measured HC alone was not associated with increased EAS ($r = 0.16$, $p \geq 0.05$).

Discussion

Although some studies have suggested that an enlarged SAS predisposes an infant to develop SDH after minor head trauma, this study found no such association. We did find that increased SAS size was associated with ICH (overall), more specifically SAH/SPH and multiple ICHs. Macrocrania alone was not associated with an increased incidence of ICH, a finding that is supported by the literature.²⁶

Overall, our population had a higher incidence of ICH and skull fractures than described in other studies of falls from a lower height.^{14,22,27} This is not unexpected since we identified subjects primarily through the child abuse team consult database, with supplemental cases identified through billing codes focused on head injuries with falls. While the hospital protocol requires all children younger than 2 years with head injury to undergo a child abuse team consult, our methods would not be expected to capture all children who presented to our institution after a

TABLE 2. EAS size and ICH

ICH Type	Mean EAS, mm (SD)	% EAS >4 mm
SAH/SPH (n = 81)		
Yes	5.4 (0.8)*	100*
No	2.6 (1.5)	13.2
SDH (n = 81)		
Yes	2.7 (1.1)	0.0
No	2.6 (1.5)	13.2
EAH (NOS) (n = 91)		
Yes	3.3 (2.2)	20.0
No	2.6 (1.5)	13.2
EDH (n = 80)		
Yes	2.8 (2.1)	25.0
No	2.6 (1.5)	13.2
Multiple ICHs (n = 81)		
Yes	4.1 (1.2)†	80.0†
No	2.6 (1.5)	13.2
All ICH Types (n = 110)		
Yes	3.6 (1.9)†	38.2†
No	2.6 (1.5)	13.2

* $p < 0.001$.

† $p < 0.05$.

short fall and underwent neuroimaging but did not have an identified head injury.

While a portion of our sample had large HCs, the majority of our sample consisted of children with average HCs. Similarly, most did not have BEH, when using the definition of EAS greater than 4 mm. However, the number of children who did have EAS greater than 4 mm (21%) was somewhat higher than expected. This suggests that either the condition is quite common or a higher cutoff in defining BEH may be justified.

Another limitation of the study is its retrospective design, which relied on information documented in the medical record. In addition, caregivers may have provided vague or false details about the trauma. It is possible that some children with inflicted injuries may have been unintentionally included in this study, and some children with accidental injuries may have been wrongly excluded. This concern is somewhat mitigated by our institution's protocol mandating thorough social work assessments and child abuse pediatrician consults on children younger than 2 years with head injuries. In addition, variations in the degree of angulation of the CT scans potentially impacted measurements of SAS, although this limitation was minimized by only including children who had CT scans that were determined by a neuroradiologist to be of sufficient quality for interpretation. The size of our study population is another limitation. While there were 110 children in the study, the numbers in the ICH subgroups were small.

While this study represents an important first step in evaluating the relationship between SAS size and SDH in the setting of accidental falls from a low height, larger prospective studies are needed. There is also a need to study children with markedly enlarged SAS to determine whether our results are replicated in this population.

Conclusions

Large SAS size was not associated with SDH, but it was associated with SAH/SPH after trauma. While children with larger SASs tended to have larger heads, increased HC was not independently associated with an increase in SAH/SPH. Our findings do not support the hypothesis that BEH predisposes children to SDH following minor accidental trauma, although the condition may predispose to SAH/SPH.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: all authors. Acquisition of data: Fingarson, Ryan, Bregman. Analysis and interpretation of data: Ryan, McLone, Flaherty. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: Fingarson. Approved the final version of the manuscript on behalf of all authors: Fingarson. Statistical analysis: McLone.

Correspondence

Amanda Fingarson, Department of Pediatrics, Division of Child Abuse Pediatrics, Ann and Robert H. Lurie Children’s Hospital of Chicago, 225 E Chicago Ave., Box 16, Chicago, IL 60611. email: afingarson@luriechildrens.org.