Received:
18 November 2019

Revised:
14 May 2020

Accepted:
27 July 2020

<https://doi.org/10.1259/bjr.20190968>

Cite this article as:

Call L, Qiu Q, Morris J, Flaherty B, Vavilala MS, Mills B, et al. Characteristics of pediatric patients with traumatic epidural hematomas who can be safely observed: a clinical validation study. *Br J Radiol* 2020; **93**: 20190968.

FULL PAPER

Characteristics of pediatric patients with traumatic epidural hematomas who can be safely observed: a clinical validation study

¹LINDSAY CALL, ²QIAN QIU, ³JEFFREY MORRIS, MD, ⁴BRIAN FLAHERTY, MD, ⁵MONICA S. VAVILALA, MD, ²BRIANNA MILLS, PhD, ⁴SUSAN BRATTON, MD and ³MAHMUD MOSSA-BASHA, MD

¹Amherst College, 220 South Pleasant Street, Amherst, MA 01002

²Harborview Injury Prevention Research Center, 401 Broadway St, Seattle, WA 98104, United States

³Department of Radiology, University of Washington, 1959 NE Pacific St, Seattle, WA 98195, United States

⁴Department of Pediatrics, University of Utah, 100 N Mario Capecchi Drive, Salt Lake City, UT 84113, United States

⁵Department of Anesthesia, Harborview Medical Center, 325 9th Ave, Seattle, WA 98104, United States

Address correspondence to: Dr Mahmud Mossa-Basha

E-mail: mmossab@uw.edu

Objective: The study aimed to validate admission clinical and radiographic features of pediatric patients with traumatic epidural hematoma (EDH) that lead to safe observation.

Methods: A Level I trauma center radiology and electronic medical record databases were retrospectively queried for pediatric patients with EDH on CT scan between 1/1/2016 and 10/1/2016. Patient imaging, treatment and outcome variables were abstracted. Characteristics of the cohort were compared to an external cohort used to develop prediction rules for surgical intervention. External validity of the prediction rules was assessed.

Results: 195 eligible subjects were included in the study, 37 of which failed observation and required surgery while 158 underwent successful observation. The surgical cohort had significantly thicker ($p < .001$) and higher volume ($p < .001$) EDH, increased midline shift ($p < .001$) and higher likelihood of mass effect ($p < .001$). There was significantly higher residual neurologic deficit

rate (54% vs 23%, $p < .001$) and hospital mortality (5% vs 0%, $p = .035$) amongst the surgical group. There were significant differences in patient demographic, clinical and imaging characteristics between the internal and external cohorts. The predictive rules externally developed yielded positive predictive value of 97.7% (95% CI = 93.3–99.5%), negative predictive value of 24.5% (95% CI = 16.2–34.4%), specificity of 88.5% (95% CI = 69.9–97.6%), and sensitivity of 63.8% (95% CI = 56.6–70.5%) for successful observation.

Conclusion: The current study validates previously developed prediction rules for safe observation of pediatric EDH in a cohort with distinct characteristics from the external cohort. Specifically, patients with no mass effect, EDH volume <15 ml and no neurological deficits are less likely to fail observation.

Advances in knowledge: The current study validates prediction rules for safe observation of pediatric EDH in a distinct pediatric cohort that provides further support to conservative management in these circumstances.

INTRODUCTION

Traumatic brain injury (TBI) is an often-devastating injury and a leading cause of mortality among children, with nearly 3000 deaths per year in the United States.¹ Epidural hematoma (EDH) is a serious complication that arises in approximately 3% of TBI cases.² Historically, EDH has been emergently treated with surgical evacuation because only large, symptomatic EDH were detected due to lack of cross-sectional imaging access. The increased access to and reliance on CT imaging in the emergency department, however, has led to increased detection of small EDH presenting with mild or no symptoms that may not

require surgical evacuation. Given the increased detection of these smaller EDH,^{3,4} a change in management may be warranted. As research surrounding the use of CT scans to diagnose EDH continues to grow, some adult and pediatric TBI studies indicate that some patients with EDH can be treated conservatively with favorable outcomes.^{2,5,6}

In recent years, observation has become the preferred method of initial treatment, as it results in shorter hospital stays, avoids surgery when unnecessary and is generally less expensive.⁷ In some cases, patients will fail observational management due to worsening condition or hematoma

growth and require surgical evacuation. However, it is often difficult to prospectively determine whether observation will suffice. Adult guidelines have been developed to aid decisions regarding whether a patient can be safely observed in response to this issue, and previous research among pediatric patients sustaining EDH has aimed to identify clinical and radiological factors that could predict whether patients could be safely observed.^{5,8} The existing literature is limited due to a small number of studies with small sample sizes. The goal of this study is to validate pediatric EDH prediction rules developed in a prior study² indicating that the absence of mass effect and neurologic deficits and EDH volume <15 ml predict high likelihood of successful observation.

METHODS AND MATERIALS

Patient population

The study was approved by the University of Washington and the University of Utah Institutional Review Boards. The radiology database at Harborview Medical Center (HMC) was queried to identify a study cohort. HMC is a Level I trauma center serving a 5-state region (Washington, Wyoming, Idaho, Alaska and Montana). HMC's radiology database was reviewed for patients seen between the dates of January 1, 2016 and September 30, 2016. Inclusion criteria were: 1) pediatric patients between the ages of 0–18; 2) EDH documented on CT head without contrast; and 3) patients were initially treated at our Level I trauma center and admitted to the intensive care unit. Patients were excluded if: 1) no initial CT head scan was available, 2) immediate surgical drainage was undertaken for treatment of EDH or other cranial injuries, 3) there was lack of consensus between the neurosurgery and radiology evaluators as to whether the hematoma was located in the epidural space, or 4) the patient was determined to have non-accidental trauma.

Patients who underwent observation and did not require surgical intervention for treatment of their EDH were defined as the “observational” group. Patients who underwent surgical evacuation of EDH following failed observation were defined as the “surgical” group.

Data collection

Patient demographic data were abstracted from the electronic medical record. Hematoma characteristics were extracted for each patient from the initial non-contrast CT head study performed post-injury, specifically hematoma maximum width (mm) and ellipsoid volume (mm) calculated as $4/3 \times \pi \times \text{length}/2 \times \text{width}/2 \times \text{height}/2$, presence of qualitative mass effect, and the degree of midline shift (mm) measured at the level of the septum pellucidum. Patient medical records were surveyed for injury mechanism, Glasgow Coma Scale score (GCS) upon initial evaluation and at discharge, neurological deficits presented during observation (seizures, decreased level of consciousness non-attributable to medication or other injuries, motor or sensory deficits, cranial nerve dysfunction, language deficits or pupillary dysfunction), death, and residual neurologic deficits at discharge (similar to the above group). For surgical patients, the indication for undergoing surgery was extracted from the neurosurgery operative note. Additionally, Injury Severity Score (ISS) was abstracted from

descriptions of patient's full registry of injuries at the time of admittance and the time from injury to initial evaluation was estimated given data provided in the patient's medical charts surrounding mode of transportation.

Statistical analysis

Patient demographic and clinical characteristics were compared between the observation-only group and the surgery group from HMC, within the “validation” cohort. Demographic and clinical characteristics from the validation cohort were also compared to the University of Utah (UU) “development” cohort.² Continuous data were presented as median and interquartile range (IQR). Categorical data were reported as count and percentage. To determine if comparisons were statistically significant, Wilcoxon rank-sum test was used for continuous data, while χ^2 /Fisher's exact test was used for categorical data. Prediction rules developed for patients with EDH at low risk for failing observation² were applied to the validation cohort. To validate the prediction rules, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated and compared with those reported in the Flaherty et al manuscript.² Our analysis was set-up to identify patients who could be safely observed. Therefore, a true positive is a patient predicted to be safely observed and who was observed; a false positive is someone who was predicted to be safely observed, but had surgery; a true negative is someone predicted to need surgery and did have surgery; and a false negative is someone who was predicted to need surgery, but did not have surgery. All statistical analyses were conducted using Stata 14 software (StataCorp LP, College Station, TX).

RESULTS

Patient population

A total of 195 subjects with EDH were included, of whom 37 failed observation and underwent surgical decompression; the remaining 158 subjects did not undergo surgery. Patient demographic data are described in Table 1. There was no significant difference between observational and surgical subjects in patient age, gender, time to initial presentation and mechanism of injury, respectively. There was a significant difference in ISS between the two groups (observational-median 6, IQR 6–11; surgery-median 11, IQR 6–24; $p < 0.001$), however, indicating more severe total injuries in patients undergoing surgery for EDH. In 92% (34/37) of failed observation subjects, there was hematoma growth, while 32% (12/37) showed reduced level of consciousness and decreased responsiveness, 8% (3/37) had progressive headaches, 8% (3/37) had fixed pupils, and 5% (2/37) had evidence of increased intracranial pressure. 43% (16/37) showed two or more of the above. Mean time from admission to surgery was 1.3 days $\pm$ 0.72.

Clinical characteristics

Clinical presentation characteristics are summarized in Table 2. There were significant differences in initial GCS (observational-median 15, IQR 14–15; surgical-median 10, IQR 6–15; $p < 0.001$) and presence of neurological deficits (observational-49%, surgical-86%; $p < 0.001$) between observational and surgical groups.

Table 1. Patient demographics

Characteristics	Observational N = 158	Surgical N = 37	p-value
Demographic			
Age in year, median (IQR)	12 (4, 15)	13 (7, 15)	0.2066
Male, n (%)	105 (66)	28 (76)	0.278
ISS, median (IQR)	6 (6, 11)	11 (6, 24)	<0.001
Time to presentation in hours, median (IQR) ^a	7.5 (4, 24)	5 (4.5, 7)	0.4144
Injury mechanism, n (%)			0.356
Fall	49 (31.0)	10 (27.0)	
Bicycle fall	7 (4.4)	0	
Bicycle vs MV	7 (4.4)	0	
MV accident	55 (34.8)	18 (48.7)	
Sports-related	26 (16.5)	4 (10.8)	
Assault	3 (1.9)	0	
Other	11 (7.0)	5 (13.5)	

GCS, Glasgow Coma Scale; IQR, interquartile range; ISS, Injury Severity Score; MV, motor vehicle.

Continuous data are presented as medians (25th –75th percentile) and categorical data are indicated as totals (percentages).

Mann-Whitney *U* test used for continuous data; χ^2 or Fisher's exact test used for categorical data.

a. 145 (74%) cases with missing transfer time from scene to hospital.

b. 9 (5%) cases with missing GCS at admission and at discharge.

c. 1 (0.5%) cases with missing Midline shift.

Radiographic characteristics

Table 2 summarizes the imaging characteristics. There was a significant difference in EDH thickness (observational-median 0.7 cm, IQR 0.4–1; surgical-median 1.3 cm, IQR 1–1.7; $p < 0.001$) and volume (observational-median 2.7 cm³, IQR 0.7–8.1;

surgical-median 19.4 cm³, IQR 9.5–35.8; $p < 0.001$), the qualitative presence of mass effect (observational 39% vs surgical 92%; $p < 0.001$), and the degree of midline shift (observational-median 0, IQR 0–0; surgical-median 0.3 cm, IQR 0–0.5; $p < 0.001$) between observational and surgical groups, respectively.

Table 2. Clinical and imaging presentation

Characteristics	Observational N = 158	Operational N = 37	p-value
Clinical symptoms			
Initial GCS, median (IQR) ^a	15 (14, 15)	10 (6, 15)	<0.001
Neurologic deficit, n (%)	78 (49)	32 (86)	<0.001
CT findings			
EDH thickness, median (IQR)	0.7 (0.4, 1)	1.3 (1, 1.7)	<0.001
EDH Volume in mL, median (IQR)	2.7 (0.7, 8.1)	19.4 (9.5, 35.8)	<0.001
Presence of mass effect, n (%)	62 (39)	34 (92)	<0.001
Midline shift in mm, median (IQR) ^b	0 (0, 0)	0.3 (0, 0.5)	<0.001
Outcomes			
GCS at discharge, median (IQR) ^b	15 (15, 15)	15 (15, 15)	0.5051
Residual neurologic deficit, n (%)	36 (23)	20 (54)	<0.001
Death, n (%)	0	2 (5)	0.035

EDH, epidural hematoma; GCS, Glasgow Coma Scale; IQR, interquartile range.

Continuous data are presented as medians (25th –75th percentile) and categorical data are indicated as totals (percentages).

Mann-Whitney *U* test used for continuous data; χ^2 or Fisher's exact test used for categorical data.

a. 9 (5%) cases with missing GCS at admission and at discharge.

b. 1 (0.5%) cases with missing Midline shift.

Figure 1. Validation of prediction rules for EDH patients at low risk for failing observation. EDH, epidural hematoma.

Validation of prediction rules for patients at low risk for failing observation

Figure 1 summarizes the validation of prediction rules developed by Flaherty et al² using the validation cohort from HMC, which yielded a positive predictive value of 100% (95% CI = 92.1–100%), negative predictive value of 24.7% (95% CI = 18–32.4%), specificity of 100% (95% CI = 90.5–100%), and a sensitivity of 28.5% (95% CI = 21.6–36.2%).

Outcomes

There was no significant difference in GCS at discharge between the observational and surgical groups (Table 2). There were significantly more subjects with residual neurological deficits (54% vs 23%, $p < 0.001$), and a higher mortality rate (5% vs 0%, $p = 0.035$) in the surgical group.

Demographic and characteristics comparison

Table 3 summarizes demographic comparisons between the current pediatric patient population (“validation” cohort) and that of Flaherty et al (“development” cohort).² There were significant differences in patient age ($p < .001$), gender ($p < .01$), ISS, initial GCS ($p < .001$), neurologic deficits ($p < .001$), EDH thickness ($p < .001$) and volume ($p = .002$), presence of mass effect ($p < .001$) and residual neurologic deficits ($p < .001$). Time to presentation, degree of midline shift and death rate were not significantly different between the two cohorts.

DISCUSSION

The objective of the study was to validate pediatric EDH prediction rules developed in a prior study,² indicating that the absence of mass effect and neurologic deficits and EDH volume <15 ml predict high likelihood of successful observation.

Table 3. Comparison between validation and development groups

Characteristics	Validation N = 195	Development N = 222	p-value
Demographics			
Age in year, median (IQR)	12 (5, 15)	6 (3, 10)	<0.001
Male, n (%)	133 (68.2)	124 (55.9)	0.0097
ISS, median (IQR)	6 (6, 11)	16 (9, 17)	<0.001
Time to presentation in hours, median (IQR)	6.5 (4, 24)	5.5 (2.7, 19.8)	0.36
Clinical symptoms			
Initial GCS, median (IQR)	15 (11, 15)	15 (15, 15)	<0.001
Neurologic deficit, n (%)	85 (43.6)	32 (14.4)	<0.001
CT findings			
EDH thickness, median (IQR)	0.8 (0.5, 1.1)	6 (4.2, 9.2)	<0.001
EDH volume in mL, median (IQR)	3.8 (0.9, 11.8)	2.3 (0.8, 7.2)	0.006
Presence of mass effect, n (%)	96 (49.2)	67 (30.0)	<0.001
Midline shift in mm, median (IQR)	0 (0, 0)	0 (0, 0)	0.19
Outcomes			
Residual neurologic deficit, n (%)	56 (28.7)	6 (2.7)	<0.001
Death, n (%)	2 (1.0)	1 (0.0)	0.6006

EDH, epidural hematoma; IQR, interquartile range; ISS, Injury Severity Score.

Continuous data are presented as medians (25th –75th percentile) and categorical data are indicated as totals (percentages).

Mann-Whitney *U* test used for continuous data; χ^2 or Fisher's exact test used for categorical data.

Predictive tools may allow clinicians to determine which patients may require surgery earlier, potentially improving patient outcomes, while also potentially avoiding unnecessary surgeries in those that can be successfully observed.

Flaherty et al² reviewed 222 pediatric patients with EDH who were initially observed and divided them into those that failed or underwent successful observation. 26 (11.7%) failed observation, and were found to be 20-fold more likely to present with altered mental status, have significantly larger median bleed thickness and median bleed volume, and have mass effect. A lack of mass effect, EDH volume <15 ml, and no neurologic deficits predicted patients at low risk of failure of observation with a positive predictive value of 98% (95% CI 93–99%). Our findings are in agreement, showing similar significant differences between observational and failed observational cohorts in the presence of mass effect, midline shift and neurologic deficits, EDH volume, and hematoma thickness.

When comparing data between the two cohorts (internal validation cohort and external development cohort) (Table 3), there were significant differences in patient age, gender, ISS, median initial GCS, percentage with initial and residual neurologic deficits, EDH thickness and volume and the presence of mass effect. These differences in patient population characteristics indicate that our population had larger EDH with higher corresponding deficits, though milder overall injury scores. Despite these differences in these unique populations, the significant results and associations were very similar,

suggesting that these results are more likely to be generalizable to other pediatric populations presenting with EDH. The externally developed prediction rules proved very sensitive and moderately specific for safe observation for the internal validation cohort.

A few studies have shown the potential benefits of observation of pediatric EDH patients in certain circumstances. A case series of 11 pediatric patients who underwent observational management of EDH indicated successful observation of 9 of 11 cases.⁶ Binder et al⁹ retrospectively reviewed 41 pediatric patients with EDH, 31 of which started with observation. 11 of the observational management cases subsequently required delayed surgical intervention. There was a significantly lower rate of somnolence or coma in the successfully observed group (30%) as compared to the delayed surgery (92%) and immediate surgery (100%), $p < .001$. 17 (85%) of the observational group had good outcomes, while 2 (10%) had moderate disability and 1 patient died. Khan et al⁵ retrospectively evaluated 17 pediatric patients with EDH >1 cm in thickness who were observed, and found 15 patients were successfully managed observationally while 2 patients required hematoma evacuation due to neurological worsening. All patients had good outcomes with Glasgow outcome scale scores of 5 at 1 year follow-up. These studies show the feasibility and efficacy of observation of EDH in small patient cohorts.

Validation of imaging and patient characteristics that predict successful conservative management has a number of

potential benefits. With established markers, less reliance of sequential imaging follow-up and reduced radiation exposure can be pursued. Shorter monitoring and reduced imaging will also lead to reduced costs. With established markers of failed observation of EDH, intervention decision-making can be implemented earlier, which could potentially lead to better patient outcomes, though further investigation is necessary.

Our study is limited by its nature as a retrospective study. Additionally, this is a single-center study, which may introduce geographic bias. The current study is predictive but not explanatory. The presence of additional non-cerebral injuries in the case of each patient also has the potential to confound our results. However, considering that the results are similar to prior studies despite differences in patient, clinical and imaging characteristics makes it more likely that these results are generalizable. This study addresses only patients who are

initially treated with conservative management, and does not address nor predict outcomes for patients requiring emergent surgical intervention.

CONCLUSION

Our results validate previous reports that indicate significant differences in initial GCS, initial and residual neurologic deficit, EDH thickness and volume, midline shift, and presence of mass effect exist between patients who are successfully observed and patients who require surgical intervention. These characteristics can potentially predict pediatric EDH patients that are more likely to have successful observation as opposed to those that may require earlier surgical intervention. By analyzing these characteristics in patients presenting with EDH, more appropriate patient management can be pursued earlier, potentially allowing for improved patient outcomes.

REFERENCES

1. Masoumi B, Heydari F, Hatamabadi H, Azizkhani R, Yoosefian Z, Zamani M. The relationship between risk factors of head trauma with CT scan findings in children with minor head trauma admitted to hospital. *Open Access Maced J Med Sci* 2017; **5**: 319–23. doi: <https://doi.org/10.3889/oamjms.2017.071>
2. Flaherty BF, Moore HE, Riva-Cambrin J, Bratton SL. Pediatric patients with traumatic epidural hematoma at low risk for deterioration and need for surgical treatment. *J Pediatr Surg* 2017; **52**: 334–9. doi: <https://doi.org/10.1016/j.jpedsurg.2016.09.005>
3. Kuppermann N, Holmes JF, Dayan PS, Hoyle JD, Atabaki SM, Holubkov R, et al. Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet* 2009; **374**: 1160–70. doi: [https://doi.org/10.1016/S0140-6736\(09\)61558-0](https://doi.org/10.1016/S0140-6736(09)61558-0)
4. Osmond MH, Klassen TP, Wells GA, Correll R, Jarvis A, Joubert G, et al. Catch: a clinical decision rule for the use of computed tomography in children with minor head injury. *CMAJ* 2010; **182**: 341–8. doi: <https://doi.org/10.1503/cmaj.091421>
5. Khan MB, Riaz M, Javed G. Conservative management of significant supratentorial epidural hematomas in pediatric patients. *Childs Nerv Syst* 2014; **30**: 1249–53. doi: <https://doi.org/10.1007/s00381-014-2391-x>
6. Pang D, Horton JA, Herron JM, Wilberger JE, Vries JK. Nonsurgical management of extradural hematomas in children. *J Neurosurg* 1983; **59**: 958–71. doi: <https://doi.org/10.3171/jns.1983.59.6.0958>
7. Tallapragada K, Peddada RS, Dexter M. Paediatric mild head injury: is routine admission to a tertiary trauma Hospital necessary? *ANZ J Surg* 2018; **88**: 202–6. doi: <https://doi.org/10.1111/ans.14175>
8. Paiva WS, Andrade AFde, Mathias Júnior L, Guirado VMdeP, Amorim RL, Magrini NN, et al. Management of supratentorial epidural hematoma in children: report on 49 patients. *Arq Neuropsiquiatr* 2010; **68**: 888–92. doi: <https://doi.org/10.1590/S0004-282X2010000600011>
9. Binder H, Majdan M, Tiefenboeck TM, Fochtmann A, Michel M, Hajdu S, et al. Management and outcome of traumatic epidural hematoma in 41 infants and children from a single center. *Orthop Traumatol Surg Res* 2016; **102**: 769–74. doi: <https://doi.org/10.1016/j.otsr.2016.06.003>