



Role of follow-up CT scans in the management of traumatic pediatric epidural hematomas

D. Clay Samples¹ · Michael T. Bounajem² · David J. Wallace¹ · Lillian Liao³ · Izabela Tarasiewicz¹

Received: 5 March 2019 / Accepted: 27 May 2019 / Published online: 8 June 2019
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

Abstract

Introduction Management of pediatric epidural hematoma (PEDH) ranges from observation to emergent craniotomy. Guidelines for management remain poorly defined. More so, serial CT imaging in the pediatric population is often an area of controversy given the concern for excessive radiation as well as increased costs. This work aims to further elucidate the need for serial imaging to surgical decision-making.

Methods A prospectively maintained single-institution trauma database was reviewed at a level-1 trauma center to identify patients 18 years old and younger presenting with PEDH over a 10-year period. Selected charts were reviewed for demographic information, mechanisms of injury, neurologic exam, radiographic findings, and treatment course. Surgical decisions were at the discretion of the neurosurgeon on call, often in discussion with a pediatric neurosurgeon.

Results Two hundred and ten records with traumatic epidural hematomas were reviewed. Seventy-three (35%) were taken emergently for hematoma evacuation. Of these, 18 (25%) underwent repeat imaging prior to surgery. One hundred and thirty-seven (65%) were admitted for observation. Seventy-two patients (53%) did not undergo repeat imaging. Sixty-five (47%) admitted for conservative management had at least one repeat scan during their hospitalization. Indications for follow-up imaging during conservative management included routine follow-up (74%), initial scan in our system following transfer (17%), neurological decline (8%), and unknown (1%). Thirteen patients (9%) were taken for surgery in a delayed fashion following admission. Twelve patients who went to surgery in a delayed fashion demonstrated progression on follow-up imaging; however, increase in hematoma size on repeat imaging was the sole surgical indication in only four patients (3%). There were no deaths related to the epidural hemorrhage or postoperatively, regardless of management, and all patients recovered to their pre-trauma baseline.

Conclusion Given that isolated hematoma expansion accounted for an exceptionally small proportion of operative indications, this data suggests changes seen on CT should not be solely relied upon to dictate surgical management. The benefit of obtaining follow-up imaging must be strongly considered and weighed against the known deleterious effects of excessive radiation in pediatric patients, let alone its clinical utility.

Keywords TBI · Follow-up imaging · EDH

✉ Michael T. Bounajem
bounajem@livemail.uthscsa.edu

¹ Department of Neurosurgery, University of Texas Health - San Antonio, San Antonio, TX, USA

² Long School of Medicine, University of Texas Health - San Antonio, San Antonio, TX, USA

³ Division of Trauma and Emergency Surgery, Department of Surgery, University of Texas Health - San Antonio, San Antonio, TX, USA

Introduction

Traumatic brain injury (TBI) is the leading cause of death in children worldwide. Epidural hematoma (EDH) is a well-known complication of pediatric head injury, occurring in up to 6% of patients [1–4]. Classic neurosurgical teaching compels that EDH must be promptly evacuated [3, 5, 6]. Prior to the advent of CT imaging, diagnosis of EDH required invasive procedures (angiography, exploratory burr holes, pneumoencephalography, etc....) and there was reluctance to perform these tests on

minimally symptomatic patients. As such, much of the literature supported emergent craniotomy given that documented patients had neurological deficits/deterioration [7]. Alternatively, the ubiquitous nature of CT scans has resulted in diagnosis and treatment of lesions in otherwise asymptomatic patients, with surgical rates ranging from 38 to 100% [1, 8].

Currently, there exist surgical guidelines for EDH management in adults to include GCS, EDH thickness and volume, and degree of midline shift (MLS) [1]. Despite a growing body of literature regarding the topic, many with successful conservative observation of these patients, a pediatric correlate has yet to be established [1–3, 7, 9–18]. Furthermore, based on pathophysiologic differences between adult and pediatric patients, management of EDH in the latter may differ notably from the former [16, 17]. Given this, clinical practice remains highly variable and there is little consistency between agreed upon risk factors predictive of surgery. A few centers have attempted to produce specific clinical guidelines; however, the literature remains scant, being primarily composed of small, retrospective works [2, 3, 10–12, 19, 20].

Computed tomography is invaluable in the diagnosis of traumatic EDH, and support for such imaging can be found within decision-making tools used nationally [21–23]. However, there exists no consensus regarding acquisition of repeat imaging in pediatric trauma patients. Much of the work supporting conservative management describes obtaining follow-up imaging [7, 9, 11–13, 17, 20, 24, 25]. Serial CT imaging in this population is often an area of controversy given the concern for excessive radiation as well as increased costs. The most recent pediatric TBI guidelines quote a lifetime risk of fatal cancer from one head CT in a 1-year-old to be as high as 1 in 1500 [26]. Furthermore, despite repeat imaging rates up to nearly 90%, literature has demonstrated that this practice often has very little clinical value in the setting of acute EDH [2, 3, 14, 25, 27–29]. The rates of change in management following repeat imaging in the setting of pediatric head trauma are low (<10%). However, variability in this number across the literature further highlights the lack of consistent management [1, 2, 24, 28]. What continues to be emphasized is the role of clinical risk factors, particularly changes in neurological status [2, 14, 16, 17, 24, 26]. The work that follows aims to help optimize treatment of pediatric trauma patients to further elucidate the clinical role of CT imaging in the management of traumatic epidural hematomas via review of the literature as well as a large pediatric trauma database from a single institution.

Methods

We identified a retrospective cohort of all pediatric patients who were treated for traumatic EDH between January 2006 and July 2017 at our University Hospital (UH), a level I

pediatric trauma center, in San Antonio, Texas. Approval was obtained through the Institutional Review Board of our institution. Subjects' age 0 to 18 years with a diagnosis of intracranial epidural hematoma were included. Patients transferred from outside facilities with imaging were included, as they were transferred with imaging or underwent CT imaging at our institution. Subjects were excluded if they did not carry a diagnosis of traumatic EDH confirmed on CT scan. Clinical data was obtained from a prospectively maintained single-institution trauma database. Selected charts were reviewed for demographic information, mechanisms of injury, neurologic exam, radiographic findings, and treatment course. Neurosurgical and trauma documentation was reviewed for age, ethnicity, mechanism of injury, presenting Glasgow Coma Scale (GCS), neurological findings, fontanelle status (if appropriate), time to surgery, and type of surgery (craniotomy vs. craniectomy). Possible mechanisms of injury include assault, domestic fall (less than 10 ft), fall from height (greater than 10 ft), motor vehicle accident, non-vehicle road accident (i.e., motor vehicle vs. pedestrian, cycling accident), and sports-related injury. Neurological findings recorded included the presence of a lucid interval, dilated pupils, focal neurological deficits, and a decline in GCS. Data extraction was obtained by three of the authors (DCS, MTB, DJW). Imaging on arrival was reviewed for location of hematoma, venous sinus involvement, presence and type of skull fracture, and concurrent intracranial injury (i.e., SAH, SDH, ICH). Measured variables included hematoma thickness (in the axial, sagittal, and coronal planes), hematoma volume using the ABC/2 formula, the amount of midline shift, and biparietal skull diameter. The acquisition of the follow-up CTs in conservatively managed patients was noted and examined for change in hematoma thickness. Imaging was reviewed by board-certified radiologists and/or neuroradiologists and measurements obtained by author MTB. Surgical decisions were at the discretion of the neurosurgeon on call, often in discussion with a pediatric neurosurgeon. Outcomes were evaluated on the basis of documentation on subsequent clinical follow-up visits with the neurosurgery team.

Results

Two hundred and ten patients presented to UH with traumatic epidural hematomas on imaging. Seventy-three (35%) were taken emergently for hematoma evacuation. Of these, 18 (25%) underwent repeat imaging prior to surgery. One hundred and thirty-seven (65%) were admitted for observation. This includes 72 patients (53%) that did not undergo repeat imaging. Sixty-five (47%) admitted for conservative management had at least one repeat scan during their hospitalization. Indications for follow-up imaging for immediately operative patients include initial scan in our system following transfer

(83%) and neurological decline (17%). Indications for follow-up imaging during conservative management included routine follow-up (74%), initial scan in our system following transfer (17%), neurological decline (8%), and unknown (1%). An MRI was obtained as follow-up imaging in 11 patients (14%) admitted for conservative management, with eight (10%) of these being the initial follow-up.

Thirteen (6%) were taken for surgery in a delayed fashion following admission. Indications for repeat imaging in these patients include an initial scan in our institution following transfer (33%), neurological decline (33%), routine follow-up (25%), and having an unreliable clinical exam to follow (9%). The most common indication for delayed surgical evacuation was a decline in neurological exam with or without progression on imaging. Other indications included EDH size, the presence of a focal neurological deficit, and progression on repeat CT. Twenty-five patients (35%) demonstrated hemorrhage progression on repeat imaging. Twelve patients who went to surgery in a delayed fashion demonstrated progression on follow-up imaging; however, increase in hematoma size on repeat imaging was the sole surgical indication in only four patients. The indication for follow-up scans in these four patients was routine follow-up (75%) or neurological decline (25%). Demographics for patients demonstrating progression can be found in Table 1.

As a result of their cranial injury, the mortality rate in patients found to have progression was 0%, regardless of management. Follow-up for this group ranged from 2 weeks to 18 months. All patients recovered fully to their pre-trauma neurological status. For the remainder of the cohort for which follow-up was available, there were no deaths related to their extra-axial hemorrhage or postoperatively, and recovery to their pre-trauma baseline was observed where follow-up was available. Overall, conservative management was successful in 91% of patients.

The average size of surgically treated hematomas was significantly larger than that which were conservatively managed by every measurement, including axial thickness, coronal thickness, sagittal thickness, and volume ($p < 0.05$). Average midline shift was also significantly larger in the surgically treated group (4.59 mm vs. 0.87 mm; $p < 0.05$). The cohort that received surgery without repeat imaging also displayed significantly larger hematomas in terms of axial thickness, sagittal thickness, volume, and MLS, but not coronal thickness when compared with those that received repeat imaging before surgery ($p < 0.05$). While there was no pre-determined cutoff above which patients were decidedly operated on, retrospective analysis of the data showed that the largest hematoma that was not evacuated measured 19 mm in axial thickness. Mechanism of trauma was not significantly associated with a particular outcome. CT findings and stratification by age can be found in Tables 2 and 3, respectively.

Discussion

The advent of CT imaging has resulted in over diagnosis of many epidural hematomas that do not require surgical intervention, and would not have been picked up clinically otherwise. While no standardized practice or widely implemented guidelines exist with respect to the management of such, it is common for routine follow-up imaging to be obtained for lesions that are managed non-operatively. Our institution contributes to this trend in that we have no established functional algorithm to guide treatment. Classic teaching emphasizes a need for surgical evacuation of traumatic epidural hematomas in pediatric patients [3, 5, 6]. However, as early as the 1980s, there exists literature that urges consideration of conservative treatment following diagnosis [7]. That being said, the operative rates for pediatric EDH range from 36 to 100% [3, 8, 13, 18, 20, 27]. Ersahin et al. document surgical treatment of every one of the 146 patients in their cohort, a perspective more in line with historical teaching despite citing cases of successful observation [8]. Duthie et al. suggest that clinical presentation may not always be reliable and describe good results with surgical intervention [14]. Unfortunately, as opposed to adult literature, there is a notable paucity of guidelines with respect to traumatic EDH in pediatric patients. Few series over the last couple decades have attempted to define objective indices to triage surgical patients; however, these are not widely utilized or validated [3, 10].

Despite a lack of consensus on significant risk factors to elucidate triage of these patients to surgery versus observation, the implementation of the latter continues to bolster support. High success rates of conservative treatment of pediatric EDH have been published, ranging from 60 to 88% [1, 11, 12, 18, 27]. Successful observation in our study correlates with contemporary literature, being even slightly higher at 91%. Our operative rate is much lower, however, at 29% for immediate surgery with an additional 12% that underwent delayed evacuation. Far beyond the understanding that surgically insignificant lesions are more readily diagnosed in an era of widespread computed tomography, a better comprehension of the pathophysiology of EDH in this population reinforces the need for a different mindset in its management. Aspects such as the safety of delayed surgery, the physiological ability of children to better tolerate these lesions, more thorough understanding of the natural history of EDH, and an absence of long-term functional imaging and neuropsychological changes in non-operative patients further contribute toward a potential paradigm shift in the management of these children [7, 15–18, 27].

Analysis of ways to optimize care with respect to appropriate initial CT imaging in the setting of TBI has been validated throughout the literature and is widely utilized [19, 21, 22]. Alternatively, the vast majority of work describing EDH continues to utilize subsequent imaging for standard management

Table 1 Demographics of patients who demonstrated hemorrhage progression on head CT that were managed conservatively and operatively. MVA, motor vehicle accident

	Conservatively managed	Operations (all indications)	Operative for progression alone
<i>N</i> (male/female)	13 (6/7)	12(9/3)	4(2/2)
Mean age (years)	6.3	6.2	4
Ethnicity			
White, non-Hispanic	2	2	2
Hispanic	10	9	2
Black	1	0	0
Asian	0	1	0
MOI			
Domestic fall	6	4	3
Fall from height	1	0	0
MVA	3	1	0
Non-MVA road accident	3	4	0
Assault	0	0	0
Sport injury	0	2	0
Others	0	1	1
Decline in GCS	1	1	0
Lucid interval	0		0
Dilated pupil	0	2	0
Focal neuro deficit	0	0	0
Location			
Frontal	6	8	2
Temporal	6	6	2
Parietal	7	5	1
Occipital	1	2	0
Infratentorial	0	2	1
Fracture	13	9	3
Concomitant ICH	3	5	2

[7, 9, 12, 13, 16–18, 23, 27]. The utility of serial imaging is often an area of controversy, and yet, still no definitive guidelines have persisted. Specific concerns such as excessive radiation exposure on the developing nervous system as well as financial and logistical costs of repeat computed tomography for pediatric patients must be considered. Various radiographic features such as hemorrhage location, herniation, hemorrhage size, and midline shift have been analyzed and emphasized in attempts to guide operative decision-making [1, 3, 7, 10, 13, 16]. Those closest resembling guidelines are based on level III evidence and recommend that further imaging may not be indicated later than 24 h following admission, and only in the presence of neurological change [26, 30].

The results of the current work support the idea that EDH in pediatric patients can be successfully managed non-operatively, as observed in our high rate of successful observation and lower surgical rate. More specifically, our goal was to lend clarity to the role of subsequent CT imaging following diagnosis, with efforts to highlight the importance of other clinical factors to

guide surgical decision-making. This potentially removes the concept of “routine” follow-up imaging, that is, repeat imaging that is not prompted by clinical change. While the importance of the neurological exam is apparent throughout the literature, as it is mentioned above, the overwhelming majority of work focusing on non-operative management continues to use additional CT scans [7, 16–18, 26, 30]. In our cohort, which is on par with, if not larger than, many series to date, an exceptionally small number of patients (four) underwent surgery for isolated hemorrhage progression on follow-up CT. Furthermore, over half of the children who underwent conservative management did not undergo routine imaging and were successfully managed non-operatively. Both of these points highlight the significance of other factors in addition to, if not aside from, radiographic findings. The authors therefore suggest that the use of follow-up scans in non-operatively managed patients be incumbent upon a change in clinical exam, specifically a decline in neurological status, rather than for exclusively routine purposes. Additionally, the majority of operative patients were

Table 2 CT findings of both operatively and non-operatively managed patients. Divided into groups for which follow-up imaging was obtained and for which no follow-up imaging was obtained

	All	Follow-up imaging	No follow-up imaging
Non-operative			
Axial thickness (mm)	7.67	7.91	7.25
Sagittal thickness (mm)	32.9	33.5	32
Coronal thickness (mm)	35.9	34.8	37.5
Volume (cc)	5.22	5.96	4.34
Midline shift (mm)	0.87	0.88	0.84
Operative			
Axial thickness (mm)	21.9	17.2	23.6
Sagittal thickness (mm)	66.2	57.7	69.5
Coronal thickness (mm)	65.4	59.6	67.6
Volume (cc)	47.2	35.3	51.1
Midline shift (mm)	4.59	2.59	5.33
Craniectomy	6	0	6
Craniotomy	67	18	49

managed as such with only an initial CT scan as guidance. This is in line with other contemporary analyses and is understandable given the general knowledge regarding neurosurgical teaching with respect to EDH [13, 18, 27].

In contrast, with respect to the benefit of repeat imaging, it is well published that additional scans often contribute little in isolation to changes in surgical management [3, 24, 25, 29].

This is supported by our series as well. While changes on repeat imaging in our group served to influence management decisions, our results align with other published data. A recent analysis of 184 pediatric EDH patients by Flaherty et al. attempted to clarify the role of repeat CT scans. For them, repeat imaging was “meaningful” if it was documented to contribute to changing management from conservative to

Table 3 Preoperative data and CT findings in all patients when stratified by age group

	All	Infant (under 12 months old)	Toddler (1–3 years old)	Child (4–12 years old)	Teen (13–18 years old)
<i>N</i>	210	37	53	87	33
Mean age (years)	5.96	0.54	1.92	7.52	14.5
Decline in GCS	15	1	4	8	2
Lucid interval	13	2	5	3	3
Dilated pupil	11	1	7	2	1
Focal neuro deficit	2	0	1	1	0
Concomitant injury					
SDH	14	2	4	5	3
SAH	11	3	3	4	1
IPH	21	4	1	10	6
Thickness (mm)					
Axial	12.7	12.2	14.2	11.3	14.5
Sagittal	44.6	42.1	46.9	43.8	45.6
Coronal	46.3	50.9	45.9	45.1	46.4
MLS (mm)	2.17	2.12	2.91	1.75	2.28
Volume (cc)	23.1	22.9	27.1	15.6	18.6
Craniotomy	67	10	24	23	10
Craniectomy	6	2	0	2	2

GCS, Glasgow Coma Scale; SDH, subdural hematoma; SAH, subarachnoid hemorrhage; IPH, intraparenchymal hemorrhage; MLS, midline shift

operative. However, these scans were not specified as the only reason for the treatment change. They conclude that, while repeat scanning is a common practice for pediatric EDH, it rarely changes management [2]. Some advocate that additional imaging is necessary to monitor for hemorrhage progression as such phenomenon is possible and often discussed, with rates over 40% [25]. Progression was observed in just over a third of patients managed conservatively who underwent repeat imaging, and nearly all of them avoided surgery despite this fact. Other series also demonstrate that progression need not be an absolute indication for surgery or even considered failure of conservative management [7, 25, 28, 31].

While not common, some support additional imaging and more immediate surgical intervention, even in the absence of clinical change, out of a fear that delayed surgery will lead to worse outcomes as well as the possibility that EDH can manifest as a delayed injury [24]. This work, however, included very few EDH patients (< 5%), and of their surgical cases that demonstrated progression on imaging, 75% has accompanying clinical changes. Other literature suggests that outcomes in the setting of delayed surgery remain favorable [2, 11]. More so, as discussed above, support for the decision to undergo surgical evacuation is more often predicated on clinical change than merely imaging findings.

It is not to say that there is no role for additional imaging in the care of these patients; simply that, in the absence of other important considerations, namely clinical deterioration, its value may be well outweighed by their risks. As discussed prior, radiation exposure is a significant concern for pediatric patients [17, 19, 22, 28]. Factors such as cost, proper resource allocation, and need for additional medication or sedation to obtain imaging must also be considered. Together, these may well outweigh the contribution of additional scans to EDH management. On an even more significant level, the avoidance of repeat imaging may even eliminate the costs and risks of unnecessary surgical intervention. In our series, 3 of the 4 patients taken to the operating room for radiographic changes alone underwent repeat imaging as “routine” follow-up. It is fair to suggest that, where subsequent scans reserved for clinical changes, these individuals may have been spared intervention. Within the series as a whole, despite no established management algorithm in our hospital, the reason for repeat imaging in 74% of patients was “routine.” This indication is common across practices and, as discussed, often does not change management [3, 14, 28, 30]. To be able to eliminate this indication without accompanying clinical change would be a significant step in optimizing management of these patients. Taken a step further, if acquisition of repeat imaging was limited to patients demonstrating neurological worsening, then over 90% of the repeat scans in our study could have been avoided.

Together, these points further emphasize the need for evidence-based guidelines.

In an attempt to eliminate the problems of radiation while still utilizing follow-up imaging in the management of pediatric EDH, there is an ongoing investigation into the use of fast MRI [5, 24, 28]. Fourteen percent of patients in our study underwent MRI imaging for hemorrhage evaluation and were successfully managed non-operatively. With respect to MRI for initial imaging, Ryan et al. report that MRI with GRE is sensitive for most intracranial hemorrhages but only when there is a prior CT for comparison, while Buttram et al. report that MRI is comparable to CT [5, 32]. Cohrs et al. also suggest that MRI may be an effective tool in the evaluation of pediatric intracranial trauma [33]. The use of MRI may therefore be a very valuable tool in the evaluation and re-assessment of children with traumatic intracranial pathology; however, further work is needed to address the utility of such modality. MRI more often requires concurrent sedation, as motion can obscure smaller hemorrhage volumes, and hospital systems are not universally equipped to quickly and effectively obtain MRIs for these children [24]. The cost of MRI scans also exceeds that of CT scans. But more importantly, as the authors of this paper would propose, repeat imaging in general is likely to be unnecessary without concurrent clinical concerns, regardless of the imaging modality chosen. Efforts to minimize radiation exposure in the pediatric population remain an ongoing challenge across various pathologies. Given evidence in the literature regarding EDH, inclusive of our work, limiting additional imaging all together may be not only viable but also optimal.

Ultrasound has also been utilized as an alternative to CT in following pediatric TBI, with reports of success at various institutions. Historically, the usage of ultrasound has been confined to infants with open fontanelles, which allows for a viewing window unobstructed by bony artifact [34]. This is becoming less of an issue with the advancements made in high-definition ultrasonography, and the role of ultrasound in TBI follow-up may become significant, though as of yet, there has not been an update in the current literature on the matter [33]. The use of ultrasound was not addressed in this study as it is not commonly conducted at the authors’ home institution, and therefore, there were no cases in which ultrasound was performed.

While it is beyond the scope of this work, a consensus on pediatric EDH management would improve decision-making based on surgical need while providing added benefits of more prudent resource utilization, particularly the role of imaging. Attempts to establish guidelines often utilize small cohorts and retrospective data that compares patients who underwent immediate surgery with those with whom conservative management was attempted [3, 10]. Despite the inherent limitations of such analysis, it also fails to consider the possibility that some patients who were taken immediately

for surgery could have done well with conservative management. A similar observation can be made with our own patient data given realities such as a lack of a standardized treatment algorithm in our institution as well as the widespread, classically accepted, teaching/understanding that epidural hematomas often necessitate surgical evacuation. Examples of such variability in treatment can be observed in Fig. 1. Patients with similar head CTs underwent different treatments (Fig. 1a–d). One patient demonstrated classically surgically concerning features (i.e., uncal herniation) and was successfully managed conservatively (Fig. 1d). These also serve to support the importance of clinical data in addition to radiographic findings in the management of these patients.

Our work carries limitations similar to much of the published literature. It is retrospective in nature and thus contains no randomization. While the cohort size is similar if not larger than many other studies, aspects such as the absence of standardized management for EDH and low rates of follow-up imaging further limit available clinical information. However, given the aim of the current work, patients who succeeded with observation that did not undergo repeat imaging intrinsically lend support to our proposition. Alternatively, there may be clinical data that was not available and/or not included that affected clinical decision-making, and this cohort does not reveal patients that underwent surgery who may have been successfully observed. Also, since the study is comprised of trauma patients, patient follow-up is less than ideal. That being said, given the understanding of traumatic EDH, postoperative follow-up is typically no more than a few months to ensure good wound healing, at which time patients are often discharged from surgical care. While there is ongoing work

by our group to implement a local protocol to aid in the surgical care of these patients, larger, prospective investigation is warranted with hopes of compiling a set of comprehensive and objective guidelines for management of pediatric epidural hematomas.

Conclusions

Epidural hematoma is a traumatic injury commonly encountered by neurosurgeons. Management of EDH in the pediatric population, unlike adults, has not yet been standardized with larger, prospective trials. As such, there is wide variability in practice from center to center. Numerous aspects of clinical treatment have been analyzed with the goal of facilitating care of these patients. Based on the long supported, though more recent, notion that pediatric EDH need not be always met with surgical intervention, the current work proposes that there are aspects of conservative management that can be safely considered, specifically the need for repeat CT imaging and/or initiation of surgical management in isolation of significant clinical change. The decision to obtain repeat imaging should therefore rely heavily upon clinical examination, and not be made in the absence of such changes. Given that isolated hematoma expansion accounted for an exceptionally small proportion of operative indications, this data suggests changes seen on CT should not be solely relied upon to dictate surgical management. The benefit of obtaining follow-up imaging must be strongly considered and weighed against the known deleterious effects of radiation in pediatric patients and increased economic burden, let alone its clinical utility.

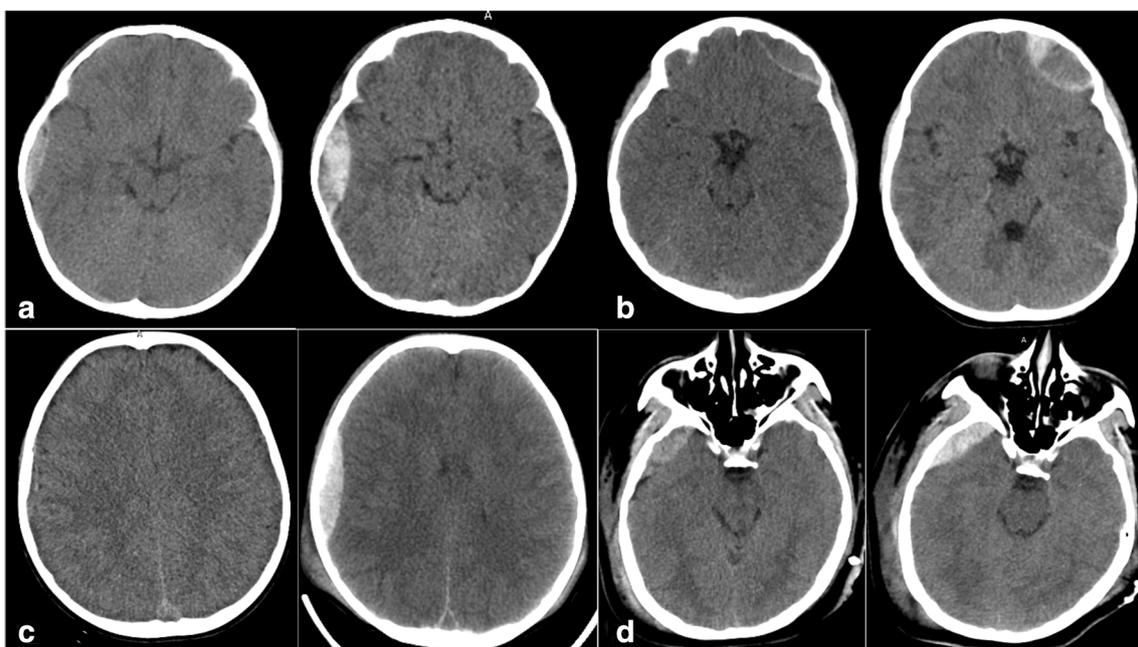


Fig. 1 Initial and follow-up CT scans of radiographically worsened acute epidural hematomas treated operatively (a, b) and non-operatively (c, d) in four patients

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

- Flaherty BF, Moore HE, Riva-Cambrin J, Bratton SL (2017) Pediatric patients with traumatic epidural hematoma at low risk for deterioration and need for surgical treatment. *J Pediatr Surg* 52(2):334–339. <https://doi.org/10.1016/j.jpedsurg.2016.09.005>
- Flaherty BF, Moore HE, Riva-Cambrin J, Bratton SL (2018) Repeat head CT for expectant management of traumatic epidural hematoma. *Pediatrics* 142(3):e20180385. <https://doi.org/10.1542/peds.2018-0385>
- Flaherty BF, Loya J, Alexander MD, Pandit R, Ha BY, Torres RA, Schroeder AR (2013) Utility of clinical and radiographic findings in the management of traumatic epidural hematoma. *PNE* 49(4):208–214. <https://doi.org/10.1159/000363143>
- Holsti M, Kadish HA, Sill BL, Firth SD, Nelson DS (2005) Pediatric closed head injuries treated in an observation unit. *Pediatr Emerg Care* 21(10):639–644. <https://doi.org/10.1097/01.pec.0000181426.25342.a9>
- Ryan ME, Jaju A, Ciolino JD, Alden T (2016) Rapid MRI evaluation of acute intracranial hemorrhage in pediatric head trauma. *Neuroradiology* 58(8):793–799. <https://doi.org/10.1007/s00234-016-1686-x>
- Sheng H-S, You C-G, Yang L, Zhang N, Lin J, Lin FC, Wang MD (2017) Trephination mini-craniectomy for traumatic posterior fossa epidural hematomas in selected pediatric patients. *Chin J Traumatol* 20(4):212–215. <https://doi.org/10.1016/j.cjtee.2017.01.004>
- Pang D, Horton JA, Herron JM, Wilberger JE, Vries JK (1983) Nonsurgical management of extradural hematomas in children. *J Neurosurg* 59(6):958–971. <https://doi.org/10.3171/jns.1983.59.6.0958>
- Erşahin Y, Mutluer S, Güzelbag E (1993) Extradural hematoma: analysis of 146 cases. *Childs Nerv Syst* 9(2):96–99. <https://doi.org/10.1007/BF00305316>
- Balmer B, Boltshauser E, Altermatt S, Gobet R (2006) Conservative management of significant epidural haematomas in children. *Childs Nerv Syst* 22(4):363–367. <https://doi.org/10.1007/s00381-005-1254-x>
- Bejjani GK, Donahue DJ, Rusin J, Broemeling LD (1996) Radiological and clinical criteria for the management of epidural hematomas in children. *Pediatr Neurosurg* 25(6):302–308. <https://doi.org/10.1159/000121144>
- Binder H, Majdan M, Tiefenboeck TM, Fochtmann A, Michel M, Hajdu S, Mauritz W, Leitgeb J (2016) Management and outcome of traumatic epidural hematoma in 41 infants and children from a single center. *Orthop Traumatol Surg Res* 102(6):769–774. <https://doi.org/10.1016/j.otsr.2016.06.003>
- Champagne P-O, He KX, Mercier C, Weil AG, Crevier L (2017) Conservative management of large traumatic supratentorial epidural hematoma in the pediatric population. *PNE* 52(3):168–172. <https://doi.org/10.1159/000455925>
- Ciurea AV, Kapsalaki EZ, Coman TC, Roberts JL, Robinson JS III, Tascu A, Brehar F, Fountas KN (2007) Supratentorial epidural hematoma of traumatic etiology in infants. *Childs Nerv Syst* 23(3):335–341. <https://doi.org/10.1007/s00381-006-0230-4>
- Duthie G, Reaper J, Tyagi A, Crimmins D, Chumas P (2009) Extradural haematomas in children: a 10-year review. *Br J Neurosurg* 23(6):596–600. <https://doi.org/10.3109/02688690902978157>
- Flannery AM (2009) Cautions in the conservative management of epidural hematomas. *Pediatr Neurosurg; Basel* 45(3):185
- Jamous MA, Abdel Aziz H, Al Kaisy F, Eloqayli H, Azab M, Al-Jarrah M (2009) Conservative management of acute epidural hematoma in a pediatric age group. *Pediatr Neurosurg* 45(3):181–184. <https://doi.org/10.1159/000218200>
- Khan MB, Riaz M, Javed G (2014) Conservative management of significant supratentorial epidural hematomas in pediatric patients. *Childs Nerv Syst* 30(7):1249–1253. <https://doi.org/10.1007/s00381-014-2391-x>
- Skadorwa T, Zygańska E, Eibl M, Ciszek B (2013) Distinct strategies in the treatment of epidural hematoma in children: clinical considerations. *PNE* 49(3):166–171. <https://doi.org/10.1159/000359954>
- Kuppermann N, Holmes JF, Dayan PS, Hoyle JD, Atabaki SM, Holubkov R, Nadel FM, Monroe D, Stanley RM, Borgialli DA, Badawy MK, Schunk JE, Quayle KS, Mahajan P, Lichenstein R, Lillis KA, Tunik MG, Jacobs ES, Callahan JM, Gorelick MH, Glass TF, Lee LK, Bachman MC, Cooper A, Powell EC, Gerardi MJ, Melville KA, Muizelaar JP, Wisner DH, Zuspan SJ, Dean JM, Wootton-Gorges SL (2009) Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. *Lancet* 374(9696):1160–1170. [https://doi.org/10.1016/S0140-6736\(09\)61558-0](https://doi.org/10.1016/S0140-6736(09)61558-0)
- Rocchi G, Caroli E, Raco A, Salvati M, Delfini R (2005) Traumatic epidural hematoma in children. *J Child Neurol* 20(7):569–571. <https://doi.org/10.1177/08830738050200070501>
- Babl FE, Oakley E, Dalziel SR, Borland ML, Phillips N, Kochar A, Dalton S, Cheek JA, Gilhotra Y, Furyk J, Neutze J, Donath S, Hearps S, Molesworth C, Crowe L, Bressan S, Lyttle MD (2018) Accuracy of clinician practice compared with three head injury decision rules in children: a prospective cohort study. *Ann Emerg Med* 71(6):703–710. <https://doi.org/10.1016/j.annemergmed.2018.01.015>
- Babl FE, Lyttle MD, Bressan S, Borland M, Phillips N, Kochar A, Dalziel SR, Dalton S, Cheek JA, Furyk J, Gilhotra Y, Neutze J, Ward B, Donath S, Jachno K, Crowe L, Williams A, Oakley E, PREDICT research network (2014) A prospective observational study to assess the diagnostic accuracy of clinical decision rules for children presenting to emergency departments after head injuries (protocol): the Australasian Paediatric Head Injury Rules Study (APHIRST). *BMC Pediatr* 14(1):148. <https://doi.org/10.1186/1471-2431-14-148>
- Simon B, Letourneau P, Vitorino E, McCall J (2001) Pediatric minor head trauma: indications for computed tomographic scanning revisited. *J Trauma* 51(2):231–237 discussion 237–238
- Durham SR, Liu KC, Selden NR (2006) Utility of serial computed tomography imaging in pediatric patients with head trauma. *J Neurosurg Pediatr* 105(5):365–369. <https://doi.org/10.3171/ped.2006.105.5.365>
- Givner A, Gurney J, O'Connor D, Kassarian A, LaMorte WW, Moulton S (2002) Reimaging in pediatric neurotrauma: factors associated with progression of intracranial injury. *J Pediatr Surg* 37(3):381–385. <https://doi.org/10.1053/jpsu.2002.30825>
- Kochanek PM, Carney N, Adelson PD et al (2012) Guidelines for the acute medical management of severe traumatic brain injury in infants, children, and adolescents—second edition. *Pediatr Crit Care Med* 13(Suppl 1):S1–S82. <https://doi.org/10.1097/PCC.0b013e31823f435c>
- Teichert JH, Rosales PR Jr, Lopes PB, Enéas LV, da Rocha TS (2012) Extradural hematoma in children: case series of 33 patients. *PNE* 48(4):216–220. <https://doi.org/10.1159/000345849>
- Patel SK, Gozal YM, Krueger BM, Bayley JC, Moody S, Andaluz N, Falcone RA Jr, Bierbrauer KS (2018) Routine surveillance imaging following mild traumatic brain injury with intracranial hemorrhage may not be necessary. *J Pediatr Surg* 53(10):2048–2054. <https://doi.org/10.1016/j.jpedsurg.2018.04.027>
- Tabori U, Kornecki A, Sofer S, Constantini S, Paret G, Beck R, Sivan Y (2000) Repeat computed tomographic scan within 24–48

- hours of admission in children with moderate and severe head trauma. *Crit Care Med* 28(3):840–844
30. Figg RE, Stouffer CW, Vander Kolk WE, Connors RH (2006) Clinical efficacy of serial computed tomographic scanning in pediatric severe traumatic brain injury. *Ped Surg Int* 22(3):215–218. <https://doi.org/10.1007/s00383-005-1560-0>
 31. Stippler M, Smith C, McLean AR et al (2012) Utility of routine follow-up head CT scanning after mild traumatic brain injury: a systematic review of the literature. *Emerg Med J* 29(7):528–532. <https://doi.org/10.1136/emermed-2011-200162>
 32. Buttram SDW, Garcia-Filion P, Miller J, Youssfi M, Danielle Brown S, Dalton HJ, David Adelson P (2015) Computed tomography vs magnetic resonance imaging for identifying acute lesions in pediatric traumatic brain injury. *Hosp Pediatr* 5(2):79–84. <https://doi.org/10.1542/hpeds.2014-0094>
 33. Cohrs G, Huhndorf M, Niemczyk N, Volz LJ, Bernsmeier A, Singhal A, Larsen N, Synowitz M, Knerlich-Lukoschus F (2018) MRI in mild pediatric traumatic brain injury: diagnostic overkill or useful tool? *Childs Nerv Syst* 34(7):1345–1352. <https://doi.org/10.1007/s00381-018-3771-4>
 34. Huisman TAGM (2005) Intracranial hemorrhage: ultrasound, CT and MRI findings. *Eur Radiol* 15(3):434–440. <https://doi.org/10.1007/s00330-004-2615-7>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.