Repeat Head CT for Expectant Management of Traumatic Epidural Hematoma

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BACKGROUND AND OBJECTIVES: Guidelines regarding the role of repeated head computed tomography (CT) imaging in the nonoperative management of traumatic epidural hematomas (EDHs) do not exist. Consequently, some children may be exposed to unnecessary additional ionizing radiation. We describe the frequency, timing, and utility of reimaging of EDHs to identify patients who might avoid reimaging.

METHODS: A retrospective cohort study of subjects aged 0 to 18 years with a traumatic EDH treated at a level I pediatric trauma center from 2003 to 2014. Radiographic and clinical findings, the frequency and timing of reimaging, and changes in neurologic status were compared between subjects whose management changed because of a meaningful CT scan and those whose did not.

RESULTS: Of the 184 subjects who were analyzed, 19 (10%) had a meaningful CT. There was no difference in the frequency of CT scans between the meaningful CT scan and no meaningful CT groups (median 1 [interquartile range 1–2] in no meaningful CT and median 1 [interquartile range 1–2] in meaningful CT scans; \( P = .7 \)). Only 7% of repeated CTs changed management. Neurologic status immediately before the repeat scan (odds ratio 45; 95% confidence interval 10–200) and mass effect on the initial CT (odds ratio 4; 95% confidence interval 1.5–13) were associated with a meaningful CT. Reimaging only subjects with concerning pre-CT neurologic findings or mass effect on initial CT would have decreased imaging by 54%.

CONCLUSIONS: Reimaging is common, but rarely changes management. Limiting reimaging to patients with concerning neurologic findings or mass effect on initial evaluation could reduce imaging by >50%.

WHAT’S KNOWN ON THIS SUBJECT: Patients with minimal neurologic symptoms and small-to-moderate-sized epidural hematomas often can be safely managed nonoperatively. Repeat computed tomography (CT) scans are common, but their optimal role in monitoring for delayed operative needs is unknown.

WHAT THIS STUDY ADDS: Only 7% of repeat CT scans lead to a change to operative management. Limiting reimaging to patients with either abnormal neurologic symptoms or mass effect on initial imaging could decrease repeat CT scans by 54%.


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WHAT THIS STUDY ADDS: Only 7% of repeat CT scans lead to a change to operative management. Limiting reimaging to patients with either abnormal neurologic symptoms or mass effect on initial imaging could decrease repeat CT scans by 54%.
Epidural hematomas (EDHs) complicate ~3% of traumatic brain injuries (TBIs).1 While classic neurosurgical teaching advocated for immediate surgical evacuation, the advent of computed tomography (CT) scanning allowed for the identification of asymptomatic lesions and expectant management in some cases.2–15 Given the potential for EDH progression, reimaging is frequently part of expectant management plans, but little is known regarding the benefits and costs of repeated head imaging.3,5,6,9–16 Wide variation in the timing and frequency of reimaging and its impact on case management has been reported.6,10,17,18 A current lack of strong evidence prevents the creation of guideline recommendations in pediatric TBIs regarding specific indications for reimaging.19 It is likely that with this paucity of data, children are exposed to excess repeat CT scans with radiation exposure, which increases long-term cancer risk and medical costs without adding value.20–23

We aim to describe the frequency and timing of repeat head CT imaging and the evolution of EDH size in a large cohort of patients who were initially managed nonsurgically. In addition, we aim to identify features that are associated with a “meaningful” repeat CT scan, which is defined as one that has influenced the decision for a surgical evacuation, and to identify circumstances in which reimaging is unlikely to be of value.

METHODS

We identified a retrospective cohort of all pediatric patients who were treated for a traumatic EDH between 2003 and 2014 at Primary Children’s Hospital (PCH), a level I pediatric trauma center in Salt Lake City, Utah. Subjects were identified from a previously published study regarding the conservative (nonsurgical) treatment of pediatric EDHs and from the PCH trauma registry.9 The University of Utah Institutional Review Board approved the study protocol and waived the requirement for informed consent.

Inclusion Criteria

Subjects from 0 to 18 years of age with a traumatic EDH that was identified on initial CT imaging, whose initial treatment strategy was observation, and who received ≥1 repeat head CT were included.

Exclusion Criteria

Subjects were excluded if their initial clinical notes or CT images were unavailable for review. Children with injuries so severe that the subjects were deemed to be nonoperative and directed to palliative or compassionate care were excluded. Patients were also excluded if their neurosurgical operative notes specified that they had undergone a craniotomy for an indication other than an EDH.

Data Extraction

Presenting clinical data were abstracted from the emergency department trauma flowsheet, trauma service intake, and neurosurgery consult notes. The trauma service–assigned initial postresuscitation Glasgow Coma Scale (GCS) score was used. Subsequent daily trauma, neurosurgery, and ICU teams’ physician notes and nursing notes were reviewed for decreasing GCS score, symptoms of headache, vomiting, blurry vision, altered mental status, and focal neurologic examination findings in the 8 hours before a repeat CT scan (“pre-CT neurologic status”). Subjects with resolved, improving, or no neurologic signs and/or symptoms as specified above were classified as having “non-concerning pre-CT neurologic status”; all others were classified as having “concerning pre-CT neurologic status.” Improvement in some symptoms but a lack of improvement or worsening in any other symptom or any new symptom was also classified as concerning pre-CT neurologic status. Additional abstracted data included discharge GCS score and neurologic status documented by the trauma service discharge note. The Glasgow Outcome Scores (GOSs) were obtained from the trauma registry. For subjects who failed observation, the neurosurgery operative note was reviewed to determine the indications for surgery.

All initial and subsequent inpatient head CT scans were reviewed. All scans were originally reviewed by a pediatric radiologist at PCH. The investigators reviewed the initial reports for evidence of a mass effect, a midline shift, herniation, and additional injuries (B.F.F. and H.E.M.). For all initial and subsequent repeat scans, the EDH thickness, height, and length and the midline shift were measured independently of the initial radiology evaluation (B.F.F. and H.E.M.). The EDH volume was calculated by using the formula for an ellipsoid.9,18 The reviewers were blinded to the CT scan effect on care management.

Measurement consistency was evaluated by using intraclass correlation coefficients. Twenty scans were reviewed by B.F.F and H.E.M together, and an additional 20 scans were reviewed separately, with intraclass correlation coefficients of thickness 0.95 (interquartile range [IQR] 0.89–0.98), height 0.82 (IQR 0.6–0.92), length 0.98 (IQR 0.94–0.99), and volume 0.96 (IQR 0.89–0.98).

Statistical Analysis

Subjects with a meaningful CT scan were compared to those without. A meaningful CT scan was defined
as a scan in which the findings were specifically mentioned in the neurosurgical operative note as contributing to the decision to change case management from observation to surgery. However, given the limitations of retrospective review, it was not possible to reliably determine if a CT scan specifically prevented a subject from being converted from conservative to surgical management because this information would not reliably be recorded in the medical records.

Summary data are presented as means with SDs or as medians with IQRs as appropriate for continuous variables and counts with percentages for categorical variables. Continuous, subject-level data were compared by using a 2-sided Student’s t test or Mann–Whitney U test as appropriate. \( \chi^2 \) and Fisher’s exact tests were used as appropriate to compare categorical data.

The time to CT scan and pre-CT neurologic status were compared by using generalized estimating equations (GEEs). In developing the models, both exchangeable and autoregression-1 working correlation matrices were trialed, and the model with the lowest quasi-likelihood under independence model criterion (QIC) was chosen. To determine which factors were independently associated with a meaningful CT scan, a multivariable GEE model was developed. We determined a priori that 1 predictor variable could be included for every 5 positive priori that 1 predictor variable could have no repeat imaging, with 2 of 34 (6%) having a clinical decline and undergoing surgical intervention. This left 184 subjects with a total of 262 repeated scans for analysis. In the study group of 184 subjects, 23 (13%) had a change in management to surgery. The indication for surgery was solely a clinical decline in 4 patients (2%), a combination of clinical and CT scan findings in 17 patients (9%), and solely CT scan findings in 2 patients (1%). Of the 262 repeated scans, only 19 (7%) were meaningful, with 2 of those (1%) occurring in isolation from clinical concerns. Table 1 compares the demographics, presenting clinical status, and mechanism of injury between those subjects with and without a meaningful CT scan. To assess if there were non-EDH injuries that potentially contributed to the outcome or resuscitation efforts, we analyzed the injury severity score (ISS) and maximum nonhead Abbreviated Injury Scale (AIS) score between the groups. Although the ISS was higher in the meaningful CT scan group (\( P < .01 \)), this likely reflects a more severe head injury because there was no difference in the nonhead AIS score (\( P = .75 \)) between the groups. More specifically, this reflects larger EDHs because the AIS score of an EDH is based on size.

**RESULTS**

**Study Population**

As noted in Fig 1, 388 patients presented to PCH with an EDH on the initial scan, with 218 being admitted for initial observation. This included 34 patients (16%) who had no repeat imaging, with 2 of 34 (6%) having a clinical decline and undergoing surgical intervention. This left 184 subjects with a total of 262 repeated scans for analysis. In the study group of 184 subjects, 23 (13%) had a change in management to surgery. The indication for surgery was solely a clinical decline in 4 patients (2%), a combination of clinical and CT scan findings in 17 patients (9%), and solely CT scan findings in 2 patients (1%). Of the 262 repeated scans, only 19 (7%) were meaningful, with 2 of those (1%) occurring in isolation from clinical concerns. Table 1 compares the demographics, presenting clinical status, and mechanism of injury between those subjects with and without a meaningful CT scan. To assess if there were non-EDH injuries that potentially contributed to the outcome or resuscitation efforts, we analyzed the injury severity score (ISS) and maximum nonhead Abbreviated Injury Scale (AIS) score between the groups. Although the ISS was higher in the meaningful CT scan group (\( P < .01 \)), this likely reflects a more severe head injury because there was no difference in the nonhead AIS score (\( P = .75 \)) between the groups. More specifically, this reflects larger EDHs because the AIS score of an EDH is based on size.

**Evolution of EDH Size**

Of the 184 first repeat head CT scans, the EDH decreased in size by >10% in 65 patients (35%), increased in size >10% in 60 patients (33%), and the EDH was either unchanged or within 10% of its size on the initial CT scan in 59 patients (32%). Fig 2 plots the absolute change in the EDH thickness over time for CT scans obtained within the first 72 hours of the injury (\( n = 208 \) scans). When using GEE analysis, the time from the injury was not significantly associated with a change in EDH thickness for scans that were obtained within 72 hours (\( P = .14 \)).

**Univariate Analysis of Postadmission and Radiographic Variables Associated With a Meaningful CT Scan**

Of the 262 total repeat scans, 205 of 243 (84%) scans in the no meaningful CT scan group and 2 of
19 (5%) scans in the meaningful CT scan group were preceded by non-concerning pre-CT neurologic status. Univariate GEE analyses revealed an association between pre-CT neurologic status and a meaningful CT scan ($P < .001$). The GEE analysis did not reveal an association between the time from the injury to a repeat scan and a meaningful CT scan ($P = .23$).

The comparison of the presenting radiographic findings between the no meaningful CT scan and meaningful CT scan groups is summarized in Table 3. All variables used to quantify the EDH size were significantly different between the study groups. Signs of herniation were uncommon and did not significantly differ between groups.

**Multivariable Analysis of Variables Associated With a Meaningful CT Scan**

Because of the small number of meaningful CT scans ($n = 19$), only 3 variables could reasonably be included in the multivariate GEE model. Concerning pre-CT neurologic status was significantly predictive of a meaningful CT scan ($P < .001$; odds ratio 45; 95% confidence interval [CI] 10–200), as was positive mass effect on the initial CT scan ($P = .006$; odds ratio 4; 95% CI 1.5–13). Given the impact of these 2 factors, the addition of other variables did not further improve the corrected QIC.

On the basis of this modeling, concerning pre-CT neurologic status and mass effect on initial CT could be used to help screen for patients who are likely to have a meaningful CT scan and optimize the use of serial imaging. In our data set, if only subjects with concerning pre-CT neurologic status and/or positive mass effect on initial CT scan received reimaging, 54% of scans could have been avoided. Such a screening test would yield a sensitivity of 100 (95% CI 79–100), a specificity of 58 (95%
CI 51–64), a negative predictive value of 100 (95% CI 97–100), and a positive predictive value of 16 (95% CI 10–23) for a meaningful CT scan.

Outcomes

In Table 4, we compare the outcomes of subjects with no meaningful CT scan versus those with a meaningful CT scan. Overall, both groups had low morbidity, and no significant differences were found between the groups. To further assess whether potential negative effects may occur if repeat head imaging were not obtained, we compared the outcomes of the 19 subjects with meaningful CT scans with the 4 subjects who had surgery solely on the basis of clinical signs and/or symptoms. In this exploratory analysis, there were no significant differences in discharge GCS score ($P = 1$), GOS ($P > .99$), neurologic deficits at discharge ($P > .99$), or mortality ($P = 1$).

Among the 34 subjects with no repeat imaging, all were discharged from the hospital with a GCS score of 15 and no neurologic deficits.

DISCUSSION

The management of pediatric patients undergoing observation for traumatic EDH represents an understudied area of head injury research, especially with regard to the role of repeated CT imaging. We sought to investigate the role of repeat imaging in a cohort of pediatric subjects with initial nonoperative management of a traumatic EDH. We found that 84% had ≥1 repeat scan occurring at a median time of 14 hours after injury. Overall, EDH growth was relatively unchanged on serial imaging, with approximately two-thirds of the initial repeat scans revealing no change or decrease in EDH size. We found that only 7% of all scans contributed to changing case management to surgery. Finally, we found that concerning pre-CT neurologic status and mass effect on an initial CT scan were significantly associated with a meaningful CT scan that prompted a change from conservative management to surgical decompression. Specifically, the absence those features had a negative predictive value of 100% (95% CI 79%–100%) for predicting a meaningful CT scan.

TABLE 1 Comparison of Demographics, Presenting Characteristics, and Mechanism of Injury of Patients With and Without a Meaningful CT Scan

<table>
<thead>
<tr>
<th></th>
<th>No Meaningful CT Scan (n = 165)</th>
<th>Meaningful CT Scan (n = 19)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age in y, mean (SD)</td>
<td>7 (±5)</td>
<td>8 (±3)</td>
<td>.12</td>
</tr>
<tr>
<td>Female sex, n (%)</td>
<td>72 (44)</td>
<td>7 (37)</td>
<td>.85</td>
</tr>
<tr>
<td>On scene loss of consciousness, n (%)</td>
<td>48 (29)</td>
<td>7 (37)</td>
<td>.45</td>
</tr>
<tr>
<td>Yes</td>
<td>48 (29)</td>
<td>7 (37)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>85 (523)</td>
<td>7 (37)</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>32 (19)</td>
<td>5 (26)</td>
<td></td>
</tr>
<tr>
<td>Seizure before hospital arrival, n (%)</td>
<td>7 (4)</td>
<td>1 (5)</td>
<td>.59</td>
</tr>
<tr>
<td>Arrival GCS score, median (IQR)</td>
<td>15 (15)</td>
<td>15 (14–15)</td>
<td>.23</td>
</tr>
<tr>
<td>ISS, median (IQR)</td>
<td>16 (10–17)</td>
<td>25 (16–25)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Highest nonhead AIS score, median (IQR)</td>
<td>1 (0–1)</td>
<td>0 (0–1)</td>
<td>.075</td>
</tr>
<tr>
<td>Mechanism of injury, n (%)</td>
<td></td>
<td></td>
<td>.74</td>
</tr>
<tr>
<td>Fall greater than or equal to standing height</td>
<td>87 (53)</td>
<td>11 (58)</td>
<td></td>
</tr>
<tr>
<td>Fall less than standing height</td>
<td>15 (9)</td>
<td>2 (11)</td>
<td></td>
</tr>
<tr>
<td>Fall from unknown height</td>
<td>7 (4)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Bicycle crash</td>
<td>18 (11)</td>
<td>3 (16)</td>
<td></td>
</tr>
<tr>
<td>Bicycle versus motor vehicle crash</td>
<td>1 (1)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pedestrian versus motor vehicle</td>
<td>4 (2)</td>
<td>1 (5)</td>
<td></td>
</tr>
<tr>
<td>Motor vehicle at &gt;60 mph</td>
<td>1 (1)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Motor vehicle at ≤60 mph</td>
<td>5 (3)</td>
<td>2 (11)</td>
<td></td>
</tr>
<tr>
<td>Motor vehicle at unknown speed</td>
<td>5 (3)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Assault</td>
<td>10 (6)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sports related</td>
<td>3 (2)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Unknown cause</td>
<td>9 (5)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2 Frequency and Timing of Repeat CT Scans by Meaningful CT Scan Group

<table>
<thead>
<tr>
<th>Repeat Scan No.</th>
<th>Subjects Receiving No. Scans, n (%)</th>
<th>Median Time From Injury to Scan, h (IQR)</th>
<th>Subjects Receiving No. Scans, n (%)</th>
<th>Median Time From Injury to Scan, h (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>111 (67)</td>
<td>14 (8–20)</td>
<td>12 (63)</td>
<td>13 (6–18)</td>
</tr>
<tr>
<td>2</td>
<td>42 (26)</td>
<td>38 (18–45)</td>
<td>5 (29)</td>
<td>37 (23–46)</td>
</tr>
<tr>
<td>3</td>
<td>10 (5)</td>
<td>85 (64–102)</td>
<td>1 (5)</td>
<td>269 (51–478)</td>
</tr>
<tr>
<td>4</td>
<td>2 (1)</td>
<td>68 (48–80)</td>
<td>1 (5)</td>
<td>95</td>
</tr>
</tbody>
</table>

FIGURE 2

Change in EDH thickness (in millimeters) from initial scan during the first 72 hours after injury.

FIGURE 2

Change in EDH thickness (in millimeters) from initial scan during the first 72 hours after injury.
5 to 16 days postinjury, others with the peak size occurring in the first several days after injury and some achieving maximal EDH size in the largest recorded EDH size, with a bimodal distribution in the time to series of 11 EDH subjects noted a time frame for peak epidural size. With our analysis, we did not identify a repeat scan from 6 to 8 hours after injury, and the authors of previous pediatric studies, who frequently report trauma, did not have enough data points within this interval to confidently identify a peak. It is also important to note that currently, no methods to continually monitor an intracranial bleed volume are available for clinical use. Instead, serial imaging provides snapshots in time, so it remains uncertain if a single repeat scan can accurately capture the maximal EDH volume.

Our analysis on the effect of repeat imaging on a change in management found that only 7% of CT scans were meaningful. Although authors of previous studies discussed that a meaningful CT scan is infrequent in an otherwise well-appearing patient, we did not find any studies in which the authors provided the data to calculate the rate of meaningful CT scans to compare with our study.6,7,10,18,27,28 It is important to note that our study, as well as 2 previous studies of pediatric EDH, contained subjects with a change to operative management based solely on worsening CT findings.16,28 The authors of neither of these previous studies describe if the repeated scans were obtained on the basis of routine practice standards or if the initial CT scan revealed concerning findings that prompted follow-up imaging.

Noting that a majority of repeat CT scans did not change management, we then investigated factors that may help identify patients who would benefit from repeat imaging and those who could avoid further imaging. We found that concerning pre-CT neurologic status and the presence of mass effect on initial imaging were associated with meaningful CT scans. We did not identify other pediatric reports in which factors that are associated with a meaningful CT scan in subjects with traumatic EDHs were specifically evaluated. However, there are several studies examining all types of pediatric blunt TBIs, which include a small number of EDH subjects. Similar to our findings, these studies noted that neurologic status and increased severity of brain injury were associated with injury progression on subsequent repeat imaging.18,28–30 Further arguing for the potential importance of neurologic status in determining the use of reimaging are the upcoming third edition of the Brain Trauma Foundation Guidelines for Acute Management of Pediatric Severe TBI, which includes a level III recommendation that routinely obtaining a repeat CT scan >24 hours after admission is not suggested when making decisions about neurosurgical intervention unless there is evidence of neurologic deterioration or increasing intracranial pressure (N. Carney, PhD, personal communication, 2018).

### TABLE 3 Comparison of Presenting CT Scan Findings by Meaningful CT Scan Group

<table>
<thead>
<tr>
<th></th>
<th>Patients Without a Meaningful CT Scan (n = 165)</th>
<th>Patients With a Meaningful CT Scan (n = 19)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDH thickness, mm, mean (SD)</td>
<td>7 (5)</td>
<td>11 (6)</td>
<td>.02</td>
</tr>
<tr>
<td>EDH vol, mL, median (IQR)</td>
<td>3 (1–7)</td>
<td>13 (2–27)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Midline shift, mm, median (IQR)</td>
<td>0 (0)</td>
<td>0 (0–1)</td>
<td>.01</td>
</tr>
<tr>
<td>Mass effect, n (%)</td>
<td>49 (30)</td>
<td>13 (68)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Herniation, n (%)</td>
<td>3 (2)</td>
<td>1 (5)</td>
<td>.36</td>
</tr>
<tr>
<td>Location, n (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frontal</td>
<td>42 (26)</td>
<td>6 (32)</td>
<td>.59</td>
</tr>
<tr>
<td>Parietal</td>
<td>86 (52)</td>
<td>10 (53)</td>
<td>1</td>
</tr>
<tr>
<td>Occipital</td>
<td>13 (8)</td>
<td>1 (5)</td>
<td>1</td>
</tr>
<tr>
<td>Temporal</td>
<td>58 (35)</td>
<td>8 (42)</td>
<td>.09</td>
</tr>
<tr>
<td>Posterior Fossa</td>
<td>16 (10)</td>
<td>2 (11)</td>
<td>1</td>
</tr>
</tbody>
</table>

### TABLE 4 Comparison of Patient Outcomes by Meaningful CT Scan Group

<table>
<thead>
<tr>
<th></th>
<th>Patients Without a Meaningful CT Scan (n = 165)</th>
<th>Patients With a Meaningful CT Scan (n = 19)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge GCS score, median (IQR)</td>
<td>15 (15–15)</td>
<td>15 (15–15)</td>
<td>.73</td>
</tr>
<tr>
<td>GOS, n (%)</td>
<td></td>
<td></td>
<td>.50</td>
</tr>
<tr>
<td>5</td>
<td>121 (73)</td>
<td>13 (68)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>7 (4)</td>
<td>2 (11)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2 (1)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>35 (21)</td>
<td>4 (21)</td>
<td></td>
</tr>
<tr>
<td>Neurologic deficit, n (%)</td>
<td>4 (2)</td>
<td>1 (5)</td>
<td>.42</td>
</tr>
<tr>
<td>Death, n (%)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td></td>
</tr>
</tbody>
</table>

—, not applicable.

We first examined the frequency and timing of repeat imaging and EDH evolution. Eighty-four percent of subjects underwent ≥1 repeat CT scan, which was consistent with the findings of authors of previous pediatric studies, who frequently report reimage rates of >50%.3,5,7,8,10,17 With our analysis, we did not identify a time frame for peak epidural size. Authors of a previous pediatric series of 11 EDH subjects noted a bimodal distribution in the time to the largest recorded EDH size, with some achieving maximal EDH size in the first several days after injury and others with the peak size occurring 5 to 16 days postinjury.3 Authors of adult studies estimated that peak size generally occurred from 5 to 8 hours postinjury, and the authors of current adult guidelines recommend a repeat scan from 6 to 8 hours after injury.16,25,26 In our study, few repeat scans were obtained <8 hours after injury, so it is possible that we did not have enough data points within this interval to confidently identify a peak. It is also important to note that currently, no methods to continually monitor an intracranial bleed volume are available for clinical use. Instead, serial imaging provides snapshots in time, so it remains uncertain if a single repeat scan can accurately capture the maximal EDH volume.

## References

38. X. A. Carney, personal communication, 2018.
Routine reimagining has been used to facilitate the early detection and treatment of an expanding lesion, but it is unknown if earlier detection results in better outcomes compared with waiting to reimage and operate until the patient displays concerning clinical symptoms. Because our data were collected retrospectively, we could not determine the fraction of repeat scans that were “routine.” We were able to determine if there was no notation of concerning neurologic status to prompt reimagining and signify a potentially routine scan. Only 2 (1%) of these potentially routine scans led to surgery that might have been delayed without the scan, revealing that surgical delay would likely be infrequent if routine imaging was not used. To explore if waiting for clinical indications before obtaining imaging altered the outcome, we compared subjects who had a meaningful CT scan to those who deteriorated clinically and were taken to the operating room without immediate reimagining. Although small in number, both groups appeared to have similar outcomes in terms of mortality, discharge GCS score, neurologic deficits, and GOS score. Further prospective work is needed to better identify if any difference in outcome is associated with potentially avoiding scans in stable patients without clinical signs and/or symptoms.

Our study does have some additional limitations. The small number of meaningful CT scans limited the number of risk factors that could be evaluated in multivariable analysis. Similarly, we were limited in analyzing the predictive ability of specific neurologic signs and symptoms, such as declining GCS score, and instead used the composite measure of pre-CT neurologic status. A larger sample with more meaningful CT scans could be used to further refine this analysis. Despite these sample size limitations, our findings are likely generalizable because our cohort is similar to those of previous studies in terms of age, the mechanism of injury, the presenting clinical symptoms, and conservative management failure rates.3,5,6,9–16 The retrospective design also has some limitations. On the basis of clinical notes, we could not reliably determine if a repeat scan prevented a surgery. There may have been patients with concerning neurologic status for whom surgery was considered, but improved radiographic findings weighed against surgical intervention. Such cases would bias our results toward a lower number of meaningful CT scans. Due to the retrospective nature of the study, we were also unable to determine the severity of persistent symptoms. We chose to code patients with unchanging symptoms regardless of severity as having concerning pre-CT neurologic status to avoid underappreciating an injury in a patient with persistent but stable symptoms. This may affect the specificity of our results, especially in patients with minimal symptoms and a small EDH who might not be expected to benefit from further imaging. We also did not have detailed long-term outcome data to more finely evaluate if delayed surgical care was associated with subtle brain injury. Finally, there is a potential for additional predictors of a meaningful CT scan that were not listed in the medical record and were missed in our analysis. To address these limitations, a larger, prospective study is recommended.

CONCLUSIONS
Repeated CT imaging is common in pediatric patients with EDH, although it rarely changes management from observation to surgery. The use of pre-CT neurologic status and the presence of mass effect on the initial CT scan may provide criteria that could substantially reduce the frequency of unneeded repeat scans with a reduction in ionized radiation and health care costs.

ABBREVIATIONS
AIS: Abbreviated Injury Scale
CI: confidence interval
CT: computed tomography
EDH: epidural hematoma
GCS: Glasgow Coma Scale
GEE: generalized estimating equation
GOS: Glasgow Outcome Score
IQR: interquartile range
ISS: injury severity score
PCH: Primary Children’s Hospital
QIC: quasi-likelihood under independence model criterion
TBI: traumatic brain injury
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