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Development and Implementation of a Pilot Radiation Reduction Protocol for Pediatric Head Injury

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ABSTRACT

Background: Traumatic brain injury is the leading cause of morbidity and mortality for children in the United States. The aim of this study was to develop and implement a guideline to reduce radiation exposure in the pediatric head injury patient by identifying the patient population where repeat imaging is necessary and to establish rapid brain protocol magnetic resonance imaging as the first-line modality.

Methods: A retrospective chart review of trauma patients between 0 and 14 y of age admitted at a pediatric level 2 trauma center was performed between January 2013 and June 2019. The guideline established the appropriateness of repeat scans for patients with Glasgow Coma Scale >13 with clinical neurological deterioration or patients with Glasgow Coma Scale ≤13 and intracranial hemorrhagic lesion on initial head computed tomography (CT).

Results: Our trauma registry included 592 patients during the study period, 415 before implementation and 161 after implementation. A total of 132 patients met inclusion criteria, 116 pre-guideline and 16 post-guideline. The number of patients receiving repeat head CTs significantly decreased from 34.5% to 6.3% ($P < 0.02$). There was also a significant decrease in the mean number of head CT/patient pre-guideline 1.63 (range 1-7) compared with post-guideline 1.06 (range 1-2) ($P < 0.02$).

Conclusions: CT head imaging is invaluable in the initial trauma evaluation of pediatric patients. However, it can be overused, and the radiation may lead to long-term deleterious

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effects. Establishing a head imaging guideline which limits use with clinical criteria can be effective in reducing radiation exposure without missing injuries.

Introduction

Traumatic brain injury (TBI) is the leading cause of morbidity and mortality for children in the United States.[1] It is critical that pediatric trauma patients are quickly and effectively evaluated for head injury, and the modality of choice has long been computed tomography (CT). CT head is an imaging modality that uses x-ray beam radiation to create a three-dimensional reconstruction of the patient's head within a matter of seconds. Compared with the general population, children are at an increased risk of radiation-induced malignancy resulting from CT.[2,3] Given the prevalence of head injury among children and frequency of CT utilization in pediatric trauma settings, numerous studies and quality improvement initiatives have aimed to reduce radiation exposure in the pediatric population over the last 2 decades.[4-13] These initiatives have successfully resulted in a decline in CT usage among pediatric head trauma patients since 2008[14]; however, lack of universally accepted guidelines on management of these patients leaves room for further improvement.

In 2009, the Pediatric Emergency Care Applied Research Network presented a prediction rule for identifying pediatric blunt head trauma patients who can be safely managed without a CT scan.[4] However, overutilization of CT continued to be a problem in the subsequent management of patients with abnormal initial head CT scans. Follow-up studies were routinely ordered within 6-8 h of the initial abnormal study, which is a practice not unique to our institution. The necessity of these repeat scans has been called into question, with several studies showing that patients with mild TBI, defined as Glasgow Coma Scale (GCS) 14-15, and an intracranial hemorrhage can safely be monitored with clinical neurological examination rather than CT.[9-13,15,16]

Radiation exposure in this population has also been reduced since the recent development of rapid brain magnetic resonance imaging (rbMRI).[7,8,17,18] With the goal of shortening the overall scan time of pediatric MRI, the rbMRI consists of four sequences that can retrospectively correct for patient motions and takes approximately 7-9 min. The rbMRI sequences include the following: a T1-weighted 3D short-axis propeller echo planar imaging (SAP-EPI) sequence 1, a T2-weighted 3D SAP-EPI sequence 2, a fluid attenuated inversion recovery (FLAIR) sequence using the readout-segmented (RS)-EPI trajectory 3, and a dual-echo diffusion-weighted-imaging (DWI) sequence 4.[19] rbMRI allows for rapid evaluation of intracranial injury without the need for sedation. Drawing from these recent advances, our institution developed and implemented a guideline that instructs clinicians on which pediatric head trauma patients should receive repeat imaging and which imaging modality should be used. The goal was to reduce radiation exposure in this population by decreasing the overall frequency of imaging and by replacing repeat CT with rbMRI for follow-up studies when needed. The present study evaluates the impact of this guideline, with the primary outcome being a decrease in the percentage of patients who undergo repeat imaging. Secondary outcomes included reductions in the average number of CT scans per patient.

Materials and methods

The study was performed as a retrospective chart review of all trauma patients between 0 and 14 y of age seen at our pediatric level 2 trauma center. This pilot study was approved by the Lehigh Valley Health Network Institutional Review Board, and consent was waived because of the emergent nature of the patients' presentation to our trauma center. Patient data were obtained using our institutional trauma registry. Patients were excluded for the following reasons: no radiological head evaluation was performed, no abnormalities were identified in initial imaging, radiological evaluations were performed at an outside facility or to evaluate a pretrauma comorbidity, or the mechanism of injury was burn or drowning. The study period was January 1, 2013 to June 15, 2019, and the patients were divided into pre-guideline (January 1, 2013 to February 28, 2018) and post-guideline (March 1, 2018 to June 15, 2019) groups.

Demographic and injury-specific data were reviewed along with classification, significance, and appropriateness of each radiological evaluation as determined by a pediatric surgery trauma attending physician. Repeat imaging studies were defined as those obtained within 24 h of the initial head CT and were classified as either a repeat head CT or a repeat rbMRI. Total numbers of head CTs and MRIs during the hospital stay and within 30 d of the encounter were recorded for every patient. Appropriateness of repeat scans was determined in accordance with the implemented guideline, which stated that a repeat scan should be performed only in patients with GCS >13 with clinical neurological deterioration or patients with GCS ≤ 13 and intracranial hemorrhagic lesion on initial head CT and that the scan should be rbMRI unless contraindicated. Clinical neurological deterioration was defined as a worsening or new onset of symptomatology (headache, nausea, vomiting, and/or focal neurologic deficit). The contraindications included rapid neurologic decline, unstable intracranial pressures, and/or retained metal. Patients who received multiple head CTs were evaluated to determine whether or not rbMRI was contraindicated. All patients who received multiple imaging studies were evaluated to determine whether or not each scan resulted in a change in care, as defined by neurosurgical intervention.

Statistical analysis was performed using SAS software (SAS Institute Inc, Cary, NC). Chi-square tests (or Fisher's exact tests when expected cell counts were less than five) and Mann–Whitney *U*-tests were performed with $P < 0.05$ considered statistically significant.

Results

For this pilot study, the trauma registry included 592 patients, 415 before implementation and 161 after implementation. There were a total of 132 patients who met inclusion criteria, 116 pre-guideline and 16 post-guideline. The demographics of the pre-guideline and post-guideline groups included the following: median age in years 5.0 (2.0-12.0) and 9.0 (5.0-10.5), gender male 73 (62.9%) and 11 (68.8%), median injury severity score 11.0 (7.0-17.5) and 10.0 (5.0-14.0), and median GCS 15.0 (11.5-15.0) and 15.0 (12.0-15.0), respectively, shown in Table 1. Most patients were Caucasian, and all patients sustained blunt trauma.

After guideline implementation, there was a significant reduction in the percentage of patients who received repeat head imaging (34.5% pre-guideline *versus* 6.3% post-guideline), see Table 2. There were no readmissions nor missed injuries noted on 30-day review and no patients in the post-guideline group who received nonindicated repeat imaging, compared with 37.5% from the pre-guideline period. There was also a significant decrease in the average number of head CTs

Table 1 – Demographics and clinical characteristics.

	Total ($n = 132$)	Pre-guideline ($n = 116$)	Post-guideline ($n = 16$)	P-value
Age, years median (IQR)	6.0 (2.0-11.5)	5.0 (2.0-12.0)	9.0 (5.0-10.5)	0.2131‡
Gender				0.6501*
Male	84 (63.6)	73 (62.9)	11 (68.8)	
Female	48 (36.4)	43 (37.1)	5 (31.3)	
Race ($n = 131$)				0.0284†
White	87 (66.4)	78 (67.2)	9 (60.0)	
Black	11 (8.4)	10 (8.6)	1 (6.7)	
Asian/Pacific Islander	2 (1.5)	0	2 (13.3)	
Other	31 (23.7)	28 (24.1)	3 (20.0)	
Injury type				1.0000†
Blunt	131 (99.2)	115 (99.1)	16 (100)	
Penetrating	1 (0.8)	1 (0.9)	0	
Cause of injury				0.4041†
Motor vehicle accident	49 (37.1)	39 (33.6)	10 (62.5)	
Motor vehicle accident *versus* pedestrian	23 (17.4)	19 (16.4)	4 (25.0)	
Fall on the same level	11 (8.3)	10 (8.6)	1 (6.3)	
Multilevel fall	20 (15.2)	19 (16.4)	1 (6.3)	
Bicycle injury	3 (2.3)	3 (2.6)	0	
Bicycle *versus* auto	8 (6.1)	8 (6.9)	0	
Contact sports	4 (3.0)	4 (3.5)	0	
Other	14 (10.6)	14 (12.1)	0	
Glasgow Coma Scale—initial median (IQR)	15.0 (11.5-15.0)	15.0 (11.5-15.0)	15.0 (12.0-15.0)	0.7979‡
Injury severity score median (IQR)	11.0 (6.0-17.0)	11.0 (7.0-17.5)	10.0 (5.0-14.0)	0.3015‡
Results of head CT				0.9152†
Skull fracture	20 (15.2)	18 (15.5)	2 (12.5)	
Subarachnoid bleed	10 (7.6)	9 (7.8)	1 (6.3)	
Epidural bleed	2 (1.5)	2 (1.7)	0	
Subdural bleed	23 (17.4)	19 (16.4)	4 (25.0)	
No injury	0	-	-	
Other	9 (6.8)	7 (6.0)	2 (12.5)	
Multiple injuries	37 (28.0)	33 (28.5)	4 (25.0)	
Scalp hematoma	23 (17.4)	20 (17.2)	3 (18.8)	
Intraparenchymal bleed	8 (6.1)	8 (6.9)	0	

IQR = interquartile range; AMA = against medical advice; ICU = intensive care unit.
Data are n (%) unless otherwise stated. Percentages might not add to 100% because of rounding.
* Chi-square test used to calculate *P*-value.
† Fisher's exact test used to calculate *P*-value.
‡ Mann–Whitney *U*-test used to calculate *P*-value.

Table 2 – Patient outcomes.

	Total ($n = 132$)	Pre-guideline ($n = 116$)	Post-guideline ($n = 16$)	P-value
Length of stay, days median (IQR)	2.0 (1.0-4.0)	2.5 (1.0-4.0)	2.0 (1.0-4.5)	0.6062[†]
Was a repeat CT performed?				0.0218[*]
Yes	41 (31.1)	40 (34.5)	1 (6.3)	
No	91 (68.9)	76 (65.5)	15 (93.8)	
Was the repeat CT indicated? ($n = 41$)				1.0000[*]
Yes	26 (63.4)	25 (62.5)	1 (100)	
No	15 (36.6)	15 (37.5)	0	
Was rbMRI possible instead of a repeat head CT? ($n = 41$)				N/A
Yes	41 (100)	40 (100)	1 (100)	
No	0	0	0	
Did repeat imaging result in a change in care? ($n = 41$)				1.0000[*]
Yes	3 (7.3)	3 (7.5)	0	
No	38 (92.7)	37 (92.5)	1 (100)	

IQR = interquartile range; AMA = against medical advice; ICU = intensive care unit.
Data are *n* (%) unless otherwise stated. Percentages might not add to 100% because of rounding.
[*] Fisher's exact test used to calculate *P*-value.
[†] Mann–Whitney *U*-test used to calculate *P*-value.

performed per patient within 30 d of admission (1.63 pre-guideline *versus* 1.06 post-guideline). Of the 41 patients who received a repeat CT (31.1%), 40 patients were pre-guideline and one was post-guideline; all of which, per guideline, could have been a rbMRI. Repeat CT resulted in a change in care for only three patients (7.5%) without any missed injuries, see Table 2.

The median length of stay decreased after guideline implementation, although it did not reach statistical significance (2.5 *versus* 2.0). In addition, after implementation, there was an increased trend toward sending patients home directly from the emergency department (0.8% *versus* 6.3%), without readmission.

Discussion

The use of imaging in the management of pediatric trauma patients is an important target for quality improvement initiatives. Unnecessary scans dramatically increase costs and complexity of care and expose children to radiation without conferring any medical benefit. By using a multidisciplinary approach and drawing from the increasing volume of published work in this area from recent years, we implemented a guideline that has significantly reduced the number of head imaging performed on pediatric trauma patients at our institution. The consequent reduction in radiation exposure and resource consumption has reduced costs and improved satisfaction without compromising care.

The development and implementation of our pilot radiation reduction guideline required input from relevant parties, including radiology, neurosurgery, pediatric trauma, and adult trauma. It was essential to obtain buy-in from these groups to ensure successful implementation. This was part of a larger culture change at our institution involving a shift to avoiding unnecessary radiation. Since 2016, our institution has performed several radiation reduction quality improvement projects including limiting radiation in our pediatric trauma patients. In 2017, our focus was on the overutilization of head CT scans in this population. Pediatric Emergency Care Applied Research Network criteria were made standard by our pediatric emergency room colleagues for the initial head evaluation. However, because we are partnered with a larger adult trauma system, the utilization of head CT scans for follow-up evaluation was considered automatic at the 6-h period. We used this pilot study to gather evidence to support our conclusion of overutilization. With the initial data gathered, we were able to establish a work group of key stakeholders from pediatric trauma surgery, adult trauma surgery, neurosurgery, radiology, and general surgery residents to discuss these findings and brainstorm reduction strategies. As many of these providers are primarily not pediatric, concerns regarding limited imaging needed to be discussed and either validated or debunked using evidence-based medicine and best practices from other institutions. First, we agreed that not all patients with head injury findings needed follow-up imaging; thus, a protocol for repeat head imaging was established, seeFigure . Within this protocol, it was agreed that if repeat imaging was needed, that rbMRI would be used as first-line therapy in the effort to limit radiation exposure. Next, rbMRI was a new technology to our institution and not every neuroradiologist was comfortable with its use in children. It was agreed that this would be used for follow-up scans only and not for initial evaluation, see Figure. At the completion of the protocol, the stakeholder representatives were responsible for educating the members of their divisions and for addressing their concerns. The protocol adherence was evaluated monthly, and any unnecessary repeat head CT scan was discussed at our monthly trauma meetings and re-education was performed. Because of the dedicated involvement of the

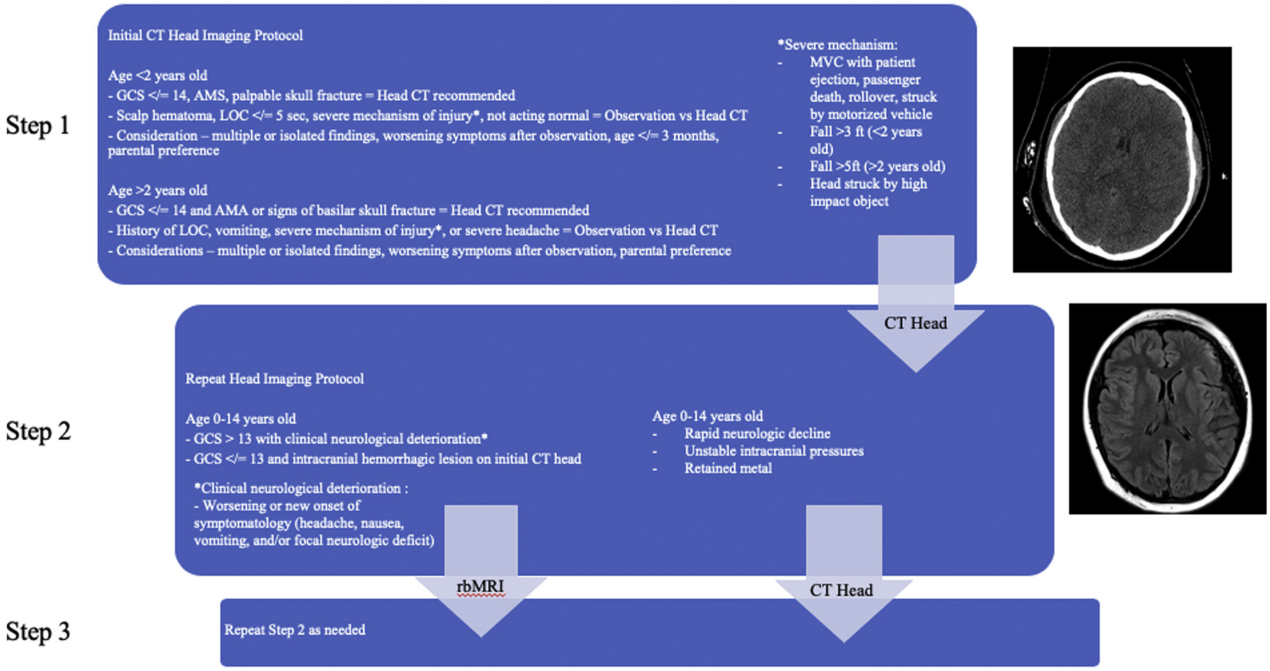

Fig – Visual representation of the pilot radiation reduction protocol created for pediatric head injury. Step one represents our criteria used for initial CT head imaging when a pediatric patient presents for trauma evaluation. Step two represents this study addressing the repeat imaging used in pediatric patients with diagnosed head trauma. Step three is to be used as needed. (Color version of figure is available online.)

stakeholder representatives, failure to adhere to the new protocol was limited, but when noted, it was usually due to lack of education or comfort with new technology. This quality improvement initiative has proved to inspire larger-scale change as we have observed subsequent reductions in adult trauma CT utilization as well.

There is a growing body of evidence demonstrating that pediatric patients are particularly susceptible to increased risk of malignancy because of radiation exposure.[2,3] Specifically, children who undergo head CT are at an increased risk of developing brain tumors and thyroid tumors.[2,3] Although the lifetime risk of tumor induction attributable to CT is minimal for a single scan, it is dose dependent and can therefore quickly multiply with successive scans in the setting of a trauma patient.[3] CT imaging performed at our institution for pediatric patients is based on the patient's age and head size. The age ranges include 0-12 mo, 1-3 y, 3-5 y, 5-8 y, 9-15 y, and then adult. The individual radiation dose follows a protocol for the number of CT sections required for head size, and it is customized for each patient. The 0-12 mo age range exposes the patient to less than 315.93 milligrays, and the adult range exposes the patient to approximately 829.36 milligrays. rbMRI does not expose the patient to any radiation. Before the implementation of our guideline, many patients underwent routine repeat head CT scans, some of which led to further unnecessary scanning to evaluate for growing bleeds that would not have impacted clinical care. The increased size of a bleed is not a reliable predictor of clinical progression.[13]

The effectiveness of the guideline in reducing both the percentage of patients receiving follow-up scans and the average number of imaging studies performed per patient has benefits beyond reducing radiation. The decrease in length of stay after guideline implementation is desirable not only for reducing resource consumption and cost, but also for improving patient and provider satisfaction.[20] In addition, the charge for a head CT without contrast at our institution is $3,415, whereas the cost of an rbMRI is $1160. Assuming a similar percentage across study periods of patients that will be indicated for repeat imaging, and assuming that this imaging could be rbMRI, the guideline should theoretically decrease charges by an average of $927.68 per patient. The small size of our post-guideline sample limited our ability to verify this prediction.

Importantly, there were no patients in the pre-guideline or post-guideline periods who underwent an operation or were readmitted for an event that would have been prevented by a repeat imaging study. Moreover, only three repeat CTs from the pre-guideline period resulted in an operation, and the repeat scans would have been indicated by the guideline.

It is worth noting that some studies have recommended that clinical monitoring replace repeat head imaging for patients with moderate (GCS 8-13), in addition to mild (GCS 14-15), TBI.[9,10] The evidence in support of this is not strong, and the Italian guidelines on pediatric TBI management recommend repeat head imaging for all patients with GCS $\leq$13 and an intracranial bleed.[16] Our guideline follows these recommendations.

The other benefit of the guideline is that it recommends rbMRI be used in lieu of head CT for repeat imaging. Several studies have demonstrated the effectiveness of rbMRI for detecting intracranial injuries, with some authors suggesting it is more sensitive than head CT.[7,8,17,18] In the setting of pediatric head injury, MRI has long been held as preferable to CT in terms of study quality and radiation exposure, but its utility has been limited by the time and sedation required.[1,21] rbMRI has eliminated these barriers while preserving much of the image quality. It has been proposed that rbMRI could also replace head CT for initial evaluation of head injuries, but our institution was initially limited by experience and comfort level with using this technology to determine acute clinical care decisions. With the success of this guideline, we hope to expand the use of rbMRI in our pediatric population.

Among the post-guideline patients in our study, none received an rbMRI. We encountered six other patients who received rbMRIs after initial head CT scans for various reasons, but all were excluded because of immediate operations, scans performed for evaluation of pretrauma conditions, scans performed at outside institutions, or normal initial head CT scans. This suggests that our study underestimates the impact of the guideline on limiting radiation because the focus of the present study is on eliminating routine but unnecessary repeat imaging, rather than on the replacement of head CT with rbMRI. Nevertheless, the single repeat imaging study in the post-guideline period was a head CT scan that could have been replaced with rbMRI. Further review is needed to evaluate adherence to this aspect of the guideline.

This study has several limitations that deserve mention. The retrospective nature of the study may have limited our ability to determine the necessity of the repeat scan. It is possible that we were unable to identify neurologic changes that were present in a patient, but not clearly included in notes. Furthermore, there appeared to be variability in GCS measurements among providers, which brings into question the reliability of strict GCS cutoffs.

Another substantial limitation is the small sample size, particularly in the post-guideline period. The post-guideline patients had less severe head injuries requiring less initial scans, thus reducing the percentage of patients who were indicated for repeat imaging. As noted, only one patient who did not meet exclusion criteria received an indicated repeat imaging, and there were otherwise no patients with an intracranial bleed and either neurologic changes or a GCS of less than 14. This study was unable to capture the true use of rbMRI because of the patients who were excluded for workup at an outside hospital and/or child abuse. Because of these limitations, we define this as a pilot study warranting prospective analysis through a significantly larger cohort to further support our positive findings.

Conclusion

Using an interdisciplinary approach, we identified an overutilization of CT among pediatric trauma patients at our institution and developed a guideline aimed at reducing both the quantity of patients receiving CT and the number of CT scans performed on each patient. On review, the implemented guideline has succeeded in these areas without compromising care, thereby reducing the excess radiation exposure, cost, and inconvenience associated with unnecessary CT use. However, an opportunity for investigation exists to determine the safety and utility of using rbMRI as an initial imaging modality for pediatric head trauma.

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Authors' contributions: M.L., R.S., M.D., and M.B worked in collaboration to develop pediatric guidelines for repeat head imaging in the setting of traumatic injury to reduce radiation exposure. T.H., R.A., S.A., M.D, and M.B. performed a retrospective chart review from January 1, 2013 to June 15, 2019 to evaluate the impact these guidelines had on repeat head imaging. T.H., R.A., and M.B. summarized the results of this study in the manuscript that follows.

Disclosure

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article. This initiative was presented at the Association for Academic Surgery's 15th Annual Academic Surgical Congress on Thursday, February 6th, 2020 in Orlando, Florida.

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