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BIG Kids: Application of a modified brain injury guideline in a pediatric trauma center

Allison G. McNickle[a,*], Stephanie A. Jones[a], Mais Yacoub[b], Stephanie M. Streit[a], Dina Bailey[c], Judith Ben Ari[b], Douglas R. Fraser[a]

[a] Department of Surgery, Kirk Kerkorian School of Medicine at UNLV, 1701 West Charleston Blvd, Suite 490, Las Vegas, NV 89102, USA
[b] Pediatric Critical Care Medicine, University Medical Center of Southern Nevada, 1800 West Charleston Blvd, 4th Floor Trauma Building, Las Vegas, NV 89102, USA
[c] Trauma Administration, University Medical Center of Southern Nevada, 1800 West Charleston Blvd, 5th Floor Trauma Building, Las Vegas, NV 89102, USA

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ABSTRACT

Background: Brain Injury Guidelines (BIG) were developed to stratify traumatic brain injuries (TBIs) by severity to decrease unnecessary CT imaging and neurosurgical consultation in low-risk cases. This study evaluated the potential effect of a modified pediatric BIG (pBIG) algorithm would have on resource utilization.

Methods: Isolated TBIs (<18 years) were queried from our Pediatric Trauma Registry from 2017 to 2020. Injuries were classified as mild (pBIG 1), moderate (pBIG 2), or severe (pBIG 3) based on neurologic status, skull fractures, size, and the number of bleeds. Modifications from the institutional adult algorithm were upgrading <4 mm epidural hematomas to pBIG 2 and eliminating interfacility transfer as a pBIG 2 criteria. The proposed pBIG 1 and 2 care plans do not include routine repeat CTs or neurosurgical consultation.

Results: A total of 314 children with a mean age of 4.9 years were included. Skull fractures (213, 68%) and subdural hematomas (162, 52%) were the most common injuries. 89 (28%) children had repeat head CTs (2 (7%) pBIG 1, 26 (25%) pBIG 2, 61 (34%) pBIG 3). Neurosurgical consultation was obtained in 306 (98%), with 50 (16%) requiring intervention (1 (1%) pBIG 2 and 49 (27%) pBIG 3). Following the proposed pBIG would decrease neurosurgical consults to 181 (58%) and repeat CTs to 63 (20%). Following the algorithm, 91 (29%) kids would have been admitted to a higher level of care and 45 (14.3%) to a lower level.

Conclusions: Implementation of our pBIG algorithm would decrease neurosurgery consults (40% reduction) and repeat head CTs (29% reduction).

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1. Introduction

The worldwide incidence of pediatric traumatic brain injury (TBI) is estimated at 47–280 per 100,000 children, with greater than 80% classified as mild TBI [1]. In 2014, there were over 812,000 TBI-related emergency department visits, 23,000 hospitalizations, and 2500 deaths among children in the United States [2]. Emergency department visits related to pediatric TBI have increased relating to concussions and mild TBIs, rather than severe TBI [3]. The management of this large spectrum of pediatric TBIs continues to evolve. The Pediatric Emergency Care Applied Research Network (PECARN) has developed a set of criteria to identify children at low risk for clinically significant TBIs that may avoid computerized tomography (CT) imaging [4]. For children with mild TBI and a positive head CT, repeat imaging is not indicated in the absence of clinical deterioration [5–7]. Furthermore, other studies have elucidated that many mild pediatric TBIs can be managed without transfer to a pediatric trauma center [8,9].

For adults diagnosed with a radiographic TBI, the Brain Injury Guidelines (BIG) stratify the severity to reduce resource utilization in lower-risk cases. Intensive care unit (ICU) admission, neurosurgical consultation, and interval repeat head CT are reserved for BIG 3 patients, the most severe injuries based on abnormal neurologic exam, intoxicants, anticoagulant use, and bleed size/number. Those

Abbreviations: BIG, brain injury guideline; CT, computerized tomography; ED, emergency department; EDH, epidural hematoma; EVD, extra ventricular drain; GCS, Glasgow coma scale; ICP, intracranial pressure; ICU, intensive care unit; IMC, intermediate care; IPH, intraparenchymal hemorrhage; IQR, interquartile range; IVH, intraventricular hemorrhage; LOS, length of stay; OR, operating room; pBIG, pediatric brain injury guideline; PECARN, pediatric emergency care applied research network; SAH, subarachnoid hemorrhage; SD, standard deviation; SDH, subdural hematoma; TBI, traumatic brain injury.

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* Corresponding author at: Department of Surgery, Kirk Kerkorian School of Medicine at UNLV, 1701W. Charleston Blvd, Suite 490, Las Vegas, NV 89102.
E-mail address: allison.mcnickle@unlv.edu (A.G. McNickle).

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Table 1
Modified pediatric brain injury guidelines.

Pediatric brain injury guidelines			
Variable	pBIG 1	pBIG 2	pBIG 3
GCS	15	13–14	≤12
Neurologic Exam	Normal	Normal	Focal
Skull fracture*	No	Non-depressed	Depressed
EDH	No	<8 mm	≥ 8mm
SDH	≤ 4 mm	5–7 mm	≥ 8mm
IPH	≤ 4 mm, in 1 location	5–7 mm and/or 2 locations	≥ 8 mm or multiple locations
SAH	Trace	Localized	Scattered
IVH	No	No	Yes
Therapeutic Plan			
Hospitalization	Pediatric ED x 6 h or Pediatric floor x 23 h	Pediatric IMC unit	Pediatric ICU
Frequency of neuro checks	Every 4 h	Every 2 h	Every 1 h
Repeat head CT	No	No	Per neurosurgery
Neurosurgery consult	No	No	Yes

GCS, Glasgow Coma Scale; EDH, epidural hematoma; SDH, subdural hematoma; IPH, intraparenchymal hematoma; SAH, subarachnoid hemorrhage; IVH, intraventricular hemorrhage; ED, Emergency Department; IMC, intermediate care unit; ICU, intensive care unit.
* Non-depressed skull fractures without intracranial hemorrhages are managed as part of a separate pediatric pathway.

with mild or moderate injuries (BIG 1 and 2) do not receive routine neurosurgical consultation or repeat head CTs [10]. Subsequent research has suggested that pediatric TBIs meeting BIG 1 criterion can be safely managed without repeat head CTs and limited neurosurgical consultations [11,12]. The purpose of this study is to evaluate the resource utilization of a proposed pediatric BIG (pBIG) algorithm using a retrospective cohort of patients diagnosed with TBI. We hypothesize that the number of repeat head CTs, neurosurgical consultations, and ICU admissions would decrease with implementation.

2. Methods

The institutional review boards at the University Medical Center of Southern Nevada (Las Vegas, NV, UMC-2020–334) and the Kirk Kerkorian School of Medicine at the University of Nevada-Las Vegas (1701356-2) approved this protocol. The hospital is an American College of Surgeons-verified and Nevada state-designated Level 1 Adult Trauma Center and Level 2 Pediatric Trauma Center. This was a retrospective review of pediatric TBIs from January 2017 through December 2020. Patients 18 years and older, those with multisystem trauma, death before hospital admission, penetrating head injury, and incomplete records were excluded. The outcome of interest was the change in resource utilization, specifically neurosurgical consultation and repeat head CT, with the implementation of a pediatric BIG algorithm.

Datasets included age, gender, admission Glasgow Coma Scale (GCS) and neurologic exam (normal vs. abnormal), and transfer from an outside facility. Information on the TBI was abstracted, including type and size of hemorrhage, presence of a skull fracture (non-depressed or depressed), repeat head CTs and change from prior imaging, neurosurgical consultations, and interventions. Hospital data included admission level of care, length of stay (LOS, as 30-day hospital free days), emergency department (ED) visits or readmissions, and mortality.

Our adult trauma center adopted an institutional Brain Injury Guideline in June 2017, based upon the algorithm proposed by Joseph et al. [10]. This guideline was modified for use in the local pediatric population (pBIG) by a multidisciplinary team of acute care surgeons, pediatric surgeons, pediatric intensivists, pediatric emergency medicine physicians, and neurosurgeons. Children were classified as pBIG 1 (mild), pBIG 2 (moderate), and pBIG 3 (severe) injuries based on neurologic exam, skull fractures, hemorrhage size, type, and number (Table 1). For our pediatric population, further modifications included upgrading all small epidural hematomas to pBIG 2 and eliminating transfer from another facility as a pBIG 2 criterion. As epidural hematomas carry a higher risk of clinical deterioration [13], they warrant closer observation. Locally, greater than half of children with TBIs are transferred from other facilities. Transfer status was eliminated as a criterion in favor of the child's clinical condition. Given an existing institutional pathway for isolated linear (non-depressed) skull fractures without intracranial hemorrhage, these children were excluded from this guideline. Previously, pediatric TBIs were managed at the discretion of the admitting trauma surgeon and pediatric intensivist without a clearly defined protocol. After implementation, practitioners use the child's age-appropriate GCS, neurologic exam, and imaging finding to determine the pBIG treatment plan to follow. Children with concern for non-accidental trauma receive additional focused evaluation. Continuing education has been provided that clinical judgement or special circumstance supersedes the proposed guideline.

Statistical analysis was performed with Stata Version 14 (College Station, TX). Descriptive variables are reported as the number of patients and percentage of the cohort. Non-normally distributed data are presented as medians with interquartile ranges (IQR). Hospital-free days were calculated with a 30-day benchmark. A Kruskal Wallis test was conducted to investigate subgroup differences in age and hospital-free days. Categorical differences between pBIG subgroups were compared with Chi-square/Fisher exact test. Primary outcomes of interest were the change in frequency of neurosurgical consultation and repeat head CTs in our pediatric TBI cohort. A secondary outcome of interest was the change in ICU admissions with guideline implementation. Significance was set at a p-value of less than 0.05. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for cohort studies [14].

3. Results

3.1. Demographics

From 2017 through 2020, a total of 561 children under 18 years of age with a head injury were managed at this Level 2 pediatric trauma center. After excluding 126 (74.6% due to multisystem trauma) and 121 with isolated skull fractures, there were 314 children with intracranial hemorrhages that met inclusion criteria. Fig. 1. The median age of the cohort was 2.0 years (IQR 0.5 to 8.8) with 178 males (56.7%). Two-hundred and eight (66.2%) of patients were transferred in from other facilities.

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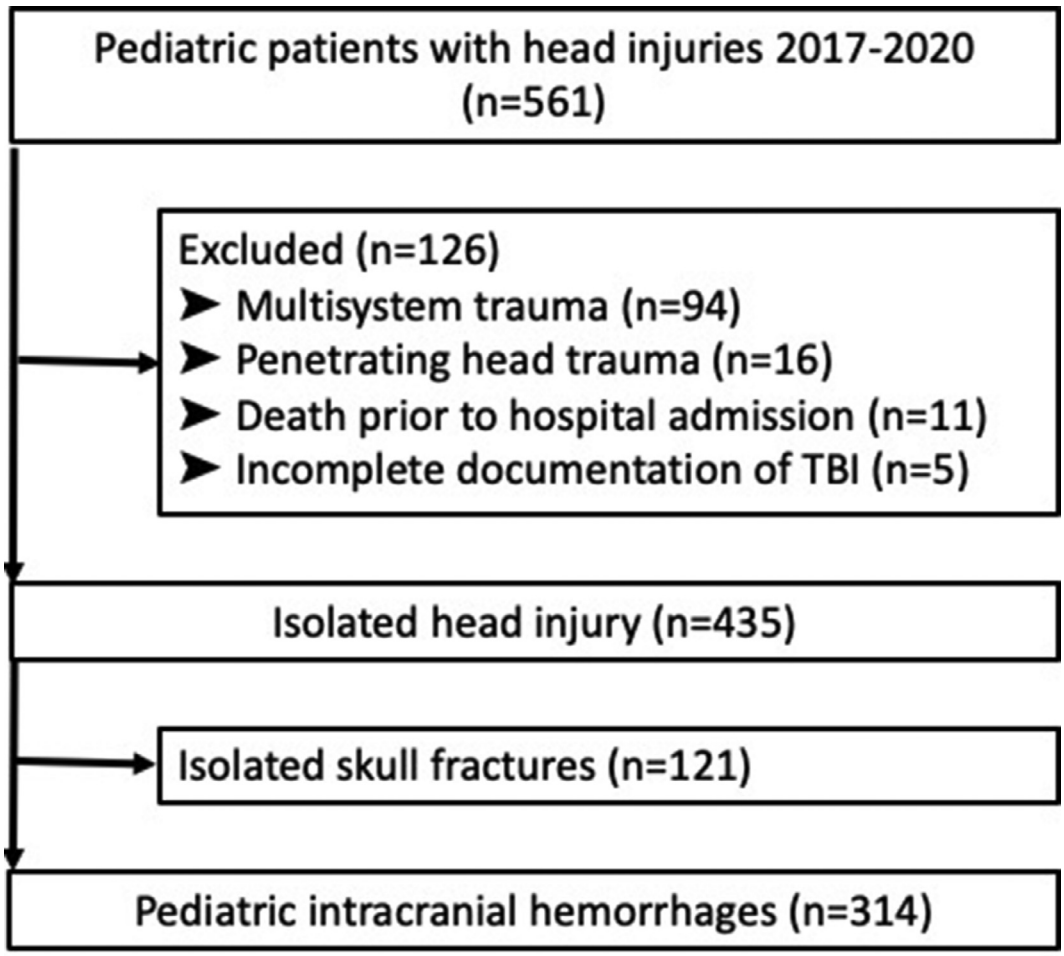


Fig. 1. Inclusion of children with traumatic brain injuries.

3.2. TBI characteristics and management

Twenty-nine children (9.2%) had injuries classified as pBIG 1, with 104 pBIG 2 (33.1%) and 181 (57.6%) pBIG 3 TBIs. Age ($p = 0.95$) and gender distribution ($p = 0.18$), as well as the percentage of the subgroup transferred from other facilities ($p = 0.55$), were not different between pBIG groups. Skull fractures were present in 67.8% ($n = 213$) of this cohort. Subdural hematomas (162, 51.6%) were the most common type of intracranial bleed followed by subarachnoid hemorrhages (72, 22.9%) (Table 2). Repeat head CTs were obtained in 122 children (38.9%), 2 pBIG 1, 26 pBIG 2, and 94 pBIG 3. Thirty-three (27.0%) were obtained postoperatively, and 19 of 89 (15.6%) serial scans (not post-op) demonstrated progression of the TBI. Worsening on repeat head CT was seen in 2 children in pBIG 2: with 1 child receiving an extraventricular drain (EVD) for increasing hydrocephalus. Neurosurgical consultation was obtained in 306 children (97.5%) with 50 (16.3%) of the total cohort requiring intervention. Forty-nine of 50 interventions (98.0%) were performed in children with pBIG 3 TBI (Table 3).

3.3. Outcomes

All children with isolated head injuries were admitted to the hospital, with 18 (5.7%) going directly to the operating room, 106 (33.8%) to the intensive care unit, 153 (48.7%) to the intermediate care unit, and 37 (11.8%) to the pediatric floor. Median hospital-free days were 28 (IQR 27 to 29) with pBIG 3 patients having significantly fewer hospital-free days ($p<0.01$). Table 4. Post-discharge CTs were obtained in 12 (3.8%) kids and 22 (7.0%) had a post-discharge ED visit or readmission. Thirteen children (4.1%) died, all having severe (pBIG 3) TBIs.

3.4. Resource utilization

Following the pBIG protocol would eliminate automatic neurosurgical consultation and repeat CT scans in pBIG 1 and 2 injuries. Neurosurgical consultations would decrease from 306 to 181 (40.8% reduction) and serial CT imaging from 89 to 63 (29.2% reduction). Two patients in pBIG 2 with clinical change accompanied by progression on repeat CT and neurosurgical consultations were not counted in the reductions. Based on this clinical decision tool, 45 kids (14.3%) would have been admitted to a lower level of care and 91 (29.0%) to a higher level of care. At this institution, pediatric intermediate care and ICU utilize the same pool of beds, with a different frequency of nursing care (e.g. neurologic checks every 1 hour vs. every 2 h). The net effect of the level of care changes would be an additional 8 children being admitted to this unit over the 4-year study period (Table 4).

4. Discussion

TBI is a common diagnosis encountered at trauma centers and community hospitals treating children, spanning a spectrum of disease and management. The purpose of this study was to evaluate how a proposed pediatric BIG algorithm would affect the use of neurosurgical consultations and repeat head CTs. Specific

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Table 2
Pediatric TBI demographics and injuries.

	All (n = 314)	pBIG 1 (n = 29)	pBIG 2 (n = 104)	pBIG 3 (n = 181)
Age, years, median [IQR]*	2.0 [0.5–8.8]	4.1 [0.3–13.4]	1.8 [0.6–7.7]	2.1 [0.5–8.3]
Males, n (%)*	178 (56.7)	12 (41.4)	58 (55.8)	108 (59.7)
Admission GCS, n (%)				
3–8	31 (9.9)	0	0	31 (17.1)
9–12	15 (4.8)	0	0	15 (8.3)
13–14	31 (9.9)	0	13 (12.5)	18 (10.0)
15	237 (75.5)	29 (100)	91 (87.5)	117 (64.6)
Abnormal neuro exam, n (%)	54 (17.2)	0	0	51 (28.2)
Transfer, n (%)*	208 (66.2)	17 (58.6)	72 (69.2)	119 (65.8)
Skull fracture, n (%)	213 (67.8)	–	81 (77.9)	132 (72.9)
Depressed, n (%)	91 (29.0)	–	–	91 (68.9)
Non-depressed, n (%)	122 (38.9)	–	81 (100)	41 (31.1)
Epidural hematoma, n (%)	50 (15.9)	0	16 (15.4)	34 (18.8)
Subdural hematoma, n (%)	162 (51.6)	16 (55.2)	59 (56.7)	87 (48.1)
Intraparenchymal hemorrhage, n (%)	47 (15.0)	1 (3.5)	15 (14.4)	31 (17.1)
Subarachnoid hemorrhage, n (%)	72 (22.9)	12 (41.4)	21 (20.2)	39 (21.6)
Intraventricular hemorrhage, n (%)	10 (3.2)	0	0	10 (5.6)

* Differences in median age, gender distribution and percent of group transferred from an outside facility were not statistically different between pBIG subgroups (p>0.05). GCS, Glasgow Coma Scale; IQR, interquartile range; n, number.

Table 3
Imaging and neurosurgical care of pediatric isolated traumatic brain injuries.

	All (n = 314)	pBIG 1 (n = 29)	pBIG 2 (n = 104)	pBIG 3 (n = 181)
Repeat head CT, n (%)*	122 (38.9)	2 (6.9)	26 (25.0)	94 (51.9)
Progression on repeat CT, n (%)†				
Yes	19 (15.6)	0	2 (7.7)	17 (18.1)
No	70 (57.4)	2 (100)	24 (92.3)	44 (46.8)
Post-op	33 (27.0)	–	0	33 (35.1)
Neurosurgery consult, n (%)	306 (97.5)	27 (93.1)	100 (96.2)	179 (98.9)
Intervention, n (%)‡	50 (16.3)	0	1 (1.0)	49 (27.4)
Craniectomy	7	–	0	7
Craniotomy/Burr hole	38	–	0	38
EVD	2	–	1	1
ICP monitor	3	–	0	3

* Differences in the frequency of repeat head CTs is significant at the p<0.01 level. The observed frequency of neurosurgical consultation was not different between pBIG groups. (p = 0.11).
† Denominator is repeat head CTs.
‡ Denominator is neurosurgery consults; CT, computed tomography; EVD, extraventricular drain; ICP, intracranial pressure monitor.

Table 4
Outcomes in pediatric isolated traumatic brain injuries.

	All (n = 314)	pBIG 1 (n = 29)	pBIG 2 (n = 104)	pBIG 3 (n = 181)
Admission Location, n (%)				
OR	18 (5.7)	0	0	18 (9.9)
ICU	106 (33.8)	⬇ ***3 (10.3)***	⬇ ***24 (23.1)***	79 (43.7)
IMC	153 (48.7)	⬇ ***18 (62.1)***	73 (70.2)	***62 (34.3)*** ⬆
Floor	37 (11.8)	8 (27.6)	***7 (6.7)*** ⬆	***22 (12.2)*** ⬆
Hospital-free days, median [IQR]*	28 [27–29]	29 [29–29]	29 [28–29]	27 [24–29]
CT post-discharge, n (%)	12 (3.8)	0	5 (4.8)	7 (4.2)
ED visit or readmission, n (%)	22 (7.0)	0	11 (10.6)	11 (6.6)
Mortality, n (%)	13 (4.1)	0	0	13 (7.2)

In the proposed algorithm, children marked ⬇ would be admitted to a lower level of care based on their neurological exam and bleed characteristics. Conversely, patients marked ⬆ would be admitted to a higher level of care.
* Difference in hospital-free days is significant at the p<0.01; OR, operating room; ICU, intensive care unit; IMC, intermediate care unit; IQR, interquartile range; n, number; ED, emergency department.

modifications of our adult BIG guideline were made to address the local pediatric TBI cohort and health system. This Children's Hospital, as the only designated Pediatric Trauma Center in Nevada manages a significant volume of TBIs, with over half being transferred from other facilities. The most common injures identified were skull fractures and subdural hemorrhages. Implementation of the pBIG criteria would allow the management of mild and moderate isolated TBIs by a multidisciplinary team of acute care surgeons, pediatric emergency medicine physicians, and pediatric intensivists. Forty-two percent of our pediatric TBI population, or approximately 3 cases per month, would fall into the mild and moderate categories.

A modified BIG algorithm has been used since June 2017 for adult patients cared for at our trauma center. A review of the adult experience thus far demonstrated a reduction in neurosurgery consults, ICU admissions, and repeat imaging without an increase in mortality [Kuruvilla et al., unpublished data]. Several adjustments were made in developing the pBIG, including upgrading small (1–4 mm) epidural hematomas to a pBIG 2 treatment plan and eliminating transfer from an outside facility as a pBIG 2

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criteria. Transfer from another hospital is an adult BIG criterion at this institution given the high frequency of admission to internal medicine for isolated mild TBIs.

Despite the development of the PECARN clinical prediction rules to identify children at low risk of clinically significant TBI, referring hospitals are observed to obtain head CTs at a high frequency [4,9]. One Level I pediatric trauma center reported only 17% of transfers had a radiographically apparent TBI, with 6% being considered clinically significant [15]. Management of children transferred to a Pediatric Emergency Department with a mild head injury most frequently includes neurosurgical consultation (57%) and imaging (27%), but rarely requires neurosurgical intervention (1.3%). Two-thirds of this study cohort were able to be discharged directly from the ED [9]. Mowbray et al. defined avoidable transfers for a mild head injury as not needing procedural sedation, anticonvulsants, subspecialist consultation, ICU admission or hospital admission for more than 2 nights, intubation, or surgical intervention. In their cohort, 42% of transfers were avoidable, with children less than 2 years of age (OR 1.75) and low-risk stratification (OR 1.66) having the greatest odds of avoidable transfer [8]. Locally, two-thirds of children presented as referrals. The inclusion of this as an automatic pBIG 2 would have up-stratified nearly 60% (17/29) of pBIG 1. Rather, this element was eliminated in favor of the clinical characteristics.

Epidural hematoma is recognized to carry an elevated risk of clinical deterioration. A multicenter review of adult TBIs stratified by the original BIG found epidural hematoma was an independent predictor (OR 6.73) of progression in BIG 1/2 patients. Thus, the authors recommended upgrading all epidurals to BIG 3 classification [13]. Studies of pediatric epidural hematomas suggest that the absence of mass effect, no neurologic deficits, and volume less than 15 mL are likely to be successfully observed [16]. Bejjani et al. observed that the criteria of epidural thickness greater than 18 mm, midline shift of greater than 4 mm, moderate to severe mass effect, and temporal location correctly predicted therapy in 31 of 33 patients [17]. Similarly, Chen et al. identified in patients with a GCS 13–15, epidural thickness of greater than 15 mm and a midline shift of greater than 5 mm often required surgical evacuation within 3 days [18]. Binder et al. reviewed 41 children presenting with epidural hematoma with 49% conservatively managed, 24% undergoing operative intervention, and 27% requiring delayed surgery. Children requiring surgical intervention had low GCS scores, a midline shift greater than 5 mm, and compressed or closed basal cisterns. No differences were observed in the outcomes of the immediate and delayed operative groups [19].

In our cohort, there were no epidural hematomas of 1–4 mm in size and 16 (5.1%) of 5–7 mm thickness seen in 4 years. Based on the pBIG tool, these would be admitted to the Intermediate Care Unit with clinical neurological exams every 2 h. In the setting of small epidurals with a GCS of 13 to 15, this was felt to be an appropriate frequency of examination to detect clinical deterioration. A previous study observed that all children with mild TBI requiring neurosurgical intervention for progression were identified through clinically significant neurologic change rather than repeat imaging [7]. Upgrades in care plans based upon clinical factors have been encouraged with the implementation of these guidelines.

Management of mild pediatric TBIs using clinical algorithms is safe and resource effective. Studies of the Cincinnati Children's Hospital Medical Center *Minor Head Injury Algorithm* demonstrated a reduction in the mean number of head CTs, length of stay and hospital charges after implementation [5]. Additionally, children with progression to intervention were identified on clinical neurologic exam rather than repeat imaging [7]. Similarly, the Brain Injury Guidelines appear applicable in the pediatric population. Applying Joseph et al.'s adult BIG 1 criterion to a pediatric cohort safely reduced the number of repeat head CTs and neurosurgical consultations. Seven children managed without neurosurgical consultation were compared to 21 with neurosurgical involvement, with no differences observed in unadjusted outcomes [12]. Similarly, a propensity-matched cohort of pediatric BIG 1 TBI managed without neurosurgical consultation had a decrease in the frequency of repeat head CTs without change in 30-day outcomes [11]. Other centers have identified few ICU care needs in mild pediatric TBI. A study of infants and young children with mild TBI at a Level 1 pediatric trauma center found nearly half (48%) were admitted to the ICU for monitoring with less than 10% overall requiring ICU-specific interventions, defined as non-elective intubation, neuromonitoring after neurosurgical procedures and management of seizures or status epilepticus. Risk factors for intervention included loss of consciousness or seizures, neurologic deficits, and extra-axial hemorrhage. The only clinical predictor of ICU admission in this cohort was GCS <15 in the trauma bay; rather the decision for ICU admission was frequently made on imaging findings [20]. Within our cohort, there were 2 patients classified as pBIG2 that had repeat head CTs with worsened appearance. One child ultimately required an EVD for increasing hydrocephalus. These types of cases, those outside of the pBIG3 treatment plan requiring ICU upgrade, repeat head CT or intervention, will be scrutinized during the implementation phase of the algorithm. Providers are routinely reminded that clinical concern supersedes the pBIG protocol. Upgrade to a higher level of care or neurosurgical consultation should be utilized in atypical cases.

This study has limitations as a retrospective chart review. We applied a newly developed guideline to a historical cohort to predict change in resource utilization after implementation. The true impact on resource utilization, potential for morbidity (e.g., progression of a pBIG 1/2 TBI) and guideline adherence can only be accurately assessed after adoption of the protocol in June 2021. Several datasets were excluded due to missing data and the exact indication for repeat head CTs (clinical change vs. planned follow-up) was often difficult to determine. This proposed pBIG algorithm is based on the local pediatric TBI population (a single level 2 pediatric trauma center with a tri-state catchment area for transfers) and practice style (no neurosurgery graduate medical education program); thus, may not apply to centers and systems with different populations or resources. Additionally, this institution has an intermediate care unit for monitoring of moderate TBIs, while other facilities may have only floor and ICU levels of care. The utility and safety of an intermediate level of care for neurological monitoring in moderate TBIs will be evaluated prospectively and may provide a novel option for other facilities in the management of pediatric TBI.

5. Conclusion

Implementation of this pediatric BIG algorithm would allow over 40% of these children to be managed by trauma surgeons and pediatric intensivists while reducing the number of neurosurgical consultations and repeat CT scans in children at low risk for clinical progression of their TBIs. A multicenter trial with a large cohort of children may further refine the management of mild to moderate pediatric TBIs without neurosurgical consultation.

Level of evidence

Level IV, Therapeutic/Care Management

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Conflict of Interest

There are no conflicts of interest with this work.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jpedsurg.2022.07.020.

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