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Small Change, BIG Impact: Proposal of the Brain Injury Guidelines for Kids (kBIG)

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A B S T R A C T

Background: The adult Brain Injury Guidelines (BIG) stratify patients with traumatic intracranial hemorrhage into one of three risk categories and supports management of lower risk traumatic brain injury (TBI) with minimal resources. While the BIG have been widely adopted by adult trauma centers, application to pediatric populations remains unvalidated. The objective of this study was to determine the efficacy of BIG in a pediatric trauma population and develop adapted criteria based on injury patterns that may be unique to children with TBI.
Methods: BIG was applied to a retrospective cohort of pediatric TBI patients, defined as <18 years old with skull fracture or intracranial hemorrhage on CT scan, from January 2018 to April 2024. Misclassification of BIG was defined as patients categorized as low- or moderate-risk who required neurosurgical intervention. Based on the performance of BIG, modifications were made to derive a pediatric-specific guideline, BIG for Kids (kBIG).
Results: 1894 patients were analyzed. The misclassification rate of BIG 1 and 2 was 0 % and 1.4 %, respectively. We derived kBIG, with modifications to the categorization of minor skull fracture, epidural hematoma, neurologic exam and injury mechanism, which improved the misclassification rate of kBIG 2 to 0.8 % and maintained a rate of 0 % for all low-risk patients.
Conclusions: We propose BIG for Kids, a modified version of the adult BIG for the management of TBI in pediatric patients. The kBIG was conservatively designed to ensure safety and to reduce unnecessary radiation exposure and resource utilization.
Level of evidence: Cohort study/IV.

1. Background

Traumatic brain injury (TBI) is the most common cause of pediatric injury and death worldwide [1]. Routine practice for pediatric patients with traumatic intracranial hemorrhage (ICH) includes transfer to a trauma center, repeat head computed tomography (RHCT), and neurosurgery consultation (NSC). With resource allocation at the forefront, there is an increasing focus on the judicious use of healthcare resources in managing TBI across all ages. In children, sufficient evidence exists to guide initial imaging decisions after head trauma [2] and there is a growing body of literature evaluating potentially avoidable transfers in mild TBI [3–7]. However, consensus on the stratification and management of mild to moderate pediatric TBI is lacking.

In 2013, the Brain Injury Guidelines (BIG) were proposed in adult trauma patients [8], which has since undergone multicenter validation [9]. Many trauma centers across the country have adopted these guidelines, and efforts to implement them across health systems and trauma networks are ongoing [10–15]. The BIG

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stratifies patients into one of three categories based on neurologic exam, preinjury anticoagulation, and radiographic findings. Low- (BIG 1) and moderate-risk (BIG 2) patients can be safely managed without RHCT, NSC, and, in some cases, hospital admission or transfer, representing a significant departure from historical practice. Recent single-institution reports have found that BIG may safely reduce RHCT, NSC, and admission in pediatric TBI populations [16–21].

We aimed to retrospectively apply the BIG, as described for adults, to a pediatric TBI population and hypothesized that it would safely reduce RHCT, NSC, and unnecessary hospital admissions in mild to moderate TBI. Additionally, we aimed to develop adapted criteria for kids based on injury patterns that may be unique to children with TBI.

2. Methods

2.1. Study design and population

Following exemption from the Institutional Review Board (#00176573), we performed a retrospective review of pediatric (<18 years old) trauma patients with TBI seen at a level 1 pediatric trauma center from January 2018 to April 2024. Initial data was queried from the trauma registry, followed by a comprehensive chart review. All patients with a blunt mechanism of injury and a head abbreviated injury scale (AIS) score ≥1 were captured. Patients were included in the analysis if there was a radiographic abnormality on head CT, defined as skull fracture and/or traumatic ICH. While not in the original BIG, isolated skull fracture (ISF) patients were included. Patients with a penetrating mechanism, no radiographically evident TBI, or ≥18 years were excluded.

2.2. Data points

Trained personnel abstracted data including age, sex, race, ethnicity, mechanism, transfer status, AIS scores, injury severity score (ISS), initial emergency department (ED) Glasgow Coma Scale (GCS), pupillary response, intoxication, and preinjury anticoagulation. Patients with AIS scores ≤1 in all non-head body regions were classified as isolated TBI. Medical records and CT head images for TBI-related data were reviewed, including ICH type, measurement in millimeters or sulci, and presence of skull fracture. Skull fracture was classified as minor (non-displaced or minimally displaced ≤1 cranium width) or displaced (>1 cranium width). Extra-axial hemorrhage was considered an epidural hematoma (EDH) if associated with skull fracture and subdural hematoma (SDH) if without. All CTs were initially read by and when necessary reviewed by board-certified pediatric radiologists.

2.3. Guideline application

We applied BIG (Table 1) to the study cohort, with the following working definitions [8]: abnormal neurologic exam was defined as ED GCS score ≤12, abnormal pupillary response, and focal neurologic examination. Preinjury anticoagulation included warfarin, direct oral anticoagulants, aspirin, or clopidogrel. The presence of multiple ICH types was categorized as BIG 3. Progression on RHCT was defined as either the appearance of new ICH or an increase in the size of initial ICH. Operative neurosurgical procedures included craniotomy, craniectomy, and/or external ventricular drain (EVD) or intracranial pressure monitor placement. We utilized a modification for subarachnoid hemorrhage (SAH) similar to previous reports to enhance reproducibility [14], which further defined “trace” as ≤3 sulci total, “localized” as >3 sulci and single hemisphere, and “scattered” as >3 sulci and bi-hemispheric.

Patients were first stratified by BIG score to determine the efficacy of categorization and management. The primary outcome was neurosurgical intervention in BIG 1 and 2 patients and the misclassification rate of the guideline. Secondary outcomes included RHCT, NSC, hospital admission, hospital transfer, length of stay (LOS), and return-to-ED visits. In addition, we considered how management of minor skull fracture with and without ICH was addressed by BIG, accounting for the increased incidence of skull fracture observed in children compared to their adult counterparts. Based on the initial performance of BIG and with input from pediatric neurosurgery, pediatric surgery, trauma surgery, and pediatric radiology, classification modifications were devised to generate Big for Kids, or kBIG (Table 3).

2.4. Statistical analysis

Data were analyzed using R software (version 4.4.1, R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics were performed on patient demographics, baseline characteristics, and clinical outcomes. Continuous variables were reported as medians with interquartile ranges, while categorical variables were presented as frequency and percentage. To test the hypothesis and evaluate whether the guideline could classify low-risk patients as not requiring hospitalization, the negative predictive value (NPV) and the misclassification rate were calculated based on need for neurosurgical intervention. Misclassification was defined as cases where patients categorized as low- or moderate-risk required neurosurgical intervention, potentially indicating inadequacies in the risk

Table 1
Original brain injury guidelines (BIG).

Variables	BIG 1	BIG 2	BIG 3
Loss of consciousness	Yes/No	Yes/No	Yes/No
Neurologic examination	Normal	Normal	Abnormal
Intoxication	No	Yes/No	Yes/No
Anticoagulation/antiplatelet	No	No	Yes
Skull fracture	No	Non-displaced	Displaced
Epidural hematoma	≤4 mm	5–7 mm	≥8 mm
Subdural hematoma	≤4 mm	5–7 mm	≥8 mm
Intraparenchymal hematoma	≤4 mm, 1 location	3–7 mm, 2 locations	≥8 mm, multiple locations
Subarachnoid hemorrhage	Trace	Localized	Scattered
Intraventricular hemorrhage	No	No	Yes
Therapeutic plan			
Hospitalization	Observation (6 h)	Yes	Yes
Repeat head computed tomography	No	No	Yes
Neurosurgery consultation	No	No	Yes

stratification process. True negatives were defined as BIG 1 patients who did not require neurosurgery, while false negatives were patients incorrectly classified as low-risk because of a subsequent neurosurgical intervention. The misclassification rate was calculated as false negatives divided by total low-risk sample size. We repeated the analysis on moderate-risk patients (BIG 2) and finally on kBIG, with low-risk defined as kBIG 0 and kBIG 1 and moderate-risk as kBIG 2. We implemented the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for reporting observational studies.

3. Results

3.1. Overall characteristics

A total of 5271 records were identified with TBI and 3377 were excluded due to the absence of positive CT findings. Therefore, 1894 patients were included in the analysis. The overall study population was on average 5.5 years old, 61 % male, 78 % Caucasian, and 72 % non-Hispanic. The mean ISS was 10, and the most common mechanism was fall (49 %), followed by motor vehicle collision

Table 2
Patient characteristics and outcomes based on the original BIG.

	All (N = 1455)	BIG 1 (n = 197)	BIG 2 (n = 566)	BIG 3 (n = 692)
Patient characteristics				
ED GCS				
3–8	268 (18)	0 (0)	0 (0)	268 (39)
9–12	73 (5)	0 (0)	0 (0)	73 (11)
13–14	177 (12)	19 (10)	78 (14)	80 (12)
15	937 (64)	178 (90)	488 (86)	271 (39)
Pupillary response				
Both	1397 (96)	196 (99)	566 (100)	635 (92)
One	17 (1)	0 (0)	0 (0)	17 (2)
None	39 (3)	0 (0)	0 (0)	39 (6)
Intoxication				
Yes	2 (0)	0 (0)	1 (0)	1 (0)
No	32 (2)	3 (2)	4 (1)	25 (4)
Anticoagulation				
Yes	2 (0)	0 (0)	0 (0)	2 (0)
No	1451 (100)	197 (100)	566 (100)	688 (99)
Skull fracture				
Yes	914 (63)	0 (0)	484 (86)	430 (62)
No	541 (37)	197 (100)	82 (14)	262 (38)
Intracerebral hematoma/hemorrhage				
Epidural hematoma	401 (28)	11 (6)	163 (29)	227 (33)
Subdural hematoma	780 (54)	119 (60)	311 (55)	350 (51)
Intraparenchymal hematoma	154 (11)	12 (6)	22 (4)	120 (17)
Subarachnoid hemorrhage	318 (22)	55 (28)	70 (12)	193 (28)
Intraventricular hemorrhage	6 (0)	0 (0)	0 (0)	6 (1)
Isolated TBI	1118 (77)	160 (81)	497 (88)	461 (67)
ISS	10 (9, 17)	9 (6, 11)	10 (9, 12)	17 (10, 26)
Transferred				
Yes	1068 (73)	145 (74)	405 (72)	518 (75)
No	387 (27)	52 (26)	161 (28)	174 (25)
Patient outcomes				
Repeat head CT				
Yes	688 (47)	42 (21)	213 (38)	433 (63)
No	767 (53)	155 (79)	353 (62)	259 (37)
Progression on repeat head CT				
Yes	177 (12)	1 (1)	30 (5)	146 (21)
No	511 (35)	41 (21)	183 (32)	287 (41)
Neurosurgical consultation				
Yes	1396 (96)	190 (96)	536 (95)	670 (97)
No	59 (4)	7 (4)	30 (5)	22 (3)
OR neurosurgery				
Yes	255 (18)	0 (0)	8 (1)	247 (36)
No	1200 (82)	197 (100)	558 (99)	445 (64)
Neurosurgical intervention				
Craniectomy	37 (3)	0 (0)	0 (0)	37 (5)
Craniotomy	123 (8)	0 (0)	4 (1)	119 (17)
ICP monitor (EVD, BOLT)	125 (9)	0 (0)	4 (1)	121 (17)
Admission				
ICU	601 (41)	17 (9)	90 (16)	494 (71)
Floor	854 (59)	175 (89)	466 (82)	193 (28)
None (discharged from ED)	20 (1)	5 (3)	10 (2)	5 (1)
Ventilator day	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 2)
LOS, day	2 (1, 5)	1 (1, 2)	1 (1, 3)	4 (2, 10)
ED bounce-back				
Yes	14 (1)	3 (2)	6 (1)	5 (1)
No	1441 (99)	194 (98)	560 (99)	687 (99)

All data are presented as frequency (%) except that ISS, Ventilator day and LOS are presented as median (interquartile range).
ED: emergency department; GCS: Glasgow coma scale; ISS: injury severity score; CT: computed tomography; OR: operating room; ICP: intracranial pressure; EVD: external ventricular drainage; BOLT: subdural screw; ICU: intensive care unit; LOS: length of hospital stay.

(26 %). The majority (73 %) were transferred in from referring facilities.

3.2. BIG application

The BIG score was applied to 1455 patients, excluding 439 patients with ISF (Table 2). No BIG 1 patient underwent neurosurgical intervention. There were 8 (1.4 %) BIG 2 patients who required neurosurgical intervention. Two patients with EDH and 5 with SDH underwent craniotomy. One patient with SAH had an EVD placed. All SDH patients had a non-accidental trauma (NAT) mechanism. No low-risk (BIG 1) patients required intervention, resulting in a NPV of 100 % and a misclassification rate of 0 %. The BIG missed 8 moderate-risk (BIG 2) patients, with a NPV of 98.6 % and a misclassification rate of 1.4 %.

Evaluating skull fractures, 802 (55 %) patients had minor fractures with concomitant ICH. Of those, 375 (47 %) were GCS 13–15 with diminutive ICH that otherwise met BIG 1 criteria and were categorized as BIG 2 solely for skull fracture. None underwent neurosurgical intervention. Isolated TBI was present in 227 of the skull fracture patients. All had a LOS of ≤2 days and 180 (79 %) had a LOS ≤1 day. The majority, 164 (72 %), did not get additional imaging.

There were 255 patients who required neurosurgical intervention, 247 (97 %) of which were BIG 3. Looking at hemorrhage type, there were 104 EDH patients (26 % of all EDH), and 72 SDH patients (9 % of all SDH) that required intervention. Of the 110 patients with displaced skull fractures, 45 (41 %) had an operative intervention. In the 122 patients with suspected or confirmed NAT, 30 (25 %) required operative intervention. Initial GCS 13–15 was documented in 109 (43 %) of the operative cases.

3.3. kBIG derivation

Based on these results, six major modifications were made to derive kBIG (Table 3, Fig. 1):

1. A kBIG 0 category was created for minor ISF in neurologically normal patients, with similar management recommendations to kBIG 1.
2. Minor skull fracture was downgraded to kBIG 1.
3. Small EDH defined as < 8 mm was upgraded to kBIG 2.
4. Suspected or confirmed NAT was added as kBIG 3.
5. The definition of normal neurologic exam required for kBIG 0 and 1 was changed to GCS 15 or baseline, and without requiring admission for headache or persistent nausea and emesis.
6. The 6-h observation period was removed from kBIG 0 and 1 management pathways.

3.4. kBIG application

After derivation, kBIG was applied to the entire study population with the inclusion of ISF (n = 1894) (Table 4). No kBIG 0 or 1 patients required neurosurgical intervention. There were three kBIG 2 patients who required neurosurgical intervention. Two patients with EDH and minor skull fracture underwent craniotomy: one was a 4-year-old with a 5 mm EDH that progressed to 12 mm on hospital day 1 and the other was a 10-year-old with 7 mm EDH that progressed to 11 mm by hospital day 4. The third operative case was an 8-year-old with a nondisplaced ISF involving the temporal bone with pneumocephalus. The neurologic exam included GCS 14 and intractable nausea and vomiting. A hospital day 1 event note reported a syncopal episode and fall, which preceded a neurologic decline. RHCT demonstrated a new 2 cm EDH requiring emergent craniotomy.

The kBIG accurately identified low-risk patients (kBIG 0 and 1) in whom resources can be safely minimized, with a NPV of 100 % and a misclassification rate of 0 %. Compared to BIG, kBIG reduced the misclassification rate for moderate-risk (kBIG 2) patients from 1.4 % to 0.8 %.

3.5. Resource utilization

The rates of RHCT and NSC were 41 % and 88 %, respectively. The application of kBIG could have potentially avoided 282 RHCT, or a 36 % total reduction. Across kBIG 0, 1 and 2, 873 patients received neurosurgical consultation, representing a potential 52 % total reduction. To evaluate potentially preventable admissions and transfers, 1467 (77 %) isolated TBI patients were considered. Of those, 558 (38 %) were kBIG 0–1 patients, 45 of whom were discharged from the ED. Thus, 513 patients could have potentially avoided admission, resulting in a 36 % admissions reduction. Of those, 367 could have potentially avoided transfer, representing a 26 % potential transfer reduction.

4. Discussion

We applied BIG to a pediatric TBI cohort to evaluate its efficacy. Application of the original BIG accurately predicted the need for neurosurgical intervention in BIG 1 patients. BIG 2 categorization resulted in 8 patients who required intervention, with a misclassification rate of 1.4 %, higher than reported in adults [9]. The original BIG performed well in our pediatric cohort but required modifications to address specific gaps. These adjustments led to the development of the Brain Injury Guidelines for Kids, or kBIG. With neurosurgical intervention as the primary safety outcome, ensuring

Table 3
Proposed brain injury guidelines for kids (kBIG).

Variables	kBIG 0	kBIG 1	kBIG 2	kBIG 3
Mechanism of injury	Blunt TBI excluding NAT	Blunt TBI excluding NAT	Blunt TBI excluding NAT	Blunt TBI including NAT
Initial ED GCS	15	15	13–14	≤12
Intoxication	No	No	Yes	Yes/No
Anticoagulation/antiplatelet	No	No	No	Yes
Skull fracture	Nondisplaced/mildly displaced	Nondisplaced/mildly displaced	Nondisplaced/mildly displaced	Displaced (with or without bleed)
Epidural hematoma	No	No	<8 mm	≥8 mm
Subdural hematoma	No	≤4 mm	5–7 mm	≥8 mm
Intraparenchymal hematoma	No	≤4 mm	5–7 mm	≥8 mm, multiple locations
Subarachnoid hemorrhage	No	≤3 sulci	>3 sulci, single hemisphere	>3 sulci, bi-hemispheric
Intraventricular hemorrhage	No	No	No	Yes
Therapeutic plan				
Hospitalization	No	No	Yes	Yes
Repeat head CT	No	No	No	Per neurosurgery request
Neurosurgery consultation	No	No	No	Yes

TBI: traumatic brain injury; NAT: Non-accidental trauma; ED: emergency department; GCS: Glasgow coma scale; CT: computed tomography.

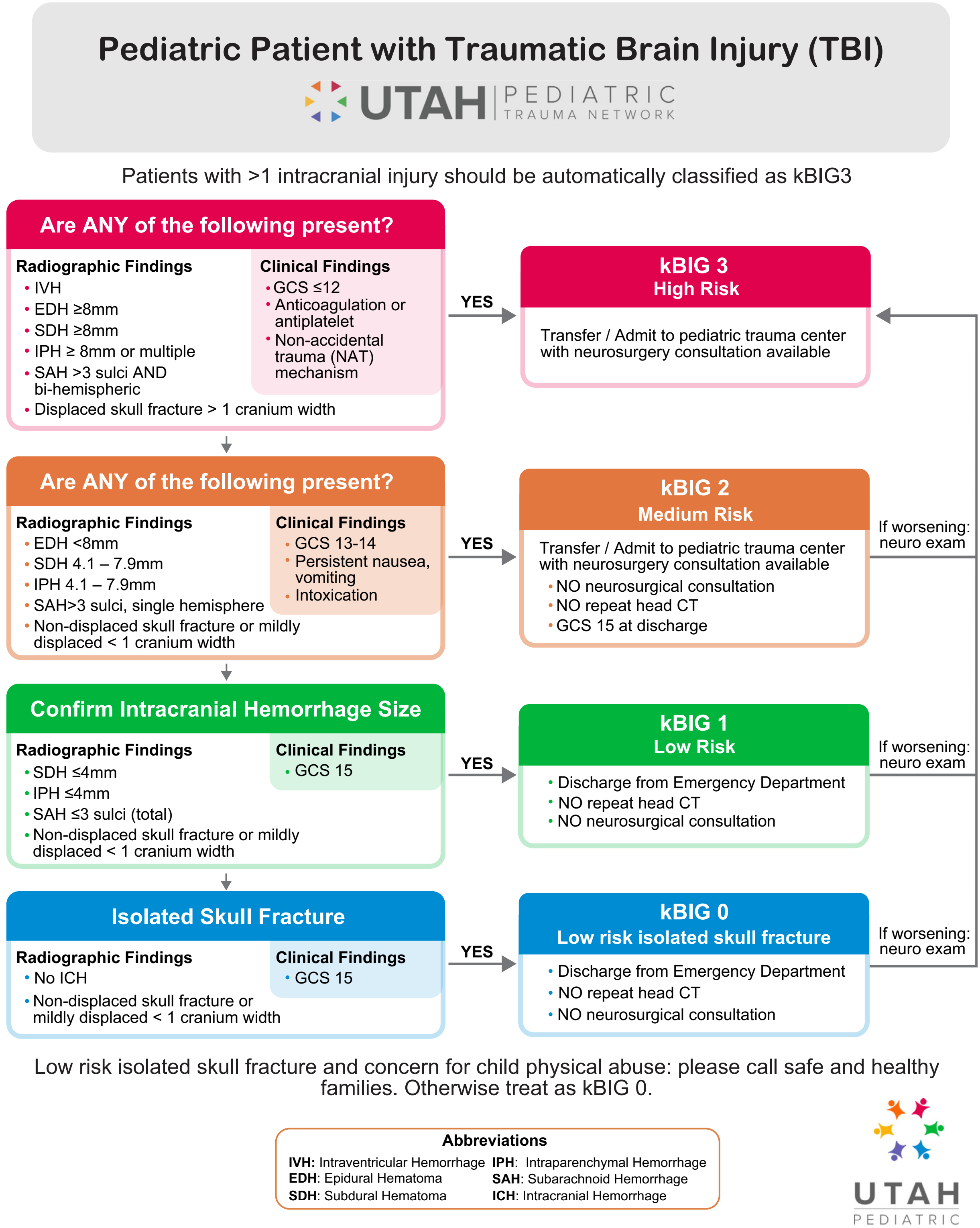

Fig. 1. The Brain Injury Guidelines for Kids (kBIG) clinical flow diagram is designed to facilitate scoring and management of children with traumatic brain injury. For kBIG 0–2 patients, any decline in neurologic exam from presentation escalates the patients to kBIG 3 category.
GCS, Glasgow coma scale; IVH, intraventricular hemorrhage; EDH, epidural hematoma; SDH, subdural hematoma; IPH, intraparenchymal hematoma; SAH, subarachnoid hemorrhage; ICH, intracranial hemorrhage; FU, follow-up.

that no low-risk patients and limited moderate-risk patients required neurosurgical intervention was critical. In the kBIG derivation process, six significant changes were made. The kBIG maintained safety for low-risk patients with a misclassification rate of 0 %, while improving the misclassification rate of moderate-risk patients from 1.4 % to 0.8 %. The application of kBIG would have

Table 4
Patient characteristics and outcomes based on the proposed Brain Injury Guidelines for Kids (kBIG).

	All (N = 1894)	kBIG 0 (n = 318)	kBIG 1 (n = 336)	kBIG 2 (n = 393)	kBIG 3 (n = 847)
Patient characteristics					
ED GCS					
3–8	297 (16)	0 (0)	0 (0)	0 (0)	297 (35)
9–12	81 (4)	0 (0)	0 (0)	0 (0)	81 (10)
13–14	218 (12)	0 (0)	0 (0)	125 (32)	93 (11)
15	1298 (69)	318 (100)	336 (100)	268 (68)	376 (44)
Pupillary response					
Both	1396 (74)	0 (0)	335 (100)	355 (90)	706 (83)
One	18 (1)	0 (0)	0 (0)	0 (0)	18 (2)
None	40 (2)	0 (0)	0 (0)	0 (0)	40 (5)
Intoxication					
Yes	2 (0)	0 (0)	0 (0)	1 (0)	1 (0)
No	32 (2)	0 (0)	2 (1)	4 (1)	26 (3)
Anticoagulation					
Yes	2 (0)	0 (0)	0 (0)	0 (0)	2 (0)
No	1890 (100)	318 (100)	336 (100)	393 (100)	843 (100)
Skull fracture					
Yes	1355 (72)	318 (100)	184 (55)	328 (83)	525 (62)
No	539 (28)	0 (0)	152 (45)	65 (17)	322 (38)
Intracerebral hematoma/hemorrhage					
Epidural hematoma	401 (21)	0 (0)	0 (0)	150 (38)	251 (30)
Subdural hematoma	780 (41)	0 (0)	242 (72)	140 (35)	398 (47)
Intraparenchymal hematoma	153 (8)	0 (0)	13 (4)	21 (5)	119 (14)
Subarachnoid hemorrhage	317 (17)	0 (0)	80 (24)	44 (11)	193 (23)
Intraventricular hemorrhage	5 (0)	0 (0)	0 (0)	0 (0)	5 (1)
Isolated TBI	1467 (77)	271 (85)	287 (85)	335 (85)	575 (68)
ISS	10 (9, 17)	9 (5, 10)	9 (9, 10)	10 (9, 14)	17 (10, 25)
Transferred					
Yes	1388 (73)	239 (75)	240 (71)	281 (72)	628 (74)
No	506 (27)	79 (25)	96 (29)	112 (28)	219 (26)
Patient outcomes					
Repeat head CT					
Yes	780 (41)	50 (16)	72 (21)	160 (41)	498 (59)
No	1114 (59)	268 (84)	264 (79)	233 (59)	349 (41)
Progression on repeat head CT					
Yes	182 (10)	1 (0)	1 (0)	29 (7)	151 (18)
No	599 (32)	49 (15)	71 (21)	131 (33)	348 (41)
Neurosurgical consultation					
Yes	1676 (88)	193 (61)	318 (95)	362 (92)	803 (95)
No	218 (12)	125 (39)	18 (5)	31 (8)	44 (5)
OR neurosurgery					
Yes	277 (15)	0 (0)	0 (0)	3 (1)	274 (32)
No	1617 (85)	318 (100)	336 (100)	390 (99)	573 (68)
Neurosurgical intervention					
Craniectomy	38 (2)	0 (0)	0 (0)	0 (0)	38 (4)
Craniotomy	135 (7)	0 (0)	0 (0)	3 (1)	132 (16)
ICP monitor (EVD, BOLT)	131 (7)	0 (0)	0 (0)	0 (0)	131 (15)
Admission					
ICU	652 (34)	6 (2)	22 (7)	72 (18)	552 (65)
Floor	1181 (62)	274 (86)	307 (91)	315 (80)	285 (34)
None (discharged from ED)	61 (3)	38 (12)	7 (2)	6 (2)	10 (1)
Ventilator day	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0 (0, 1)
LOS, day	2 (1, 4)	1 (1, 1)	1 (1, 2)	1 (1, 3)	4 (2, 9)
ED bounce-back					
Yes	20 (1)	5 (2)	5 (1)	3 (1)	7 (1)
No	1874 (99)	313 (98)	331 (99)	390 (99)	840 (99)

All data are presented as frequency (%) except that ISS, Ventilator day and LOS are presented as median (interquartile range).
ED: emergency department; GCS: Glasgow coma scale; ISS: injury severity score; CT: computed tomography; OR: operating room; ICP: intracranial pressure; EVD: external ventricular drainage; BOLT: subdural screw; ICU: intensive care unit; LOS: length of hospital stay.

saved significant resources in the form of RHCT, NSC, and hospital admissions in pediatric TBI defined as low-to moderate-risk while protecting those at higher risk for decline. This guideline may also serve as a model to direct location of care and transport decisions at the trauma system-level.

Previous evaluations of BIG in pediatric TBI have demonstrated efficacy and a potential for reduced resource utilization [16–21]. Others have proposed pediatric-specific modifications, including the addition of minor skull fracture to BIG 1 criteria and the upgrade of small EDH to BIG 2 [17–19]. One group implemented a pediatric-specific TBI guideline in 139 patients and showed improvement in all outcomes, including reduced RHCT, NSC, and transfers [19]. These reports are limited by small sample sizes and retrospective single-center methodology.

The kBIG score includes two changes related to skull fracture given its high incidence in pediatric patients compared to adults [9] and based on previous work evaluating management strategies similar to BIG 1 [6,17,19,23]. First, minor ISF without ICH was added as its own category, kBIG 0. ISF was common, representing 23 % of the entire cohort, and evidence suggests these kids, if neurologically normal, can be managed with limited resources [18,19,22,23]. Second, we classified minor skull fracture with ICH as low-risk (kBIG 1) rather than moderate-risk as long as all other BIG 1 criteria were met [17]. A significant portion of the study population with minor skull fractures was categorized as BIG 2 solely due to presence of skull fracture. Most patients underwent a hospital LOS of ≤1 day, with no additional imaging, and none required neurosurgical intervention. Based on this and aligning with our previous definition of potentially avoidable transfer [4], we concluded these could be downgraded to low-risk. While modifications to skull fracture stratification have been supported in pediatric guidelines for TBI [17,19], no evaluation has included both the incorporation of ISF and the risk downgrade of minor skull fracture with concomitant ICH. Our amendments expand the population of pediatric head injuries that can be safely observed and discharged. Of note, displaced skull fracture with or without ICH continues to be categorized as high-risk, given the high potential for operative intervention.

Another change was the escalation of small EDH <8 mm kBIG 2. The original BIG defines a subset of small EDH (≤4 mm) as low-risk, supporting observation without RHCT, NSC, or hospital admission, which has been demonstrated to be safe in two retrospective pediatric reports [20,21]. In adults, a modified BIG (mBIG) proposed that EDH be categorized as BIG 3 regardless of size based on two BIG 2 EDH patients who required craniotomy [14]. Our proposal aligns with another published pediatric modification which moved small EDH from the lowest-risk category to moderate-risk. They reported no neurosurgical interventions in this moderate-risk group but poor guideline compliance suggesting discomfort managing any EDH without RHCT or NSC [18,19]. Similarly, others have cautioned against limiting resource utilization in small to moderate EDH [21]. While no BIG 1 size EDH patients in the study population underwent neurosurgical intervention, two kBIG 2 patients did for moderate sized EDH. Furthermore, with the movement of minor skull fracture to kBIG 1 we decided to adopt a more conservative approach with EDH until larger numbers are attained. More data is needed to better elucidate the risk of minor EDH with and without skull fracture in children.

Injury mechanism has not been addressed in previous iterations of the BIG. It was imperative that these guidelines would not inadvertently increase cases of missed child physical abuse or NAT. In the study population, 25 % of NAT underwent neurosurgical intervention, including all the patients who met original BIG 2 criteria and required operations that were not EDH. NAT often involves repeated episodes resulting in acute on chronic head injury and requires neurosurgical attention. Given the concern for child physical abuse in pediatrics, we recommend the highest level of resources for any suspected case. Because of these reasons, suspected and confirmed NAT was added as a discrete kBIG 3 criterion.

Finally, we propose a more conservative definition for normal neurologic exam in children than has been utilized in adults [8,14], whereby GCS 15 is required for low-risk TBI (kBIG 0−1). GCS 13−14 mandates kBIG 2 and thus admission, as does intractable headache, nausea, and vomiting [18,19]. GCS is widely used to assess consciousness, but significant variability exists in its interpretation and GCS is particularly unreliable in young trauma patients [24,25]. Furthermore, GCS 13−15 does not preclude the need for neurosurgical intervention [26], as 43 % of the operative cases in our cohort had an initial GCS of 13−15. There was a single patient in the current study with a nondisplaced temporal bone ISF who declined at 30 h and required a craniotomy for a new EDH. Exam was significant for initial GCS of 14, and severe nausea and vomiting. While this patient may have been categorized as low-risk, potentially failing the algorithm if discharged home, discharge was not clinically appropriate. With no room for error, kBIG is designed to protect kids at risk for decline while allowing those at neurological baseline with minor CT findings to be discharged home safely. Importantly, any change in neurologic exam identified during observation escalates care. Requiring neurologic baseline for low-risk categorization, the 6-h observation period was removed from kBIG 0−1 management because this would not have changed outcomes and may be a barrier to implementation [27]. Detailed return precautions must be emphasized.

Potentially preventable hospital transfers in pediatric patients with mild TBI are common [3−7]. Uniform guidelines do not exist to support interfacility transfer decisions, and referring providers are often uncomfortable with pediatric trauma patients. We looked at this previously and found that 27 % of pediatric trauma patients transferred to our level 1 pediatric trauma center were considered preventable [4]. Evaluating the isolated TBI group in the current study, the application of kBIG could have potentially reduced transfers by 26 % and admissions by 36 %. With generalizability in mind, we intend for this kBIG algorithm to stimulate reevaluation of site and region-specific resource utilization for the care of pediatric TBI across the country.

There are limitations inherent to the retrospective design, where the proposed guideline is based on a historical cohort at a single center and expert opinion. We identified radiographic findings that warrant future evaluation for their association with neurologic decline or neurosurgical intervention including midline shift, cranial suture diastasis, and pneumocephalus. We may have missed return-to-ED patients outside our system, but our system does capture greater than 70 % of patients in the state. Patients with low-risk TBI who were discharged from the ED may not have met trauma registry inclusion and thus may have been unaccounted for. Importantly, this study does not address the long-term sequelae of TBI.

5. Conclusions

BIG functions well when applied to injured children, but important limitations were identified. We propose an enhanced version of BIG for the management of pediatric TBI called BIG for Kids, or kBIG. The kBIG was conservatively designed primarily to ensure safety and secondarily to reduce unnecessary radiation exposure and resource utilization with a patient-centered approach. While we intend to adopt this locally, multicenter and prospective kBIG validation efforts are underway to support broader implementation.

Conflict of interest

There are no financial disclosures from any of the authors. All JTACS disclosure statement forms have been supplied and provided as supplemental digital content.

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