Validating the Brain Injury Guidelines: Results of an American Association for the Surgery of Trauma prospective multi-institutional trial

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INTRODUCTION: Brain Injury Guidelines (BIG) was developed to effectively use health care resources including repeat head computed tomography (RHCT) scan and neurosurgical consultation in traumatic brain injury (TBI) patients. The aim of this study was to prospectively validate BIG at a multi-institutional level.

METHODS: This is a prospective, observational, multi-institutional trial across nine Levels I and II trauma centers. Adult (16 years or older) blunt TBI patients with a positive initial head computed tomography (CT) scan were identified and categorized into BIG 1, 2, and 3 based on their neurologic examination, alcohol intoxication, antiplatelet/anticoagulant use, and head CT scan findings. The primary outcome was neurosurgical intervention. The secondary outcomes were neurologic worsening, RHCT progression, postdischarge emergency department visit, and 30-day readmission.

RESULTS: A total of 2,432 patients met the inclusion criteria, of which 2,033 had no missing information and were categorized into BIG 1 (301 [14.8%]), BIG 2 (295 [14.5%]), and BIG 3 (1,437 [70.7%]). In BIG 1, no patient worsened clinically, 4 of 301 patients (1.3%) had progression on RHCT with no change in management, and none required neurosurgical intervention. In BIG 2, 2 of 295 patients (0.7%) worsened clinically, and 21 of 295 patients (7.1%) had progression on RHCT. Overall, 7 of 295 patients (2.4%) would have required upgrade from BIG 2 to 3 because of neurologic examination worsening or progression on RHCT, but no patient required neurosurgical intervention. There were no TBI-related postdischarge emergency department visits or 30-day readmissions in BIG 1 and 2 patients. All patients who required neurosurgical intervention were BIG 3 (280 of 1,437 patients [19.5%]). Agreement between assigned and final BIG categories was excellent ($\kappa = 99\%$). In this cohort, implementing BIG would have decreased CT scan utilization and neurosurgical consultation by 29% overall, with a 100% reduction in BIG 1 patients and a 98% reduction in BIG 2 patients.

CONCLUSION: Brain Injury Guidelines is safe and defines the management of TBI patients by trauma and acute care surgeons without the routine need for RHCT and neurosurgical consultation. (*J Trauma Acute Care Surg.* 2022;93: 157–165. Copyright © 2022 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level III.

KEY WORDS: Management of traumatic brain injury; Brain Injury Guidelines; neurosurgical consultation; neurosurgical intervention; trauma and acute care surgeons.

Traumatic brain injury (TBI) is associated with high morbidity and mortality,[1] it places significant burden on health care resources,[2] and its management accounts for a large proportion of emergency surgical, neurosurgical, and critical care practice.[3] Beyond the significant loss of life and long-term disability, TBI management also accounts for nearly 10% of annual total health

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care expenditure in the United States,[4] with each presentation often involving the use of multiple imaging studies, intensive care unit (ICU) admission, and neurosurgical consultation. However, there is now increased evidence to support effective triage and judicious use of health care resources for patients with TBI.[5–8]

Trauma and acute care surgeons represent an integral component of management of TBI since they are often the first providers of care in the acute phase of trauma. Management of TBI is increasingly becoming nonoperative, and the role of trauma and acute care surgeons in the nonoperative management of TBI has been highlighted in the literature.[6,9] Furthermore, recent advancements in imaging technology have meant that increasing numbers of emergency department (ED) admissions are being identified with miniscule intracranial hemorrhages (ICHs), often leading to reflex utilization of health care resources such as repeated imaging, prolonged hospital admission for observation, and neurosurgical consultation. However, these small bleeds would rarely alter the course of management if not associated with concomitant clinical/neurological deterioration. To standardize the management of traumatic brain injuries, the Brain Injury Guidelines (BIG) was developed based on a retrospective review of nearly 4,000 TBI patients presenting to a Level I trauma center.[6] These guidelines took into account patient's history, physical examination, and initial head computed tomography (CT) findings and accordingly provided recommendations on whether hospitalization, repeat imaging, and/or neurosurgical consultation were required. With the help of BIG, the proportion of TBI patients managed exclusively by trauma and acute care surgeons has increased significantly at a Level I trauma center from 6.8% to 40.1% over the course of time between 2009 and 2014.[10]

The BIG has been previously validated at a Level I trauma center and was found to be a feasible, safe, and effective triage tool for the management of TBI patients while at the same time reducing hospital costs.[6,8,9] The aim of this study was to prospectively validate the BIG at a multi-institutional level. We hypothesized that the BIG would reliably predict requirement of neurosurgical intervention, neurologic examination worsening, progression on repeat head CT, postdischarge ED visits, and 30-day readmissions among patients presenting with TBI to 1 of 10 participating trauma centers.

PATIENTS AND METHODS

Study Population

Patients with TBI were enrolled from 10 Level I and Level II trauma centers participating in this multicenter, prospective, observational study conducted with the American Association for the Surgery of Trauma Multi-institutional Trials Committee. The AAST Multi-Institutional Trials Committee approved the study protocol, and each participating center obtained approval from its respective institutional review board. Participating centers securely uploaded data through the AAST multicenter study portal. These data were subsequently collected at the end of the study period and analyzed by the principal investigators.

Inclusion and Exclusion Criteria

Adult patients 16 years and older with TBI and positive initial head CT findings presenting to 1 of 10 trauma centers during a 3-year period from January 2018 to December 2020 were included. Patients transferred from other institutions, those requiring emergent surgical intervention, and those with missing information were excluded from our study. Positive head CT findings were defined by the presence of skull fracture and/or ICH.

Data Points

The following data points were prospectively recorded for each patient: patient demographics, which included age, sex, race, and insurance status; injury parameters, including mechanism of injury, Injury Severity Score, and body regions Abbreviated Injury Scale scores; vital parameters on presentation, which included systolic blood pressure, heart rate, respiratory rate, temperature, and Glasgow Coma Scale score; neurologic examination on presentation; intoxication (drugs or alcohol); details regarding antiplatelet and/or anticoagulation therapy; loss of consciousness; blood product transfusion (including packed red blood cells, platelets, fresh frozen plasma, and prothrombin complex concentrate); trauma center verification level; initial head CT scan findings, which included information on the presence of skull fracture and whether it was displaced or not, and type(s) and size(s) of ICH(s); worsening of neurologic examination within 24 hours of admission; reasons and findings of repeat head computed tomography (RHCT); neurosurgical consultation; neurosurgical intervention details; hospital and ICU length of stay (LOS); and in-hospital mortality. Patients were followed up to 30 days after their initial discharge for any ED visits and/or readmissions.

Independent board-certified attending radiologists reviewed the initial head CT scan and any subsequent repeat head CT scans at each participating institution, and the final reports were reviewed by the attending trauma surgeon for the type(s) and size(s) of ICH(s). Repeat head CT scan reports were compared with the initial head CT scan report and assessed for progression of ICH, defined as an increase in the size of the initial hemorrhage (in mm) or the development of a new hemorrhage.

Abnormal neurologic examination on presentation was defined as focal neurological deficit, abnormal pupillary examination result, and/or Glasgow Coma Scale <12 on presentation. Normal neurologic examination was defined as the absence of focal neurologic deficits, normal pupillary examination, and Glasgow Coma Scale score of 12 to 15. The pupillary examination included assessment of the size and equality of pupils, pupillary shape, and reactivity to light. A normal pupillary examination was defined as pupils that were equally and normally sized (normal diameter defined as 2–5 mm), round, and reactive to light on both direct and indirect light reflex testing.

Outcome Measures

The primary outcome measure was requirement of neurosurgical intervention. The secondary outcome measures were neurologic examination worsening, progression on RHCT, postdischarge ED visits, and 30-day readmissions.

Neurosurgical intervention was defined as craniotomy, craniectomy, intracranial pressure monitor placement, and/or external ventricular drain placement. Neurological examination worsening was defined as new-onset/worsening of focal neurological deficit, abnormal pupillary examination, and/or Glasgow Coma Scale <12 within 24 hours of admission. Progression on

Brain Injury Guidelines			
Variables	**BIG 1**	**BIG 2**	**BIG 3**
LOC	Yes/No	Yes/No	Yes/No
Neurologic examination	Normal	Normal	Abnormal
Intoxication	No	No/Yes	No/Yes
CAMP	No	No	Yes
Skull Fracture	No	Non-displaced	Displaced
SDH	≤ 4mm	5 - 7 mm	≥ 8 mm
EDH	≤ 4mm	5 - 7 mm	≥ 8 mm
IPH	≤ 4mm, 1 location	3 – 7 mm, 2 locations	≥ 8 mm, multiple locations
SAH	Trace	Localized	Scattered
IVH	No	No	Yes
THERAPEUTIC PLAN			
Hospitalization	No Observation (6hrs)	Yes	Yes
RHCT	No	No	Yes
NSC	No	No	Yes

BIG, brain injury guidelines; CAMP, Coumadin, Aspirin, Plavix; EDH, epidural hemorrhage; IVH, intraventricular hemorrhage; IPH, intraparenchymal hemorrhage; LOC, loss of consciousness; NSC, neurosurgical consultation; RHCT, repeat head computed tomography; SAH, subarachnoid hemorrhage; SDH, subdural hemorrhage

Figure 1. Brain Injury Guidelines.

RHCT was defined as an increase in the size of the initial hemorrhage or the development of a new hemorrhage.

Development of the BIG

We developed the BIG based on patients' medical history (antiplatelet or anticoagulation therapy, loss of consciousness, and intoxication), findings from physical examination (focal neurological examination, pupillary examination, and Glasgow Coma Scale score on admission), and CT scan findings (size and location of ICH and type of skull fracture).[6] Patients had to meet all the criteria for categorization into BIG 1 or BIG 2 (Fig. 1; Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C445). Failure to meet even one criterion (in BIG 1 or BIG 2) categorized the patient into the BIG 3 category and altered the treatment plan for the patient based on the BIG 3 category.

Figure 1 (Supplemental Digital Content, Supplementary Data 1, http://links.lww.com/TA/C445) describes the three categories of the BIG. Patients who were categorized as BIG 1 (minor head injury) had normal findings on neurological examination, were not taking any antiplatelet or anticoagulation medications, and had minuscule findings on initial CT scan of the head. A 6-hour period of observation in the ED was proposed for patients who were categorized as BIG 1, without the need for neurosurgical consultation or an RHCT scan. The BIG 2 category was composed of moderately injured patients with a nondisplaced skull fracture and/or a localized ICH of 5 to 7 mm, and the treatment plan proposed was a 24-hour period of hospitalization without the need for neurosurgical consultation or an RHCT scan. Patients who were categorized as BIG 3 had a severe head injury, and the optimal therapeutic plan for these patients consisted of hospitalization for more than 24 hours, neurosurgical consultation, and a follow-up RHCT scan. Patients who were categorized as BIG 3 had at least one of the following high-risk features: an abnormal neurological examination finding, intoxication, antiplatelet or anticoagulation medication use, concerning CT scan findings (displaced skull fractures, diffused

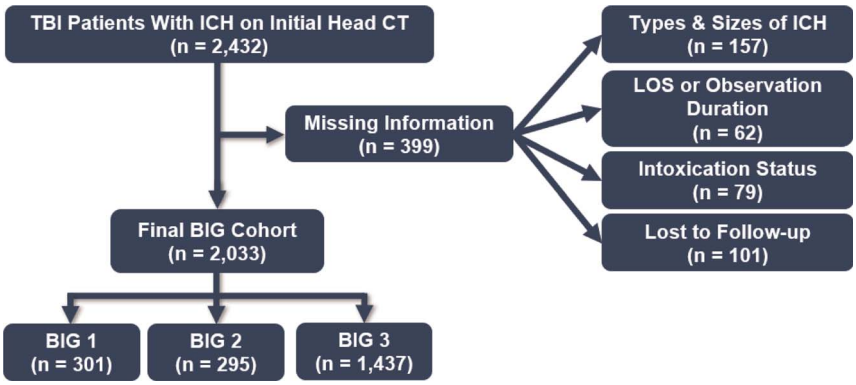

Figure 2. Flow diagram of patients included in final analysis.

subarachnoid hemorrhage, multiple types of bleeding, or an ICH ≥8 mm). Patients who could not be examined and those who were intubated were also categorized as BIG 3.

Assigned Versus Actual Therapeutic Plan

Following categorization into BIG 1, BIG 2, or BIG 3, the patients were hypothesized to follow a guideline therapeutic plan based on their respective BIG category. Patients were then followed throughout their hospital length of stay and 30 days postdischarge to assess the actual management they received. The guideline therapeutic plan was then compared with the actual hospital course of the patient, defined as the actual verified therapeutic plan. Deviation of actual hospital course/therapeutic plan from the guideline-based assigned therapeutic plan was considered failure of the BIG assigned therapeutic plan. Deviation from the guideline therapeutic plan was considered if BIG 1 or BIG 2 patients had clinical worsening requiring neurosurgical intervention or ICU admission. We chose not to consider repeat head CT imaging or neurosurgical consultation as failure of the BIG criteria, as this was an observational study where the centers participating had varying degrees of compliance with implementation of the BIG. Finally, Cohen's κ statistic was used to assess the degree of correlation between the guideline therapeutic plan and the actual/verified therapeutic plan using the aforementioned definitions.

Missing Data

A total of 399 patients had missing information related to types and sizes of ICH on initial head CT scan (n = 157), hospital length of stay or observation duration (n = 62), or intoxication status (n = 79) or were lost to follow-up after discharge (n = 101). Missing data were found to be missing completely at random using Little's Missing Completely at Random test. We chose to exclude all samples with missing values, as the missing data pertained to methods of stratification of patients into the different categories of BIG.

Data Analysis

Data are reported as means ± SD for normally distributed continuous descriptive variables, as medians [interquartile ranges] for nonnormally distributed ordinal descriptive variables, and as proportions for categorical variables. Cohen's κ statistic was used to assess agreement between the guideline assigned therapeutic plan and the actual verified therapeutic plan. κ Values greater than 0.75 indicate high agreement. We adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (see Supplemental Digital Content, Supplementary Data 2, http://links.lww.com/TA/C446, for full Strengthening the Reporting of Observational Studies in Epidemiology checklist).

RESULTS

A total of 2,432 patients with TBI with positive head CT scan findings met the inclusion criteria, of which 2,033 patients had no missing data and were included in the final analysis. Figure 2 illustrates the flow diagram of patients included in the final analysis (Supplemental Digital Content, Supplementary Data 3, http://links.lww.com/TA/C447). A total of 399 patients had missing information related to types and sizes of ICH on initial head CT scan (n = 157), hospital length of stay or observation duration (n = 62), or intoxication status (n = 79) or were lost to follow-up after discharge (n = 101). The final patient cohort was then stratified into one of the three BIG categories: BIG 1 (n = 301 [14.8%]), BIG 2 (n = 295 [14.5%]), and BIG 3 (n = 1,437 [70.7%]). Overall, the mean ± SD age was 55 ± 23 years, 1,361 patients (67%) were male, and 1,521 (75%) were White. Table 1 highlights the baseline characteristics of the study population. The BIG was implemented with varying degrees of compliance across the institutions participating in

TABLE 1. Baseline Characteristics of Patient Cohort

	BIG 1 (n = 301)	BIG 2 (n = 295)	BIG 3 (n = 1,437)
Demographics			
Age, mean ± SD, y	57 ± 22	51 ± 22	55 ± 23
Male, n (%)	164 (54.5)	194 (65.8)	1,003 (69.8)
White, n (%)	254 (84.4)	226 (76.6)	1,041 (72.4)
Insurance status			
Medicare, n (%)	125 (41.5)	68 (23.1)	478 (33.3)
Medicaid, n (%)	51 (16.9)	61 (20.7)	251 (17.5)
Private, n (%)	71 (23.6)	90 (30.5)	302 (21.0)
Uninsured, n (%)	31 (10.3)	38 (12.9)	152 (10.6)
Antithrombotic use			
Aspirin, n (%)	Nil	Nil	178 (12.4)
Coumadin, n (%)	Nil	Nil	71 (4.9)
Plavix, n (%)	Nil	Nil	95 (6.6)
Factor Xa inhibitors, n (%)	Nil	Nil	85 (5.9)
Direct thrombin inhibitors, n (%)	Nil	Nil	9 (0.6)
Other anticoagulants, n (%)	Nil	Nil	44 (3.1)
ED assessment			
GCS, median [IQR]	15 [15–15]	15 [15–15]	14 [8–15]
Heart rate, median [IQR], bpm	87 [76–98]	87 [77–102]	89 [75–105]
SBP, median [IQR], mm Hg	136 [122–156]	137 [121–154]	139 [120–155]
Respiratory rate, median [IQR], bpm	18 [16–20]	18 [16–20]	18 [16–21]
Intoxication, n (%)	Nil	75 (25.4)	275 (19.1)
Abnormal neurologic examination, n (%)	Nil	Nil	799 (55.6)
Loss of consciousness, n (%)	91 (30.2)	152 (51.5)	823 (57.3)
Injury parameters			
Blunt injury, n (%)	299 (99.3)	294 (99.7)	1,392 (96.9)
ISS, median [IQR]	13 [9–17]	14 [10–17]	18 [10–26]
Head AIS, median [IQR]	3 [2–3]	3 [2–3]	4 [3–5]
Face AIS, median [IQR]	1 [1–2]	2 [1–3]	2 [1–2]
Thorax AIS, median [IQR]	3 [2–3]	3 [2–4]	3 [3–3]
Abdomen AIS, median [IQR]	2 [1–3]	3 [2–3]	2 [2–3]
Extremity AIS, median [IQR]	2 [2–3]	2 [2–3]	2 [2–3]
Blood product transfusion			
pRBCs, n (%)	9 (3.0)	9 (3.1)	281 (19.6)
FFP, n (%)	2 (0.7)	5 (1.7)	151 (10.5)
Platelets, n (%)	2 (0.7)	5 (1.7)	97 (6.8)
PCC, n (%)	Nil	Nil	30 (2.1)
Trauma center verification level			
Level I, n (%)	280 (93.0)	276 (93.6)	1,428 (99.4)
Level II, n (%)	21 (7.0)	19 (6.4)	9 (0.6)

AIS, Abbreviated Injury Scale; FFP, fresh frozen plasma; GCS, Glasgow Coma Scale; IQR, interquartile range; ISS, Injury Severity Score; LOC, loss of consciousness; PCC, prothrombin complex concentrate; pRBC, packed red blood cell; SBP, systolic blood pressure.

TABLE 2. Initial Head CT Findings Among the Patient Cohort

	BIG 1 (n = 301)	BIG 2 (n = 295)	BIG 3 (n = 1,437)
Skull fracture			
Nondisplaced, n (%)	Nil	53 (17.9)	323 (22.4)
Displaced, n (%)	Nil	Nil	178 (12.4)
ICH			
SDH, n (%)	179 (59.5)	134 (45.4)	850 (59.2)
EDH, n (%)	2 (0.7)	9 (3.1)	93 (6.5)
SAH, n (%)	113 (37.5)	183 (62.0)	867 (60.3)
IPH/contusion, n (%)	23 (7.6)	36 (12.2)	437 (30.4)
IVH, n (%)	Nil	Nil	187 (13.0)

EDH, epidural hemorrhage; IPH, intraparenchymal hemorrhage; IVH, intraventricular hemorrhage; SAH, subarachnoid hemorrhage; SDH, subdural hemorrhage.

this study. Five centers had greater than 30% compliance with the BIG with regard to routine repeat head CT imaging and neurosurgical consultation. These five centers accounted for 1,279 of the 2,033 TBI patients overall (63%) and 321 of the 596 BIG 1 and 2 patients (54%).

No BIG 1 patients had a skull fracture, while 53 BIG 2 patients (17.9%) had a nondisplaced skull fracture, and 501 BIG 3 patients (34.8%) had a skull fracture. The most common type of ICH was subdural hemorrhage among BIG 1 patients and subarachnoid hemorrhage among BIG 2 and BIG 3 patients. Table 2 highlights the findings on initial head CT.

Table 3 demonstrates the outcomes of the study population belonging to the three BIG categories. No patient in BIG 1 category had clinical neurological deterioration, and only four BIG 1 patients (1.3%) had progression of hemorrhage on RHCT. No BIG 1 patients required neurosurgical intervention. Only 2 BIG 2 patients (0.7%) had clinical deterioration, and 21 BIG 2 patients (7.1%) had progression on RHCT; however, none required neurosurgical intervention. A total of 230 BIG 3 patients (16.0%) had clinical deterioration, and 21.6% of patients in BIG 3 had progression on RHCT. For our entire study population, the rate of neurosurgical intervention was 13.8% (n = 280) (craniectomy/craniotomy in 191 patients [68.2%]; external ventricular drain in 27 patients [9.6%]; intracranial pressure monitor placement in 54 patients [19.3%]). All these patients met the BIG 3 category criteria. A total of 13 BIG 1 patients (4.3%), 19 BIG 2 patients (6.4%), and 146 BIG 3 patients (10.2%) presented to the ED within 30 days of discharge. Among those, 1 BIG 1 patient (0.3%), 6 BIG 2 patients (2.0%), and 85 BIG 3 patients (5.9%) were readmitted to the hospital. None of these postdischarge ED visits readmissions were TBI related for BIG 1 and BIG 2 patients.

The actual verified management of the study cohort is provided in Table 4. Among patients, 77% (1,569 of 2,033) received an RHCT, of which 90.3% (n = 1,418) were performed as a routine measure, and 9.6% (n = 151) were performed because of a change in clinical status. Of the 432 RHCT scans performed among the BIG 1 and 2 patients, 430 (99.5%) were performed as a routine measure. Only two RHCT scans were performed among the BIG 2 patients because of neurologic examination deterioration. Furthermore, 518 BIG 1 and BIG 2 patients received a neurosurgical consultation, and 408 BIG 1 and BIG 2 patients received a prolonged hospitalization, defined as hospital admission for BIG 1 and hospital LOS >24 hours for BIG 2 patients. Excluding the 7 BIG 2 patients who required upgrade to BIG 3 status, BIG implementation would have resulted in 425 fewer RHCT scans, 401 fewer prolonged hospitalizations, and 511 fewer neurosurgical consultations. This represents a decrease of 26% overall, with a 100% reduction in BIG 1 patients and a 97% reduction in BIG 2 patients.

The actual/verified therapeutic plans of all patients categorized as BIG 1 and BIG 3 were consistent with the BIG-assigned therapeutic plans. Only seven patients categorized as BIG 2 were not managed in concordance with the established BIG 2 guidelines and required ICU admission. The agreement between assigned and verified BIG categories was excellent (κ = 0.992; 95% confidence interval, 0.986–0.998; Table 5). Table 6 describes in detail the seven patients who failed the BIG 2 criteria. Five patients had no deterioration of neurological examination findings and failed only because of progression on RHCT, requiring hospital LOS >24 hours, ICU admission, and neurosurgical consultation. The remaining two patients had a deterioration of neurological examination findings resulting in upgrade of the patient to BIG 3 classification. All seven BIG 2 patients who required an upgrade to BIG 3 status did so within 24 hours of admission. None of the patients who failed BIG 2 criteria required neurosurgical intervention.

DISCUSSION

The BIG defines the management of TBI based on initial clinical and radiologic findings and outlines a therapeutic management plan based on the need for hospitalization, neurosurgical consultation, and repeat head CT imaging. In this study, we have prospectively validated the BIG at a multi-institutional level. Among approximately 2,000 TBI patients presenting to 10 trauma centers, no BIG 1 or BIG 2 patients required

TABLE 3. Analysis of Study Outcome Measures Among the Patient Cohort

	BIG 1 (n = 301)	BIG 2 (n = 295)	BIG 3 (n = 1,437)
Neurologic examination deterioration, n (%)	Nil	2 (0.7)	230 (16.0)
Progression of hemorrhage on RHCT, n (%)	4 (1.3)	21 (7.1)	311 (21.6)
Neurosurgical intervention, n (%)	Nil	Nil	280 (19.5)
Postdischarge ED visit, n (%)	13 (4.3)	19 (6.4)	146 (10.2)
30-d Readmissions, n (%)	1 (0.3)	6 (2.0)	85 (5.9)

TABLE 4. Actual Management of Study Cohort

	BIG 1 (n = 301)	BIG 2 (n = 295)	BIG 3 (n = 1,437)
Received RHCT, n (%)	231 (76.7)	201 (68.1)	1,156 (80.4)
RHCT as routine measure, n (%)	231 (100.0)	199 (99.0)	988 (85.5)
Neurosurgical consultation, n (%)	263 (87.4)	255 (86.4)	1,354 (94.2)
Prolonged hospitalization,* n (%)	206 (68.4)	202 (68.5)	1,254 (87.3)

*Prolonged hospitalization was defined as hospital admission for BIG 1 patients and hospitalizations longer than 24 hours for BIG 2 or BIG 3 patients.

TABLE 5. Analysis of Agreement Between Assigned and Verified Therapeutic Plan

	Verified Therapeutic Plan		
Assigned Therapeutic Plan	**BIG 1**	**BIG 2**	**BIG 3**
BIG 1	301	0	0
BIG 2	0	288	7
BIG 3	0	0	1,437

$\kappa = 0.992$; 95% confidence interval, 0.986 to 0.998.

neurosurgical interventions, and only 7 BIG 2 patients required upgrade to the BIG 3 category. If the BIG had been followed in our study cohort, 425 RHCT scans, 401 prolonged hospitalizations, and 511 neurosurgical consultations would have been avoided. The BIG establishes a clear therapeutic plan for the acute management of TBI patients while avoiding unnecessary utilization of health care resources.

It has been standard practice for years to request repeat imaging and neurosurgical consultation for all types of ICH. Presence of an ICH on initial scan regardless of size would reflexively initiate a neurosurgical consultation and a routine repeat head CT scan, without any consideration for clinical neurologic examination. Indeed, the findings of our study show that nearly 70% of adult TBI patients, regardless of initial CT findings and neurological examination, received repeat head CT scan as a routine measure. However, the results of our study, consistent with the emerging literature, also show that radiologic worsening in and of itself did not lead to neurosurgical intervention or change in management.

The aim of this study was to prospectively observe the management of TBI patients at 10 US trauma centers and determine if the implementation of the BIG in such a cohort would have been safe, while effectively reducing health care resource utilization. The BIG was not implemented at all of the trauma centers during the study period. Among the 21 BIG 2 patients and 4 BIG 1 patients who were found to have progression of hemorrhage on RHCT, none resulted in neurosurgical intervention. Only seven BIG 2 patients (two with worsening of neurologic examination findings and five who had significant progression of RHCT determined by the attending physician) required prolonged hospitalization for more than 24 hours and ICU admission. We believe that these seven BIG 2 patients would have benefited from upgrade to BIG 3 status and represent failure of the BIG criteria.

The literature has previously demonstrated that neurologic examination worsening and not progression of hemorrhage on RHCT predicts requirement of neurosurgical intervention and should warrant higher levels of care among mild-moderate TBI patients who are not on anticoagulation.[5,11–16] Many studies have also questioned the need for routine neurosurgical consultation for minimal to moderate ICH in patients with TBI who can be examined.[9,17,18] Thus, we believe that the 18 BIG 1 and 2 patients who had progression on RHCT but did not require a major change in management such as ICU admission or neurosurgical intervention would have been safely managed without RHCT and neurosurgical consultation and did not consider them to be failure of the BIG criteria.

Because the BIG had not been implemented in all the participating centers, a large proportion of BIG 1 and BIG 2 patients received RHCT scans, neurosurgical consultations, and prolonged hospitalizations. However, our findings show that there were no adverse outcomes such as ICU admission or neurosurgical intervention requirement for these patients except for the seven BIG 2 patients previously mentioned. We have shown that BIG implementation would have safely resulted in a reduction in health care resource utilization, and the majority of its effects would have been seen among the BIG 1 and BIG 2 patients. The findings of our study demonstrate that BIG effectively categorized and defined the management plan for almost all patients presenting with TBI, especially those with mild to moderate injuries, using only patient history, and physical examination and initial head CT findings.

By following the BIG protocol, we would have been able to avoid hospitalizations, neurosurgical consultations, and repeated imaging for 26% of our overall patient cohort. The greatest effect from implementation of BIG would have been observed in the BIG 1 category of patients, who were the minimally injured subgroup of patients with normal findings on initial neurological examination and no high-risk factors. In accordance with BIG, these patients would have been treated exclusively by trauma and acute care surgeons, with a 6-hour observation period in the ED only. This practice would have resulted in a 100%

TABLE 6. Characteristics and Hospital Course of Seven Patients Not Meeting BIG 2 Criteria

Patient No.	Age, y	CAMP	Neurologic Examination on Presentation	ICH	Reason for RHCT	RHCT Findings	NSG Consultation	NSG Intervention	ICU Admission
1	59	No	Intact	Trace SDH, 6 mm IPH, localized SAH	Routine	Worsened, larger IPH (12 mm)	None	None	Yes
2	61	No	Intact	5 mm SDH	Neurodecline	Worsened, new CVA	Yes	None	Yes
3	63	No	Intact	Localized SAH, 5 mm IPH	Routine	Worsened, new SAH, new IPH, new 3 mm SDH	Yes	None	Yes
4	63	No	Intact	5 mm SDH	Routine	Worsened, new 3 mm IPH	Yes	None	Yes
5	64	No	Intact	Localized SAH	Neurodecline	No change	Yes	None	Yes
6	69	No	Intact	4 mm SDH, 6 mm SDH	Routine	Worsened, new 10 mm IPH	Yes	None	Yes
7	83	No	Intact	Localized SAH	Routine	Worsened, new SAH, new trace IPH	None	None	Yes

CAMP, coumadin, aspirin, motrin, and plavix; CVA, cerebrovascular accident; IPH, intraparenchymal hemorrhage; NSG, neurosurgical; SAH, subarachnoid hemorrhage; SDH, subdural hemorrhage.

reduction in hospitalizations, RHCT, and neurosurgical consultations among these patients, without subsequent adverse events such as neurosurgical intervention requirement. Furthermore, implementing the BIG would have resulted in a 97% reduction in hospitalizations, RHCT, and neurosurgical consultations among the BIG 2 category of patients, who were the moderately injured subgroup of patients with no high-risk factors but more-than-minimal ICH visible on initial head CT scan. According to the BIG, these patients would have been managed with 24-hour hospitalization and no routine repeat imaging, ICU admission, or neurosurgical consultation.

We have demonstrated how evidence-based changes in practice can standardize TBI patient care and help improve resource utilization without adversely affecting patient outcomes. There are multiple important implications of our study. First, hospital admission is associated with its own significant costs, and the implementation of BIG at these 10 trauma centers would have resulted in 206 fewer hospitalizations for BIG 1 patients and 195 fewer prolonged hospitalizations for BIG 2 patients. Second, repeat head CT scans are associated with both unnecessary cost and radiation exposure, as high as 3 to 7 rads per scan, and implementation of the BIG at these 10 trauma centers would have led to 425 fewer repeat CT scans, resulting in reduced radiation exposure and unnecessary costs for BIG 1 and 2 patients. Third, neurosurgical coverage for trauma patients is not only an understaffed and scare resource, particularly in rural areas, upon whom strain can be limited with the implementation of BIG,[19,20] but it is also an unnecessary expense especially for mildly or moderately injured TBI patients, as our study reveals that all of these patients end up not requiring neurosurgical intervention. Implementation of the BIG would have resulted in significant cost savings and reduced burden on scarce health care resources. Indeed, a previous study found that implementation of the BIG at a single Level I trauma center resulted in an average hospital cost reduction of $4,772 per patient while observing no differences in rates of mortality, progression on RHCT scans neurosurgical interventions, and 30-day readmissions.[8]

It is interesting to note that the approximately 24% incidence of antiplatelet and warfarin use (coumadin, aspirin, motrin, and plavix) among our study cohort compares favorably against previous studies on TBI patients. Our initial single-center study outlining the BIG demonstrated a coumadin, aspirin, motrin, and plavix use incidence of 21% among TBI patients, while a more recent multicenter study demonstrated a 15% prevalence of warfarin or antiplatelet medication use, namely, aspirin and clopidogrel.[6,21] Both studies consisted of similar age distributions as our current study.

There are some limitations of this study. First, we were not able to assess functional neurological outcomes of patients in each BIG category, using measures such as the Extended Glasgow Outcome Scale, the Functional Independence Measure, or quality-of-life assessments. Second, this study was conducted in centers with 24-hour access to an on-call neurosurgical service. Therefore, the generalizability of these findings should be considered accordingly. Third, although we were able to assess long-term outcomes such as postdischarge ED visits and readmissions within 30 days of discharge, we were not able to assess the long-term outcomes for patients who may have presented after discharge to a different hospital from the index trauma center. Fourth, we were not able to perform a robust cost analysis of the impact that implementation of the BIG would have had in our patient cohort. Finally, the centers participating in this study implemented the BIG with varying degrees of compliance. Only five centers had greater than 30% compliance with the BIG with regard to routine repeat head CT imaging and neurosurgical consultation. However, because of the observational and noninterventional nature of this study, we believe that this represents the natural evolution of clinical practice related to TBI management. The numbers reported as potential resources saved as a result of BIG implementation are likely underestimates, and our findings of no neurosurgical intervention requirements and TBI-related ED visits or readmissions among the BIG 1 and 2 patients and only 7 BIG 2 patients who required an ICU admission indicate that the BIG is safe to be applied in any population of TBI patients, regardless of whether routine RHCT or neurosurgical consultation is ordered or not. Despite these limitations, we demonstrate that the BIG may be safely and effectively implemented at Level I and Level II trauma centers for the treatment of patients with TBI while preventing unnecessary utilization of health care resources.

CONCLUSION

The BIG is based on patient history, neurologic examination, and findings of initial head CT scan. These guidelines emphasize the importance of using both clinical and radiographic findings for managing patients with TBI. The BIG protocol standardizes the treatment of patients with TBI without the need for neurosurgical consultation and unnecessary imaging. The implementation of BIG would reserve health care resources for patients who truly need them. The findings of our study demonstrate that the implementation of BIG at Level I and Level II trauma centers is feasible, safe, and effective while resulting in reduced health care resource utilization.

AUTHORSHIP

B.J., L.D., M.C., A.E.B., A.K., S.B., and M.G. designed this study. G.B., T.C., B.J., D.S., L.D., R.W., D.C., O.O., and D.R.M. searched the literature. B.J., L.D., M.C., S.B., A.E.B., A.K., M.G., R.W., D.C., and AAST BIG Multi-Institutional Study Group collected the data. B.J., L.D., M.C., S.B., A.E.B., A.K., M.G., R.W., O.O., and D.C. analyzed the data. All authors participated in data interpretation and manuscript preparation.

DISCLOSURE

The authors declare no conflicts of interests.

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DISCUSSION

A. BRITTON CHRISTMAS, M.D. (Charlotte, North Carolina): Dr. Michetti and Dr. West, members and guests of the AAST. With the allocation of resources at the forefront of health care, the Brain Injury Guidelines provide a method to stratify mild TBI and decrease unnecessary hospital and ICU admissions, neurosurgery consults, and repeat head CT scans of limited clinical relevance.

This multi-institutional trial sought to prospectively validate the Brain Injury Guideline criteria across nine Level 1 and 2 trauma centers to include 2,432 patients over a three-year period.

The primary outcome measures were the need for neurosurgery intervention with secondary outcomes defined as worsening of neurologic exam, progression of injury on the repeat head CT or repeat ED visits or hospital readmissions.

Of note, no BIG 1 patients experienced clinical deterioration and less than 1 percent of BIG 2 patients experienced clinical deterioration with none requiring neurosurgical or clinical interventions.

BIG 3 patients accounted for 70 percent of their total with 16 percent of these experiencing deterioration, as we would expect with more severe injuries.

It is projected that adherence to BIG criteria would have eliminated 425 head CT scans, 484 hospital admissions, and 511 neurosurgical consultations.

I have a few questions for the authors.

Number 1. Who determined the BIG categories based on the radiologic documentation, ED physicians? Trauma physicians? Or radiologists?

And were any/all of the nine included trauma centers experienced with BIG guidelines at baseline in an educational roll-out process to make sure we were adhering to them?

2. While the paper proposes that many of these patients, specifically those in BIG 1 and BIG 2 stratifications, could have been managed by acute care surgeons without the need for neurosurgery consultations, I would propose that for many of these patients, specifically the BIG 1, there are even greater cost savings to be realized by eliminating a trauma consultation all together.

While this certainly would not help our service line revenue production, it would yield even greater cost-savings by eliminating yet another consultation of limited value.

What are your thoughts regarding the need for our involvement in these patients, especially during an era when many of our trauma centers are posting all-time highs for trauma activations and admissions?

3. While this study evaluated BIG criteria across Level 1 and Level 2 trauma centers, I would propose that there are even bigger gains to be had at our non-trauma centers by reducing unnecessary patient transfers.

We have initiated these efforts within our own system but what do you propose as the stepwise progression to make this systematic change stick so that stakeholders farther downstream feel comfortable following these measures as we know all too well, all it takes is a single untoward outcome to derail even the best of efforts?

I would like to thank the association for the opportunity to serve as a discussant and congratulate the authors for this important and timely written manuscript.

Thank you.

SAMIR FAKHRY, M.D. (Nashville, Tennessee): Hi, Samir Fakhry from Nashville. Dr. Joseph, really excellent work. Great presentation. You have built a very impressive body of work here and I hope it will convince the naysayers eventually.

I may have missed this in looking at your many publications but have you ever calculated the actual cost savings or at least the charges that are saved and also the doses of radiation saved by not exposing these patients to repeated radiation?

Thanks very much and I look forward to seeing whether you are able to convince some of the reluctant people. Thank you.

PETER RHEE, M.D. (Valhalla, New York): Am I allowed to ask a question? Peter Rhee from Valhalla, New York. One statement, two questions.

When we made up the BIG guidelines we were very conservative and we used 4 millimeters which is half the diameter of the size of a pea, 1/16th of the volume of the pea. So we were very conservative just to be careful on this.

So the two questions are, one, now with all this accumulation of information and data do you have enough information to start refining the guidelines because, for example, intoxication and subarachnoid hemorrhage may not need to be a BIG 3 criteria?

And, second is just an idea from your promotion of this idea for a while, how much of the United States are early-adopters in starting to use this because I actually find some places that have never heard of it?

JODY DiGIACOMO, M.D. (East Meadow, New York): Being located in Long Island, about 20 percent of our patients are over the age of 80. And for our trauma center they constitute even more.

The average age in this study seemed to be in the 50s. Does this data really apply to those patients who are 75 and older whose brains are atrophied? Because our objective impression is that we're seeing a lot of delayed hemorrhages in these patients. Thank you.

CHRISTOPHER MICHETTI, M.D. (Falls Church, Virginia): And, Bellal, I have a question, too, if you don't mind. There were four to five times as many patients in the BIG 3 category as 1, which I found surprising. Do you think this skews the data at all?

BELLAL JOSEPH, M.D., F.A.C.S. (Tucson, Arizona): I'm going to answer the Long Island question first. I live in Tucson so we do use it for all those patients. I'll leave it at that.

To Dr. Christmas, thank you for the discussion and the very insightful questions. Number 1, who determined the BIG criteria, it was read by radiologists. Our radiologists now know how to grade the things that we need.

But, again, it was a radiology read and then each PI or there was someone from each center that went back and looked at the scans and assured that there was appropriate measurement of what we were, as we classified the data out. There was four centers that had already adopted the BIG prior to you know presenting their data.

For your second question is the whole idea of where should these patients go next, I think, you know, and Dr. Fakhry's question kind of comes to this, we did do a cost-analysis early-on in our initial study. It's about $5,000 per patient. It's hard to get the data of how much a neurosurgical consult costs.

It's about four to seven rads per CT. You put that on every repeat head CT for every one of these young or adult patients, I think it's a huge number.

But I think the most important thing of where these patients should be admitted is, and I heard it earlier in the Vegas presentation about they admit some of these to medicine. I think your system has to define those terms.

The most important thing I recommend to everyone, it has to be safe and patient centric. One patient will change this whole thing. And I think that's the most important thing: safety first. I know it's being implemented in some states as a way to do it.

For your third question on you know how to implement it across, for transfers, Dr. Goodman is in the audience, the Cincinnati trial where they used a Level 3 and a Level 1, they kind of modified the BIG criteria a little bit.

But I think, again, it goes back to what you need and how to use it. This data will help you have those conversations to develop, again, a safe system. I can't emphasize that enough.

Dr. Fakhry, for your questions, again, I think it's about $5,000 per patient. It's hard to get cost data analysis for each of those things: the CT, the consult, all of those things. But that's what we were looking at.

For Dr. Rhee's questions, when we initially did the first 4,000 patients you know we actually had 5 millimeters for BIG 1. We had one patient who had progression and the neurosurgeons were not comfortable and we moved it to four millimeters.

And I said, can you draw four millimeters and they weren't able to but I mean the whole idea is to be safe.

And maybe we do need to expand it to non-surgical, non-operative bleeds like subarachnoids or IPHs which, you know, a lot of times won't get an intervention.

As for refining the guidelines, I mean maybe we can define seizure prophylaxis and other interventions. And I congratulate the Colorado group for trying to do this however we really need to be careful and unified and work together instead of in opposite directions.

I really think it's time for others to grab it and use a different set of eyes to make it better. That's why we do what we do.

And then, you know, like aspirin, the question about 81 milligrams was asked earlier. There is data that shows that baby aspirin has no impact on progression or intervention so we don't use baby aspirin. But, again, that's a local thing. And I think each institution needs to do that.

And as far as early adopters, I see Dr. Ledgerwood sitting here. I remember after we presented this at the American Surgical she wrote me a letter asking me to email or to send her via snail-mail the protocol.

But I think institutions that adopted early, it's amazing. And then before you know it – your ED doesn't even talk to our neurosurgeons. If they call our neurosurgeons they will tell them to call us for BIG 1.

I think that's kind of impact– seen it I think Portland, Jacksonville, a couple of other centers have adopted and it's been excellent, I've heard nothing but positive things for as far as resources and ability to move patients through.

Thank you very much.