Trauma Surgery & Acute Care Open

Factors associated with receipt of intracranial pressure monitoring in older adults with traumatic brain injury

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Received 9 March 2021
Accepted 5 June 2021

To cite: Ghneim M, Albrecht J, Brasel K, *et al*. *Trauma Surg Acute Care Open* 2021;**6**:e000733.

ABSTRACT

Background The Brain Trauma Foundation (BTF) Guidelines for the Management of Severe Traumatic Brain Injury (TBI) include intracranial pressure monitoring (ICPM), yet very little is known about ICPM in older adults. Our objectives were to characterize the utilization of ICPM in older adults and identify factors associated with ICPM in those who met the BTF guidelines.

Methods We analyzed data from the American Association for the Surgery of Trauma Geriatric TBI Study, a registry study conducted among individuals with isolated, CT-confirmed TBI across 45 trauma centers. The analysis was restricted to those aged ≥60. Independent factors associated with ICPM for those who did and did not meet the BTF guidelines were identified using logistic regression.

Results Our sample was composed of 2303 patients, of whom 66 (2.9%) underwent ICPM. Relative to Glasgow Coma Scale (GCS) score of 13 to 15, GCS score of 9 to 12 (OR 10.2; 95% CI 4.3 to 24.4) and GCS score of <9 (OR 15.0; 95% CI 7.2 to 31.1), intraventricular hemorrhage (OR 2.4; 95% CI 1.2 to 4.83), skull fractures (OR 3.6; 95% CI 2.0 to 6.6), CT worsening (OR 3.3; 95% CI 1.8 to 5.9), and neurosurgical interventions (OR 3.8; 95% CI 2.1 to 7.0) were significantly associated with ICPM. Restricting to those who met the BTF guidelines, only 43 of 240 (18%) underwent ICPM. Factors independently associated with ICPM included intraparenchymal hemorrhage (OR 2.2; 95% CI 1.0 to 4.7), skull fractures (OR 3.9; 95% CI 1.9 to 8.2), and neurosurgical interventions (OR 3.5; 95% CI 1.7 to 7.2).

Discussion Worsening GCS, intraparenchymal/intraventricular hemorrhage, and skull fractures were associated with ICPM among older adults with TBI, yet utilization of ICPM remains low, especially among those meeting the BTF guidelines, and potential benefits remain unclear. This study highlights the need for better understanding of factors that influence compliance with BTF guidelines and the risks versus benefits of ICPM in this population.

Level of evidence Prognostic and epidemiological, level III.

INTRODUCTION

Traumatic brain injury (TBI) is a major health problem among older adults. Although individuals 65 years or older represent only 10% of all patients with TBI, they account for 50% of TBI-related deaths.[1] In 2013, TBI was responsible for 485 000 emergency department visits, 123 000 hospitalizations, and 21 000 deaths among adults aged 65 and older in the USA.[2] Furthermore, patients who were older than 75 years of age experienced the highest TBI-related hospitalization rate—twice that of any other age group.[2]

An important but controversial aspect of managing severe TBI is intracranial pressure monitoring (ICPM) to detect and manage intracranial hypertension and reduce secondary insults.[3–5] In the 2016 Fourth Edition of the *Guidelines for the Management of Severe Traumatic Brain Injury*, the Brain Trauma Foundation (BTF) recommended ICPM in patients with a Glasgow Coma Scale (GCS) score <9 and evidence of CT abnormality as level IIB evidence to reduce in-hospital and 2-week mortality after injury.[6] However, these guidelines do not specifically address older adults with TBI. In fact, many prior studies either excluded older patients or grouped them with younger adults in outcomes assessment.[7–10] Additionally, there is conflicting evidence on whether ICPM improves outcomes in severe TBI in both young[5 7 8 11–21] and older patient populations.[19 22–24] Given the lack of clear guidance regarding ICPM and the limited available data on outcomes, the decision of whether or not to place a monitor in an older adult presenting with TBI is typically left to an individual physician's judgment.

The normal cerebral atrophy that occurs with aging may reduce the risk of intracranial hypertension. Thus, conceptually, ICPM may not benefit many elderly patients. Yet this is not reflected in current management guidelines.[25] Given the lack of guidelines specific for ICPM in older adults due to the limited number of studies that have investigated the indications and role of ICPM[25] in this population and specifically in the setting of isolated TBI, we conducted an indepth analysis to better understand which older patients receive ICPM and

whether the current BTF recommendations are followed. The objectives of this study were to (1) characterize the utilization of ICPM in a cohort of older adults presenting with isolated TBI and (2) identify factors associated with ICPM among those patients who met the BTF guidelines. We hypothesized, given the lack of evidence-based guidelines specific for older adults, that indications for ICPM in this population are similar to their younger counterparts and in accordance with the most recent and widely available BTF guidelines.

METHODS

Study population

This was a retrospective analysis of data from the Geriatric Traumatic Brain Injury ("Geri-TBI") study. The observational Geri-TBI study was approved by the American Association for the Surgery of Trauma (AAST) Multicenter Trials Committee. Data were collected from September 2017 through February 2019 across 45 trauma centers. Data were abstracted from medical records and entered into an online data collection portal resource maintained by the AAST.

The Geri-TBI study inclusion criteria were CT-verified TBI, age ≥40 years, and presentation at a participating hospital within 24 hours of injury. To establish a population with TBI as the primary injury and minimize the confounding influence of polytrauma, we excluded patients with injury to any other body region resulting in an Abbreviated Injury Scale (AIS) score >2. Prisoners and pregnant women were also excluded. Data of patients >89 years are considered protected health information under the Health Insurance Portability and Accountability Act and were permitted for inclusion by some, but not all, sites. For the current study we restricted the analysis to older adults who were ≥60 years of age.

Covariates

Data on patient demographics, clinical and injury-related characteristics, hospital course and treatments, and discharge disposition were collected and analyzed. We also created an additional variable that is indicative of any CT worsening during the 72 hours after admission. CT worsening was defined as an increase in hematoma size, an increase in or development of new areas of intraventricular, intraparenchymal or subarachnoid hemorrhage or contusion, and worsening cerebral edema. Receipt of palliative intervention included palliative care consultation, discontinuation of life-sustaining measures, and transition to hospice care. The change in residence score evaluated a patient's preinjury residence as compared with discharge to either the same or different level of independence. This ranged from 0 to −4, with 0 representing discharge to the same preinjury location, and −1 to −4 representing discharge to facilities with increasing level of dependence. Neurosurgical intervention was defined as craniotomy or craniectomy. For this study, we defined compliance with the BTF guidelines as placement of an ICP monitor in patients with an admission GCS score <9 and an abnormal CT scan.

Statistical analysis

We first compared the distributions of covariates between study subjects who received intracranial pressure monitors and those who did not using χ^2 goodness of fit and either Student's t-test or Wilcoxon rank-sum as appropriate. Logistic regression analysis was used to identify factors independently associated with ICP monitor placement. The regression model included all clinically relevant variables associated with ICP monitor placement in bivariate analysis but that were not a result of ICP monitor placement (eg, length of stay), whose p-value was ≤0.05. This analysis was conducted without regard to temporality, and thus interpretation should be associational.

Next, we restricted our cohort to patients meeting the BTF criteria for ICPM. We conducted a second bivariate analysis as described above, comparing those who received ICPM with those who did not. We then used logistic regression, including all clinically relevant variables associated with ICP monitor placement and whose p-value was ≤0.05 in the bivariate analysis, to identify factors independently associated with ICPM.

Table 1 Characteristics of participating trauma centers (n=45)

Geographical location, n (%)	
Northeast	11 (24.4)
Mid-Atlantic	6 (13.3)
Southeast	3 (6.7)
Midwest	12 (26.7)
Southwest	11 (24.4)
Northwest	1 (2.2)
International	1 (2.2)
Location, n (%)	
Urban	32 (71.1)
Suburban	9 (20.0)
Rural	4 (8.9)
Designated level, n (%)	
1+	39 (86.7)
2	6 (13.3)
Facility size, n (%)	
<200 beds	1 (2.2)
200–400 beds	10 (22.2)
401–600 beds	10 (22.2)
>600 beds	24 (53.3)
Trauma admissions per year, mean (SD)	2571 (1550)

RESULTS

Patients were evaluated at one of 45 participating trauma centers. Most centers were level 1 (86.7%) and >600 beds (53.3%). The mean number of annual admissions was 2571±1550 among the participating centers (table 1).

Of the 3081 patients included in the Geri-TBI cohort, 2303 (74.7%) were ≥60 years of age, of whom 66 (2.9%) received ICPM. An intraparenchymal fiberoptic monitor ("bolt") was used in 33 (50.0%) patients, and 33 (50.0%) underwent placement of an external ventricular drain (EVD). Individuals who received ICPM differed significantly across demographic, clinical, and injury-related characteristics relative to those who did not receive ICPM (table 2).

On bivariate analysis, patients who received ICPM were younger (72.2±8.4 years vs. 77.1±9.1 years, p<0.001), more likely to experience CT worsening (68.2% vs. 23.3%, p<0.001), and more likely to have been injured in a motor vehicle collision (21.2% vs. 7.9%, p<0.001), even though falls were the most common cause of injury in both cohorts. Head AIS score and GCS score were significantly worse in patients who underwent ICPM (p<0.001). Those with ICPM were more likely to undergo neurosurgical intervention as well as experience both longer hospital and intensive care unit (ICU) lengths of stay. Finally, patients with ICPM were more likely to receive palliative

Table 2 Characteristics of patients with isolated traumatic brain injury aged ≥60 years, stratified by receipt of ICP monitoring (n=2303)

	ICP, n=66	No ICP, n=2237	P value*
Age in years, mean (SD)	72.2 (8.4)	77.1 (9.1)	<0.001
Age categories, n (%)			0.001
60–81	55 (83.3)	1399 (62.5)	
>81	11 (16.7)	838 (37.5)	
Sex, n (%)			0.02
Female	24 (36.4)	1129 (50.5)	
Male	42 (63.6)	1108 (49.5)	
Race, n (%)			0.03
White	45 (68.2)	1809 (80.9)	
Black	9 (13.6)	166 (7.4)	
Other	12 (18.2)	262 (11.7)	
Comorbidities, n (%)			
Neurological	19 (35.2)	890 (40.9)	0.39
Cardiac disease	44 (81.5)	1873 (86.3)	0.31
Respiratory disease	9 (16.7)	466 (21.5)	0.40
Kidney disease	10 (18.5)	347 (15.9)	0.62
Liver disease	4 (7.4)	119 (5.5)	0.54
Anticoagulants at home, n (%)	10 (15.2)	445 (19.9)	0.34
Warfarin	7 (10.6)	233 (10.4)	0.96
Direct oral anticoagulants	3 (7.0)	205 (10.0)	0.51
Antiplatelet use at home, n (%)	22 (33.3)	1059 (47.3)	0.03
Cause of injury, n (%)			<0.001
Motor vehicle collision	14 (21.2)	176 (7.9)	
Fall	46 (69.7)	1967 (88.4)	
Assault	5 (7.6)	34 (1.5)	
Other	1 (1.5)	47 (2.1)	
Head AIS score, n (%)			<0.001
2	4 (6.1)	507 (22.7)	
3	8 (12.1)	882 (39.4)	
4	15 (22.7)	488 (21.8)	
5	39 (59.1)	349 (15.6)	
6	0	11 (<1)	
GCS score†, n (%)			<0.001
13–15	11 (16.7)	1914 (85.6)	
9–12	12 (18.2)	126 (5.6)	
<9	43 (65.2)	197 (8.8)	
Initial CT results, n (%)			
Subdural hematoma	54 (81.8)	1462 (65.4)	0.01
Epidural hematoma	5 (7.6)	56 (2.5)	0.01
Intraventricular hemorrhage	16 (24.2)	163 (7.3)	<0.001
Subarachnoid hemorrhage	45 (68.2)	1089 (48.7)	0.002
Intraparenchymal hemorrhage	26 (39.4)	371 (16.6)	<0.001
Cerebral edema	9 (13.6)	74 (3.3)	<0.001
Skull fracture	29 (43.9)	195 (8.7)	<0.001
CT worsening (any), n (%)	45 (68.2)	520 (23.3)	<0.001
Pupil reactivity, n (%)			<0.001
Both	45 (68.2)	2110 (94.3)	
One	8 (12.1)	43 (1.9)	
Neither	13 (19.7)	84 (3.8)	
Neurosurgical intervention, n (%)	31 (47.0)	178 (8.0)	<0.001
Craniotomy	20 (30.3)	128 (5.7)	<0.001
Craniectomy	10 (15.2)	30 (1.3)	<0.001
Tracheostomy, n (%)	17 (25.8)	40 (1.8)	<0.001
PEG tube/gastrostomy, n (%)	21 (31.8)	73 (3.3)	<0.001
Laboratory values, n (%) INR ≥2	58 (92.1)	1814 (91.9)	0.96
Platelet transfusions, n (%)	15 (22.7)	245 (10.9)	0.003
Reversal agents administered, n (%)			
Vitamin K	7 (10.6)	157 (7.0)	0.26
Fresh frozen plasma	8 (12.1)	87 (3.9)	0.001
Three-factor prothrombin complex concentrate	1 (1.5)	25 (1.1)	0.76
Length of hospital stay in days, median (IQR)	14 (16)	4 (5)	<0.001
Length of ICU stay in days, median (IQR)	12 (10)	2 (3)	<0.001
Ventilator days, median (IQR)	6 (9)	3 (7)	<0.001
Palliative interventions, n (%)	31 (47.7)	310 (13.9)	<0.001
Do not attempt resuscitation, n (%)	18 (27.3)	191 (8.5)	<0.001
Days from admission, median (IQR)	5 (3–8)	1 (1–4)	0.004
Palliative care consult, n (%)	11 (16.7)	128 (5.7)	<0.001
Days from admission, median (IQR)	6 (2–10)	2 (1–6)	0.19
Discontinuation of life-sustaining measures, n (%)	19 (28.8)	126 (5.6)	<0.001
Days from admission, median (IQR)	5 (4–14)	3 (1–7)	0.008
Hospice care, n (%)	1 (1.5)	100 (4.5)	0.25
Days from admission, median (IQR)	3	5 (2–8.5)	0.67
Death at discharge, n (%)	31 (46.9)	209 (9.3)	<0.001
Change in residence, n (%)			<0.001
More care required/deceased	59 (89.4)	993 (44.4)	

*P value comparing across age categories from Student's t-test, Wilcoxon rank-sum, or χ^2 goodness of fit.
†Best postresuscitation GCS score.
AIS, Abbreviated Injury Scale; GCS, Glasgow Coma Scale; ICP, intracranial pressure; ICU, intensive care unit; INR, international normalized ratio; PEG, percutaneous endoscopic gastrostomy.

interventions (47.7% vs. 13.9%, p<0.001) and were more likely to discharge to a more dependent level of care as compared with their preinjury residence (89.4% vs. 44.4%, p<0.001) (table 2). Patients with ICPM in place also experienced higher mortality (46.9% vs. 9.3%, p<0.001) (table 2).

Our logistic regression model included factors independently associated with ICPM (table 3). Relative to GCS score of 13 to 15, GCS score of 9 to 12 (OR 10.2; 95% CI 4.3 to 24.4) and GCS score of <9 (OR 15.0; 95% CI 7.2 to 31.1) were significantly associated with ICPM. As well, intraventricular hemorrhage (OR 2.4; 95% CI 1.2 to 4.83), skull fractures (OR 3.6; 95% CI 2.0 to 6.6), any subsequent CT worsening (OR 3.3; 95% CI 1.8 to 5.9), and receipt of neurosurgical intervention (OR 3.8; 95% CI 2.1 to 7.0) were significantly associated with ICPM.

We identified 240 patients meeting the BTF criteria (ie, CT-verified TBI and GCS score <9) for ICPM, but only 43 (18%) underwent ICPM (table 4). An intraparenchymal fiber-optic monitor was used in 21 (48.8%) patients, and 22 (51.2%) underwent placement of an EVD. Individuals >81 years of age were less likely to undergo ICPM (11.6% vs. 30.5%, p=0.01). Those who met the BTF criteria and underwent ICPM were more likely to undergo neurosurgical intervention (47% vs.

Table 3 OR and 95% CI of factors associated with receipt of intracranial pressure monitoring among patients with isolated traumatic brain injury aged ≥60 years (n=2303)

	OR (95% CI)
Glasgow Coma Scale score	
13–15	Reference
9–12	10.2 (4.3 to 24.4)
<9	15.0 (7.2 to 31.1)
Intraventricular hemorrhage*	2.4 (1.2 to 4.8)
Skull fracture*	3.6 (2.0 to 6.6)
Any worsening CT scan	3.3 (1.8 to 5.9)
Receipt of neurosurgical intervention	3.8 (2.1 to 7.0)

*On initial CT scan.

8%, p<0.001) and go on to experience longer hospital and ICU lengths of stay. Mortality, receipt of palliative interventions, and change in residence did not differ between the two groups. However, changes in code status and discontinuation of life-sustaining measures occurred significantly later into hospitalization in those who underwent ICPM.

Our final logistic regression model of factors associated with ICPM in patients meeting the BTF criteria demonstrated independent associations with intraparenchymal hemorrhage (OR 2.2; 95% CI 1.0 to 4.7), skull fracture (OR 3.9; 95% CI 1.9 to 8.2), and receipt of neurosurgical interventions (OR 3.5; 95% CI 1.7 to 7.2) (table 5).

DISCUSSION

The aims of the study were to characterize the utilization of ICPM in a cohort of older adults presenting with isolated TBI and identify factors associated with ICPM in those meeting the BTF guidelines. ICPM occurred in less than 3% of patients. Intraparenchymal hemorrhage on initial imaging, skull fractures, and receipt of neurosurgical intervention were identified as the factors associated with ICPM in those who met the BTF guidelines. To our knowledge, this study is one of the first to identify the characteristics in those ≥60 years of age presenting with isolated TBI who meet the BTF guidelines and undergo ICPM.

It has been well established that elevated ICP associated with severe TBI leads to increased morbidity and mortality.[2 4 5 23] Consequently, ICPM and treatment of intracranial hypertension remain the mainstay of care in patients with severe TBI. As a result, all previous BTF guidelines recommend ICPM, with the most recent version presenting monitoring as level IIB evidence to reduce in-hospital and 2-week mortality after injury.[6] However, reports of compliance with BTF guidelines for ICPM vary widely (from 10% to 75%),[8 11 22] likely due to a lack of evidence to definitively associate its use with improved outcomes.[5 7 8 11–24] Chesnut *et al*[21] randomized patients to either an invasive ICP monitor or a clinical/radiological examination and failed to find differences in outcomes between the strategies. Furthermore, current BTF guidelines do not specifically recognize older adults with TBI as a distinct population, despite the association with different risk factors, mechanisms of injury, disease progression, and comorbid conditions in these patients, as well as normal anatomic changes that occur with aging and affect the development of intracranial hypertension.[25] Nevertheless, it is well established that older patients are at increased risk of adverse outcomes after TBI compared with their younger counterparts.[20 23 24] Accordingly, it is reasonable to speculate that

Table 4 Characteristics of patients with isolated traumatic brain injury aged ≥60 years and meeting the Brain Trauma Foundation guidelines for ICP monitoring, by ICP status (n=240)

	ICP, n=43	No ICP, n=197	P value*
Age in years, mean (SD)	71.2 (7.4)	75.6 (9.1)	0.004
Age categories, n (%)			0.01
60–81	38 (88.4)	137 (69.5)	
>81	5 (11.6)	60 (30.5)	
Sex, n (%)			0.19
Female	15 (34.9)	90 (45.7)	
Male	28 (65.1)	107 (54.3)	
Race, n (%)			0.17
White	27 (62.8)	151 (76.7)	
Black	7 (16.3)	19 (9.6)	
Other	9 (20.9)	27 (13.7)	
Comorbidities, n (%)			
Neurological	13 (37.1)	66 (36.3)	0.92
Cardiac disease	26 (74.3)	147 (80.8)	0.38
Respiratory disease	5 (14.3)	40 (21.9)	0.30
Kidney disease	6 (17.1)	22 (12.1)	0.41
Liver disease	2 (5.7)	10 (5.5)	0.96
Anticoagulants at home, n (%)	6 (13.9)	42 (21.3)	0.27
Warfarin	4 (9.3)	25 (12.7)	0.54
Direct oral anticoagulants	2 (7.1)	15 (10.0)	0.64
Antiplatelet use at home, n (%)	10 (23.3)	68 (34.5)	0.15
Cause of injury, n (%)			0.05
Motor vehicle collision	10 (23.3)	21 (10.9)	
Fall	30 (69.8)	164 (84.9)	
Assault	2 (4.7)	2 (1.0)	
Other	1 (2.3)	6 (3.1)	
Head AIS score, n (%)			0.73
2	1 (2.3)	9 (4.6)	
3	6 (13.9)	36 (18.3)	
4	9 (20.9)	35 (17.8)	
5	27 (62.8)	113 (57.4)	
6	0	4 (2.0)	
GCS score†, n (%)			0.12
3	17 (39.5)	108 (54.8)	
4	5 (11.6)	11 (5.6)	
5	2 (4.7)	7 (3.6)	
6	3 (6.9)	28 (14.2)	
7	9 (20.9)	21 (10.7)	
8	7 (16.3)	22 (11.2)	
Initial CT results, n (%)			
Subdural hematoma	36 (83.7)	160 (81.2)	0.70
Epidural hematoma	4 (9.3)	12 (6.1)	0.44
Intraventricular hemorrhage	10 (23.3)	33 (16.8)	0.31
Subarachnoid hemorrhage	30 (69.8)	103 (52.3)	0.04
Intraparenchymal hemorrhage	18 (41.9)	44 (22.3)	0.01
Cerebral edema	7 (16.3)	29 (14.7)	0.79
Skull fracture	23 (53.5)	39 (19.8)	<0.001
CT worsening (any), n (%)	27 (62.8)	80 (40.6)	0.01
Pupil reactivity, n (%)			0.37
Both	24 (55.8)	105 (53.3)	

Continued

Table 4 Continued

	ICP, n=43	No ICP, n=197	P value*
One	6 (13.9)	16 (8.12)	
Neither	13 (30.2)	76 (38.6)	
Neurosurgical intervention, n (%)	23 (53.5)	50 (25.4)	<0.001
Craniotomy	15 (34.9)	37 (18.8)	0.02
Craniectomy	8 (18.6)	15 (7.6)	0.03
Tracheostomy, n (%)	12 (27.9)	11 (5.6)	<0.001
PEG tube/gastrostomy, n (%)	14 (32.6)	21 (10.7)	<0.001
Platelet transfusion, n (%)	7 (16.3)	36 (18.3)	17.9
Reversal agents administered, n (%)			
Vitamin K	5 (23.8)	16 (8.1)	0.46
Fresh frozen plasma	7 (16.3)	34 (17.3)	0.88
Three-factor prothrombin complex concentrate	43 (100)	196 (99.5)	0.64
Length of hospital stay in days, median (IQR)	12 (20)	5 (8)	<0.001
Length of ICU stay in days, median (IQR)	10.5 (10)	4 (7)	<0.001
Ventilator days, median (IQR)	6.5 (10)	3 (6)	<0.001
Palliative interventions, n (%)	20 (47.6)	107 (54.6)	0.41
Do not attempt resuscitation, n (%)	14 (32.6)	65 (33.0)	0.96
Days from admission, median (IQR)	5 (3–9)	1 (1–4)	0.002
Palliative care consult, n (%)	7 (16.3)	38 (19.3)	0.65
Days from admission, median (IQR)	6 (2–11)	2 (1–5)	0.17
Discontinuation of life-sustaining measures, n (%)	13 (30.2)	66 (33.5)	0.68
Days from admission, median (IQR)	5 (5–14)	2 (1–5)	0.002
Hospice care, n (%)	0	23 (11.7)	0.02
Days from admission, median (IQR)	n/a	2 (2–6)	n/a
Death at discharge, n (%)	23 (53.5)	118 (59.9)	0.44
Change in residence, n (%)			0.97
More care required/deceased	39 (90.7)	179 (90.9)	

*P value comparing across age categories from Student's t-test, Wilcoxon rank-sum, or χ^2 goodness of fit.
†Best postresuscitation GCS score.
AIS, Abbreviated Injury Scale; GCS, Glasgow Coma Scale; ICP, intracranial pressure; ICU, intensive care unit; n/a, not available; PEG, percutaneous endoscopic gastrostomy.

older patients with TBI may need to be managed differently from younger patients.

The use of ICPM was low overall (<3% of study sample) and among those meeting the BTF criteria (18%). Although the reason for such a low compliance rate is unclear, it may reflect the fact that current BTF guidelines are not widely considered a recommended practice due to an inherent skepticism of the benefit of ICPM in older adults with severe TBI, given the lack of dedicated research focused on outcomes within this age group and the overall mixed evidence in the currently available literature. It is certainly possible that with increasing age, patients were not offered more aggressive care based on individual patient or family wishes. Additionally, physician clinical decision-making based on 24-hour survivability given injury severity (fixed and dilated pupils, uncal herniation, basal cistern effacement, midline shift), non-recoverable injuries, pre-existing neurological disabilities, overall life expectancy, and inherent bias due to limited available data undoubtedly influence the rate of ICP monitor utilization, although this information is not readily elucidated from our data. Certainly, such a low percentage of patients undergoing ICPM in a large multi-institutional trial suggests that, although the BTF guidelines may be a useful resource or starting point to guide management in older adults, additional factors (individual, provider, and institutional) also heavily influence the decision-making processes and highlights the need for further evidence-based guidelines that specifically focus on the care of older adults with TBI.

Table 5 OR and 95% CI of factors associated with receipt of ICP monitoring among patients with isolated traumatic brain injury aged ≥60 years and meeting the Brain Trauma Foundation guidelines for ICP monitoring (n=240)

	OR (95% CI)
Intraparenchymal hemorrhage*	2.2 (1.0 to 4.7)
Skull fracture*	3.9 (1.9 to 8.2)
Receipt of neurosurgical intervention	3.5 (1.7 to 7.2)

*On initial CT scan.
ICP, intracranial pressure.

One finding of our study that may account for such a small percentage of patients undergoing ICPM, despite meeting the BTF criteria, is earlier establishment of code status and implementation of palliative interventions (discontinuation of life-sustaining measures and hospice care) in those who did not undergo ICP monitor placement. It is unclear if these patients were never offered ICPM or if they opted to forego monitor placement. Given the similar head AIS and GCS scores between both groups, this difference does not likely reflect a discrepancy in injury severity as it is commonly measured. Instead, those patients who received ICPM were significantly more likely to have an underlying skull fracture and/or intraparenchymal or intraventricular hemorrhage. Skull fractures have been shown in two prior studies to be a marker of more severe underlying parenchymal injury in patients with both mild and severe TBI.[26 27] As such, this difference suggests that patients who received ICPM may have had more severe injuries, but does not account for relatively later pursuit of palliative interventions. The delay may reflect variations in the availability and utilization of palliative interventions across the different trauma centers that are not captured by our data.

There are multiple limitations to this study, the most notable of which is that the extremely small sample size limited our ability to reliably correlate clinical outcomes with ICP monitor placement. Additionally, sample size limited the ability to make comparisons in the setting of ICPM between those who did and did not undergo neurosurgical interventions. The lack of available data regarding patient characteristics, specifically frailty measures, clinical scenarios, and provider factors, may have influenced the decision whether or not to place an ICP monitor. There is also certain variability in practice management at the participating institutions, which likely introduced some selection bias related to who received an ICP monitor. Finally, our findings are affected by all the inherent limitations of an observational, retrospective study.

CONCLUSION

Although intraparenchymal hemorrhage, skull fractures, and receipt of neurosurgical intervention were associated with ICPM among older adults with TBI, the overall utilization of ICPM in those who meet the BTF criteria remains markedly low across high-volume trauma centers. Therefore, the utility and potential benefits of ICPM in this unique patient population remain unclear. Our analysis highlights the need for further, more

detailed studies of ICPM in older adults with severe TBI, as well as investigation of the clinical, patient-specific, and provider-specific factors that may influence utilization and account for current low compliance with the BTF guidelines.

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Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests JA's institution has received research funding from the American Sleep Medicine Foundation, Merck, and ResMed. The following authors are part of the Trauma Surgery & Acute Care Open editorial team: associate editors: KB, Martin Croce, and Rosemary Kozar; editorial advisory board: ZC; editorial board reviewers: TJS, Ajai K Malhotra, David Livingston, Bellal Joseph, DMS, and Krista Kaups.

Patient consent for publication Not required.

Ethics approval This study was a retrospective review of a prospective observational study. No treatment was implemented and the care provided was in accordance with the standard of care at the participating institutions. Given the observational nature of the study, no informed consent was required or obtained. All collaborating centers obtained individual local institutional review board approval before participation.

Provenance and peer review Not commissioned; internally peer reviewed.

Data availability statement No data are available.

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