An analysis of neurosurgical practice patterns and outcomes for serious to critical traumatic brain injuries in a mature trauma state

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BACKGROUND: We sought to characterize trends in neurosurgical practice patterns and outcomes for serious to critical traumatic brain injuries from 2003 to 2013 in the mature trauma state of Pennsylvania.

METHODS: All 2003 to 2013 admissions to Pennsylvania's 30 accredited Level I to II trauma centers with serious to critical traumatic brain injuries (head Abbreviated Injury Scale [AIS] score ≥ 3, Glasgow Coma Scale [GCS] score < 13) were extracted from the state registry. Adjusted temporal trend tests controlling for demographic and injury severity covariates assessed the impact of admission year on intervention rates (craniotomy, craniectomy, and intracranial pressure monitor/ventriculostomy [ICP]) and outcome measures for the total population as well as serious (head AIS score ≥ 3; GCS score, 9–12) and critical (head AIS score ≥ 3, GCS score ≤ 8) subgroups.

RESULTS: A total of 22,229 patients met inclusion criteria. Admission year was significantly associated with an adjusted increase in craniectomy (adjusted odds ratio [AOR], 1.12 [1.09–1.14]; $p < 0.001$) and ICP rates (AOR, 1.03 [1.02–1.04]; $p < 0.001$) and a decrease in craniotomy rate (AOR, 0.96 [0.95–0.97]; $p < 0.001$). No significant trends in adjusted mortality were found for the total study population (AOR, 1.01 [1.00–1.02]; $p = 0.150$); however, a significant reduction was found for the serious subgroup (AOR, 0.95 [0.92–0.98]; $p = 0.002$), and a significant increase was found for the critical subgroup (AOR, 1.02 [1.01–1.03]; $p = 0.004$).

CONCLUSION: Total study population trends showed a reduction in rates of craniotomy and increase in craniectomy and ICP rates without any change in outcome. Despite significant adaptations in neurosurgical practice patterns from 2003 to 2013, only patients with serious head injuries are experiencing improved survival. (*J Trauma Acute Care Surg.* 2016;80: 755–763. Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Prognostic and epidemiologic study, level III; therapeutic study, level IV.

KEY WORDS: Neurosurgical intervention; traumatic brain injury; mortality.

Traumatic brain injury (TBI) is a leading cause of death and disability, accounting for approximately 31% of all injury-related deaths in the United States.[1–3] Despite TBI-related emergency department visits and hospitalizations drastically increasing from 2001 to 2010 (420.6–715.7 per 100,000 and 82.7–91.7 per 100,000, respectively), mortality rate has significantly decreased (from 18.5 to 17.1 per 100,000), according to a nationwide investigation conducted by the Centers for Disease Control and Prevention (CDC).[4] While this reduction in TBI-related deaths is likely caused by multiple factors, including changes in public policy and safety laws,[5] it is feasible to suggest that improvements in neurotrauma and critical care were also influential.[5–7]

The most recent edition of the Guidelines for the Management of Severe Traumatic Brain Injury released by the Brain Trauma Foundation in 2007 provides neurosurgical intensivists with 15 individual process-of-care recommendations designed to optimize treatment and outcomes in severe TBI patients.[8] Emphasizing pressure monitoring and the maintenance of adequate cerebral perfusion, these guidelines detail management approaches, treatment thresholds, and indications for several invasive procedures including intracranial pressure monitoring, craniotomy, and craniectomy.[8–10] Although the literature is replete with investigations analyzing the effects of these neurosurgical invasive approaches on patient outcomes,[11–17] few studies have analyzed specific trends in the use of these interventions over time.[18]

The purpose of this investigation was to add to the literature on this underrepresented facet of neurocritical intensive care by characterizing neurosurgical practice patterns and outcomes for serious to critical TBI patients across an 11-year time frame in Pennsylvania's mature, statewide trauma system. Because of national investigations by the CDC reporting improved survival for TBI-afflicted patients from 2001 to 2010,[4] we hypothesized that a reduction in in-hospital mortality would be observed for TBI patients presenting with serious to critical injuries in the Commonwealth of Pennsylvania. In addition, as research detailing improved functional recovery with craniectomy procedures has become more prevalent,[11–13] we hypothesized that an increased rate of craniectomy would be observed during the study period.

PATIENTS AND METHODS

Following review and approval by the institutional review board of Lancaster General Health, the Pennsylvania Trauma

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This study was presented at the 74th annual meeting of the American Association for the Surgery of Trauma, September 9–12, 2015, in Las Vegas, Nevada.
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Outcome Study (PTOS) database, a statewide trauma registry of the Pennsylvania Trauma Systems Foundation (Digital Innovations, Forest Hill, MD), was retrospectively reviewed for all admissions from 2003 to 2013. The population under investigation included all TBI patients presenting with a head Abbreviated Injury Scale (AIS) score of 3 or higher and a Glasgow Coma Scale (GCS) score of lower than 13 to the 30 Level I to II trauma centers in the Commonwealth of Pennsylvania. Patients dying in the field and subsequently not presenting to a Pennsylvania Level I to II trauma center were not included in the statewide database. Extracted variables included demographics/admission statistics (age, sex, race, mechanism of injury, admission systolic blood pressure [SBP], Injury Severity Score [ISS], GCS score, head AIS score, prolonged loss of consciousness [LOC > 1 hour]), neurosurgical interventions (craniotomy, craniectomy, intracranial pressure monitor/ventriculostomy [ICP]), and outcomes (in-hospital mortality, intensive care unit [ICU] length of stay, ventilator days). Craniotomy was defined as International Classification of Diseases—9th Rev. (ICD-9) 01.24; craniectomy as ICD-9 01.25; ICP as ICD-9 01.10, 02.20–02.22; and LOC for more than 1 hour as AIS PREDOT codes 140628, 140645, 140649, 140677, 140683, 140695, 140698, 140703, 161006–161008, and 161011–161013. Univariate analysis in the form of χ^2 test and *t* tests was implemented to determine differences in baseline demographics between operative (patients receiving neurosurgical intervention) and nonoperative (no neurosurgical intervention) groups. Continuous data were presented as means and SDs, whereas categorical variables were presented as counts and percentages. Statistical significance was defined as $p < 0.05$.

To analyze trends in neurosurgical intervention rates (craniotomy, craniectomy, ICP) and outcomes (mortality, ventilator days for >6, ICU days for >6) during the study period, unadjusted and adjusted temporal analyses were performed. Unadjusted temporal trend tests modeled the relationship between raw neurosurgical intervention/outcome measures and admission year, while adjusted trend tests used these same methods in a multivariate modeling approach controlling for variables predictive of intervention/outcome measures in univariate analysis. To further evaluate trends found in the entire study population, subanalyses separating the population into serious (GCS score, 9–12 head AIS score ≥ 3) and critical (GCS score ≤ 8, head AIS score ≥ 3) head injury subgroups were performed. Similar to the analyses run on the entire head injury population, adjusted temporal trend tests were used to assess changes in intervention rates and outcomes for the two subgroups from 2003 to 2013.

To assess the impact of prolonged LOC on outcome pertaining to the three neurosurgical interventions under investigation (craniotomy, craniectomy, ICP), participants were separated into LOC and non-LOC subgroups. Separate multivariate logistic regression mortality models were run on these subgroups controlling for identical patient demographics/admission statistics and neurosurgical intervention variables. The purpose of these models was to gain adjusted insight into which procedures, if any, are more effective in patients presenting with head injuries based predominantly on anatomic insult (non-LOC), compared with those with more global cerebral injuries (LOC). To determine the discrimination of each multivariate model used in this investigation, the area under the receiver operating characteristic curve (AUROC) was calculated.

RESULTS

During the 11-year study period, 22,229 serious to critical TBI patients presented to the 30 Pennsylvania Trauma Systems Foundation–accredited Level I to II trauma centers in the Commonwealth of Pennsylvania. The study population was predominantly middle-aged, male, critical head-injured trauma patients. A complete breakdown of study population demographics, including mechanism of injury, is available in Table 1. The average number of head injury admissions per year was 2,021 (lowest admission year: 2011, n = 1,886; highest admission year: 2005, n = 2,101). Neurosurgical intervention rate for the study population was 27.9% (6,207 of 22,229), and overall in-hospital mortality rate was 35.8% (7,950 of 22,229).

Within the operatively managed population (n = 6,207), 74.4% of the patients (4,617 of 6,207) received only one of the three neurosurgical procedures under investigation (craniotomy, craniectomy, or ICP), 23.4% received two of the three (1,454 of 6,207), and 2.2% underwent all three procedures (136 of 6,207). The most common operative intervention performed was ICP (61.4%), followed by craniotomy (27.6%) and craniectomy (11.0%). Compared with the nonoperative group, operatively managed patients were significantly younger (operative, 39.7 ± 22.1 [21.0–56.0], nonoperative, 45.4 ± 26.2 [22.0–69.0]; $p < 0.001$) and presented with significantly higher ISS (operative median, 29.0 [25.0–38.0]; nonoperative median, 25.0 [17.0–33.0]; $p < 0.001$) and head AIS scores (operative, 4.72 ± 0.95 [4.00–5.00]; nonoperative, 4.32 ± 1.22 [3.00–5.00]; $p < 0.001$) and significantly lower GCS scores (operative, 4.70 ± 2.69 [3.00–6.00]; nonoperative, 5.34 ± 3.25 [3.00–8.00]; $p < 0.001$). In-hospital mortality rate was significantly lower in the operative group compared with the nonoperative group (operative, 32.5% [2,016 of 6,207]; nonoperative, 37.0%; $p < 0.001$) (Table 1).

When analyzing the total head injury population (serious and critical, n = 22,229), both unadjusted and adjusted temporal trend tests revealed a significant reduction in craniotomy rate from 2003 to 2013 (2003, 11.3%; 2013, 9.20%; $p < 0.001$). The highest rate of craniotomy was observed in 2004 (252 of 2,037, 12.4%) and the lowest rate in 2012 (147 of 2,006, 7.33%). Conversely, the rate of craniectomy significantly increased across the 11-year time frame in both unadjusted and adjusted analyses (2003, 1.72%; 2013, 5.15%; $p < 0.001$), with the highest rate occurring in 2011 (100 of 1,886, 5.30%) and the lowest in 2003 (34 of 1,976, 1.72%). No unadjusted difference in ICP rate was observed from 2003 to 2013 (2003, 21.7%; 2013, 20.1%; $p = 0.909$); however, when controlling for predictors of neurosurgical intervention in multivariate analysis, temporal trend tests found admission year to be positively associated with increased ICP placement (adjusted odds ratio [AOR], 1.03 [1.02–1.04]; $p < 0.001$; Table 2). A graphical representation of raw neurosurgical intervention rates for the three analyzed procedures is presented in Figure 1.

An analysis of outcome measures for the total study population found no significant change in unadjusted in-hospital mortality rate (2003, 34.5%; 2013, 35.6%; $p = 0.613$) (Fig. 2), ICU days longer than 6 (2003, 33.9%; 2013, 33.0; $p = 0.175$), or ventilator days longer than 6 (2003, 27.6%; 2013, 26.8; $p < 0.079$). Multivariate analysis of these outcome measures controlling for demographic and injury severity covariates however found admission year to be positively associated with ICU days

TABLE 1. Total Study Population Demographics

Total Study Population (N = 22,229)		Operative (n = 6,207)	Nonoperative (n = 16,022)	
Variable	**n (%)**	**n (%)**	**n (%)**	***p***
Age, y				
Mean ± SD	43.8 ± 25.3	39.7 ± 22.1	45.4 ± 26.2	<0.001
<18	3,148 (14.2)	894 (14.4)	2,254 (14.1)	0.533
18–29	5,266 (23.7)	1,716 (27.7)	3,550 (22.2)	<0.001
30–50	5,334 (24.0)	1,656 (26.7)	3,678 (23.0)	<0.001
>50	8,481 (39.4)	1,941 (31.3)	6,540 (40.8)	<0.001
Sex				
Female	6,577 (29.6)	1,619 (26.1)	4,955 (30.9)	<0.001
Male	15,652 (70.4)	4,588 (73.9)	11,067 (69.1)	—
Mechanism of injury				
Motor vehicle collision	10,430 (46.9)	2,936 (47.3)	7,494 (46.8)	0.432
Fall	7,488 (33.7)	2,148 (34.6)	5,340 (33.3)	0.123
Other	4,281 (19.3)	1,101 (17.7)	3,180 (19.8)	0.061
Unspecified	30 (0.00)	22 (0.00)	8 (0.00)	—
TBI severity coding				
Serious (head AIS score ≥ 3; GCS score, 9–12)	4,434 (20.0)	801 (12.9)	3,633 (22.7)	<0.001
Critical (head AIS score ≥ 3, GCS score ≤ 8)	17,795 (80.1)	5,406 (87.1)	12,389 (77.3)	—
ISS				
Median (IQR)	26.0 (18.0–34.0)	29.0 (25.0–38.0)	25.0 (17.0–33.0)	<0.001
<15	2,554 (11.5)	229 (3.69)	2,325 (14.5)	<0.001
15–30	12,044 (54.2)	3,085 (49.7)	8,959 (55.9)	<0.001
>30	7,631 (34.3)	2,893 (46.6)	4,738 (29.6)	<0.001
SBP				
Median (IQR)	138 (117–160)	138 (117–160)	132 (107–155)	<0.001
Neurosurgical intervention				
Yes	6,207 (27.9)	6,207 (100.0)	0 (0.00)	<0.001
No	16,022 (72.1)	0 (0.00)	16,022 (100.0)	—
Mortality				
Dead	7,950 (35.8)	2,016 (32.5)	5,934 (37.0)	<0.001
Alive	14,279 (64.2)	4,191 (67.5)	10,088 (63.0)	—

Operative (neurosurgical intervention) versus nonoperative (no neurosurgical intervention) subgroup comparison.
IQR, interquartile range.

longer than 6 (AOR, 1.01 [1.00–1.02]; $p = 0.010$) and ventilator days longer than 6 (AOR, 1.01 [1.00–1.02]; $p = 0.021$), although in-hospital mortality trends remained nonsignificant (AOR, 1.01 [1.00–1.02]; $p = 0.150$) (Table 3). In terms of procedure-specific in-hospital mortality, no significant change in mortality rate was observed for patients undergoing craniotomy (2003, 32.1%; 2013, 28.6%; $p = 0.341$), craniectomy (2003, 41.2%; 2013, 30.6%; $p = 0.183$), or ICP (2003, 33.6; 2013, 29.6; $p = 0.163$) during the study period.

When separating the study population into serious (n = 4,434) and critical (n = 17,795) subgroups, deviations in practice patterns and outcome trends found in the total study population were observed. Within the serious TBI subgroup (head AIS score ≥ 3; GCS score, 9–12), adjusted trend tests found admission year to be significantly associated with decreased rates of craniotomy (AOR, 0.95 [0.92–0.99]; $p = 0.009$); however, no significant trends were found for craniectomy (AOR, 1.06 [1.00–1.14]; $p = 0.065$) or ICP (AOR, 1.01 [0.98–1.04]; $p = 0.528$) (Table 2). In terms of outcome measures, adjusted temporal analysis found admission year to be a significant predictor of decreased in-hospital mortality (AOR, 0.95 [0.92–0.99]; $p = 0.002$), increased ventilator days longer than 6 (1.04 [1.01–1.06]; $p = 0.010$), and increased ICU days longer than 6 (AOR, 1.03 [1.01–1.05]; $p = 0.017$) (Table 3).

Adjusted temporal trend analysis of the critical TBI subgroup found admission year to be significantly associated with a decrease in craniotomy rate (AOR, 0.96 [0.95–0.98]; $p < 0.001$) and an increase in craniectomy (AOR, 1.13 [1.10–1.15]; $p < 0.001$) and ICP rates (AOR, 1.03 [1.02–1.04]; $p < 0.001$) (Table 2). In addition, admission year was significantly associated with an increase in in-hospital mortality (AOR, 1.02 [1.01–1.03]; $p = 0.004$) and ICU days longer than 6 (AOR, 1.01 [1.00–1.02]; $p = 0.035$). No significant trends were found relating to ventilator days longer than 6 (AOR, 1.01 [1.00–1.02]; $p = 0.079$) (Table 3).

Evaluating the impact of prolonged LOC (>1 hour) on in-hospital mortality relating to the use of craniotomy, craniectomy, and ICP in multivariate analysis yielded significant findings. Compared with the LOC subgroup (n = 2,732), patients

TABLE 2. Multivariate Logistic Regression Models for Temporal Trends in Neurosurgical Interventions by Admission Year for Total Study Population, Serious TBI Subgroup, and Critical TBI Subgroup

Craniotomy	Total Study Population (N = 22,229)		Serious TBI (n = 4,434)		Critical TBI (n = 17,795)	
Variable	**AOR (95% CI)**	***p***	**AOR (95% CI)**	***p***	**AOR (95% CI)**	***p***
Admission year	0.96 (0.95–0.97)	<0.001	0.95 (0.92–0.99)	0.009	0.96 (0.95–0.98)	<0.001
Age	1.00 (0.99–1.00)	<0.001	1.00 (0.99–1.00)	0.309	1.00 (0.99–1.00)	<0.001
Sex (male)	1.12 (1.01–1.24)	0.032	1.10 (0.87–1.39)	0.428	1.12 (1.00–1.25)	0.049
SBP	1.01 (1.01–1.01)	<0.001	1.00 (1.00–1.01)	0.049	1.01 (1.01–1.01)	<0.001
Head AIS score	1.26 (1.21–1.30)	<0.001	1.43 (1.31–1.56)	<0.001	1.22 (1.17–1.27)	<0.001
ISS	1.01 (1.00–1.01)	0.001	1.02 (1.01–1.03)	<0.001	1.01 (1.00–1.00)	0.020
GCS score	0.99 (0.97–1.00)	0.133	0.99 (0.89–1.09)	0.778	1.04 (1.01–1.07)	0.016
Constant	0.02 (0.01–0.02)	—	0.01 (0.00–0.04)	—	0.02 (0.01–0.02)	—
	AUROC, 0.65 (0.64–0.66)		AUROC, 0.71 (0.68–0.74)		AUROC, 0.64 (0.63–0.65)	
Craniectomy						
Admission year	1.12 (1.09–1.14)	<0.001	1.06 (1.00–1.14)	0.065	1.13 (1.10–1.15)	<0.001
Age	0.98 (0.98–0.99)	<0.001	0.99 (0.98–1.00)	0.006	0.98 (0.98–0.99)	<0.001
Sex (male)	0.96 (0.82–1.12)	0.614	1.15 (0.74–1.78)	0.531	0.94 (0.79–1.11)	0.449
SBP	1.01 (1.01–1.01)	<0.001	1.01 (1.00–1.01)	0.153	1.01 (1.01–1.01)	<0.001
Head AIS score	1.22 (1.17–1.29)	<0.001	1.41 (1.25–1.61)	<0.001	1.19 (1.13–1.26)	<0.001
ISS	1.02 (1.01–1.02)	<0.001	1.02 (1.00–1.04)	0.021	1.02 (1.01–1.02)	<0.001
GCS score	0.97 (0.94–0.99)	0.010	0.87 (0.72–0.83)	0.126	1.05 (1.00–1.10)	0.053
Constant	0.01 (0.00–0.01)	—	0.01 (0.00–0.08)	—		
	AUROC, 0.70 (0.68–0.72)		AUROC, 0.73 (0.67–0.79)		AUROC, 0.69 (0.67–0.71)	
ICP						
Admission year	1.03 (1.02–1.04)	<0.001	1.01 (0.98–1.04)	0.528	1.03 (1.02–1.04)	<0.001
Age	0.99 (0.98–0.99)	<0.001	0.99 (0.99–1.00)	<0.001	0.99 (0.98–0.99)	<0.001
Sex (male)	1.15 (1.07–1.24)	0.001	1.45 (1.17–1.80)	0.001	1.11 (1.02–1.20)	0.015
SBP	1.01 (1.01–1.01)	<0.001	1.01 (1.01–1.01)	<0.001	1.01 (1.01–1.01)	<0.001
Head AIS score	1.17 (1.13–1.20)	<0.001	1.31 (1.21–1.42)	<0.001	1.14 (1.10–1.17)	<0.001
ISS	1.03 (1.03–1.04)	<0.001	1.05 (1.04–1.06)	<0.001	1.03 (1.03–1.03)	<0.001
GCS score	0.94 (0.93–0.95)	<0.001	0.83 (0.76–0.91)	<0.001	1.04 (1.01–1.06)	0.004
Constant	0.03 (0.02–0.04)	—	0.03 (0.01–0.10)	—	0.03 (0.02–0.03)	—
	AUROC, 0.70 (0.69–0.70)		AUROC, 0.71 (0.69–0.74)		AUROC, 0.69 (0.67–0.70)	

CI, confidence interval.

presenting with predominantly anatomically graded injuries (head AIS score, 3–6; non-LOC; n = 19,497) had better outcomes from craniotomy procedures, while controlling for identical demographic/injury severity covariates. Within this non-LOC subgroup, craniotomy resulted in a 31% reduction in in-hospital mortality (AOR, 0.69 [0.62–0.78]; $p < 0.001$). No

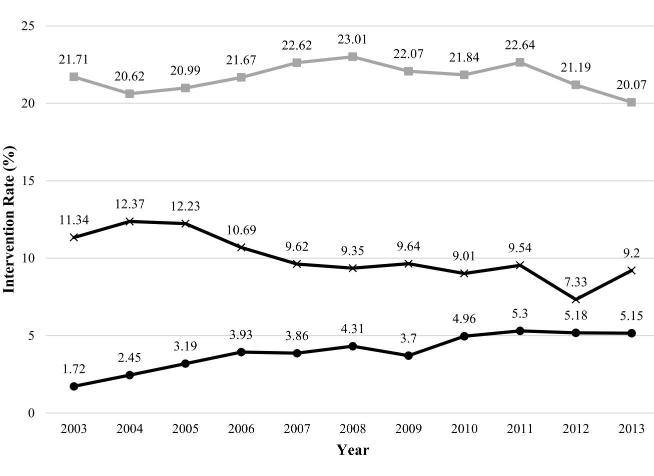

Figure 1. Raw neurosurgical intervention rates for total study population from 2003 to 2013.

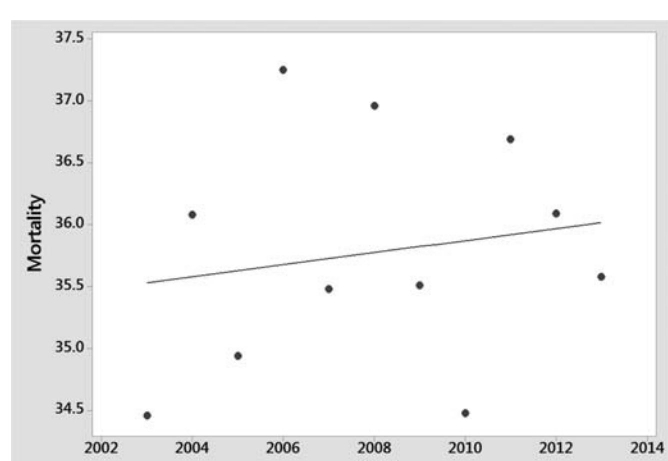

Figure 2. Unadjusted mortality rate trend for the total serious to critical TBI population from 2003 to 2013.

TABLE 3. Multivariate Logistic Regression Models for Adjusted Temporal Trends in Outcomes by Admission Year for Total Study Population, Serious TBI Subgroup, and Critical TBI Subgroup

In–Hospital Mortality	Total Study Population (N = 22,229)		Serious TBI (n = 4,434)		Critical TBI (n = 17,795)	
Variable	AOR (95% CI)	p	AOR (95% CI)	p	AOR (95% CI)	p
Admission year	1.01 (1.00–1.02)	0.150	0.95 (0.92–0.98)	0.002	1.02 (1.01–1.03)	0.004
Age	1.04 (1.04–1.04)	<0.001	1.06 (1.05–1.06)	<0.001	1.04 (1.04–1.04)	<0.001
Sex (male)	1.15 (1.07–1.24)	<0.001	1.64 (1.35–2.00)	<0.001	1.10 (1.02–1.04)	0.018
SBP	0.99 (0.99–0.99)	<0.001	1.00 (1.00–1.00)	0.352	0.99 (0.98–0.99)	<0.001
Head AIS score	1.40 (1.36–1.44)	<0.001	1.17 (1.06–1.29)	0.002	1.43 (1.38–1.47)	<0.001
ISS	1.03 (1.02–1.03)	<0.001	1.06 (1.05–1.07)	<0.001	1.02 (1.02–1.03)	<0.001
GCS score	0.80 (0.79–0.81)	<0.001	0.81 (0.75–0.89)	<0.001	0.79 (0.77–0.81)	<0.001
Constant	0.14 (0.11–0.17)	—	0.01 (0.00–0.02)	—	0.18 (0.14–0.22)	—
	AUROC, 0.81 (0.80–0.82)		AUROC, 0.82 (0.80–0.84)		AUROC, 0.79 (0.79–0.80)	
Ventilator days for >6						
Admission year	1.01 (1.00–1.02)	0.021	1.04 (1.01–1.06)	0.010	1.01 (1.00–1.02)	0.079
Age	1.00 (0.99–1.00)	<0.001	1.01 (1.00–1.01)	0.003	0.99 (0.99–1.00)	<0.001
Sex (male)	1.22 (1.14–1.31)	<0.001	1.53 (1.28–1.82)	<0.001	1.18 (1.09–1.27)	<0.001
SBP	1.01 (1.01–1.01)	<0.001	1.00 (1.00–1.01)	0.106	1.01 (1.01–1.01)	<0.001
Head AIS score	0.97 (0.94–1.00)	0.046	1.04 (0.96–1.13)	0.368	1.19 (1.13–1.26)	<0.001
ISS	1.04 (1.04–1.04)	<0.001	1.07 (1.06–1.08)	<0.001	0.95 (0.92–0.98)	<0.001
GCS score	0.97 (0.96–0.98)	<0.001	0.88 (0.82–0.95)	0.001	1.05 (1.03–1.07)	<0.001
Constant	0.05 (0.04–0.07)	—	0.05 (0.02–0.13)	—	0.05 (0.04–0.07)	—
	AUROC, 0.67 (0.66–0.68)		AUROC, 0.72 (0.70–0.74)		AUROC, 0.66 (0.65–0.66)	
ICU days for >6						
Admission year	1.01 (1.00–1.02)	0.010	1.03 (1.01–1.05)	0.017	1.01 (1.00–1.02)	0.035
Age	0.99 (0.99–1.00)	<0.001	1.01 (1.00–1.01)	0.001	0.99 (0.99–0.99)	<0.001
Sex (male)	1.17 (1.10–1.25)	<0.001	1.48 (1.28–1.73)	<0.001	1.12 (1.04–1.20)	0.003
SBP	1.01 (1.01–1.01)	<0.001	1.00 (1.00–1.01)	0.007	1.01 (1.01–1.01)	<0.001
Head AIS score	0.94 (0.91–0.96)	<0.001	1.00 (0.92–1.07)	0.909	0.91 (0.89–0.94)	<0.001
ISS	1.04 (1.03–1.04)	<0.001	1.06 (1.05–1.07)	<0.001	1.04 (1.03–1.04)	<0.001
GCS score	0.98 (0.97–1.00)	<0.001	0.87 (0.81–0.92)	<0.001	1.06 (1.04–1.09)	<0.001
Constant	0.09 (0.07–0.11)	—	0.14 (0.06–0.32)	—	0.09 (0.07–0.11)	—
	AUROC, 0.66 (0.65–0.66)		AUROC, 0.69 (0.67–0.70)		AUROC, 0.65 (0.65–0.66)	

CI, confidence interval.

associations were found for craniectomy (AOR, 1.18 [0.99–1.42]; $p = 0.068$) or ICP (1.06 [0.96–1.16]; $p = 0.262$) and adjusted in-hospital mortality in the non-LOC subgroup. For the LOC subgroup, the use of craniotomy (1.43 [1.02–1.98]; $p = 0.035$) and craniectomy (1.29 [0.87–1.92]; $p = 0.213$) did not result in improved survival, with trends for craniotomy suggesting increased in-hospital mortality with this procedure. Adjusted odds ratios for ICP use showed a decreased in-hospital mortality with this procedure in the LOC subgroup (0.78 [0.64–0.95]; $p = 0.013$) (Table 4).

TABLE 4. Multivariate Logistic Regression Mortality Models for LOC and Non-LOC Subgroups Showing Efficacy of Neurosurgical Interventions

N = 22,229	LOC (n = 2,732)		Non–LOC (n = 19,497)	
Variable	AOR (95% CI)	p	AOR (95% CI)	p
Craniotomy	1.43 (1.02–1.98)	0.035	0.69 (0.62–0.78)	<0.001
Craniectomy	1.29 (0.87–1.92)	0.213	1.18 (0.99–1.42)	0.068
ICP	0.78 (0.64–0.95)	0.013	1.06 (0.96–1.16)	0.262
Age	1.04 (1.03–1.05)	<0.001	1.04 (1.03–1.04)	<0.001
SBP	0.99 (0.99–0.99)	<0.001	0.99 (0.99–0.99)	<0.001
GCS score	0.81 (0.77–0.86)	<0.001	0.80 (0.79–0.81)	<0.001
Head AIS score	1.28 (1.16–1.41)	<0.001	1.44 (1.40–1.49)	<0.001
ISS	1.01 (1.00–1.02)	0.061	1.03 (1.03–1.04)	<0.001
Admission year	1.08 (1.04–1.12)	<0.001	1.01 (0.99–1.02)	0.348
Constant	0.27 (0.14–0.52)	—	0.13 (0.11–0.16)	—
	AUROC, 0.75 (0.73–0.77)		AUROC, 0.82 (0.82–0.83)	

CI, confidence interval.

DISCUSSION

Despite shifts in neurosurgical practice patterns in the state of Pennsylvania, our results suggest that overall in-hospital mortality for patients afflicted by serious to critical TBI has not improved from 2003 to 2013. Although our hypothesis was partially upheld for the serious TBI subgroup (head AIS score ≥ 3; GCS score, 9–12), with increased unadjusted rates of craniectomy and an unadjusted/adjusted reduction in in-hospital mortality rate occurring during the study period, our supposition was refuted when analyzing the critical TBI population (head AIS score ≥ 3, GCS score ≤ 8). While rates of craniectomy were found to increase during the study period within the critical TBI subgroup, adjusted in-hospital mortality also increased from 2003 to 2013. These findings suggest that future neurocritical efforts should focus on improving outcomes in salvageable patient populations. Although it is crucial to provide critical TBI patients with the highest level of care, our data suggest that no matter what treatment these patients receive (craniotomy, craniectomy, or ICP), their injuries are too severe to impact outcome. As the critical TBI subgroup accounted for the majority of our total head injury population (80%), analyzing both serious and critical TBIs in composite revealed a nonsignificant adjusted increase in in-hospital mortality during the study period. These results are quite alarming particularly because a nationwide investigation conducted by the CDC reported a significant drop in mortality rate for the TBI population from 2001 to 2010 (from 18.5 to 17.1 per 100,000),[4] Although the findings reported by the CDC contradict those found in our study, in review of the available literature, we found much discrepancy in reported rates of TBI-related mortality within the past decades across the United States.

An analysis by Lagbas et al.[19] examining TBI trends in the state of California from 2001 to 2009 reported a 1.3% increase in morality, despite a decrease in TBI-related hospitalizations during the study period. Conversely, an analysis of core surveillance data in the state of Iowa from 2006 to 2010 reported a 3% reduction in TBI-related mortality with decreases in both emergency department visits and hospitalizations.[20] An epidemiologic overview of TBI in the United States conducted by Summers et al.,[21] which characterized trends in TBI from 1980 to 2009, found that although TBI-related mortality substantially decreased in the 1980s to 1990s, it has since leveled off, perhaps mirroring the results found in our investigation. Considering that our study encompassed a more recent time frame than the previous investigations listed (including the national report by the CDC), it is difficult to compare our results to these findings. In addition, definitional discrepancies for TBI between studies make comparisons difficult. While the investigation conducted by the CDC used ICD-9-CM codes to define their head injury population, we used a more generalized approach, classifying patients based on head AIS scoring and GCS. It is likely that the TBI population investigated by the CDC included patients with less severe injuries not meeting inclusion criteria for our study. Because of apparent variations in TBI-related incidence and mortality trends across the United States, a more current nationwide investigation, similar to that conducted by the CDC, is necessary to gain a more global view of contemporary TBI trends.

In addition to observing TBI-related in-hospital mortality trends, we also investigated changes in neurosurgical intervention rates for craniotomy, craniectomy, and ICP monitor placement as well as the efficacy of these procedures in decreasing in-hospital mortality within LOC and non-LOC subgroups, from 2003 to 2013. General patterns observed for the total serious to critical study population suggest that adjusted rates of craniotomy are decreasing, while rates of craniectomy and ICP are increasing (although discrepancies for ICP trends were found between serious and critical subgroups). While no definitive conclusions can be drawn from our multivariate analyses, our results suggest that craniotomy procedures may incur greater survival benefits for non-LOC patients, while ICP monitors may be more effective in patients with LOC, indicative of more global cerebral injuries. Although we were unable to find any recent reports detailing neurosurgical intervention rates in the literature, previous studies have produced conflicting findings regarding these trends. A study by Cowan and Chandler[22] investigating nationwide trends in neurosurgical procedures from 1997 to 2003 found that rates of craniotomy increased, albeit nonsignificantly, during the study period from 52 per 100,000 procedures performed to 56 per 100,000 ($p = 0.06$). In terms of ICP use, statistics reported by the Brain Trauma Foundation in the Guidelines for the Management of Severe Traumatic Brain Injury reported a 46% increase in ICP monitor use from 1995 to 2005.[8] While the Brain Trauma Foundation attributes this vast increase in ICP monitor placement to the release of their evidence-based guidelines promoting their use, we attribute the later conflicting trends found in our investigation to discrepancies in the literature. While multiple studies suggest that ICP monitor placement results in improved survival in the TBI population,[14,23–25] other reports note no change in outcome[26] or even an increase in mortality associated with their use.[27] Even within our multivariate subanalyses for LOC versus non-LOC subgroups, we report conflicting results regarding the efficacy of ICP monitors in decreasing in-hospital mortality. While a decrease in in-hospital mortality with ICP use was found within the LOC subgroup, no association was observed for patients in the non-LOC subgroup, which indicates that ICP monitors may be warranted in some head injury patients but not in others. As with the literature detailing TBI mortality trends in the United States, our study covered a more recent time frame. Although the trends reported in the literature for craniotomy and ICP monitoring in previous studies may have held true during their respective study periods, it is likely that these patterns have since evolved. Neurosurgical practices are often in a state of flux. As suggested by the most recent work of the RESCUE-ASDH collaborative group,[28] significant uncertainty surrounds optimal neurosurgical techniques, which likely contributed to the broad shifts in craniotomy/craniectomy use found in this study. It is possible that the significant increase in rates of craniectomy performed during the study period resulted from an increase in evidence-based research detailing improved functional recovery with these methods.[11–13]

This investigation has the inherent limitations of any retrospective analysis. While this study analyzed trends in craniotomy, craniectomy, and ICP monitoring, we realize our work far from characterized the overall neurosurgical scope of practice (nonoperative management, other operative procedures). In addition, as mentioned in our discussion of previous reports detailing trends in TBI-related mortality, our study opted to use arrival head AIS and GCS scores to classify our head injury population as opposed to using ICD-9-CM codes. Although the purpose of this classification was to provide a more complete TBI population, it did not allow us to gain as in depth a view of the direct mechanisms of injury and presentation. Finally, despite our relatively large sample size (n = 22,229), our hospital population was relatively small, with only 30 hospitals being evaluated.

CONCLUSION

Our study found no change in adjusted in-hospital mortality rate for our total serious to critical TBI study population across an 11-year time frame despite a decrease in presentation injury severity and varying neurosurgical practice patterns. Subanalyses conducted on serious and critical TBI subgroups revealed that this trend is predominantly the result of unchanging in-hospital mortality rates within the critical TBI subgroup. Future neurocritical improvements should focus on salvageable patients because it seems that no adaptations in neurosurgical practice patterns are likely to improve outcome within the critically injured.

AUTHORSHIP

C.A.M., B.W.G., J.A., D.W., and F.B.R. designed this study. B.W.G. performed data analysis. All authors contributed to the interpretation of data and manuscript preparation. F.B.R. provided editorial oversight.

DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

Dr. Joseph Minei (Dallas, Texas): I would like to congratulate Dr. Morrison and his co-authors for this paper where they have analyzed the PTOS database and have tried to associate the changes in the proportion of patients undergoing craniotomy and craniectomy with survival post-TBI.

Unfortunately, they have found that even though the proportion of all patients undergoing any type of craniotomy or craniectomy procedure had increased over time, overall survival had not improved.

Interestingly, they showed in their sub-analysis of patients with moderately depressed GCS that an increased proportion of patients undergoing a craniotomy or craniectomy was associated with improved survival.

I have the following four comments:

The title is confusing. Anyone with an AIS greater than or equal to three is considered to have a serious (or worse) TBI. AIS equal to two is considered moderate injury. But these patients were excluded from the analysis. I agree that the GCS criteria used would be considered moderate TBI but clarification in the title would be helpful.

One interesting finding in the study is the improvements in outcome in the group with GCS nine to twelve. It may be that this is where we should be focusing our efforts, in those salvageable patients. It may be that no matter what we do in severely-brain injured patients, craniotomy or craniectomy or not, their injuries are too severe for meaningful salvage. Can you please comment?

I believe the authors have an opportunity to tease out the data even further to tell us when craniotomy or craniectomy may be particularly beneficial. There are a number of ways for TBI patients to end up with an AIS severity or post-DOT score of greater than or equal to three, particularly related to length of loss of consciousness.

I think you have an opportunity to reanalyze the data around this potential variable and see whether you can further delineate associations between craniotomy, craniectomy, and good outcome. I would posit that those with an AIS greater than or equal to three, based predominantly on anatomic grading, would have a better outcome from an open procedure than those who have the same severity score obtained predominantly by prolonged loss of consciousness, suggesting a more global brain injury. Thus, can you tell us whether there is a right time to do a craniotomy or craniectomy procedure and a wrong time?

The findings of an association between GCS and better outcome associated with higher proportions of craniotomy or craniectomy hints at this but you could more directly analyze this by teasing out the detail within the six-digit, pre-DOT AIS score.

Finally, can the authors provide data and trends in procedure-specific mortality? Specifically, for those undergoing a craniotomy or a craniectomy what was the procedure-specific mortality over time? And did it change?

I would like to thank the Association for the privilege of the floor and the authors for their timely submission of the manuscript.

Dr. Kamalesh Shah (Allentown, Pennsylvania): Were you able to identify a group of the hospitals or a trauma center which had a higher propensity to perform craniectomy as opposed to craniotomy and then whether that made a difference in how you actually analyzed your data?

Dr. Harry Wilkins, III (Quincy, Illinois): This is almost similar to the earlier paper that was presented regarding craniectomies and the author noted that the change in management of head injuries has not changed much over the study period. This is from 2013 to 2014. And I would like to suggest that perhaps some initiatives have changed.

We have seen an increased adoption of the 1:1:1 resuscitation which has decreased volume. We have seen an increased use of hypertonic saline that involved myself and the Adams Williams initiative, which has gained traction in terms of being more aggressive in this.

Secondly, you mentioned at the end of your slide that we, as trauma surgeons, have to look at the effect that we are having on prevention efforts. Within the state of Pennsylvania can we assume that some of the efforts there are gaining traction as shown by your decreasing ISS scores of your cohort?

And then, finally, can you look at some of the variables that would also impact this? We saw no breakdown between blunt and penetrating injuries and also the effects of management with use of anti-convulsions which is shown to have decreased GCS and also, as Dr. Soderstrom pointed out, the effects of alcohol and other toxins present in the cohorts prior to their injuries.

Dr. Chet Morrison (Lancaster, Pennsylvania): Well, mindful of the time I will try to deal with these questions concisely and pardon me if I talk a little bit fast.

And I thank Dr. Minei and the questioners for their very, very insightful comments which, frankly, have inspired me.

First, I apologize for the confusion of the title. It is my intent to bring light. However, in our goal of our study we really wanted to focus on patients that could potentially require an intervention.

And while I agree that a moderately-injured head injured patient with an AIS of greater than three really is significantly injured, we certainly wanted to exclude the patients who, frankly, may have just had a depressed admission GCS from alcohol or other intoxicants and would be appropriate targets for an intervention. I just didn't want to use a weasel word like "significant" that may be hard to define.

Secondly, the exact goal was this: We thought that there might be a group of patients who are potentially salvageable and that's why we concentrated on them.

One of the things that I am happy to sort of bring up is that we are now seeing a lot of patients who come in with a POLST, which are these nice little forums that specify no aggressive treatment, not just DNR. They say, "Please do not do anything invasive to me."

And very often they are geriatric patients at the end of their life but, because they have fallen, and because we seem to put anticoagulants in the water, would be classified as the severe-head injury group. Because of their POLST, they are treated non-aggressively, and I think that may be one of the reason for decreasing craniotomy.

Thank you for suggesting potential future directions of this research in terms of teasing out AIS. That may be somewhat difficult in our database but we certainly are going to redouble our efforts and perhaps in a future time we can discuss this, particularly because I absolutely agree with Dr. Minei's hypothesis that there are going to be differences in mechanism and the type of injury, more prolonged unconsciousness and so forth, versus things like skull fracture which, again, may differentiate those who require intervention from those who do not.

Our overall craniotomy mortality, interestingly enough, when you look at the patients who had craniotomy, decreased from 37% to 33% to 32%. And that was statistically significant. And, again, we are trying to tease that data out a little bit further in terms of procedure specific mortality.

I just didn't want to overstate this in the study, since we are doing linear trend tests and not regression analysis. That would, maybe take into account some of the variables that my second questioner indicated in terms of our demographics.

I can't answer the question of whether there is a differentiation between level one and level two trauma centers in terms of whether they are more likely to use monitoring and/or craniotomy and craniectomy. But I thank you for the suggestion because that is something to look at for future work.

And, finally, I agree that there is a specific and rather pernicious influence of toxins that come in our patients, as well as things that we try to do in terms of pressing for better drunk driving laws in Pennsylvania, road safety awareness, things like getting the Amish to put little reflectors on their buggies so when the, you know, inattentive driver maybe doesn't plow into them anymore.

Unfortunately, there are things in Pennsylvania such as the fact that at about the start of this study we repealed our motorcycle helmet law so I think we really need to be vigorous in our opposition of saying that those are really not very good ideas at all and keep on saying that.

Once again, I thank everybody for the opportunity to present.