Morbidity and mortality in elderly patients undergoing evacuation of acute traumatic subdural hematoma

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OBJECTIVE Acute traumatic subdural hematoma (atSDH) can be a life-threatening neurosurgical emergency that necessitates immediate evacuation. The elderly population can be particularly vulnerable to tearing bridging veins. The aim of this study was to evaluate inpatient morbidity and mortality, as well as predictors of inpatient mortality, in a national trauma database.

METHODS The authors queried the 2016–2017 National Trauma Data Bank registry for patients aged 65 years and older who had undergone evacuation of atSDH. Patients were categorized into three age groups: 65–74, 75–84, and 85+ years. A multivariable logistic regression model was fitted for inpatient mortality adjusting for age group, sex, race, presenting Glasgow Coma Scale (GCS) category (3–8, 9–12, and 13–15), Injury Severity Score, presence of coagulopathy, presence of additional hemorrhages (epidural hematoma [EDH], intraparenchymal hematoma [IPH], and subarachnoid hemorrhage [SAH]), presence of midline shift > 5 mm, and pupillary reactivity (both, one, or none).

RESULTS A total of 2508 patients (35% females) were analyzed. Age distribution was as follows: 990 patients at 65–74 years, 1096 at 75–84, and 422 at 85+. Midline shift > 5 mm was present in 72% of cases. With regard to additional hemorrhages, SAH was present in 21%, IPH in 10%, and EDH in 2%. Bilaterally reactive pupils were noted in 90% of patients. A major complication was observed in 14.4% of patients, and the overall mortality rate was 18.3%. In the multivariable analysis, the presenting GCS category was found to be the strongest predictor of postoperative inpatient mortality (3–8 vs 13–15: OR 3.63, 95% CI 2.68–4.92, $p < 0.001$; 9–12 vs 13–15: OR 2.64, 95% CI 1.79–3.90, $p < 0.001$; 30% of overall variation), followed by the presence of SAH (OR 2.86, 95% CI 2.21–3.70, $p < 0.001$; 25% of overall variation) and the presence of midline shift > 5 mm (OR 2.40, 95% CI 1.74–3.32, $p < 0.001$; 11% of overall variation). Model discrimination was excellent (c-index 0.81). Broken down by age decile group, mortality increased from 8.0% to 15.4% for GCS 13–15 to around 36% for GCS 9–12 to almost as high as 60% for GCS 3–8, particularly in those aged 85 years and older.

CONCLUSIONS The present results from a national trauma database will, the authors hope, assist surgeons in preoperative discussions with patients and their families with regard to expected postoperative outcomes following surgical evacuation of an atSDH.

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KEYWORDS hematoma; trauma; subdural; epidural; craniotomy; elderly

THE incidence of traumatic brain injury (TBI) has been increasing in the United States despite the progress made in decreasing motor vehicle accidents.¹ This increase is attributed to a rising elderly population (defined as an age ≥ 65 years), who are especially susceptible to TBI secondary to falls.² Based on data from the National Inpatient Sample, there were 950,132 TBI-related hospitalizations and 107,666 TBI-related deaths among adults aged ≥ 65 years from 2000 to 2010, with

falls representing the most common mechanism of injury.³ More importantly, geriatric patients experience worse mortality rates and functional outcomes than nonelderly TBI patients even though their head and overall injury burdens are seemingly less severe.⁴ These patients also tend to have increased dependence postinjury given their decreased brain reserves.⁵

Elderly patients are particularly prone to shearing of cortical bridging veins even in the setting of minor trauma,

ABBREVIATIONS atSDH = acute traumatic SDH; EDH = epidural hematoma; GCS = Glasgow Coma Scale; ICP = intracranial pressure; IPH = intraparenchymal hematoma; ISS = Injury Severity Score; NSQIP = National Surgical Quality Improvement Program; NTDB = National Trauma Data Bank; SAH = subarachnoid hemorrhage; SDH = subdural hematoma; TBI = traumatic brain injury.

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predisposing them to acute subdural hematomas (SDHs). The frequent use of antithrombotic agents in this population may further exacerbate the risk of complications and death.⁶ Previous analyses of the National Inpatient Sample and National Surgical Quality Improvement Program (NSQIP) have demonstrated the overall risk of inpatient and 30-day mortality among patients with SDH (including both traumatic and nontraumatic) treated operatively to be 12% and 17%, respectively.^{7,8} An older age has been shown to be a predictor of adverse outcomes following surgical evacuation; however, the effect of surgical intervention on short- and longer-term functional outcomes has not been well characterized in the elderly.^{7,9} Currently available evidence on prognosis following acute traumatic SDH (atSDH) evacuation in this population consists of single-institution studies.^{10–17} Moreover, there is a paucity of literature elucidating the risk factors predictive of outcomes. To further complicate things, advance directives are not always available at the time of critical decision-making or are rather vague with regard to patient wishes; thus, families often find themselves in situations in which it is unclear whether surgery would serve the patient's best interests and wishes. The financial and emotional costs to patients and their families are sometimes not taken into account, particularly amid an emergency department crisis when a lifesaving decision needs to be made within a few minutes.^{18,19} The availability of representative outcomes data could help facilitate discussions between providers and families to allow for more informed decision-making. Herein, we sought to determine the outcomes of surgical evacuation of atSDH in elderly patients, as well as elucidate factors predictive of outcomes, by utilizing a national trauma registry.

Methods

Data Source and Inclusion Criteria

We queried the National Trauma Data Bank (NTDB) for the years 2016–2017 for patients aged 65 years and older who had undergone craniotomy for a diagnosis of atSDH. To identify our cohort, we utilized the ICD-10 diagnosis codes denoting atSDH (Supplemental Table 1) in combination with an evacuation procedure code (00940ZZ, 00940ZX, 009400Z). The NTDB represents the largest aggregation of trauma registry data in the United States.²⁰ It was created in 1989 by the American College of Surgeons Committee on Trauma to serve as a “central national repository of data on trauma and trauma care.”²⁰ The registry contains a wealth of information, including demographics, comorbidities, injury severity, hospital characteristics, and inpatient outcomes, on over 8 million records from 765 hospitals across the country (2017 data).²¹ The data contained in the NTDB is de-identified and therefore exempt from institutional review board approval.

Outcomes of Interest

Inpatient mortality was the primary outcome of interest. Secondary outcomes consisted of inpatient major complication rate, ICU length of stay, and discharge disposition.

Covariates of Interest

We recorded the following covariates: demographics (sex, race, ethnicity, primary insurance payer, BMI), comorbidities and functional status, injury characteristics (vital signs upon presentation to the emergency department, Injury Severity Score [ISS], Glasgow Coma Scale [GCS] score, pupillary response, presence of brain midline shift > 5 mm [as defined in the National Trauma Data Standard dictionary]), and presence of additional intracranial hemorrhages (Supplemental Table 2), as well as complications in the postoperative setting.

Statistical Analysis

Descriptive statistics (medians with interquartile ranges for continuous data and frequencies with proportions for categorical data) are used to present available information. The Wilcoxon rank-sum test and Pearson's chi-square test were used to compare continuous and categorical variables, respectively. Age was analyzed as a continuous variable and was stratified in the following groups in order to facilitate comparisons: 65–74 years, 75–84 years, and 85+ years. A multivariable logistic regression model was fitted for inpatient mortality adjusting for age, sex, race, GCS score at presentation, ISS, presence of bleeding disorder, presence of additional intracranial hemorrhages (epidural hematoma [EDH], intraparenchymal hematoma [IPH], and subarachnoid hemorrhage [SAH]), presence of midline shift, and pupillary response. To assess the robustness of our findings, we repeated the multivariable analysis within each age decile group.

Collinearity between the included covariates was examined using the variance inflation factor. Model discrimination was assessed using the c-statistic. Missing variables were imputed using multiple imputation from the rms package, which employs a combination of additive regression, bootstrapping, and predictive mean matching.²² A total of 10 imputed data sets were created, and imputation-specific coefficients were subsequently pooled to produce a single result. Finally, we also assessed the relative impact of each variable on inpatient mortality by using an importance metric defined as Wald chi-square penalized by the factor degrees of freedom, with a higher score indicating higher predictive importance.²³ Statistical analysis was performed using R, an open-source software (R Foundation for Statistical Computing, <https://www.R-project.org/>), and the rms package. A p value was statistically significant if it was less than 0.05.

Results

Patient Demographics and Comorbidities

A total of 2508 patients (median age 77 years, 35% females) were included in the analysis. The majority of patients were White (1964 [80%]), while only 8% (190) were Hispanic. The most common primary insurance payer was Medicare (1926 [78%]), followed by private insurance (362 [14.6%]). Significant differences were observed among the age groups with regard to sex ($p = 0.008$), BMI ($p < 0.001$), insurance status ($p < 0.001$), and functional dependency ($p = 0.001$), as well as the presence of hypertension ($p < 0.001$), a bleeding disorder ($p = 0.04$), dementia ($p < 0.001$),

TABLE 1. Summary of patient characteristics and comorbidities per age group

Variable	Available Data (no. of cases)	All (n = 2508)	65–74 Yrs (n = 990)	75–84 Yrs (n = 1096)	85+ Yrs (n = 422)	p Value
Female sex, no. (%)	2508	873 (34.8)	311 (31.4)	396 (36.1)	166 (39.3)	0.008
Race, no. (%)	2463					0.19
White		1964 (79.7)	750 (77.6)	870 (80.4)	344 (83.1)	
Black		227 (9.2)	106 (11.0)	90 (8.3)	31 (7.5)	
Asian		102 (4.1)	42 (4.3)	48 (4.4)	12 (2.9)	
Other		170 (6.9)	69 (7.1)	74 (6.8)	27 (6.5)	
Hispanic ethnicity, no. (%)	2386	190 (8.0)	81 (8.6)	81 (7.8)	28 (6.9)	0.55
Median BMI [IQR]	2508	25.8 [22.8, 29.3]	26.6 [23.1, 30.4]	25.8 [23.0, 29.0]	24.7 [21.9, 27.4]	<0.001
Insurance status, no. (%)	2472					<0.001
Private		362 (14.6)	179 (18.4)	132 (12.2)	51 (12.2)	
Medicare		1926 (77.9)	690 (70.8)	883 (81.8)	353 (84.2)	
Medicaid		70 (2.8)	36 (3.7)	30 (2.8)	4 (1.0)	
Self-pay		42 (1.7)	26 (2.7)	12 (1.1)	4 (1.0)	
Other		72 (2.9)	43 (4.4)	22 (2.0)	7 (1.7)	
Dependent functional status, no. (%)	2508	338 (13.5)	109 (11.0)	152 (13.9)	77 (18.2)	0.001
Comorbidities, no. (%)	2508					
Hypertension		1682 (67.1)	621 (62.7)	755 (68.9)	306 (72.5)	<0.001
On chronic steroids		26 (1.0)	13 (1.3)	8 (0.7)	5 (1.2)	0.38
Cirrhosis		24 (1.0)	12 (1.2)	10 (0.9)	2 (0.5)	0.44
Alcohol abuse		154 (6.1)	107 (10.8)	37 (3.4)	10 (2.4)	<0.001
Coagulopathy		366 (14.6)	123 (12.4)	179 (16.3)	64 (15.2)	0.04
Dementia		279 (11.1)	66 (6.7)	147 (13.4)	66 (15.6)	<0.001
Chronic renal failure		96 (3.8)	39 (3.9)	46 (4.2)	11 (2.6)	0.34
On chemotherapy		17 (0.7)	11 (1.1)	4 (0.4)	2 (0.5)	0.11
Drug use disorder		32 (1.3)	27 (2.7)	4 (0.4)	1 (0.2)	<0.001

Boldface type indicates statistical significance.

a drug use disorder ($p < 0.001$), and alcohol abuse ($p < 0.001$). This information is summarized in Table 1.

Baseline Injury Severity Characteristics

The median ISS was 25 (IQR 17–26). The most common presenting GCS score was 13–15 (1722 [73%]), followed by 3–8 (449 [19.1%]) and 9–12 (177 [7.5%]). With regard to pupillary response, 90% of the patients ($n = 2053$) had both reactive pupils, whereas 3.6% had one reactive pupil and 6.4% had nonreactive pupils. Midline shift greater than 5 mm was observed in 72% of the cohort ($n = 1676$). In terms of additional hemorrhages, an EDH was encountered in 2% of the patients, SAH in 21%, and IPH in 10%. We observed significant differences among the groups with regard to pupillary response (overall $p = 0.004$), as well as the presence of EDH ($p = 0.046$), SAH ($p < 0.001$), and IPH ($p = 0.001$). Finally, an external ventricular drain and intraparenchymal monitor were placed in 20% and 6% of patients, respectively. Patients aged 85+ years were significantly less likely to receive an intracranial pressure (ICP) monitoring device than those who were 75–84 and those who were 65–74 (20.6% vs 23% vs 28%, respectively; $p = 0.004$). This information is presented in Table 2.

Postoperative Outcomes

At least one major complication occurred in 14.4% of patients with no significant difference with regard to age group ($p = 0.15$). Unplanned return to the operating room was the most common complication (4.9%), followed by cerebrovascular accident (2.1%) and cardiac arrest (1.4%). There was no major difference among the three groups in terms of complications ($p = 0.15$). Complication and outcome information is summarized in Tables 3 and 4.

Inpatient Mortality

Patients who died during their hospital stay were more likely to have a coagulopathy (including antithrombotic use; 19% vs 14%, $p = 0.01$), cirrhosis (2% vs 0.7%, $p = 0.03$), and chronic renal failure (5.6% vs 3.4%, $p = 0.035$). These patients also had lower total GCS scores (10 vs 15, $p < 0.001$) and were more likely to have one reactive pupil (7.1% vs 2.8%) or no reactive pupils (18% vs 3.7%, overall $p < 0.001$). Finally, the presence of EDH (4.6% vs 1.8%, $p = 0.001$), SAH (46% vs 16%, $p < 0.001$), or IPH (21% vs 7.4%, $p < 0.001$) was also more frequent in patients with inpatient mortality. The results of univariate analyses are presented in Supplemental Tables 3–5.

TABLE 2. Summary of baseline injury characteristics

Variable	Available Data (no. of cases)	All (n = 2508)	65–74 Yrs (n = 990)	75–84 Yrs (n = 1096)	85+ Yrs (n = 422)	p Value
Vital signs in ED, median [IQR]	2508					
Systolic blood pressure		151 [134, 170]	150 [133, 169]	151 [134, 171]	153 [136, 172]	0.049
Heart rate		80.0 [69.0, 92.0]	81.0 [70.0, 95.0]	80.0 [68.0, 91.0]	78.0 [69.0, 89.0]	<0.001
Respiratory rate		18.0 [16.0, 20.0]	18.0 [16.0, 20.0]	18.0 [16.0, 20.0]	18.0 [16.0, 20.0]	0.85
Oxygen saturation		98.0 [96.0, 99.0]	98.0 [96.0, 100]	97.0 [96.0, 99.0]	97.0 [95.0, 99.0]	<0.001
Median ISS [IQR]	2508	25.0 [17.0, 26.0]	25.0 [18.0, 26.0]	25.0 [17.0, 26.0]	25.0 [17.0, 26.0]	0.06
Total GCS score, no. (%)	2348					<0.001
3–8		449 (19.1)	227 (24.4)	175 (16.9)	47 (12.2)	
9–12		177 (7.5)	78 (8.4)	69 (6.7)	30 (7.8)	
13–15		1722 (73.3)	625 (67.2)	789 (76.4)	308 (80.0)	
Pupillary response, no. (%)	2282					0.004
Both reactive		2053 (90.0)	798 (87.5)	904 (90.7)	351 (94.1)	
One reactive		83 (3.6)	41 (4.5)	37 (3.7)	5 (1.3)	
Neither reactive		146 (6.4)	73 (8.0)	56 (5.6)	17 (4.6)	
MLS >5 mm, no. (%)	2340	1676 (71.6)	687 (74.0)	723 (70.4)	266 (68.6)	0.08
Other injuries, no. (%)	2508					
EDH		57 (2.3)	31 (3.1)	21 (1.9)	5 (1.2)	0.046
SAH		534 (21.3)	259 (26.2)	197 (18.0)	78 (18.5)	<0.001
IPH		247 (9.8)	124 (12.5)	93 (8.5)	30 (7.1)	0.001
ICP monitor, no. (%)	2508	615 (24.5)	276 (27.9)	252 (23.0)	87 (20.6)	0.004
EVD, no. (%)	2508	494 (19.7)	205 (20.7)	210 (19.2)	79 (18.7)	
Intraparenchymal catheter, no. (%)	2508	142 (5.7)	79 (8.0)	53 (4.8)	10 (2.4)	
Licor monitor, no. (%)	2508	14 (0.6)	7 (0.7)	4 (0.4)	3 (0.7)	>0.99
Jugular venous bulb monitor, no. (%)	2508	11 (0.4)	8 (0.8)	3 (0.3)	0 (0)	>0.99

ED = emergency department; EVD = external ventricular drain; MLS = midline shift.
 Boldface type indicates statistical significance.

Multivariable Analysis

In the multivariable logistic regression analysis, age (75–84 vs 65–74: OR 1.57, 95% CI 1.21–2.04, $p < 0.001$; 85+ vs 65–74: OR 2.26, 95% CI 1.61–3.15, $p < 0.001$), lower total GCS score (3–8 vs 13–15: OR 3.63, 95% CI 2.68–4.92, $p < 0.001$; 9–12 vs 13–15: OR 2.64, 95% CI 1.79–3.90, $p < 0.001$), higher ISS (OR 1.56, 95% CI 1.32–1.85, $p < 0.001$), presence of SAH (OR 2.86, 95% CI 2.21–3.70, $p < 0.001$), presence of IPH (OR 1.68, 95% CI 1.20–2.34, $p = 0.02$), and coagulopathy/antithrombotic use (OR 1.41, 95% CI 1.05–1.91, $p = 0.02$) were associated with increased inpatient mortality. Patients with no reactive pupils also had significantly higher odds of death during their hospital stay (OR 1.81, 95% CI 1.18–2.76, $p = 0.006$). Model discrimination was found to be excellent (c-index 0.81). The results of the multivariable analysis are presented in Table 5.

Predictor importance is graphically depicted in Fig. 1. The three most important predictors of inpatient mortality were, in order of decreasing frequency, presenting GCS category (30% of overall Wald chi-square), presence of traumatic SAH (25% of overall Wald chi-square), and presence of midline shift > 5 mm (11% of overall Wald chi-square).

Subgroup Analysis

When we subsetting our sample based on age decile, we found the same factors to be significant, that is, presenting GCS score, midline shift greater than 5 mm, presence of SAH, and ISS. These results are presented in Supplemental Tables 6–8. We also graphed mortality rates within each age decile group (Fig. 2). Mortality rates ranged from 8.0% to 15.4% for GCS 13–15, 27.6%–36.2% for GCS 9–12, and 41.9%–57.4% for GCS 3–8.

Discussion

In the present study, we investigated inpatient outcomes following surgical evacuation of an atSDH in a cohort of 2508 elderly patients from a national trauma registry. In summary, we found an overall inpatient mortality rate of 18.3%. Within the group of patients presenting with GCS 3–8, inpatient mortality was found to be 42%, 46%, and 57% for the 65–74, 75–84, and 85+ age groups, respectively. In addition, the three most important independent predictors of inpatient mortality were presenting GCS score, the presence of traumatic SAH, and the presence of midline shift (> 5 mm according to trauma criteria).

The current literature consists of small, single-institution series and has yielded variable results. According to

TABLE 3. Summary of postoperative complications

Major Complication	All (n = 2508)	65–74 Yrs (n = 990)	75–84 Yrs (n = 1096)	85+ Yrs (n = 422)	p Value
Total	362 (14.4)	158 (16.0)	142 (13.0)	62 (14.7)	0.15
ARDS	27 (1.08)	16 (1.62)	7 (0.64)	4 (0.95)	0.10
Cardiac arrest	36 (1.44)	20 (2.02)	13 (1.19)	3 (0.71)	0.11
Myocardial infarction	12 (0.48)	5 (0.51)	4 (0.36)	3 (0.71)	0.59
Pulmonary embolism	19 (0.76)	9 (0.91)	8 (0.73)	2 (0.47)	0.79
Cerebrovascular accident	53 (2.11)	21 (2.12)	27 (2.46)	5 (1.18)	0.30
Sepsis	18 (0.72)	5 (0.51)	8 (0.73)	5 (1.18)	0.36
Catheter-related bloodstream infection	2 (0.08)	2 (0.20)	0 (0.00)	0 (0.00)	0.46
Ventilator-associated pneumonia	58 (2.31)	36 (3.64)	17 (1.55)	5 (1.18)	0.002
Unplanned return to OR	122 (4.86)	61 (6.16)	38 (3.47)	23 (5.45)	0.01

ARDS = acute respiratory distress syndrome; OR = operating room.

Only the most common major complications are listed. Values are expressed as the number (%) of patients, unless indicated otherwise. Boldface type indicates statistical significance.

Evans and colleagues⁷ recently published systematic review of 7 studies and 396 elderly patients with a diagnosis of atSDH (sample size range 27–119), 30-day mortality ranged from 27% to 70%, most likely reflecting disparities in management, baseline population mix, and injury severity.¹⁷ Interestingly, the authors found an initial GCS score of 3–8 to be the most consistent negative prognostic factor, an observation that corroborates the results of our risk-adjusted analysis. It should be noted though that both operative and nonoperative cases were included in that review, which could confound the interpretation of results. Finally, in an NSQIP 2005–2012 study of 746 craniotomy cases for SDH, 30-day mortality was 17%.⁷ A higher American Society of Anesthesiologists (ASA) class, ascites, a “bleeding disorder,” and coma correlated with higher odds of 30-day mortality.

An important finding in our analysis was the association between antithrombotic use/coagulopathy and postoperative mortality. In a study of 157 elderly patients,

Rozzelle et al. found that a GCS score of 7 or less and an age greater than 80 correlated with worse inpatient mortality; previous antithrombotic medication use, nature of the trauma, comorbidity score, and presence of midline shift were not found to be significant.²⁴ On the contrary, Scotti et al. showed that anticoagulation use (warfarin or novel oral anticoagulants), as well as dual antiplatelet therapy, in elderly TBI patients was associated with a higher mortality risk and functional dependency at discharge.²⁵ In a similar fashion, Baraniskin et al. observed inferior outcomes in acute SDH patients on prehospital antithrombotic therapy (OR for recurrence or in-hospital mortality: 2.86–5.50, all $p < 0.05$).⁶

Although pupillary response was found to be a statistically significant and important negative predictor for in-hospital mortality in our analysis, others have not found a significant relationship.^{10,13–16} Pupillary changes can occur from uncal herniation due to mass effect leading to compression of the oculomotor nerve and brainstem, but

TABLE 4. Summary of postoperative outcomes

Variable	Available Data (no. of cases)	All (n = 2508)	65–74 Yrs (n = 990)	75–84 Yrs (n = 1096)	85+ Yrs (n = 422)	p Value
ICU LOS, median [IQR]	2508	6.00 [4.00, 10.0]	6.00 [4.00, 11.0]	5.00 [3.00, 9.00]	5.00 [4.00, 9.00]	0.001
Ventilation days, median [IQR]	2508	5.00 [2.00, 10.0]	6.00 [2.00, 11.0]	5.00 [2.00, 9.00]	4.00 [2.00, 9.00]	0.037
Inpatient mortality, no. (%)	2508	460 (18.3)	172 (17.4)	199 (18.2)	89 (21.1)	0.24
Withdrawal of care, no. (%)	2392	420 (17.6)	147 (15.5)	180 (17.2)	93 (23.3)	0.003
Discharge disposition, no. (%)	2508					<0.001
Home/home health		469 (18.7)	228 (23.0)	202 (18.4)	39 (9.2)	
Nursing home		546 (21.8)	150 (15.2)	266 (24.3)	130 (30.8)	
Inpatient rehab		647 (25.8)	273 (27.6)	274 (25.0)	100 (23.7)	
Short-term inpatient care		37 (1.5)	23 (2.3)	12 (1.1)	2 (0.5)	
Hospice		184 (7.3)	56 (5.7)	86 (7.8)	42 (10.0)	
Died		460 (18.3)	172 (17.4)	199 (18.2)	89 (21.1)	
Other		51 (2.03)	25 (2.53)	20 (1.82)	6 (1.42)	

LOS = length of stay.

Boldface type indicates statistical significance.

TABLE 5. Results of multivariable logistic regression analysis for inpatient mortality

Variable	OR	95% CI	p Value
Age 75–84 vs 65–74 yrs	1.57	1.21–2.04	<0.001
Age 85+ vs 65–74 yrs	2.26	1.61–3.15	<0.001
F vs M sex	0.86	0.67–1.09	0.21
Black vs White race	0.58	0.35–0.95	0.03
Asian vs White race	0.69	0.36–1.34	0.28
Other vs White race	0.75	0.47–1.21	0.24
Total GCS score 3–8 vs 13–15	3.63	2.68–4.92	<0.001
Total GCS score 9–12 vs 13–15	2.64	1.79–3.90	<0.001
ISS (26:17)*	1.56	1.32–1.85	<0.001
Coagulopathy	1.41	1.05–1.91	0.02
Presence of IPH	1.68	1.20–2.34	0.02
Presence of EDH	1.86	0.99–3.48	0.052
Presence of SAH	2.86	2.21–3.70	<0.001
Presence of MLS >5 mm	2.40	1.74–3.32	0.001
One vs both reactive pupils	1.36	0.79–2.34	0.27
No vs both reactive pupils	1.81	1.18–2.76	0.006

Boldface type indicates statistical significance. The c-index was 0.81 (excellent discrimination).

* Odds ratios for continuous variables are presented as 75th:25th percentile.

they can also occur due to orbital/ocular trauma; therefore, the true etiology of the pupillary changes must be understood before it can be used in treatment or prognostic decisions. In a systematic review by Evans et al., the strength of currently available evidence for pupillary response as a prognostic factor was “very low” because of inconsistencies and limitations in the study design.¹⁷ It is interesting to note that pupillary response was nonsignificant in studies that included very elderly patients (age ≥ 75 years and ≥ 80 years), as opposed to the studies that defined the elderly as those older than 65 years.^{10,15} This might be due to the fact that pupillary reaction may already be highly sluggish at baseline in very elderly patients, thereby leading to questionable prognostic value in this subpopulation. It is also important to note that midline shift greater than 5 mm was also found to be independently associated with mortality in our analysis, with relatively high predictive importance. Petridis et al. further defined the relationship between mass effect from the hematoma causing midline shift and found that midline shift greater than hematoma width was associated with adverse outcomes (on univariate analysis alone).¹⁴ Midline shift should likely be evaluated on a continuous variable basis, as each increased millimeter likely increases morbidity and mortality. In a secondary analysis of the Citicoline Brain Injury Treatment (COBRIT) trial, Puffer et al. demonstrated worsening outcomes as midline shift increased from no shift to 1–5 mm, further worsening at shifts of 6–10 mm, and significantly poor outcomes with shifts > 10 mm, as expected.²⁶ However, the trial was inclusive of all TBI patients and not limited to elderly patients undergoing surgical evacuation of atSDH. Nonetheless, increasing midline shift at presentation correlates with worse outcomes, but like all individual patient

characteristics, this imaging variable should not be used alone as a prognostic factor but should be interpreted with the overall injury severity and comorbidity burden of each patient encountered.

Prior evidence exploring the relationship among ICP monitoring, older age, and TBI outcomes is very limited. Interestingly, a study by Thompson et al. showed that older TBI patients are offered a lower intensity of care after adjusting for sex, comorbidities, and injury-related factors.²⁷ In a similar fashion, Schupper et al. found age disparities with regard to adherence to the Brain Trauma Foundation guidelines among blunt TBI patients presenting with a GCS score of 3–8.²⁸ The differential effect of ICP monitoring and age on short- and long-term outcomes following severe TBI certainly merits further investigation and remains to be determined in future research. Furthermore, whether ICP monitoring contributes to lower mortality rates in severe TBI remains an area of contention among the scientific community, with the literature demonstrating conflicting results. In our study, we decided not to include ICP monitoring in the risk-adjusted analysis, as we focused on factors that are available to surgeons at the time of initial evaluation.

Ultimately, early and accurate prognostication in TBI is often premature and very challenging; neurosurgeons are very commonly called upon to provide information regarding prognosis and what kind of goals can or cannot be achieved with each intervention. Advance directives can certainly be helpful to provide a guiding framework. A recent report demonstrated that an estimated 67% of seriously ill patients in 2010 had an advance directive compared to only 21% in 1994, primarily involving the elderly population.²⁹ Despite their increasing use though, the utility of advance directives to document patient wishes remains uncertain.³⁰ More importantly, a readily available, easily interpreted, and applicable advance directive may not be present in the acuity of a traumatic event; thus, a patient may have undesired, invasive procedures performed.³⁰ It is of paramount importance to establish well-defined goals of care and set realistic expectations with the patient's family, which is one of the most critical aspects of trauma surgery, including neurosurgery.

Study Limitations

Our study has several limitations. First, although it is registry based, there is still a risk for coding errors. Second, we were not able to discern with high specificity whether the procedure performed was craniotomy versus burr hole evacuation. Third, the large number of patients in database studies often leads to statistically significant differences in variables that may not be clinically relevant. Fourth, we were only able to investigate inpatient outcomes and not longer-term outcomes, including functionality and degree of independence. Fifth, we did not have access to laboratory parameters (e.g., platelet count) or specific anti-thrombotic medications (e.g., aspirin vs warfarin vs dabigatran, etc.) in order to decipher their role on postoperative mortality. Sixth, we could not analyze midline shift as a continuous variable. There may also be a risk of residual confounding, as some radiological and clinical covariates such as hematoma size and postoperative seizures were

FIG. 1. Plot of predictor variables in decreasing importance. MLS = midline shift.

not available. This may be important, as seizures following evacuation have also been found to be associated with worse early functional outcomes, although these patients can still attain a delayed favorable recovery.^{11,31} Last, and most importantly, selection bias is always a concern when investigating outcomes in the elderly population; sicker, dependent patients are less likely to be offered an aggres-

sive surgical intervention, unless the patient and/or their family decide to pursue every possible means of care regardless of the potential postoperative outcome. Although we were not able to measure this bias, our study essentially represents an actuarial analysis of elderly patients with atSDH in the United States on a national scale while preserving a degree of data granularity close to that seen

FIG. 2. Inpatient mortality rates broken down by age group and presenting GCS score. All within-group comparisons were statistically significant ($p < 0.001$).

with single-institution series. Furthermore, the large sample size allowed us to perform subgroup analysis as well as risk-adjusted analysis controlling for a multitude of clinically relevant confounding variables. Despite the level of detail, the registry lacks variables pertinent to estimating frailty in the TBI population, such as the level of independence in activities of daily living, nutritional status, degree of dementia when present, etc. Existing literature on this topic is rather limited; therefore, future research into the relationship between frailty indices (novel or previously established) and short- and long-term outcomes is highly encouraged.

Conclusions

In summary, the findings of our nationwide study suggest an overall in-hospital mortality rate of 18% and a major complication rate of 14.4% among elderly patients (age ≥ 65) undergoing surgical evacuation of atSDH. In a multivariable analysis, the three most important predictors were found to be the presenting GCS score, presence of traumatic SAH, and presence of midline shift > 5 mm. The same factors were also significant in a subgroup analysis by age decile. Finally, we showed that mortality increased from 8% to 15.4% for patients with a GCS 13–15 to around 36% for GCS 9–12, and almost as high as 60% for GCS 3–8, particularly in those aged 85 and older.

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Disclosures

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Author Contributions

Conception and design: Bydon, Kerezoudis, Goyal. Acquisition of data: Bydon, Kerezoudis, Goyal. Analysis and interpretation of data: Kerezoudis, Goyal, Puffer, Parney, Meyer. Drafting the article: Kerezoudis, Goyal, Puffer, Parney, Meyer. Critically revising the article: Kerezoudis, Goyal, Puffer, Parney, Meyer.

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