ORIGINAL ARTICLE

Intensive Care Unit Admission Patterns for Mild Traumatic Brain Injury in the USA

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Abstract

Background: Patients with mild traumatic brain injury (TBI) are frequently admitted to an intensive care unit (ICU), but routine ICU use may be unnecessary. It is not clear to what extent this practice varies between hospitals.

Methods: We conducted a retrospective cohort study using the National Trauma Data Bank. Patients with at least one TBI ICD-9-CM diagnosis code, a head abbreviated injury score (AIS) ≤ 4 , and Glasgow coma scale (GCS) ≥ 13 were included; individuals with only a concussion and those with a non-head AIS > 2 were excluded. Primary outcomes were ICU admission and “overtriage” to the ICU, defined by: ICU stay ≤ 1 day; hospital stay ≤ 2 days; no intubation; no neurosurgery; and discharged to home. Mixed effects multivariable models were used to identify patient and facility characteristics associated with these outcomes.

Results: A total of 595,171 patients were included, 44.7% of whom were admitted to an ICU; 17.3% of these met the criteria for overtriage. Compared with adults, children < 2 years were more likely to be admitted to an ICU (RR 1.21, 95% CI 1.16–1.26) and to be overtriaged (RR 2.06, 95% CI 1.88–2.25). Similarly, patients with isolated subarachnoid hemorrhage were at greater risk of both ICU admission (RR 2.36, 95% CI 2.31–2.41) and overtriage (RR 1.22, 95% CI 1.17–1.28). The probabilities of ICU admission and overtriage varied as much as 16- and 11-fold across hospitals, respectively; median risk ratios were 1.67 and 1.53, respectively. The likelihood of these outcomes did not vary substantially with the characteristics of the treating facility.

Conclusions: There is considerable variability in ICU admission practices for mild TBI across the USA, and some of these patients may not require ICU-level care. Refined ICU use in mild TBI may allow for reduced resource utilization without jeopardizing patient outcomes.

Keywords: Traumatic brain injury, Intensive care units, Health resources

Background

Patients with traumatic brain injury (TBI) account for several hundred thousand hospital admissions annually in the USA [1]. The majority of these injuries are mild, traditionally defined by a Glasgow Coma Scale (GCS) score of 13 or greater [2]. While some patients with mild TBI (mTBI) require emergent neurosurgical intervention upon arrival to the hospital, most do not and are managed expectantly [3–7]. Occasionally, individuals

with initially reassuring neurological examinations and imaging findings can deteriorate, requiring neurosurgical intervention, intubation, or other emergent lifesaving procedures [7]. For this reason, individuals with mTBI are often admitted to the intensive care unit (ICU) for close monitoring so that any deterioration can be quickly identified and acted upon.

The routine admission of patients with mTBI to the ICU constitutes a significant use of healthcare resources, and in some cases, the benefits are dubious [4–8]. Indeed, a meta-analysis of 49 studies found that the rates of clinical deterioration or death among patients with GCS ≥ 13 were 11% and 1.4%, respectively [8], suggesting that

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the majority of these patients do not require such close observation. One large retrospective study conducted across eight level 1 trauma centers in the western USA found that only 5% of mild TBI patients with a GCS of 15 admitted to an ICU required ICU-level care, defined as neurosurgical intervention, vasopressor administration, invasive hemodynamic monitoring, mechanical ventilation, or blood product transfusion [7]. The same study also reported substantial variability in the triage patterns for patients with mTBI, with a 30-fold difference in the adjusted odds of ICU admission between the facilities with the most aggressive and least aggressive ICU admission practices [7]. A separate analysis using prospectively collected TRACK-TBI pilot data similarly demonstrated that one of two participating centers was five times more likely to admit patients to the ICU [4]. Importantly, no study has demonstrated evidence of worse in-hospital or long-term outcomes when patients were triaged to the acute care ward rather than to the ICU. To the contrary, functional and neuropsychiatric outcomes were comparable [4].

Variable use of an intervention such as an ICU admission without evidence of differential outcomes indicates that there may be an opportunity to improve resource utilization by standardizing triage and admission practices. While it has been demonstrated that significant variability can exist between academic trauma centers within a geographic region [7], it is not known to what extent ICU admission practices vary on a national level and between facilities of different characteristics. Furthermore, the majority of studies published on this topic have not analyzed patients by the type of intracranial injury identified. This limitation is important because the risk of clinical deterioration and the probability of intervention vary considerably depending on the type of injury present [9–11].

This study was conducted to identify the clinical factors prompting admission to the ICU among individuals with mild complicated TBI, defined by a GCS of 13–15, a head Abbreviated Injury Scale (AIS) of less than five, and an abnormal computed tomography (CT) scan. We also sought to examine the extent to which these patients are “overtriaged” to the ICU, only to rapidly discharge to home without intervention. A final goal was to assess the variability of this practice around the country and to identify facility characteristics associated with an increased likelihood of ICU admission.

Methods

Data from the National Trauma Data Bank (NTDB) were used to conduct a retrospective cohort study spanning the years 2007 through 2014. Because the NTDB contains fully anonymized records, human subjects approval was not required for this study. Data regarding demographics,

comorbidities, vital signs, GCS, injury mechanisms, injury diagnoses, inpatient procedures, hospital disposition, and facility characteristics were obtained from the database.

The NTDB records patient injuries using two diagnosis coding systems: the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) and the AIS. While manually entered AIS codes contain granular details regarding injury location and severity that are lacking in ICD-9-CM diagnosis codes, the majority of records obtained from the NTDB contained only ICD-9-CM codes. To generate estimates of injury severity, we used the Stata package ICDPIC to map ICD-9-CM diagnosis codes to maximum AIS scores for each body region and to calculate an overall injury severity score (ISS). ICDPIC has been shown to have excellent discrimination for injury severity when applied to large datasets [12].

We included all patients with one or more of the standard ICD-9-CM diagnosis codes for TBI [13] (800.0–801.9, 803.0–804.9, 850.0–854.1, 950.1–950.3, 959.01, 995.55) who had a post-resuscitation emergency department (ED) GCS of 13 or greater and an AIS head of less than five. While recent research has increasingly categorized patients with a GCS of 13 as moderate TBI, this reclassification has not necessarily translated to clinical practice; GCS 13 and higher has long been used to define mild TBI and was thus the definition employed for the purposes of this study [14, 15].

Because significant extracranial injuries may influence the decision to admit a patient with mild TBI to the ICU, individuals with a maximum AIS greater than two in any other body region (max non-head AIS) were excluded. We also excluded patients who died in the ED, required prehospital cardiopulmonary resuscitation, were intubated in the ED, were taken to surgery directly from the ED, or were discharged from the hospital without an inpatient admission following ED care. Because patients with concussion and no intracranial pathology are at very low risk of delayed deterioration and are frequently discharged to home from the ED [16], patients with no diagnoses other than concussion were also excluded. Two cohorts were constructed from the resulting sample based on their disposition from the ED: patients admitted to the acute care ward and patients admitted to the ICU. In general, the decision whether or not to admit individuals to the ICU or to the acute care ward is made after expert consultation and review of neuroimaging studies.

Variable Definitions

We also examined the extent to which patients admitted to the ICU may have been overtriaged (i.e., admitted to the ICU when acute care observation may have sufficed). A patient was considered to have been overtriaged if all

the following conditions were met: admitted to the ICU from the ED; had an ICU length of stay less than or equal to 1 day; had a total hospital length of stay of 2 days or less; was not intubated at any point during the hospital stay; did not undergo neurosurgical intervention; and discharged from the hospital to home or self-care. For the purposes of classifying patients as overtriaged or not, the small number of records with missing values for length of stay and discharge disposition were assumed to have ICU length of stay > 1 day, hospital length of stay > 2 days, and a discharge disposition other than home; missing values for ventilator days were assumed to be zero. Neurosurgical intervention was defined as placement of an intracranial pressure monitor or surgery such as burr holes or craniotomy, which were identified using ICD-9-CM procedure codes (01.09, 01.10, 01.16, 01.17, 01.26, 02.21, 01.23, 01.24, 01.25, 02.02, 02.12, 02.13, 01.32, 01.39, 01.53, 01.31). Data regarding some critical care interventions, such as vasopressor use [17], were not available in the NTDB. This strict definition of an overtriaged admission was used in order to construct a group of patients who required little more than brief observation.

For the purposes of our analyses, hypotension was defined as a systolic blood pressure less than 90 mmHg in patients 10 years and older; age-specific cutoffs based on the Pediatric Advanced Life Support guidelines were used for younger patients [18].

Because each patient may have multiple TBI diagnoses, there are a large number of possible permutations. To account for patients with multiple TBI diagnoses and to simplify our analysis, we created a variable with mutually exclusive categories for each diagnosis (for patients with a single TBI ICD-9-CM diagnosis code) and categories for multiple diagnoses (for patients with more than one TBI ICD-9-CM diagnosis code). This variable included seven categories for patients with a single TBI diagnosis code: skull fracture without intracranial hemorrhage (ICH); skull fracture with ICH; subdural hematoma (SDH); subarachnoid hemorrhage (SAH); epidural hematoma (EDH); cerebral contusion; and other TBI (other and unspecified intracranial injury based on ICD-9-CM codes). Because of the large number of possible TBI diagnosis combinations in patients with multiple diagnoses, we sought to limit our analysis only to the permutations that were sufficiently frequent to merit analysis. To accomplish this, we included only combinations that constituted at least 2% of the sample; the only multiple diagnosis combination over the 2% cutoff was SDH with SAH, which was added as an eighth category. All other rare combinations (<2% or less) were combined into a ninth category called “multiple diagnoses.”

Statistical Analysis

Demographics, clinical data, injury characteristics, and facility details were analyzed descriptively. To identify characteristics associated with a greater likelihood of ICU admission, a mixed-effect Poisson regression with robust standard errors was performed using a random intercept for each facility. Covariates included patient demographics (gender, age, race, insurance status), medical comorbidities (total number of comorbidities, the presence of a bleeding diathesis), clinical factors (the presence of hypotension, total GCS, suspected alcohol or drug use), injury details (TBI diagnosis, injury mechanism), facility characteristics (teaching status, region, number of total beds, number of ICU beds for trauma patients), and the year of admission. A second mixed-effect regression with a random intercept for each facility and the same covariate structure was performed to identify characteristics that were independently associated with overtriage to the ICU. Patients with missing values for covariates were excluded from these analyses. Once the multivariable models were created, the resulting intercepts for each facility were log-transformed to risk ratios and plotted from lowest to highest to visualize facility-to-facility variation. Finally, median risk ratios were calculated to demonstrate the extent to which inter-facility variation influenced the probability of ICU admission and overtriage. The median risk ratio is calculated by ranking facilities based on the risk of an outcome, calculating the risk differential of all pairwise comparisons between lower- and higher-ranked facilities, and then taking the median value of the resulting distribution. Conceptually, the median risk ratio corresponds to the median increase in risk of an outcome between a lower- and higher-ranked facility for a patient with a given set of covariates [19–21]. All data analysis was performed using Stata version 14 (StataCorp LLC, College Station, TX).

Results

We identified a total of 1,869,614 patients with at least one ICD-9-CM diagnosis code for TBI in the NTDB dataset. A total of 948,436 of them had a mild isolated TBI, defined by a GCS of 13 or greater and a maximum AIS score of two or less in any body region other than the head. After excluding individuals who were taken directly to surgery from the ED and those with no TBI diagnosis other than concussion, the final cohort consisted of 595,171 patients.

Of the resulting cohort, 44.7% ($n=265,857$) were admitted to an ICU. Over 95% of these patients never underwent neurosurgical intervention and more than 90% never required mechanical ventilation (Table 1). A minority of patients had an ICU length of stay of 1 day or less and a total hospital length of stay of 2 days or less;

Table 1 Proportion of ICU-admitted patients meeting the definition for overtriage

	Number of patients	Percentage of all ICU admissions (%)
Total hospital length of stay ≤ 2 days	75,310	28.3
ICU Length of stay ≤ 1 day	106,122	39.9
Never intubated	242,530	91.2
No neurosurgical intervention	254,557	95.7
Discharged to home or self-care	182,951	68.8
Overtriaged (all of the above)	45,953	17.3

ICU intensive care unit

more than two-thirds of patients were discharged directly to home after their hospitalization. In total, 17.3% of patients admitted to the ICU ($n=45,953$) met the criteria for overtriage.

The demographic, clinical, and facility characteristics of the overall sample are presented in Table 2. Patients admitted to the ICU tended to be older and to have more medical comorbidities than those admitted to the acute care ward. More ICU-admitted patients had a GCS < 15 or an intracranial hemorrhage; SDH and EDH in particular were more common among those triaged to the ICU compared with those admitted to acute care.

Once admitted to the ICU, patients younger than 35 made up a greater proportion of those meeting our definition of overtriage than those not meeting these criteria (Table 3). Patients 55 and older made up a much smaller proportion of the overtriaged group than they did of the overall ICU admission cohort, due in large part to a greater proportion of these patients remaining in the hospital for a total of two or more days and/or discharging to a skilled nursing facility. For example, 66.7% of patients aged 85 and older who were admitted to the ICU ultimately required discharge to a facility compared with 17.5% of those 36–54 years. Similarly, 85.0% of those 85 and older were hospitalized for longer than 2 days, whereas only 71.6% of 36–54 years olds remained hospitalized for that duration. Patients with an intracranial hemorrhage or a GCS less than 15 were much less likely to have been overtriaged than those without hemorrhage and with a normal GCS (Table 3).

In multivariable analysis, age was a significant independent predictor of both ICU admission and overtriage to the ICU (Table 4). Pediatric patients aged ≤ 18 years and those 55 and older were more likely to be admitted to the ICU. However, once admitted to the ICU, children < 2 years were twice as likely to meet our criteria for overtriage compared with those aged 36–54 (RR 2.06, 95% CI 1.88–2.25). Conversely, patients 55 and older were significantly less likely to have been overtriaged.

A number of other patient characteristics were independently associated with ICU admission and/or

overtriage to the ICU (Table 4). For example, patients with multiple medical comorbidities, coagulopathies, hypotension, or depressed GCS were more likely to be admitted to the ICU than those without, and they were significantly less likely to have been overtriaged. This pattern was also present for most patients with any type of intracranial hemorrhage; a notable exception is patients with isolated SAH, who had a higher risk of overtriage (RR 1.22, 95% CI 1.17–1.28).

Facilities located outside of the Northeast were all more likely to admit patients to the ICU, and individuals receiving care in the Midwest and South were also more likely to have been overtriaged (Table 4). While there were some differences between facilities of varying sizes and trauma levels, no clear pattern was evident.

The predicted probability of ICU admission and overtriage for the average patient varied considerably among hospitals (Figs. 1a and 1b, respectively). The risk of ICU admission at the most aggressive facility (RR 2.74, 95% CI 2.28–3.30) was 16-fold higher than at the most conservative facility (RR 0.17, 95% CI 0.09–0.32); the median risk ratio for ICU admission between lower- and higher-ranked facilities was 1.67. Similarly, we observed an 11-fold difference between the hospitals with the highest risk of overtriage (RR 2.84, 95% CI 2.32–2.84) and the lowest risk (RR 0.25, 95% CI 0.17–0.38); the median risk ratio for overtriage was 1.53. There was not an obvious correlation between a facility's probabilities of ICU admission and overtriage (Fig. 1c).

Discussion

Using a national sample from the NTDB, we conducted a large retrospective study examining the patterns of ICU admission for mild TBI in the USA. We found that there was substantial variability between facilities with regard to patient triage from the emergency department. We also identified a number of patient characteristics that predicted a higher likelihood of ICU admission. Finally, we examined how commonly ICU admission may have been unnecessary by identifying patients with brief ICU

Table 2 Clinical and demographic characteristics of mTBI patients admitted to acute care and to the ICU

	ED disposition		
	Acute care admission	ICU admission	% Difference
	(n = 329,314)	(n = 265,857)	(95% CI)
Gender			
Male	202,087 (61.4%)	166,416 (62.6%)	1.2% (0.9%, 1.5%)
Age			
< 2 years	22,082 (7.0%)	11,375 (4.5%)	− 2.4% (− 2.5%, 2.3%)
2–10 years	20,902 (6.6%)	12,290 (4.8%)	− 1.7% (− 1.8%, − 1.6%)
11–18 years	22,641 (7.2%)	15,760 (6.2%)	− 0.9% (− 0.8%, − 1.1%)
19–35 years	61,550 (19.5%)	39,907 (15.7%)	− 3.7% (− 3.9%, − 3.5%)
36–54 years	61,550 (19.5%)	46,094 (18.1%)	− 1.4% (− 1.5%, − 1.2%)
55–69 years	47,999 (15.2%)	46,396 (18.2%)	2.9% (2.7%, 3.1%)
70–85 years	56,614 (17.9%)	60,782 (23.8%)	5.7% (5.5%, 5.9%)
85+ years	22,524 (7.1%)	22,268 (8.7%)	1.5% (1.4%, 1.7%)
Race/ethnicity			
White	228,239 (72.0%)	188,388 (73.3%)	1.6% (1.3%, 1.8%)
African-American	36,019 (11.4%)	24,586 (9.6%)	− 1.7% (− 1.8%, − 1.5%)
Hispanic	34,200 (10.8%)	28,342 (11.0%)	0.2% (0.1%, 0.4%)
Asian	6392 (2.0%)	5948 (2.3%)	0.3% (0.2%, 0.4%)
Other	12,107 (3.8%)	9796 (3.8%)	0.0% (0.0%, 0.1%)
Payer			
Private	83,362 (28.3%)	63,622 (26.0%)	− 1.4% (− 1.6%, − 1.2%)
Medicare	96,913 (32.9%)	96,608 (39.5%)	6.9% (6.7%, 7.1%)
Medicaid	42,759 (14.5%)	29,944 (12.2%)	− 1.7% (− 1.9%, − 1.6%)
Self-pay/not billed	41,229 (14.0%)	31,215 (12.7%)	− 1.3% (− 1.4%, − 1.1%)
Auto	13,588 (4.6%)	9291 (3.8%)	− 0.8% (− 1.0%, − 0.6%)
Worker comp	5649 (1.9%)	4300 (1.8%)	− 0.1% (− 0.2%, 0.0%)
Other	11,347 (3.8%)	9874 (4.0%)	0.2% (0.1%, 0.3%)
Number of comorbidities			
0	170,864 (51.9%)	112,665 (42.4%)	− 9.5% (− 9.8%, − 9.3%)
1	75,395 (22.9%)	64,954 (24.4%)	1.5% (1.3%, 1.8%)
≥ 2	83,055 (25.2%)	88,238 (33.2%)	8.0% (7.7%, 8.2%)
Transferred in			
Yes	118,400 (36.0%)	101,511 (38.2%)	2.2% (2.0%, 2.5%)
Hypotensive			
Yes	2415 (0.8%)	2439 (0.9%)	0.1% (0.1%, 0.2%)
Mechanisms			
Fall	175,519 (53.3%)	156,783 (59.0%)	5.7% (5.4%, 5.9%)
Motorcycle	9779 (3.0%)	7911 (3.0%)	0.0% (0.0%, 0.0%)
Motor vehicle collision	47,993 (14.6%)	31,307 (11.8%)	− 2.8% (− 3.0%, − 2.6%)
Pedestrian	22,583 (6.9%)	17,725 (6.7%)	− 0.2% (− 0.3%, 0.0%)
Struck by	41,501 (12.6%)	27,242 (10.2%)	− 2.4% (− 2.5%, − 2.2%)
Other	39,288 (11.9%)	29,743 (11.2%)	− 0.7% (− 0.9%, − 0.5%)
Injury type			
Blunt	311,691 (99.1%)	251,469 (98.8%)	− 0.3% (− 0.4%, − 0.2%)
Penetrating	2819 (0.9%)	3114 (1.2%)	0.3% (0.3%, 0.4%)
Injury intent			
Unintentional	286,587 (87.9%)	235,309 (89.3%)	1.4% (1.3%, 1.6%)
Assault	38,760 (11.9%)	27,148 (10.3%)	− 1.6% (− 1.7%, − 1.4%)
Self-inflicted	770 (0.2%)	1044 (0.4%)	0.2% (0.1%, 0.2%)

Table 2 continued

	ED disposition		
	Acute care admission	ICU admission	% Difference
	(n = 329,314)	(n = 265,857)	(95% CI)
Max non-head AIS			
0	103,473 (31.4%)	88,883 (33.4%)	2.0% (1.7%, 2.3%)
1	126,490 (38.4%)	103,178 (38.8%)	0.4% (0.2%, 0.6%)
2	99,350 (30.2%)	73,792 (27.8%)	−2.4% (−2.6%, −2.2%)
ED composite GCS			
15	279,989 (85.0%)	197,792 (74.4%)	−10.6% (−10.8%, −10.4%)
14	41,439 (12.6%)	53,323 (20.1%)	7.5% (7.3%, 7.7%)
13	7886 (2.4%)	14,742 (5.5%)	3.1% (3.0%, 3.3%)
Injury diagnosis			
Skull fracture without ICH	65,825 (20.0%)	16,514 (6.2%)	−13.8% (−13.9%, −13.6%)
Skull fracture with ICH	27,516 (8.4%)	34,251 (12.9%)	4.5% (4.4%, 4.7%)
EDH	2341 (0.7%)	3556 (1.3%)	0.6% (0.6%, 0.7%)
SDH	50,393 (15.3%)	59,420 (22.4%)	7.1% (6.9%, 7.2%)
SAH	37,635 (11.4%)	35,010 (13.2%)	1.7% (1.6%, 1.9%)
SAH and SDH	9401 (2.9%)	16,000 (6.0%)	3.2% (3.1%, 3.3%)
Cerebral contusion	16,696 (5.1%)	13,815 (5.2%)	0.1% (0.0%, 0.2%)
Other TBI	88,142 (26.8%)	26,523 (10.0%)	−16.8% (−17.0%, −16.6%)
Multiple diagnoses	31,365 (9.5%)	60,768 (22.9%)	133% (13.1%, 13.5%)
Hospital teaching status			
Community	108,833 (33.0%)	106,015 (39.9%)	6.9% (6.6%, 7.1%)
Non-teaching	35,576 (10.8%)	34,489 (13.0%)	2.2% (2.0%, 2.3%)
University	184,905 (56.1%)	125,353 (47.2%)	−8.9% (−9.3%, −8.7%)
Hospital region			
Northeast	69,531 (21.6%)	46,618 (17.8%)	−3.8% (−3.9%, −3.5%)
Midwest	87,879 (27.3%)	67,214 (25.7%)	−1.6% (−1.8%, −1.4%)
West	61,964 (19.2%)	62,565 (23.9%)	4.7% (4.5%, 4.9%)
South	103,042 (32.0%)	85,563 (32.7%)	0.7% (0.6%, 0.9%)
Hospital size			
≤ 200 beds	15,874 (4.8%)	11,865 (4.5%)	−0.3% (−0.4%, −0.3%)
201–400 beds	86,670 (26.3%)	72,808 (27.4%)	1.1% (0.8%, 1.3%)
401–600 beds	100,223 (30.4%)	85,110 (32.0%)	1.6% (1.3%, 1.8%)
> 600 beds	126,547 (38.4%)	96,074 (36.1%)	−2.3% (−2.5%, 2.0%)
Number of trauma ICU beds			
≤ 10 beds	25,741 (7.8%)	18,289 (6.9%)	−0.9% (−1.1%, −0.8%)
11–25 beds	135,815 (41.3%)	107,854 (40.6%)	−0.7% (−0.9%, −0.4%)
> 26 beds	167,522 (50.9%)	139,459 (52.5%)	1.6% (1.3%, 1.8%)

AIS abbreviated injury scale, ED emergency department, EDH epidural hematoma, GCS Glasgow coma scale, ICH intracranial hemorrhage, ICU intensive care unit, IPH intraparenchymal hemorrhage, mTBI mild traumatic brain injury, MVC motor vehicle collision, SAH subarachnoid hemorrhage, SDH subdural hematoma, TBI traumatic brain injury

and hospital stays who did not require neurosurgical intervention and who discharged to self-care.

After adjusting for covariates, pediatric patients were significantly more likely to be admitted to the ICU than adults 36–54 years, but they were also twice as likely as adults 36–54 years old to meet our definition of over-triage. This finding suggests that a substantial portion

of pediatric ICU admissions for mild TBI are unnecessary. Heightened vigilance among practitioners caring for children may be responsible. Indeed, the majority of pediatric trauma care is delivered at hospitals without a pediatric trauma designation [22], and providers who do not typically care for young children may err on the side of caution by triaging these patients to the ICU. These

Table 3 Clinical and demographic characteristics of ICU-admitted mTBI patients who did and did not meet the criteria for overtriage

	Overtriage among those admitted to ICU		
	Not overtriaged (n = 219,904)	Overtriaged (n = 45,953)	% Difference (95% CI)
Gender			
Male	135,643 (61.7%)	30,773 (67.0%)	5.3% (4.8%, 5.8%)
Age			
< 2 years	6487 (3.1%)	4888 (10.8%)	7.7% (7.4%, 8.0%)
2–10 years	7168 (3.4%)	5122 (11.3%)	7.9% (7.6%, 8.2%)
11–18 years	10,846 (5.2%)	4914 (10.8%)	5.6% (5.4%, 6.0%)
19–35 years	30,691 (14.6%)	9216 (20.3%)	6.3% (5.7%, 6.5%)
36–54 years	38,050 (18.2%)	8044 (17.7%)	−0.5% (0.7%, −0.3%)
55–69 years	39,985 (19.1%)	6411 (14.1%)	−5.0% (−5.3%, −4.7%)
70–85 years	55,388 (26.4%)	5394 (11.9%)	−14.5% (−14.8%, −14.2%)
85+ years	20,923 (10.0%)	1345 (3.0%)	−7.0% (−7.2%, −6.8%)
Race/ethnicity			
White	157,778 (74.1%)	30,610 (69.2%)	−4.9% (−5.5%, −4.5%)
African-American	20,527 (9.6%)	4059 (9.2%)	−0.4% (−0.7%, −0.2%)
Hispanic	22,089 (10.4%)	6253 (14.1%)	3.7% (3.2%, 3.9%)
Asian	4815 (2.3%)	1133 (2.6%)	0.3% (0.1%, 0.4%)
Other	7597 (3.6%)	2199 (5.0%)	1.4% (1.1%, 1.5%)
Payer			
Private	48,586 (24.0%)	15,036 (35.6%)	11.6% (11.2%, 12.1%)
Medicare	87,642 (43.2%)	8966 (21.2%)	−22.0% (−22.4%, −21.6%)
Medicaid	22,738 (11.2%)	7206 (17.1%)	4.9% (4.6%, 5.3%)
Self-pay/not billed	24,569 (12.1%)	6646 (15.7%)	3.6% (3.3%, 4.0%)
Auto	7725 (3.8%)	1566 (3.7%)	−0.1% (−0.3%, 0.0%)
Worker comp	3630 (1.8%)	670 (1.6%)	−0.2% (−0.3%, −0.1%)
Other	7763 (3.8%)	2111 (5.0%)	1.2% (1.0%, 1.4%)
Number of comorbidities			
0	84,538 (38.4%)	28,127 (61.2%)	22.8% (22.3%, 23.3%)
1	54,904 (25.0%)	10,050 (21.9%)	−3.1% (−3.5%, −2.7%)
≥ 2	80,462 (36.6%)	7776 (16.9%)	−19.7% (−20.1%, −19.3%)
Transferred in			
Yes	81,766 (37.2%)	19,745 (43.0%)	5.8% (5.3%, 6.3%)
Hypotensive			
Yes	2103 (1.0%)	336 (0.8%)	−0.2% (−0.3%, −0.1%)
Mechanisms			
Fall	133,114 (60.5%)	23,669 (51.5%)	−9.0% (−9.5%, −8.5%)
Motorcycle	6626 (3.0%)	1285 (2.8%)	−0.2% (−0.3%, 0.0%)
Motor vehicle collision	25,437 (11.6%)	5870 (12.8%)	1.2% (0.9%, 1.5%)
Pedestrian	14,112 (6.4%)	3613 (7.9%)	1.5% (1.2%, 1.7%)
Struck by	20,367 (9.3%)	6875 (15.0%)	5.7% (5.4%, 6.0%)
Other	23,890 (10.9%)	5853 (12.7%)	1.8% (1.5%, 2.2%)
Injury type			
Blunt	207,739 (98.8%)	43,730 (98.9%)	0.1% (0.0%, 0.1%)
Penetrating	2622 (1.2%)	492 (1.1%)	−0.1% (−0.2%, 0.0%)
Injury intent			
Unintentional	195,341 (89.7%)	39,968 (87.6%)	−2.1% (−2.4%, −1.8%)
Assault	21,563 (9.9%)	5585 (12.2%)	2.3% (2.0%, 2.7%)

Table 3 continued

	Overtriage among those admitted to ICU		
	Not overtriaged (<i>n</i> = 219,904)	Overtriaged (<i>n</i> = 45,953)	% Difference (95% CI)
Self-inflicted	961 (0.4%)	83 (0.2%)	−0.2% (−0.3%, −0.2%)
Max non-head AIS			
0	71,922 (32.7%)	16,961 (36.9%)	4.2% (3.7%, 4.7%)
1	81,906 (37.2%)	21,272 (46.3%)	9.1% (8.7%, 9.5%)
2	66,072 (30.0%)	7720 (16.8%)	−13.2% (−13.6%, 12.9%)
ED composite GCS			
15	158,415 (72.0%)	39,377 (85.7%)	13.7% (13.2%, 14.0%)
14	47,835 (21.8%)	5488 (11.9%)	−9.9% (−10.2%, −9.5%)
13	13,654 (6.2%)	1088 (2.4%)	−3.8% (−4.0, −3.7%)
Injury diagnosis			
Skull fracture without ICH	11,240 (5.1%)	5274 (11.5%)	6.4% (6.1%, 6.7%)
Skull fracture with ICH	27,887 (12.7%)	6364 (13.8%)	1.1% (0.8%, 1.5%)
EDH	2883 (1.3%)	673 (1.5%)	0.2% (0.0%, 0.3%)
SDH	51,145 (23.3%)	8275 (18.0%)	−5.3% (−5.6%, −4.9%)
SAH	26,993 (12.3%)	8017 (17.4%)	5.1% (4.8%, 5.5%)
SAH and SDH	14,290 (6.5%)	1710 (3.7%)	−2.8% (−2.9%, −2.6%)
Cerebral contusion	10,624 (4.8%)	3191 (6.9%)	2.1% (1.9%, 2.4%)
Other TBI	20,723 (9.4%)	5800 (12.6%)	3.2% (2.9%, 3.5%)
Multiple diagnoses	54,119 (24.6%)	6649 (14.5%)	−10.1% (−10.5, −9.8%)
Hospital teaching status			
Community	88,480 (40.2%)	17,535 (38.2%)	−2.1% (−2.6%, −1.6%)
Non-teaching	29,165 (13.3%)	5324 (11.6%)	−1.7% (−2.0%, −1.4%)
University	102,259 (46.5%)	23,094 (50.3%)	3.8% (3.3%, 4.3%)
Hospital region			
Northeast	39,010 (18.0%)	7608 (16.8%)	−1.2% (−1.6%, −0.8%)
Midwest	55,979 (25.8%)	11,235 (24.8%)	−1.0% (−1.4%, −0.6%)
West	49,345 (22.8%)	13,220 (29.2%)	6.4% (5.9%, 6.8%)
South	72,310 (33.4%)	13,253 (29.2%)	−4.2% (−4.6%, −3.7%)
Hospital size			
≤ 200 beds	9292 (4.2%)	2573 (5.6%)	1.4% (1.1%, 1.6%)
201–400 beds	60,042 (27.3%)	12,766 (27.8%)	0.5% (0.0%, 0.9%)
401–600 beds	69,528 (31.6%)	15,582 (33.9%)	2.3% (1.8%, 2.8%)
> 600 beds	81,042 (36.9%)	15,032 (32.7%)	−4.2% (−4.6%, −3.7%)
Number of trauma ICU beds			
≤ 10 beds	15,070 (6.9%)	3219 (7.0%)	0.1% (−0.1%, 0.4%)
11–25 beds	88,843 (40.4%)	19,011 (41.4%)	1.0% (0.5%, 1.5%)
> 26 beds	115,803 (52.7%)	23,656 (51.6%)	−1.1% (−1.7%, 0.7%)

AIS abbreviated injury scale, ED emergency department, EDH epidural hematoma, GCS Glasgow coma scale, ICH intracranial hemorrhage, ICU intensive care unit, IPH intraparenchymal hemorrhage, mTBI mild traumatic brain injury, MVC motor vehicle collision, SAH subarachnoid hemorrhage, SDH subdural hematoma, TBI traumatic brain injury

tendencies could be amplified by the difficulty in obtaining a reassuring neurological examination in children too young to follow commands. Given concerns regarding the effects of ionizing radiation in children, close observation in an ICU may also be used in lieu of repeat CT scans.

By contrast, patients 55 and older were slightly more likely to be admitted to the ICU, but substantially less likely to be overtriaged than adults 36–54 years old. This difference is likely in part due to the greater need for post-discharge facility placement and the concomitant increase in length of stay (thus not meeting our

Table 4 Multivariable models for ICU admission and overtriage to the ICU

	Admission to the ICU from the ED				Overtriage among those admitted to ICU			
	RR	95% CI		P	RR	95% CI		P
Age								
< 2 years	1.21	1.16	1.26	< 0.001	2.06	1.88	2.25	< 0.001
2–10 years	1.28	1.23	1.32	< 0.001	1.85	1.70	2.02	< 0.001
11–18 years	1.12	1.09	1.15	< 0.001	1.45	1.35	1.55	< 0.001
19–35 years	0.96	0.95	0.98	< 0.001	1.23	1.19	1.27	< 0.001
36–54 years	[ref]				[ref]			
55–69 years	1.06	1.04	1.08	< 0.001	0.86	0.83	0.89	< 0.001
70–85 years	1.08	1.07	1.10	< 0.001	0.61	0.58	0.64	< 0.001
85+ years	1.05	1.03	1.08	< 0.001	0.42	0.39	0.45	< 0.001
Comorbidities								
0	[ref]				[ref]			
1	1.03	1.02	1.04	< 0.001	0.91	0.89	0.94	< 0.001
≥ 2	1.06	1.04	1.07	< 0.001	0.67	0.64	0.70	< 0.001
Coagulopathy	1.18	1.16	1.20	< 0.001	0.74	0.67	0.80	< 0.001
Injury intent								
Unintentional	[ref]				[ref]			
Assault	0.92	0.90	0.94	< 0.001	1.12	1.08	1.16	< 0.001
Self-inflicted	1.15	1.06	1.26	0.001	0.32	0.22	0.45	< 0.001
Transferred in	1.04	1.03	1.05	< 0.001	1.17	1.14	1.20	< 0.001
Alcohol or drug use	1.08	1.06	1.09	< 0.001	1.10	1.07	1.14	< 0.001
Hypotension in the ED	1.11	1.06	1.16	< 0.001	0.85	0.77	0.94	0.001
Max non-head AIS								
0	[ref]				[ref]			
1	0.98	0.97	0.99	< 0.001	1.12	1.08	1.15	< 0.001
2	1.01	1.00	1.02	0.06	0.59	0.56	0.61	< 0.001
GCS in ED								
15	[ref]				[ref]			
14	1.21	1.20	1.23	< 0.001	0.62	0.60	0.64	< 0.001
13	1.39	1.37	1.42	< 0.001	0.41	0.38	0.44	< 0.001
Penetrating injury	1.19	1.14	1.25	< 0.001	0.84	0.76	0.92	< 0.001
Diagnoses								
Skull fracture, no ICH	[ref]				[ref]			
Skull fracture, ICH	2.85	2.79	2.92	< 0.001	0.65	0.61	0.68	< 0.001
EDH	2.96	2.83	3.09	< 0.001	0.66	0.60	0.72	< 0.001
SDH	2.58	2.52	2.64	< 0.001	0.91	0.87	0.95	< 0.001
SAH	2.36	2.31	2.41	< 0.001	1.22	1.17	1.28	< 0.001
SAH and SDH	2.97	2.89	3.05	< 0.001	0.71	0.66	0.75	< 0.001
Cerebral contusion	2.17	2.11	2.23	< 0.001	1.06	1.01	1.12	0.02
Other TBI	1.22	1.19	1.25	< 0.001	1.06	1.01	1.11	0.01
Multiple diagnoses	3.10	3.04	3.17	< 0.001	0.56	0.53	0.60	< 0.001
Facility trauma level								
I	[ref]				[ref]			
II	1.08	1.05	1.11	< 0.001	1.05	0.96	1.16	0.29
III	1.09	1.05	1.12	< 0.001	1.08	0.99	1.18	0.07
IV/V	1.02	0.96	1.08	0.47	1.02	0.87	1.19	0.80
Facility type								
Community	[ref]				[ref]			
Non-teaching	1.02	0.96	1.08	0.48	0.97	0.85	1.10	0.63

Table 4 continued

	Admission to the ICU from the ED				Overtriage among those admitted to ICU			
	RR	95% CI		P	RR	95% CI		P
University	1.00	0.95	1.05	0.91	1.07	0.98	1.17	0.14
Facility size								
≤ 200 beds	0.90	0.85	0.95	< 0.001	1.08	0.95	1.22	0.24
201–400 beds	[ref]				[ref]			
401–600 beds	0.96	0.93	1.00	0.03	0.85	0.77	0.95	0.004
≥ 601 beds	0.92	0.87	0.96	< 0.001	0.89	0.78	1.01	0.08
Facility ICU size								
1–10	[ref]				[ref]			
11–25	0.95	0.90	1.00	0.03	1.02	0.86	1.22	0.80
> 25	1.02	0.97	1.07	0.47	1.04	0.86	1.26	0.66
Facility region								
Northeast	[ref]				[ref]			
Midwest	1.16	1.02	1.33	0.02	0.88	0.78	0.99	0.04
West	1.22	1.06	1.41	0.006	0.97	0.84	1.10	0.61
South	1.28	1.12	1.46	< 0.001	0.80	0.70	0.91	0.001

AIS abbreviated injury scale, CI confidence interval, ED emergency department, EDH epidural hematoma, GCS Glasgow coma scale, ICH intracranial hemorrhage, ICU intensive care unit, IPH intraparenchymal hemorrhage, RR risk ratio, SAH subarachnoid hemorrhage, SDH subdural hematoma, TBI traumatic brain injury

overtriage definition) rather than a true requirement for intensive monitoring in an ICU setting. It is not clear whether the greater level of care required following discharge is the result of worse neurological outcomes among the elderly [23], prehospitalization difficulties in the home environment that may have led to TBI (e.g., poor balance leading to a fall in an elderly patient who is unsafe to return home), or some combination of both. Favoring the former explanation, it has been shown that study populations with older patients tend to have higher rates of mortality and neurosurgical intervention [8]. Greater medical complexity requiring protracted hospitalization in this population may also contribute, as older age and medical comorbidities have found to be associated with a need for ICU care among elective neurosurgical patients [24].

We found that a number of factors known to be associated with the risk of poor outcomes and the need for surgical intervention were associated with a greater likelihood of ICU admission and a lower likelihood of overtriage. For example, patients with abnormal GCS were significantly more likely to be triaged to the ICU, with a roughly 20% increase in risk for each point below 15. They were also substantially less likely to be overtriaged. These findings align with the increasing incidence of surgical mass lesions and poor outcomes with declining GCS, even among patients with a GCS of 13 or greater [2, 8]. Similarly, the presence of hypotension or coagulopathy (iatrogenic or otherwise) was associated with greater likelihood of ICU admission and a lower likelihood of

being overtriaged; both of these clinical findings have been associated with poor neurological outcomes, and anticoagulation has independently been linked with expansion of intracranial hematomas and the need for surgical evacuation [8, 25–28]. These results are intuitive and suggest that some factors placing patients at greater risk of deterioration prompt triage to the ICU for close monitoring.

However, we did find that some patients with a low risk of requiring ICU-level care are also more likely to be admitted to the ICU. For example, patients with isolated SAH were more likely to meet our criteria for overtriage compared with patients with other types of intracranial hemorrhage. This finding is congruent with previous work, which has shown that patients with an isolated traumatic SAH are at very low risk of requiring intervention [8–10, 29, 30].

We observed considerable variation between facilities with regard to the risk of ICU admission and overtriage. The median risk ratio for ICU admission was 1.67, which indicates that taking a patient from a less aggressive to a more aggressive hospital would result in a 67% increase in the probability of ICU admission at least half of the time. For the purposes of comparison, this increase is greater than that observed for patients with GCS 13 compared with patients with a normal GCS. However, there were at most weak associations between these outcomes and facility characteristics, suggesting that the variability occurs mostly at the level of the individual facility, not between hospitals with different

Fig. 1 Risk of ICU admission and overtriage at individual facilities. Panels A and B show the risk ratios with 95% confidence intervals for ICU admission and overtriage, compared with the mean facility. Panel C shows a scatterplot comparing the risk of ICU admission to the risk of overtriage at each facility, with a dashed line representing the locally weighted scatterplot smoothing function. *ICU* intensive care unit

trauma level designations, for example. It is possible that this inter-facility variation reflects differences in the acuity of patients cared for by different hospitals rather than discrepancies in local practice, but this seems unlikely. If this were true, patients receiving care at level 1 trauma centers should have the highest probability of being admitted to the ICU, but our data demonstrate that this is not the case.

Such facility-to-facility heterogeneity may be an ideal target to optimize resource utilization in the care of patients with mild TBI without compromising patient care. Indeed, ICU admissions require substantially more resources than observation in the ED or on the acute care ward, and as a consequence, they are considerably more expensive [31, 32]. Furthermore, ICU beds are limited, and overtriaging patients who do not require ICU-level observation to these units may lead to ICU over-crowding and the boarding of patients requiring intensive care elsewhere in the hospital [7]. Given the resource-intensive nature of ICU admissions, the rarity of clinical deterioration, and the lack of an outcome benefit in previous studies [4, 6–8], routine ICU admissions for all patients with mTBI may be unwarranted. Clinical decision rules have been developed in an attempt to identify mild TBI patients at low risk of requiring critical care or neurosurgical interventions [6]. Successful validation of such instruments could help to reduce the rates of unwarranted ICU admission without jeopardizing outcomes.

This study's strength lies in the use of a national dataset spanning several hundred hospitals. As such, we have been able to examine the patterns of ICU admission across facilities of varying characteristics. Furthermore, the large number of patients identified provides robust statistical power.

However, this study does have several limitations. While the NTDB does include GCS and intracranial injuries in the form of ICD-9-CM diagnostic codes, further specificity is lacking. For example, there is no information regarding trends in GCS over time, intracranial hematoma size, midline shift, or cisternal effacement, important indicators of brain injury that may be used by practitioners triaging these patients [5, 6, 33–35]. Furthermore, the diagnoses that are submitted to the NTDB by contributing hospitals are abstracted from the medical record at the conclusion of the patient's hospital stay; thus, injuries that were known at the time of discharge and included in our analysis may not have been apparent when triage decisions were made in the ED. Finally, ICD-9-CM diagnosis codes lack specificity with regard to intracranial injuries, and this weakness may be magnified by inconsistent coding practices across centers [36]. The extent to which this limitation influences our results is unclear.

The NDTB does not include patients who are not admitted to the hospital, which may also impact our findings. Some with mild TBI are discharged from the ED after a period of observation without an inpatient stay, a practice which—like ICU admission—may vary considerably from hospital to hospital [4]. Patients sent home from the ED would presumably have otherwise been admitted to acute care rather than the ICU, and their absence may influence comparisons between ICU- and floor-admitted patients, particularly at hospitals that frequently engage in this practice. The presence or absence of dedicated trauma and/or neuroscience ICUs at individual facilities may also influence triage patterns, but the NTDB does not provide information regarding the types of ICUs present at all hospitals.

Finally, our definition of “overtriage” to the ICU was constructed conservatively to identify patients whose TBI was sufficiently mild to warrant rapid discharge from the hospital without intubation or intervention. This strict definition likely omits a number of patients who were admitted to the ICU and did not require a critical care intervention. Indeed, only 17% of ICU-admitted patients in our study met the criteria for overtriage. By contrast, a recent meta-analysis found that the pooled prevalence of clinical deterioration was only 11%, suggesting that 89% of patients would not have benefitted from close monitoring. Our approach allowed us to define an overtriaged group with the lowest likelihood of brain injuries requiring ICU-level care. It is possible that some patients in this group did require a critical care intervention or benefit from close monitoring during their brief ICU stays, but we are limited in our ability to examine this because the NTDB does not contain detailed information regarding all such interventions and observations. By including length of stay in our definition of overtriage, we may also have biased our comparison between the probabilities of ICU admission and overtriage toward the null; hospitals that more aggressively admit patients to the ICU may also be more conservative and cautious when it comes to discharge, leading to longer hospital stays and a lower probability of overtriage.

Conclusion

Using a large national dataset, we identified a number of patient characteristics that are associated with an increased probability of ICU admission, some of which were also associated with ICU admissions that may not have been necessary. Our data also suggest that there is considerable variability between facilities with regard to ICU admission practices, though hospitals that more aggressively triaged patients to the ICU did not necessarily have more unnecessary ICU admissions. A subset of mTBI patients may benefit from close observation in the

ICU, but a substantial portion can probably be observed safely in an acute care setting, or possibly even at home. Further work will be required to help clinicians make safe decisions regarding triage from the ED.

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Author Contributions

RHB drafted the manuscript, designed the study, and conducted the analysis. AQ contributed to the manuscript, designed the study, and conducted the analysis. FPR and MSV contributed to drafting of the manuscript and to study design.

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Compliance with Ethical Standards

Conflict of interest

The authors report no conflicts of interest.

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