Citation: Graves, W. C., Oyesanya, T. O., Gormley, M., Røe, C., Andelic, N., Seel, R. T., & Lu, J. (2021). Pre-and in-hospital mortality for moderate-to-severe traumatic brain injuries: an analysis of the National Trauma Data Bank (2008-2014). Brain injury, 35(3), 265-274.

Pre- and In-Hospital Mortality for Moderate-to-Severe Traumatic Brain Injuries: An Analysis of the National Trauma Data Bank (2008-2014)

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Abstract

Objectives: This cross-sectional study aimed to: (1) **evaluate pre- and in-hospital mortality** for moderate-to-severe TBI in the U.S. by injury type (blunt vs. penetrating) and (2) estimate annual regression-adjusted mortality over a seven-year period.

Methods: Data were analyzed from the National Trauma Data Bank (2008-2014; N=247,648). Multivariable logistic regression analyses were performed by injury type to assess **changes in mortality** between study periods (early period: 2008-2010; late period: 2011-2014) and to estimate annual regression-adjusted mortality. Mortality odds ratios and 95% confidence intervals were calculated.

Results: The total observed mortality was 18.8%. After adjusting for covariates, patients in the late period had an increased odds of prehospital mortality compared to patients in the early period for blunt **(OR: 4.69; 95%CI: 4.41-4.98)** and penetrating trauma **(OR: 4.71; 95%CI: 4.39-5.06)**. In contrast, patients in the late period had a decreased odds of in-hospital mortality compared to patients in the early period for both blunt **(OR: 0.95; 95%CI: 0.91-0.98)** and penetrating trauma **(OR: 0.92; 95%CI: 0.85-0.98)**.

Conclusions: The decreasing in-hospital mortality trend is consistent with previous literature. Additional research is warranted to validate the observed increase in prehospital mortality and to identify best practices that can improve **prehospital** outcomes for patients with moderate-to-severe TBI.

Keywords: Traumatic brain injury, mortality, National Trauma Data Bank, blunt and penetrating trauma

Introduction

A traumatic brain injury (TBI) is caused by an external force to the head that disturbs the functionality of the brain (1,2). In 2014, there were over 2.8 million TBI-related emergency department visits, hospitalizations, and deaths in the United States (U.S.) (1). Often classified by the nature of the injury (e.g. blunt or penetrating trauma), each TBI may differ by its epidemiologic characteristics and prognostic outcomes, which require different treatments (3,4). Blunt TBI (i.e. closed wound) results from the impact of a blunt object or surface to the head and accounts for more than 85% of all TBI diagnoses (4). In contrast, penetrating TBI (i.e. open wound) is caused by the piercing of the head by an external object and accounts for approximately 10-15% TBI cases (5). Although less common, penetrating TBIs often have worse prognoses, including an increased risk of mortality (4–6).

In the U.S., TBI accounts for 30% of all injury-related deaths and results in over 50,000 deaths each year (7–9). From 2006 to 2014, age-adjusted TBI mortality rates decreased by 6% among the U.S. population (17.9 to 16.8 per 100,000 population); yet the rate of fatalities due to intentional self-harm and unintentional falls increased during the same period (1). In addition, recent estimates also indicate that less than a quarter of U.S. states have TBI mortality rates at or below the national Healthy People 2020 target of 15.7 per 100,000 population (10). Furthermore, current national TBI mortality estimates **are not stratified** by injury type (blunt vs. penetrating) or severity — another significant predictor of TBI mortality (1,4).

Injury severity, classified as mild, moderate, or severe, is determined by a patient's level of consciousness, neurological deficits, post-traumatic amnesia, and/or structural brain imaging after sustaining a TBI (11). Approximately 80% of all TBI are considered to be mild, also known as concussions, and are commonly caused by blunt trauma (12,13). Although mild TBI are less likely to result in prolonged health outcomes compared to more severe cases, long-term sequelae are possible at all levels of severity (14). Patients with moderate-to-severe TBI are likely to result in more debilitating and potentially life-long health consequences, such as poor cognitive, motor, sensation, and behavioral outcomes, in addition to an increased risk of mortality (12,14). Prior evidence has shown high mortality among patients with penetrating trauma due to their greater severity, which may be attributed to the severe impact of direct trauma to surrounding brain tissue (6). The highest case fatality rates for penetrating TBI result from intentional self-harm (83%) and gunshot wounds (61%) (4). Consequently, this provides a limited timeframe to effectively treat penetrating TBI and increases the likelihood of prehospital mortality (4).

With 85% of TBI mortality cases occurring in the first two weeks of injury, adequate critical and acute management is essential (15,16). The primary goal of the prehospital management of moderate-to-severe TBI is to provide critical care to stabilize the patient and prevent the onset of secondary neurological complications caused by the initial TBI (17). To this end, national guidelines have been developed to increase the likelihood of better patient outcomes by improving the field triage of injured patients as recommended by the Centers for Disease Control and Prevention (18) and the pre- and in-hospital management of severe TBI as recommended by the Brain Trauma Foundation (19). Prior evidence has demonstrated the potential effectiveness of these guidelines in reducing the risk of mortality among patients with TBIs of greater severity (20). Yet, few studies have explored **changes** in both pre- and in-hospital TBI mortality over time. Evaluating these **differences** can improve pre- and in-hospital care and prognoses for patients with a TBI, especially for those with more severe cases of trauma.

Thus, the objectives of the current study were to: (1) **evaluate pre- and in-hospital mortality** by injury type among a national sample of U.S. adults with moderate-to-severe TBI and (2) estimate annual regression-adjusted TBI mortality across a seven-year period. We hypothesized that there would be **differences in pre- and in-hospital mortality across study periods for patients with** blunt and penetrating TBI.

Materials and Methods

Data for this cross-sectional study were derived from admission years 2008-2014 of the National Trauma Data Bank (NTDB). The NTDB is the largest repository of trauma data in the U.S. In 2014, the database contained more than six million records voluntarily reported from 758 U.S. trauma centers (21). To be included in the NTDB, patients with trauma must have at least one injury diagnostic code from the International Classification of Diseases ninth or tenth revisions (ICD-9-CM: 800-959.9; ICD-10-CM: S00-S99, T07, T14, T20-T28, T30-T32, T79.A1-T79.A9). In addition, patients must have a hospital admission, patient inter-hospital transfer via emergency medical services (EMS) transport, or death resulting from the traumatic injury. Additional information regarding eligibility criteria for the NTDB can be found elsewhere (21).

Patients were eligible for the current study if they: (1) had a moderate-to-severe TBI diagnosis resulting from blunt or penetrating trauma and (2) were 16 years of age or older. A TBI diagnosis was based on the following ICD-9 codes: 800-801.99, 803.0-804.99, 850.0-854.19, 950.1-950.3, and 959.01 (1). Injury type (blunt or penetrating) was determined by the nature of trauma resulting in the TBI as reported in the NTDB. Injury severity was defined by each patient's initial Glasgow Coma Scale (GCS) total score(22), as reported by EMS or at initial emergency department (ED) admission. GCS scores between 3 and 8 (severe TBI) and between 9 and 12 (moderate TBI) were used to determine the severity of the injury. A total of 297,264 patients with moderate-to-severe TBI met these criteria during the study period. Of these eligible patients, individuals were excluded if information regarding both pre- and in-hospital mortality (n=49,616) were missing. Our final sample included 247,648 patients.

Study Measures

The primary outcomes of interest were pre- and in-hospital mortality. Prehospital mortality (Yes or No) was defined as having no signs of life or being declared dead upon arrival to the ED. In-hospital mortality (Yes or No) was defined as having a discharge disposition of "died" or "expired" among patients who presented to the ED alive (21). The primary exposure of interest was the time period of admission, including both individual years (2008 to 2014) and a dichotomized study period variable (early period: 2008-2010 or late period: 2011-2014**). A dichotomized study year variable was constructed to limit the potential for measurement bias that may have occurred performing a traditional linear trend analysis. This was due to differences in how prehospital mortality was measured between observed study years (2008-2010 and 2011-2014) and was categorized based on prior literature (23).**

Additional patient demographic, vital sign, in-hospital, and injury characteristics were assessed as covariates. We included the minimum set of covariates recommended for adjusted trauma mortality outcome analysis using the NTDB (i.e. age, hypotension, pulse rate, GCS score, injury severity score (ISS), and need for ventilator use)(24,25). Demographic characteristics included age (16-24, 25-34, 35-44, 45-54, 55-64, 65 and older), sex (Male or Female), race/ethnicity (White, Black, Hispanic, or Other), and insurance status (Medicaid, Medicare, Private, Self-Pay, or Other). Patient vitals included EMS and ED hypotension (systolic blood pressure < 90 mmHg; Yes or No), EMS and ED pulse [Pulseless (0 bpm), Bradycardia (≤60 bpm), Normal (61-99 bpm) or Tachycardia (≥100 bpm)], and need for ventilator use (Yes or No).

The need for ventilator use was determined by any reported use of ventilation in the ED/hospital. Injury characteristics included cause of injury (Motor Vehicle Crash, Fall, Firearm, Stab, Other), total GCS score (3-4, 5-8, 9-12), and injury severity score (ISS) reported in the ED (Mild: 1-8; Moderate: 9-15; Severe: $\geq$ 16) (26). **Lastly, transfer status was considered due to the likely increased injury severity among patients who are directly transported to a trauma center from the scene of injury compared to patients who are first stabilized and transported from another facility (27).** Transfer status (Yes or No) was defined as whether a patient was reported as an inter-hospital transfer upon arrival to the ED (25). Employing the "missing indicator method," missing data from any variable was classified as its own category within the corresponding variable (Unknown) and included in the analysis (28).

Descriptive statistics were used to assess participant baseline characteristics. Frequencies and percentages were calculated to present the distribution of characteristics by injury type. Patients who died during the prehospital period were excluded from the in-hospital mortality analyses. Multivariate logistic regression analyses were performed separately for pre- and in-hospital mortality to estimate crude and adjusted mortality odds ratios (OR) and 95% confidence intervals (95% CI) for each injury type. Crude estimates were used to examine potential associations between study covariates and each mortality type. Regression models assessing prehospital mortality accounted for all study covariates except for ventilator use and ISS as information for these variables were only collected after ED/hospital admission. When assessing in-hospital mortality, the regression model for blunt TBI accounted for all covariates; however, the regression model for penetrating TBI accounted for all covariates except ISS due to its significant negative correlation with the patient's total GCS scores.

Annual regression-adjusted pre- and in-hospital TBI mortality were estimated separately by injury type. These analyses were performed by calculating the predicted probabilities of pre- and in-hospital mortality for each individual after performing a logistic regression model controlling for the aforementioned minimum set of covariates for trauma mortality (24). The average probability of pre- and in-hospital mortality for each study year was then calculated to assess annual regression-adjusted mortality from 2008-2014. All data analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC).

Results

Table 1 displays characteristics of the study sample by **pre- and in-hospital mortality**. Of the 247,648 eligible patients with moderate-to-severe TBI, 40.3% were admitted during the early period (2008-2010) and 59.7% were admitted in the late period (2011-2014). The overall observed mortality among the sample population was 18.8%. Observed prehospital mortality among the sample population was 6.5% compared to 12.3% for in-hospital mortality.

Participants aged 65 years and older accounted for 28.4% of the sample population. The remainder of participants were between the ages of 16-24 (17.0%), 25-34 (15.1%), 35-44 (12.5%), 45-54 (14.6%) and 55-64 (12.4%). The majority of participants were male (64.3%) and non-Hispanic White (**65.5 %**). **Among participants representing racial/ethnic minority groups, Black and Hispanic participants comprised 14.2% and 12.0% of the study population, respectively. Participants representing other racial groups comprised 5.5% of the population.** Almost a quarter of the sample had private insurance (24.5%), which was closely followed by Medicare (23.0%), other insurance (17.7%), self-pay (15.9%), and Medicaid (10.4%).

Eighty-six percent of participants sustained injuries resulting from blunt trauma, while the remaining 13.9% sustained injuries resulting from penetrating trauma. Approximately 64% and 36% of participants had a severe (GCS 3-8) or moderate TBI, respectively. The causes of injury in our sample included motor vehicle crashes (45.4%), falls (27.7%), gunshot wounds (11.0%), stabbings (2.9%) and other causes (13.0%). Among patients who arrived to the hospital alive, 54.9% had a severe ISS.

More than a quarter of participants had prehospital hypotension (27.6%) and 15.7% had in-hospital hypotension. Based on prehospital vitals, over half of participants were pulseless (7.7%) or had abnormal pulse rates (bradycardia: 8.2%; tachycardia: 38.3%). The remainder of participants had normal (40.5%) or unknown (5.4%) pulse rates. Similar pulse rates were observed in the hospital setting, with over half of participants being pulseless (5.5%) or having abnormal pulse rates (bradycardia: 5.5%; tachycardia: 41.2%). The rest of participants had normal (46.0%) and unknown (1.8%) in-hospital pulse rates. In addition, approximately 14% of patients needed to use a ventilator after being admitted to the ED. Eleven percent of patients were inter-hospital transfers upon arrival to the ED.

Table 2 presents results of the multivariable logistic regression analyses by injury and mortality type. Crude analyses displayed significant associations between the study period and pre- and in-hospital mortality for blunt and penetrating TBI. Compared to the early study period (2008-2010), the odds of prehospital mortality was significantly higher during the late period (2011-2014) for both blunt (OR: 3.10; 95% CI: 2.94-3.27) and penetrating trauma (OR: 3.04; 95% CI: 2.86- 3.23). However, the odds of in-hospital mortality during the same late period was significantly lower for blunt (OR: 0.73; 95% CI: 0.71-0.75) and penetrating trauma (OR: 0.61; 95% CI: 0.58- 0.64). All covariates were significantly associated with pre- and in-hospital mortality for both injury types, except for sex. Sex was not significantly associated with blunt prehospital mortality.

After adjusting for study covariates, the mortality trends observed in the crude analysis persisted. Prehospital mortality was significantly higher in the late period compared to the early period for both blunt (**OR: 4.69, 95% CI: 4.41-4.98**) and penetrating (**OR: 4.71; 95% CI: 4.39 - 5.06**) injuries. In contrast, in-hospital mortality was significantly lower in the late period compared to the early period for patients with blunt (**OR: 0.95, 95% CI: 0.91-0.98**) and penetrating (**OR: 0.92; 95% CI: 0.85-0.98**) TBI. Moreover, these trends were substantiated by the annual regression-adjusted pre- and in-hospital mortality estimates displayed in Figure 1, which exhibit the same increasing and decreasing pre- and in- hospital mortality trends for both injury types.

Consistent with results from the crude analyses, having a more severe TBI (GCS scores 3-8), hypotension, or abnormal pulses (i.e. pulseless, bradycardia, and unknown pulse status) were all significantly associated with increased pre- and in-hospital mortality, regardless of injury type. Higher or unknown ISS was significantly associated with increased in-hospital mortality for patients with blunt TBI. Injuries resulting from motor vehicle crashes and gunshot wounds were significantly associated with pre- and in-hospital mortality for patients with blunt and penetrating TBI, respectively. **Moreover, racial/ethnic minority patients (i.e. Black, Hispanic, and Other Races) exhibited increased odds of prehospital mortality compared to their White counterparts**. Patient age was also an independent risk factor for in-hospital mortality, as older age exhibited a significant association with increased mortality for both injury types. Ventilator use was significantly associated with increased in-hospital mortality for blunt and penetrating trauma. Conversely, inter-hospital transfer status was significantly associated with decreasing in-hospital mortality for both injury types.

Discussion

Using data from the NTDB, this study assessed pre- and in-hospital mortality trends for blunt and penetrating trauma among a national sample of U.S. adults with moderate-to-severe TBI. Between 2008 and 2014, the overall observed mortality was 18.8% (6.5% prehospital mortality and 12.3% in-hospital mortality). Similar pre- and in-hospital mortality trends were observed for both injury types. After adjusting for demographics, vital signs, and injury characteristics, prehospital mortality was more than four times as likely to occur in the late period (2011-2014) compared to the early period (2008-2010) for both injury types. In contrast, in-hospital mortality was 5.0% and **8.0%** less likely in the late period compared to the early period for blunt and penetrating trauma, respectively.

This is one of the first studies to **examine changes in** national prehospital TBI mortality **over time** for adults in the U.S. **One prior analysis of the NTDB database from 2007-2014 also revealed an increasing prehospital mortality trend among patients with injuries in all anatomical regions** (23). Yet this study only included patients with penetrating injuries caused by firearms or stabbings in the database and was not specific to **patients with moderate-to-severe TBI**. Through the investigation of prehospital TBI mortality, the current study was able to highlight a worrisome trend in need of further research to identify factors that have contributed to the increase of prehospital TBI mortality in most recent years.

The findings of this study also strengthen the existing body of in-hospital TBI mortality research by corroborating the results of previous national and state-based trauma registry reports in the U.S. (1,9,16,29–31). Although study samples, time periods, and analytic approaches may vary, a consistent overall decline of TBI-related in-hospital mortality has been well documented. National surveillance reports in the U.S. revealed decreases in age-adjusted TBI mortality between 2006-2014, despite an increase in the overall number of TBI-related deaths during the same time period (1,9). This was also previously displayed in individual state-based studies that were conducted in California (29), New York (16), Ohio (30), and Pennsylvania (31). However, all prior studies did not account for the recommended minimum set of covariates to adequately assess for trauma mortality, which can aid in enhancing study comparisons of trauma outcomes (25). In addition, the majority of these studies did not differentiate mortality by injury severity or focus on patients with severe TBI, despite the increased risk of mortality among cases with more severe TBI (14).

In the current study, prehospital mortality for patients with blunt TBI gradually increased over time, whereas mortality among patients with penetrating TBI spiked between 2010 (11.7%) and 2011 (23.5%) as shown in Figure 1. The overall observed increase in prehospital TBI mortality could be due to several reasons. One plausible explanation could be the potential increase of patients sustaining more severe injuries over time as suggested in the prior literature (23). This is an important consideration as the effective treatment window for patients with severe TBI is limited (4). Another potential explanation could be the insufficient recognition and treatment of TBI by prehospital care providers. A prior study showed that EMS providers could not accurately identify 21% of patients with severe head injuries (32), while others reported that 20-37% of patients with brain injury were undertriaged by EMS personnel (27,33,34).

Moreover, the increase in prehospital mortality could be due to ineffective care management employed in the prehospital environment. Current prehospital interventions for brain injury primarily focus on cardiopulmonary stabilization and the prevention of a secondary brain injury resulting from the initial TBI (17,35). Yet, research regarding the effectiveness of these management strategies is inconsistent. While past researchers have demonstrated success with restricted volume therapy for hemodynamically unstable trauma patients, more recent studies reported that increased volume administration either provided no significant improvement or contributed to adverse outcomes in patients with severe TBI (36,37). Further, the initiation of prehospital interventions could delay patient arrival at the hospital (38) and a previous study suggested that the time taken to perform these interventions may not be worth delaying definitive care (39).

Another factor that potentially contributed to the steady incline of prehospital blunt TBI mortality might have been the release of the 2011 Guidelines for Field Triage of Injured Patients. Initially developed by the American College of Surgeons in 1986, these guidelines were created to help EMS professionals determine the most appropriate destination facility within the local trauma care system (40). Additions to the 2011 guidelines expanded the criteria for direct transport to a trauma center, increasing inclusion to patients in need of ventilator support and those with head injury at high risk for rapid deterioration (41). This may have led to an increase in the number of dire blunt injuries directly transported to trauma centers.

In contrast to blunt injuries, the release of revisions to the field triage guidelines cannot be used to explain the increase in penetrating TBI mortality, as expedited transport to a trauma center for patients with penetrating head injuries has been recommended by field triage protocols since 1987 (42). Additionally, the results of previous studies confirmed that patients with penetrating injuries are far more likely to be directly transported to a trauma center and are less likely to be undertriaged as compared to individuals with blunt injuries (27,43). Further, fatality rates due to penetrating mechanisms (e.g., firearms) are not likely associated with a state's distribution of trauma facilities as the resulting injuries often concentrate in urban areas with accessible trauma centers (44). Thus, as triage for penetrating head injuries has not changed, the increase in prehospital mortality from penetrating TBI is more likely due to the increased incidence and severity of penetrating injuries in the U.S. and warrants further investigation (23).

Findings from the current study also illustrated improved in-hospital mortality for both injury types over the seven-year period. **This overall decrease** may be attributed to the effective implementation of in-hospital, acute management protocols. Multiple research studies have indicated that improved odds of patient survival were associated with adherence of the recommended management protocols in various settings (45–49). The Brain Trauma Foundation's Guidelines for the Management of Severe Traumatic Brain Injury has provided evidence-based recommendations for practice since 1995 (19,50). In particular, the revised 2007 guidelines included six additional topics based on interventions deemed to be effective in improving outcomes and revised recommendation levels to improve the operationalization of guidelines (50). The development and implementation of protocols based on these guidelines, at various compliance levels, have been associated with reductions in TBI mortality and related medical costs in the U.S. (16,46,48,49).

The current study has several strengths. In particular, this study specifically focused on moderate-to-severe TBI to emphasize the burden of mortality among patients at highest risk of death. In addition, **the examination of prehospital TBI mortality** among U.S. adults adds to the current literature, as this topic is currently underinvestigated. Moreover, this study benefited from the rich information contained in the NTDB. The large sample size enabled **investigators to assess mortality** over a seven-year period, which is useful to inform acute care planning and management strategies for blunt and penetrating trauma.

However, several limitations should also be acknowledged when interpreting results. As the NTDB only contains data voluntarily provided from U.S. trauma centers, our study population may not be representative of all patients with moderate-to-severe TBI in the U.S. In addition, patients who did not have GCS scores reported by EMS or ED personnel were not included in the current study, which may have resulted in biased estimates of pre- and in-hospital mortality. It is also important to note that causality cannot be inferred due to the cross-sectional nature of this study. **Further, the time between injury event to arrival in the emergency department was not accounted for in this analysis due to the high percentage of missing among the eligible study sample (>10%), but is an important consideration for future analyses with more complete data on this factor.** Finally, the presence or absence of multi-system trauma varied among patients in our sample. Therefore, it is unclear if TBI was a direct or indirect cause of mortality among patients. Despite these limitations, our study findings provide new insights into pre- and in-hospital mortality for patients with moderate-to-severe TBI using contemporary data.

Assessing moderate-to-severe TBI mortality in the U.S. across various transitions of care (i.e. from the scene of injury through hospital discharge) is an important step toward identifying effective solutions needed to reduce the overall burden of mortality among U.S. trauma patients. Additional research is recommended to investigate the **observed increase in** prehospital mortality among individuals with moderate-to-severe TBI. In addition to developing effective prehospital interventions, there should be a focus on educational efforts among EMS personnel to increase the recognition of brain injury, ensure adherence to triage criteria, and encourage mastery of skills to facilitate the expedited treatment and transport of **patients with TBI**. Nonetheless, the **decrease in** in-hospital mortality **across the observed study periods coincides** with the implementation of standardized protocols and likely reflects overall improvements in trauma care over time.

Declaration of Interest Statement

The authors report no conflicts of interest.

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Table 1. Patients with Moderate-to-Severe Traumatic Brain Injuries: Sample Characteristics by Mortality Type, National Trauma Data Bank (2008-2014)

Characteristics	Prehospital		In-Hospital[a]	
	Total Population N= 247,648 n (%)	**Mortality n=16,093** n (%)	**Total Population N= 231,555** n (%)	**Mortality n=28,563** n (%)
Study Period				
2008-2010	99,689 (40.3)	3,232 (20.1)	96,457 (41.7)	14,316 (50.1)
2011-2014	147,959 (59.7)	12,861 (79.9)	135,098 (58.3)	14,247 (49.9)
DEMOGRAPHICS				
Age				
16-24	42,154 (17.0)	2,997 (18.6)	39,157 (16.9)	4,669 (16.4)
25-34	37,333 (15.1)	2,657 (16.5)	34,676 (15.0)	4,162 (14.6)
35-44	31,010 (12.5)	2,011 (12.5)	28,999 (12.5)	3,483 (12.2)
45-54	36,103 (14.6)	2,355 (14.6)	33,748 (14.6)	3,830 (13.4)
55-64	30,628 (12.4)	1,942 (12.1)	28,686 (12.4)	3,407 (11.9)
65 and older	70,420 (28.4)	4,131 (25.7)	66,289 (28.6)	9,012 (31.6)
Sex				
Male	159,290 (64.3)	10,681 (66.4)	148,609 (64.2)	19,003 (66.5)
Female	88,262 (35.6)	5,404 (33.6)	82,858 (35.8)	9,546 (33.4)
Unknown	96 (0.04)	8 (0.05)	88 (0.04)	14 (0.05)
Race/Ethnicity				
White	168,075 (67.9)	9,978 (62.0)	158,097 (68.3)	18,765 (65.7)
Black/African-American	35,296 (14.3)	3,115 (19.4)	32,181 (13.9)	4,620 (16.2)
Hispanic	23,641 (9.6)	418 (2.6)	6,157 (2.7)	729 (2.6)
Other	6,575 (2.7)	1,715 (10.7)	21,926 (9.5)	2,762 (9.7)
Unknown	14,061 (5.7)	867 (5.4)	13,194 (5.7)	1,687 (5.9)
Payer				
Medicaid	25,689 (10.4)	1,855 (11.5)	23,834 (10.3)	2,607 (9.1)
Medicare	56,864 (23.0)	3,416 (21.2)	53,448 (23.1)	6,945 (24.3)
Private	60,622 (24.5)	3,744 (23.3)	56,878 (24.6)	6,035 (21.1)
Self-Pay	39,344 (15.9)	3,057 (19.0)	36,287 (15.7)	5,095 (17.8)
Other	43,825 (17.7)	2,753 (17.1)	41,072 (17.7)	4,629 (16.2)
Unknown	21,304 (8.6)	1,268 (7.9)	20,036 (8.6)	3,252 (11.4)
INJURY CHARACTERISTICS				
Injury Trauma Type				
Blunt	213,280 (86.1)	8,955 (55.6)	204,325 (88.2)	19,611 (68.7)
Penetrating	34,368 (13.9)	7,138 (44.4)	27,230 (11.8)	8,952 (31.3)
Glasgow Coma Scale (GCS) Score				
3-4	106,556 (43.0)	14,747 (91.6)	91,809 (39.6)	20,659 (72.3)
5-8	51,613 (20.8)	724 (4.5)	50,889 (22.0)	3,458 (12.1)
9-12	89,479 (36.1)	622 (3.9)	88,857 (38.4)	4,446 (15.6)

Mean (SD)	6.6 (3.5)	3.5 (1.6)	6.8 (3.5)	4.7 (2.9)
Injury Mechanism				
Motor Vehicle Accidents	112,429 (45.4)	6,911 (42.9)	67,519 (29.2)	12,660 (44.3)
Fall	68,586 (27.7)	1,067 (6.6)	105,518 (45.6)	4,595 (16.1)
Cut/Pierce	7,240 (2.9)	827 (5.1)	6,413 (2.8)	1,119 (3.9)
Firearm	27,121 (11.0)	6,311 (39.2)	20,810 (8.9)	7,833 (27.4)
Other	32,272 (13.0)	977 (6.1)	31,295 (13.5)	2,356 (8.3)
Injury Severity Score (ISS) [a]				
Mild (1-8)	-	-	48,422 (20.9)	4,045 (14.2)
Moderate (9-15)	-	-	42,555 (18.4)	3,914 (13.7)
Severe (16-75)	-	-	127,151 (54.9)	18,364 (64.3)
Unknown	-	-	13,427 (5.8)	2,240 (7.8)
PREHOSPITAL VITAL SIGNS				
Hypotension (EMS)				
Yes	68,267 (27.6)	13,685 (85.0)	54,582 (23.6)	16,524 (57.8)
No	179,381 (72.4)	2,408 (15.0)	176,973 (76.4)	12,039 (42.2)
Pulse (EMS)				
Pulseless	18,965 (7.7)	8,652 (53.8)	10,313 (4.5)	7,387 (25.9)
Bradycardia	20,273 (8.2)	2,194 (13.6)	18,079 (7.8)	3,484 (12.2)
Normal	100,282 (40.5)	1,771 (11.0)	98,511 (42.5)	7.095 (24.8)
Tachycardia	94,772 (38.3)	2,166 (13.5)	92,606 (40.0)	8,265 (28.9)
Unknown	13,356 (5.4)	1,310 (8.1)	12,046 (5.2)	2,332 (8.2)
IN-HOSPITAL VITAL SIGNS AND CHARACTERISTICS[a]				
Hypotension (ED)				
Yes	-	-	36,277 (15.7)	16,319 (57.1)
No	-	-	195,278 (84.3)	12,244 (42.9)
Pulse (ED)				
Pulseless	-	-	12,700 (5.5)	10,910 (38.2)
Bradycardia	-	-	12,829 (5.5)	1,878 (6.6)
Normal	-	-	106,479 (46.0)	6,569 (23.0)
Tachycardia	-	-	95,276 (41.2)	7,214 (25.3)
Unknown	-	-	4,271 (1.8)	1,992 (7.0)
Need for Ventilator Use				
Yes	-	-	31,402 (13.6)	8,308 (29.1)
No	-	-	200,153 (86.4)	20,255 (70.9)
Transfer Status				
Yes	-	-	25,673 (11.1)	1,940 (6.8)
No	-	-	205,882 (88.9)	26,623 (93.2)

TBI=Traumatic Brain Injury; EMS=Emergency Medical Services; ED=Emergency Department
[a] Frequencies only include patients that presented to the ED/hospital alive (N=231,555)

Table 2. Crude and Adjusted Pre- and In-Hospital Mortality Odds Ratios for Patients with Blunt and Penetrating TBI

Characteristics	Crude and Adjusted Odds Ratios and 95% Confidence Intervals							
	Pre-Hospital Mortality				In-Hospital Mortality			
	Blunt		Penetrating		Blunt		Penetrating	
	Crude	Adjusted[a]	Crude	Adjusted[b]	Crude	Adjusted[a]	Crude	Adjusted[c]
Study Period								
2008-2010	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
2011-2014	3.10 (2.94, 3.27)*	4.70 (4.42, 5.00)*	3.04 (2.86, 3.23)*	4.72 (4.40, 5.07)*	0.73 (0.71, 0.75)*	0.95 (0.91, 0.98)*	0.61 (0.58, 0.64)*	0.91 (0.85, 0.98)*
Age								
16-24	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
25-34	1.03 (0.96, 1.10)	0.99 (0.91, 1.08)	0.96 (0.88, 1.05)	0.94 (0.85, 1.05)	1.02 (0.97, 1.08)*	0.98 (0.91, 1.05)	0.97 (0.89, 1.05)	0.97 (0.86, 1.09)
35-44	0.91 (0.84, 0.98)*	0.92 (0.84, 1.01)	0.89 (0.81, 0.97)*	0.92 (0.82, 1.03)	0.99 (0.93, 1.05)*	0.99 (0.92, 1.06)	1.04 (0.95, 1.13)	1.08 (0.95, 1.22)
45-54	0.93 (0.87, 1.01)	0.95 (0.87, 1.04)	0.95 (0.87, 1.04)	0.98 (0.88, 1.10)	0.99 (0.94, 1.05)	1.03 (0.96, 1.11)	0.90 (0.82, 0.98)*	0.91 (0.81, 1.03)
55-64	0.88 (0.81, 0.95)*	0.88 (0.80, 0.96)*	0.97 (0.88, 1.07)	0.95 (0.85, 1.07)	1.08 (1.02, 1.14)*	1.27 (1.19, 1.37)*	0.88 (0.80, 0.97)*	0.97 (0.85, 1.10)
≥ 65	0.87 (0.82, 0.93)*	0.87 (0.79, 0.95)*	0.87 (0.81, 0.95)*	0.95 (0.84, 1.07)	1.35 (1.29, 1.41)*	1.91 (1.78, 2.04)*	0.92 (0.85, 0.99)*	1.28 (1.12, 1.46)*
Sex								
Female	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Male	1.04 (1.00, 1.09)	1.01 (0.95, 1.06)	1.10 (1.04, 1.17)*	1.07 (0.99, 1.14)	1.11 (1.07, 1.14)*	1.09 (1.05, 1.14)*	1.11 (1.06, 1.18)*	1.07 (0.99, 1.15)
Unknown	1.90 (0.83, 4.37)	1.03 (0.34, 3.07)	0.58 (0.13, 2.57)	0.67 (0.12, 3.57)	1.22 (0.58, 2.54)*	1.54 (0.67, 3.51)	1.65 (0.57, 4.75)	1.01 (0.25, 4.15)
Race/Ethnicity								
White	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Black/AA	1.25 (1.18, 1.33)*	1.20 (1.11, 1.29)*	1.41 (1.32, 1.50)*	1.17 (1.08, 1.27)	1.03 (0.99, 1.08)	1.06 (1.00, 1.12)	1.42 (1.33, 1.51)*	1.09 (0.99, 1.19)
Hispanic	1.16 (1.08, 1.24)*	1.21 (1.11, 1.32)*	1.12 (1.03, 1.22)*	1.11 (1.00, 1.24)	0.98 (0.93, 1.03)	0.96 (0.90, 1.03)	1.09 (1.00, 1.18)*	0.92 (0.82, 1.04)
Other	1.00 (0.87, 1.14)	0.99 (0.85, 1.17)	1.14 (0.97, 1.34)	1.05 (0.86, 1.29)	0.98 (0.89, 1.07)	1.05 (0.94, 1.18)	1.01 (0.86, 1.19)	1.18 (0.95, 1.47)
Unknown	1.03 (0.94, 1.13)	1.08 (0.97, 1.21)	1.11 (0.98, 1.25)	1.13 (0.98, 1.31)	1.08 (1.02, 1.15)*	1.06 (0.98, 1.14)	1.21 (1.07, 1.36)*	1.18 (0.95, 1.47)
Insurance Status								

Private	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Medicaid	1.09 (1.01, 1.18)*	0.97 (0.88, 1.06)	1.21 (1.11, 1.33)*	1.04 (0.93, 1.16)	1.01 (0.96, 1.08)	0.93 (0.87, 1.00)	1.01 (0.92, 1.12)	0.92 (0.81, 1.05)
Medicare	1.01 (0.95, 1.07)	1.00 (0.91, 1.09)	0.98 (0.90, 1.06)	0.96 (0.86, 1.08)	1.38 (1.32, 1.44)*	1.20 (1.13, 1.28)*	1.03 (0.96, 1.12)	1.04 (0.92, 1.18)
Self-Pay	1.25 (1.17, 1.34)*	1.07 (0.98, 1.16)	1.11 (1.02, 1.20)*	1.02 (0.93, 1.13)	1.33 (1.27, 1.40)*	1.33 (1.25, 1.41)*	1.28 (1.18, 1.39)*	1.17 (1.05, 1.31)*
Other	1.05 (0.98, 1.12)	0.96 (0.88, 1.04)	0.99 (0.91, 1.08)	0.95 (0.86, 1.05)	1.09 (1.04, 1.15)*	1.07 (1.01, 1.13)*	1.03 (0.94, 1.11)	1.01 (0.90, 1.13)
Unknown	0.93 (0.85, 1.02)	0.91 (0.82, 1.01)	0.84 (0.76, 0.93)*	0.67 (0.59, 0.75)*	1.51 (1.42, 1.59)*	1.28 (1.19, 1.37)*	1.83 (1.66, 2.00)*	1.25 (1.10, 1.43)*
Hypotension								
No	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Yes	17.30 (16.38, 18.26)*	4.73 (4.42, 5.07)*	8.76 (8.09, 9.49)*	3.61 (3.28, 3.97)*	10.35 (10.01, 10.69)*	3.25 (3.09, 3.41)*	9.46 (8.92, 10.04)*	2.30 (2.13, 2.50)*
Pulse								
Normal	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Pulseless	56.35 (52.54, 60.43)*	8.91 (8.18, 9.70)*	12.60 (11.50, 13.82)*	5.67 (5.09, 6.33)*	102.46 (95.31, 110.15)*	39.97 (36.69, 43.54)*	39.05 (35.38, 43.11)*	15.62 (13.89, 17.57)*
Bradycardia	6.47 (5.95, 7.03)*	3.15 (2.88, 3.45)*	3.56 (3.20, 4.00)*	2.26 (2.01, 2.54)*	2.31 (2.17, 2.46)*	2.05 (1.92, 2.20)*	2.64 (2.35, 2.97)*	1.92 (1.70, 2.18)*
Tachycardia	1.32 (1.22, 1.43)*	0.96 (0.89, 1.05)	0.92 (0.83, 1.03)	0.90 (0.80, 1.01)	1.21 (1.16, 1.26)*	1.04 (1.00, 1.09)*	1.12 (1.03, 1.21)*	1.02 (0.94, 1.12)
Unknown	6.24 (5.68, 6.84)*	1.75 (1.58, 1.95)*	3.29 (2.90, 3.73)*	1.78 (1.55, 2.05)	10.20 (9.43, 11.03)*	5.75 (5.24, 6.31)*	14.18 (12.37, 16.26)*	7.30 (6.25, 8.52)*
Ventilator use								
No	-	-	-	-	Ref	Ref	Ref	Ref
Yes	-	-	-	-	4.14 (4.00, 4.28)*	7.57 (7.27, 7.87)*	1.50 (1.40, 1.61)*	2.38 (2.17, 2.61)*
Transfer Status								
No	-	-	-	-	Ref	Ref	Ref	Ref
Yes	-	-	-	-	0.68 (0.64, 0.72)*	0.78 (0.74, 0.83)*	0.30 (0.26, 0.34)*	0.56 (0.49, 0.64)*
GCS Score								
3-4	21.04 (19.07, 23.21)*	5.85 (5.27, 6.49)*	12.13 (10.50, 14.01)*	3.96 (3.40, 4.62)*	4.13 (3.98, 4.29)*	2.08 (1.99, 2.18)*	9.46 (8.60, 10.41)*	4.16 (3.72, 4.65)*
5-8	2.04 (1.79, 2.33)*	1.71 (1.50, 1.95)*	1.79 (1.48, 2.18)*	1.54 (1.26, 1.88)*	1.31 (1.25, 1.38)*	1.20 (1.14, 1.27)*	1.82 (1.61, 2.07)*	1.58 (1.37, 1.83)*
9-12	Ref	Ref	Ref	Ref	Ref	Ref	Ref	Ref
Injury Mechanism								
Fall	Ref	Ref	-	-	Ref	Ref	-	-

Motor Vehicle Crash	4.15 (3.88, 4.42)*	2.38 (2.21, 2.56)*	-	-	1.87 (1.80, 1.93)*	1.08 (1.03, 1.12)*	-	-
Firearm	-	-	2.35 (2.18, 2.54)*	1.55 (1.42, 1.71)*	-	-	2.86 (2.67, 3.07)*	2.10 (1.91, 2.31)*
Cut/Pierce^	-	-			-	-		
Other^	1.98 (1.81, 2.16)*	1.52 (1.37, 1.67)	Ref	Ref	1.12 (1.06, 1.17)*	0.84 (0.79, 0.89)*	Ref	Ref
ISS								
1-8	-	-	-	-	Ref	Ref	Ref	-
9-15	-	-	-	-	1.18 (1.12, 1.24)*	1.07 (1.01, 1.14)	0.82 (0.74, 0.90)*	-
16-75	-	-	-	-	1.77 (1.69, 1.84)*	1.09 (1.04, 1.15)	1.41 (1.30, 1.52)*	-
Unknown	-	-	-	-	2.07 (1.93, 2.21)*	1.27 (1.17, 1.39)*	1.81 (1.62, 2.04)*	-

TBI=Traumatic Brain Injury; GCS=Glasgow Coma Scale; ISS=Injury Severity Score
[a] Adjusted for age, sex, race/ethnicity, insurance status, GCS score, injury mechanism, EMS hypotension, EMS pulse
[b] Adjusted for age, sex, race/ethnicity, insurance status, ISS, GCS score, injury mechanism, ED hypotension, ED pulse, transfer status, and need for ventilator use
[c] Adjusted for age, sex, race/ethnicity, insurance status, GCS score, injury mechanism, ED hypotension, ED pulse, transfer status, and need for ventilator use
^Combined into one category Cut/pierce/Other) for penetrating trauma analysis
*Indicates statistical significance at p-value < 0.05

Figure 1

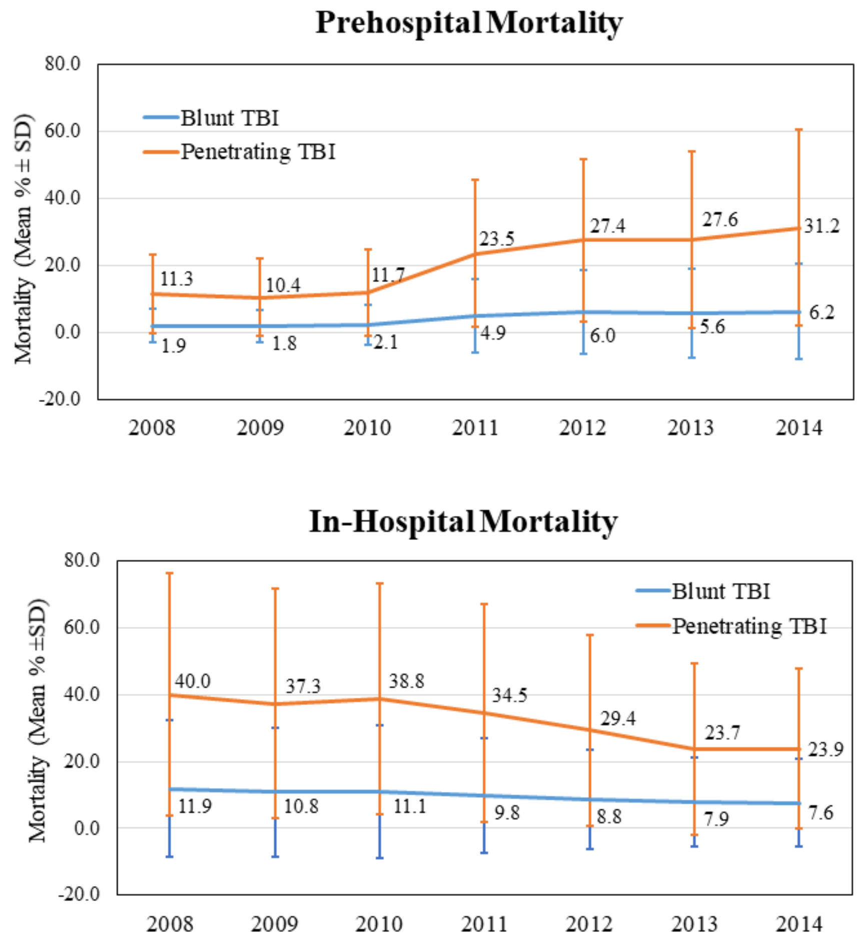

Figure 1. The above figure displays regression-adjusted annual pre- and in-hospital mortality estimates for patients with moderate-to-severe TBI between 2008-2014. Displayed estimates reflect the average percentage of mortality (mean %) and corresponding standard deviation (SD) for each study year.