The American Journal of Surgery 218 (2019) 255–260

Contents lists available at ScienceDirect

The American Journal of Surgery

journal homepage: www.americanjournalofsurgery.com

# Trends in civilian penetrating brain injury: A review of 26,871 patients

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A R T I C L E I N F O

*Article history:*
Received 7 May 2018
Received in revised form
2 November 2018
Accepted 15 November 2018

Quick Shot presentation at the 30th Annual Eastern Association for the Surgery of Trauma, January 9–13, 2018, Lake Buena Vista, Florida.

*Keywords:*
Penetrating injury
Traumatic brain injury
Gunshot
Trends

A B S T R A C T

*Introduction:* The aim of our study is to analyze the 5 years' trends, mortality rate, and factors that influence mortality after civilian penetrating traumatic brain injury (pTBI).
*Methods:* We performed a 5-year-analysis of all trauma patients diagnosed with pTBI in the TQIP. Our outcome measures were trends of pTBI.
*Results:* A total of 26,871 had penetrating brain injury over the 5-year period. Mean age was 36.2 ± 18 years. Overall 55% of the patients had severe TBI and mortality rate was 43.8%. There was an increase in the rate of pTBI from 3042/100,000 (2010) to 7578/100,000 trauma admissions (2014) ($p < 0.001$). The mortality rate has increased from 35% (2010) to 48% (2011) ($p < 0.001$) followed by a linear decrease in mortality to 40% (2014). Independent predictors of mortality were age, pre-hospital intubation, suicide attempt, and craniotomy/craniectomy.
*Conclusions:* Incidence and mortality for patients who are brought to hospitals following pTBI have gradually increased over the five-year period. Self-inflicted injury and prehospital intubation were the two most significant predictors of mortality.



## Introduction

A global health problem, traumatic brain injury (TBI) afflicts millions of people each year.[1] The most common mechanism of TBI is blunt trauma; motor vehicle crashes, falls, and assaults account for the majority of such cases in adults.[2–4] Penetrating TBI (pTBI) has a worse prognosis than blunt TBI, even though it less prevalent.[5] While decades' worth of research have led to numerous advances in the care of TBI patients (e.g., the 4th edition of the Brain Trauma Foundation's guidelines published in 2017), limited data on pTBI has resulted in insufficient guidelines regarding the treatment of pTBI patients.[6] The most recent guidelines for the management of pTBI were published, in 2001, by a task force made up of the International Brain Injury Association, the Brain Injury Association (USA), the American Association of Neurological Surgeons, and the Congress of Neurological Surgeons. In attempting to standardize both the medical and surgical management of pTBI,[7] these guidelines functioned as a paradigmatic shift away from aggressive debridement and toward more aggressive antibiotic prophylaxis to improve outcomes.[8]

Penetrating TBI is associated with high mortality, from a myriad of mechanisms. High-velocity missiles (e.g., firearms), which account for the majority of pTBI deaths, damage tissue through thermal and kinetic energy transfer.[9] Injuries due to lower velocity non-missiles damage tissue through laceration and maceration. While the mechanisms of non-missile pTBI are vast,[10] management strategies for such cases often focus almost exclusively on acute surgical and non-surgical pathways.[7,11] However, firearm-related violence is increasing in the United States (U.S.),[12] and suicides by firearms are on the rise.[13,14] This underscores the importance of incorporating other aspects of care in the management of these patients such as suicide prevention and comprehensive family resources. A relative paucity of data on integrating these aspects emphasizes the need for further investigation.

The lack of updated guidelines on pTBI management calls for an updated understanding of pTBI outcomes and predictors of

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https://doi.org/10.1016/j.amjsurg.2018.11.034
0002-9610/

mortality. In pursuit of this goal, we retrospectively evaluated the Trauma Quality Improvement Program (TQIP) database produced by the American College of Surgeons (ACS), one of the most extensively used national trauma databases. We aimed to analyze the predictors of mortality and evaluated trends, looking for ways to intervene and refine care along the spectrum of pTBI. We hypothesized that the incidence of pTBI has increased during the study period. Our hypothesis was based upon recent literature that shows an increase in gun violence among civilian trauma patients.[15]

## Methods

### *Study design and population*

We conducted a five-year (2010–2014) retrospective analysis of the TQIP database. We identified all adult patients who sustained TBI age ≥16 years, as defined by the International Classification of Disease-9th revision Clinical Modification (ICD-9-CM) procedure code 850–854 and a penetrating mechanism of injury. The TQIP database provides an opportunity for peer trauma centers to compare their processes of care- and risk-adjusted outcomes. Institutional Review Board (IRB) approval was not required for this study because the TQIP database contains only de-identified data. Although the ACS administers the program, the authors of this study are solely responsible for the analyses and conclusions presented here.

### *Inclusion and exclusion criteria*

We included all trauma patients aged ≥16 years who had a diagnosis of a TBI and a penetrating mechanism of injury.

### *Data points*

We retrieved the following data points from the TQIP database: demographics (age, gender, race and ethnicity); vitals on scene and presentation (heart rate [HR], systolic blood pressure [SBP], Glasgow Coma Scale [GCS], and temperature); injury severity score (ISS); abbreviated injury scale (AIS); hospital length of stay (LOS); mechanism of injury, including gunshot wounds (GSW) and other non-ballistic injury; physiologic data from the scene of injury via emergency medical service (EMS) and upon arrival to the emergency department (ED), including GCS and signs of life (SOL); and in-hospital mortality. "signs of life" were defined as organized EKG (electrocardiogram) activity, pupillary responses, spontaneous respiratory attempts or movement, or unassisted blood pressure.

### *Outcomes measures*

The primary outcome measures were trends in pTBI and in-hospital mortality. Secondary outcomes included predictors of in-hospital mortality as well as trends in mortality and operative procedures over the years.

### *Data analysis*

Missing data were treated as missing at random. Multiple imputations were performed using a missing value analysis technique to account for the missing values. This technique is used to reduce bias and increase the number of cases available. To impute the datasets, the original dataset was analyzed for random missing data points using Little's missing completely at random (MCAR) test. We used the Markov Chain Monte Carlo method for multiple imputations, that is, a collection of methods for simulating random draws from non-standard distributions.

Data are reported as mean ± SD for continuous parametric data, as median [IQR] for non-parametric data, and as the proportion for categorical data. The Mann-Whitney *U* test and the Student's t-test were performed to explore differences in the two groups concerning continuous variables. A chi-square test was performed to identify differences in categorical variables between the two groups. Sub-analysis was performed based on age and severity of TBI. Cochrane-Armitage trend analysis was performed to analyze the trends over the study period.

To assess the association between each variable and the binary outcomes, we performed a univariate analysis. Variables with a significant ($p < 0.2$) association on the univariate analysis were then used in a multivariate logistic regression model. On the multivariate logistic regression analysis, variables were considered significant at $p < 0.05$. The model fit was assessed by the Hosmer-Lemeshow test. In the logistic regression model, the Hosmer-Lemeshow test exceeded 0.05 and the tolerance was greater than 0.1 for all independent variables with a variance inflation factor of less than 10. To explore trends in outcomes for categorical variables, we used the Cochran-Armitage trend test with years as a covariate. For our study, a $p < 0.05$ was considered statistically significant. All statistical analyses were performed using the SPSS (version 24, SPSS, Inc., Chicago, IL).

## Results

Over the five year analysis, a total of 268,645 patients had TBI, and of these, 26,871 (10%) had pTBI. Table 1. Demonstrates the demographics and physiologic parameters of the study population. Mean age was 36.2 ± 18 years; 86.2% were males; 53.3% were white; and 10.1% were Hispanics. Median [IQR] on scene GCS was 6

**Table 1**
Demographics and physiological parameters.

| Characteristics | (n = 26871) |
|---|---|
| Age, y, (Mean ± SD) | 36.2 ± 18 |
| Males | 86.2% |
| **Race, %** | |
| White | 53.3% |
| African-American | 32.4% |
| Others | 14.3% |
| Hispanics | 10.2% |
| **Vital Parameters** | |
| **EMS** | |
| SBP, mean ± SD | 126 [100–146] |
| HR, mean ± SD | 92 [70–112] |
| GCS, median [IQR] | 6 [3–15] |
| **ED** | |
| SBP, mean ± SD | 128 [107–149] |
| HR, mean ± SD | 93 [73–114] |
| GCS, median [IQR] | 6 [3–15] |
| **Injury Severity and Pattern** | |
| ISS, median [IQR] | 21 [15–29] |
| ISS≥16, % (n) | 74.6% |
| **Mechanism of Injury, %** | |
| GSW | 98.6% |
| others | 1.4% |
| SOL, % (n) | 93.7% |
| Suicide attempt, % | 48.8% |
| **ED disposition, %** | |
| Died | 10% |
| OR | 19.5% |
| ICU | 70.5% |
| **Mortality rate, %** | 43.8% |

SD = Standard Deviation, IQR = Inter Quartile Range, EMS = Emergency Medical Service, SBP = Systolic Blood Pressure, HR = Heart Rate, ED = Emergency Department, SOL = Signs of Life, OR = Operating Room, ICU = Intensive Care Unit.

[3–15], and median on arrival to ED GCS was 6 [3–15]. Of the total patients, 25,178 (93.7%) patients presented to the ED with signs of life and 1693 (6.3%) were dead on arrival (DOA). Additionally, 2685 (10%) patients died in the ED, 17,750 (70.5%) were admitted to the ICU from ED and 4909 (19.5%) were sent to the OR. The overall mortality rate was 43.8%. Median ISS was 21 [15–29]. Most of the patients (98.6%) had gunshot wounds, and of these, 48.8% were self-inflicted.

The rate of pTBI admissions increased in 2010 from 3042/100,000 to 7578/100,000 in 2014 ($p < 0.001$). However, the mortality rate increased from 35% in 2010 to 48% in 2011 ($p < 0.001$), followed by a linear decrease in mortality to 40% in 2014 ($p < 0.001$). Fig. 1a. Demonstrates the trend of pTBI and mortality over the five-year study period.

Patients who survived were more likely to be younger ($p < 0.001$), African-American ($p < 0.001$) and Hispanic ethnicity ($p < 0.001$); have a higher scene SBP ($p < 0.001$), ED SBP ($p < 0.001$); as well as a higher scene GCS ($p < 0.001$) and ED GCS ($p < 0.001$). Moreover, they were less likely to sustain gunshot wounds ($p < 0.001$), or receive prehospital intubations ($p < 0.001$). Patients with suicide attempt were more likely to die compared to those without suicide attempt ($p < 0.001$). Furthermore, pre-hospital intubation was three times as common in the non-survivors group, but this is merely an obvious association given that the median GCS for the non-survivors group was 3 (as compared to the survivors group). Among patients in the non-survivor group, 22.8% died in the ED. Overall, highest mortality rate was seen on day 1 (29.5%, n = 7926) followed by day 2 (5.8%, n = 1558) and day 3 (2.8%, n = 752) in all pTBI patients. Of the overall mortality rate (i.e. 43.8%), 86.8% of deaths occurred within 72 h of injury. Demographics and injury parameters between the survivors and the non-survivors are summarized in Table 2.

After controlling for confounders, independent predictors of mortality were age (OR: 1.12), pre-hospital intubation (OR: 1.35), suicide attempt (OR: 1.45), and craniotomy/craniectomy (OR: 6.23). Other independent predictors were ISS and ED SBP (Table 3).

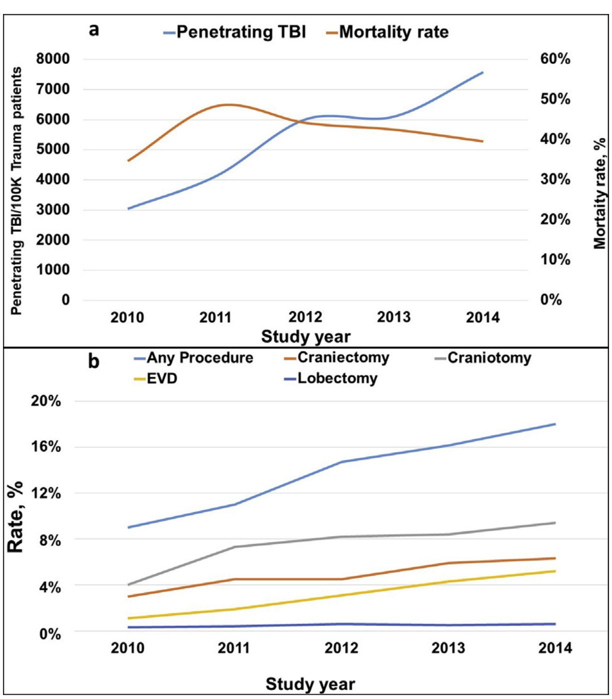


**Fig. 1.** a. Trends of penetrating TBI and mortality over the five-year study period. b. Trends of operative procedure over the five-year study period.

**Table 2**
Demographics information and Injury Characteristics.

| Characteristics | Survived (n = 15094) | Died (n = 11777) | *P* |
|---|---|---|---|
| Age, y, (Mean ± SD) | 34.7 ± 16 | 38.6 ± 21 | <0.001 |
| Males, % | 86.2% (13011) | 86.2% (10151) | 0.56 |
| **Race, %** | | | |
| White | 47.3% (7139) | 60.9% (7172) | <0.001 |
| African-American | 36.8% | 26.7% | |
| Others | 15.9% | 12.4% | |
| Hispanics | 11.7% (1766) | 8.2% (966) | <0.001 |
| **Vital Parameters** | | | |
| **EMS** | | | |
| SBP, mean ± SD | 130 [110–146] | 119 [88–147] | <0.001 |
| HR, mean ± SD | 93 [77–110] | 90 [61–118] | <0.001 |
| GCS, median [IQR] | 14 [10–15] | 3 [3-3] | <0.001 |
| **ED** | | | |
| SBP, mean ± SD | 134 [117–150] | 120 [85–146] | <0.001 |
| HR, mean ± SD | 93 [76–109] | 96 [68–121] | <0.001 |
| GCS, median [IQR] | 14 [3–15] | 3 [3-3] | <0.001 |
| **Mechanism of injury, %** | | | |
| GSW | 97.8% (14761) | 99.7% (11741) | <0.001 |
| Others | 2.2% (332) | 0.3% (35) | |
| **Injury Severity and Pattern** | | | |
| ISS, median [IQR] | 17 [13–25] | 25 [16–51] | |
| SOL, % (n) | 85.9% (12965) | 90.9% (10705) | <0.001 |
| Suicide attempt, % | 41.1% (6203) | 58.7% (6913) | <0.001 |
| Prehospital intubation, % | 8.5% (1282) | 24.3% (2862) | <0.001 |
| **ED disposition, %** | | | |
| Died | 0% (0) | 22.8% (2685) | <0.001 |
| OR | 27.3% | 9.7% | |
| ICU | 72.7% | 67.5% | |

SD = Standard Deviation, IQR = Inter Quartile Range, EMS = Emergency Medical Service, SBP = Systolic Blood Pressure, HR = Heart Rate, ED = Emergency Department, SOL = Signs of Life, CPR = Cardiopulmonary resuscitation, OR = Operating Room, ICU = Intensive Care Unit. Heart Rate, ISS = Injury Severity Score, AIS = Abbreviated Injury Score.

Overall, 14.42% of the patients underwent neurosurgical procedures. Craniotomy (7.6%) was the most common one, followed by craniectomy (4.9%). Overall, there was an increase in the operative intervention from 9% to 18% over the study period ($p < 0.001$) (Fig. 1b). Similar trends were observed for craniotomy, craniectomy, and external ventricular drain (EVD) placement, with the most significant one being the EVD placement (480% increase).

Overall, 55% of the patients had severe TBI, while 8% had moderate TBI. The highest rate of operative intervention was seen in patients with moderate TBI (28%), followed by mild TBI (13.8%). The mortality rate was highest in patients with severe TBI compared to moderate and mild TBI (72.4% vs. 19.1% vs. 6.2%, $p < 0.001$) (Table 4).

The lowest rate of mortality was seen in the age groups <20 y and 30-39 y. A significant increase in the mortality rate was observed in patients >50 years of age ($p < 0.001$) (Fig. 2). Moreover, there was a 31% increase in suicide attempts in the age group <20 y and an 81% increase in the age group >80 y ($p < 0.001$). As expected, the operative rate declined with increasing age from 19% in age group <20 y to 7% in age group >80 y ($p < 0.001$). Trends of increasing suicide rate with the time-period of the study in

**Table 3**
Multivariate regression analysis for mortality.

| Covariates | OR | 95% CI |
|---|---|---|
| Age | 1.12 | 1.08–1.13 |
| ISS | 1.45 | 1.25–1.65 |
| ED SBP | 0.95 | 0.92–0.98 |
| ED HR | 1.01 | 0.98–1.07 |
| Suicide attempt | 1.45 | 1.27–1.65 |
| Gunshot Wound | 3.4 | 1.9–6.1 |
| Prehospital intubation | 1.35 | 1.21–1.53 |
| Craniectomy/Craniotomy | 6.23 | 4.11–9.32 |

**Table 4**
Details of operative intervention.

| Intervention, % | Mild TBI (GCS≥13) (n = 9943) | Moderate TBI (GCS: 9–12) (n = 2149) | Severe TBI (GCS≤8) (n = 14779) | *p-value* |
|---|---|---|---|---|
| All intervention | 13.8% | 28% | 12.7% | <0.001 |
| Craniotomy | 8.3% | 11.8% | 6.5% | <0.001 |
| Craniectomy | 3.9% | 11.1% | 4.7% | <0.001 |
| Lobectomy/excision of brain | 4.3% | 9.8% | 5.3% | <0.001 |
| Mortality | 6.2% | 19.1% | 72.4% | <0.001 |

different age groups are demonstrated in Fig. 3.

## Discussion

Patients with pTBI have a high mortality.[16] The majority of published guidelines focus on management of severe TBI from blunt mechanism.[6,17] Decades of research have led to management guidelines for severe TBI.[6] These documents provide the current evidence-based guidelines for the management of severe TBI; however, a paucity of modern recommendations exists for pTBI. Guidelines for Management of Penetrating Brain Injury were created in 2001.[18] Direction has been evaluated and attempts have been made to use this to predict survival after pTBI.[19] Prognostic models have been developed for blunt TBI, however, due to a low incidence of pTBI, such models do not exist for pTBI.[20,21] Recently, Muehlschlegel et al. developed a prognostic model, the Surviving Penetrating Injury to the Brain (SPIN) score to help estimate survival after pTBI.[22] Even with these guidelines, however, such patients can be a vexing problem for the health care team. Nonetheless, over the subsequent years, authors have contributed to the literature and provided updates to our understanding of these patients.

In this retrospective analysis of the TQIP database we demonstrated that the incidence of pTBI is increasing and the mortality remains in the vicinity of 40%. There was a decrease in pTBI mortality noted in the time period 2011 to 2014. Potential reasons for this may be explained by the aggressive management strategies along with the advancement of neurosurgical interventions.[7] However, the overall increase of pTBI mortality over the years 2010–2014 may be explained by the increased trends of suicide attempts noticed in our analysis. Suicide attempts from gunshots led to a higher mortality and are common. This is consistent with data from the Center for Disease Control and Prevention, Web-based Injury Statistics Query and Reporting System (WISQARS) and National Center for Injury Prevention and Control, CDC.[4,23] In addition, suicide attempts are increasing at the extremes of ages (<20 y and >80 y). The reasons for this are multifactorial and involve environmental and emotional factors (such as psychological, social media, or being a widow) but are beyond the scope of this project. It does highlight the interplay between firearm-related violence, mental health, and brain injury, which is under active investigation.[24]

Several studies have demonstrated that less than 20% of all patients admitted with gunshot wounds to the head will ever undergo neurosurgical intervention.[25,26] In our analysis, 14.4% of the patients with pTBI underwent neurosurgical intervention, with most common being craniotomy. The highest rate of operative intervention was in patients with moderate TBI, while the lowest was in patients with severe TBI. This might be because patients with severe TBI were deemed unsurvivable and, therefore, they did not undergo any surgical intervention. The severity of TBI was based on admission GCS, which might be subject to change after resuscitation and, hence, can introduce a bias. However, the first GCS and the post-resuscitation GCS did not change in patients with severe TBI.[27]

External ventricular drainage (EVD) is among the most commonly performed neurosurgical procedures. Since it was first performed by Claude-Nicholas Le Cat, in 1744, there have been numerous changes in the technique, materials used, indications and safety. These technological advancements allowed for greater expansion of its indications, including ICP monitoring.[28] The results of our study demonstrate an apparent increase in the use of EVD over the study period. Its efficient effects on decreasing ICP and its pivotal role in ICP management may explain this. In addition, Lovasik et al. have shown in their multi-institutional study that EVD use was associated with trends towards decreased mortality.[29]

Several studies have analyzed prognostic factors associated with worse outcomes after pTBI in both civilian and military settings. In our analysis, factors associated with higher mortality rate were age, injury severity, admission systolic blood pressure, suicide attempt, gunshot wound, prehospital intubation, and craniotomy/craniectomy. In the literature, an age greater than 50 years has been shown to be associated with increased mortality after pTBI.[7] Additionally, suicide attempts carry high mortality because of the close-range injury.[5] Aldrich et al. analyzed the role of early hypotension in patients with pTBI.[27] They reported that 84% of those with early hypotension died compared to 76% of patients with no

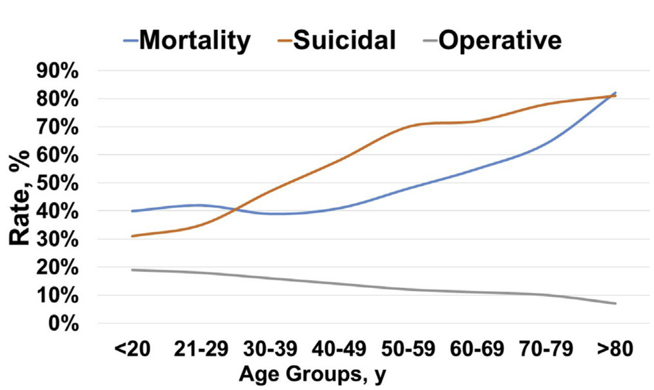


**Fig. 2.** Sub-analysis based on age.

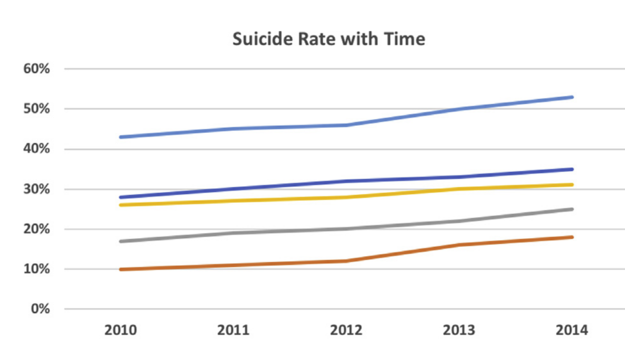


**Fig. 3.** Trends of suicide rate with time in different age groups.

hypotension. The role of prehospital intubation has been established in blunt TBI; however, to the best of our knowledge, this is the first study to evaluate the role of prehospital intubation in pTBI. Similar to blunt TBI, pre-hospital intubation in pTBI was associated with a higher mortality rate.[30] Moreover, patients requiring neurosurgical intervention had a higher mortality, which is similar to previously published literature.[31]

Penetrating traumatic brain injuries carry a dismal prognosis. The results of our study demonstrate that nearly 90% of the total patients who died actually died in the first 72 h. Additionally, Badjatia et al. have shown that around 50% of patients with severe TBI die within the first 2 h of injury.[32] Thus, a special consideration needs to be taken while managing this subset of patients including but not limited to: multidisciplinary approach mainly by acute care surgeons and neurosurgeons, which will optimize the care provided to the patient and aid in prognosis enhancement; and early family discussions with nursing and palliative care focusing on goals of care. The American College of Surgeons TQIP guidelines for the management of traumatic brain injury recommend patients be assigned to a full treatment plan for at least 72 h post-injury.[33] This should be considered when planning and conducting these multidisciplinary discussions. This also provides an adequate time frame to notify organ procurement organizations (OPO), as federal regulations require that OPO be notified of the impending death of potential donors.[34]

Our study was retrospective and involved mining a large database. Limitations exist in retrospective database research. Data entered into the TQIP database is from participating institutions nationwide with the intent to improve care of the injured. Inherent flaws and variability exist in the practices of each provider and at each institution. Some data was missing and was accounted for using advanced statistics. Moreover, we could not determine post-resuscitation GCS and whether the penetrating injury was caused by single or multiple gunshots. In addition, we could not predict any long-term outcomes including survival, cognitive, behavioral and functional outcomes. Finally, we were not able to include patients who were not brought to the hospital (i.e. declared dead at the scene). This consistent and large proportion of patients might have skewed our data.

Penetrating TBI is a complex problem and its management strategies go beyond just the pathophysiology of the patient after injury. Additional components in the care of these critically injured patients should be considered. Numerous aspects of care are interrelated. Opportunities exist to enhance preventative strategies (e.g., suicide prevention and firearm-related violence). Other avenues of potential further investigation include well-integrated and cohesive palliative care and organ donation programs. These aspects are critical to caring for the patient and the patient's family in the modern era.

## Conclusions

Incidence and mortality for patients who are brought to hospitals following pTBI have gradually increased over the five-year period. Self-inflicted injury and prehospital intubation were the two most significant predictors of mortality. Early activation of organ donation protocols, as well as resources focused on family support and counseling, should be considered. Additionally, injury prevention awareness focused on suicide might help reduce such injuries.

## Authors contributions

D.S, M.K, B.J, D.A, and G.R, designed this study.

D.S, M.K, B.J, A.H, F.M, D.E, and B.Y searched the literature.

D.S, M.K, and B.J collected the data.

D.S, M.K, B.J, A.H, F.M, D.E, B.Y, D.A, and G.R. analyzed the data.

All authors participated in data interpretation and manuscript preparation.

## Conflict of interest

There are no identifiable conflicts of interests to report.

The authors have no financial or proprietary interest in the subject matter or materials discussed in the manuscript.

## Acknowledgements

None.

## References

1. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil*. 2006;21(5):375–378.
2. Taylor CA. *Traumatic Brain Injury–related Emergency Department Visits, Hospitalizations, and Deaths—United States, 2007 and 2013. MMWR Surveillance Summaries*. 2017:66.
3. Coronado VG, Haileyesus T, Cheng TA, et al. Trends in sports-and recreation-related traumatic brain injuries treated in US emergency departments: the National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. *J Head Trauma Rehabil*. 2015;30(3):185–197.
4. *Rates of TBI-related Emergency Department Visits, Hospitalizations, and Deaths — United States, 2001–2010, Concussion, Traumatic Brain Injury*. CDC Injury Center; 2017.
5. Part 2: prognosis in penetrating brain injury. *J Trauma*. 2001;51(2 Suppl):S44–S86.
6. Carney N, Totten AM, O'reilly C, et al. Guidelines for the management of severe traumatic brain injury. *Neurosurgery*. 2017;80(1):6–15.
7. Kazim SF, Shamim MS, Tahir MZ, Enam SA, Waheed S. Management of penetrating brain injury. *J Emergencies, Trauma, Shock*. 2011;4(3):395.
8. Carey ME. The treatment of wartime brain wounds: traditional versus minimal debridement. *Surg Neurol*. 2003;60(2):112–119.
9. Davidsson J, Risling M. Characterization of pressure distribution in penetrating traumatic brain injuries. *Front Neurol*. 2015;6.
10. Zyck S, Toshkezi G, Krishnamurthy S, et al. Treatment of penetrating nonmissile traumatic brain injury. Case series and review of the literature. *World Neurosurg*. 2016;91:297–307.
11. Jehan F, Azim A, Rhee P, et al. Decompressive craniectomy versus craniotomy only for intracranial hemorrhage evacuation: a propensity matched study. *J Trauma Acute Care Surg*. 2017;83(6):1148–1153.
12. Ahmad F. *Quarterly Provisional Estimates for Selected Indicators of Mortality, 2014–Quarter 1, 2016*. National Center for Health Statistics National Vital Statistics System, Vital Statistics Rapid Release Program; 2016.
13. *Suicide Statistics — AFSP*. 2017.
14. Jehan F, Pandit V, O'Keeffe T, et al. The burden of firearm violence in the United States: stricter laws result in safer states. *J Injury Violence Res*. 2017;10(1).
15. Vakil MT, Singh AK. A review of penetrating brain trauma: epidemiology, pathophysiology, imaging assessment, complications, and treatment. *Emerg Radiol*. 2017;24(3):301–309.
16. Peek-Asa C, McArthur D, Hovda D, Kraus J. Early predictors of mortality in penetrating compared with closed brain injury. *Brain Inj*. 2001;15(9):801–810.
17. Bullock MR, Povlishock JT. Guidelines for the management of severe traumatic brain injury. Editor's commentary. *J Neurotrauma*. 2007;24, 2 p preceding S1.
18. Part 1: guidelines for the management of penetrating brain injury. Introduction and methodology. *J Trauma*. 2001;51(2 Suppl):S3–S6.
19. Turco L, Cornell D, Phillips B. Penetrating bihemispheric traumatic brain injury: a collective review of gunshot wounds to the head. *World Neurosurg*. 2017;104:653–659.
20. Khan M, O'Keeffe T, Jehan F, et al. The impact of Glasgow Coma Scale–age prognosis score on geriatric traumatic brain injury outcomes. *J Surg Res*. 2017;216:109–114.
21. Roozenbeek B, Lingsma HF, Lecky FE, et al. Prediction of outcome after moderate and severe traumatic brain injury: external validation of the IMPACT and CRASH prognostic models. *Crit Care Med*. 2012;40(5):1609.
22. Muehlschlegel S, Ayturk D, Ahlawat A, et al. Predicting survival after acute civilian penetrating brain injuries the SPIN score. *Neurology*. 2016;87(21):2244–2253.
23. *WISQARS (Web-based Injury Statistics Query and Reporting System)*. Injury Center, CDC; 2017.
24. Bertisch H, Krellman JW, Bergquist TF, Dreer LE, Ellois V, Bushnik T. Characteristics of firearm brain injury survivors in the traumatic brain injury model systems (TBIMS) national database: a comparison of assault and self-inflicted injury survivors. *Arch Phys Med Rehabil*. 2017;98(11):2288–2294.
25. Kaufman H, Levy M, Stone J, et al. Patients with Glasgow Coma Scale scores 3, 4,

5 after gunshot wounds to the brain. *Neurosurg Clin N Am*. 1995;6(4):701–714.
26. Siccardi D, Cavaliere R, Pau A, Lubinu F, Turtas S, Viale G. Penetrating craniocerebral missile injuries in civilians: a retrospective analysis of 314 cases. *Surg Neurol*. 1991;35(6):455–460.
27. Aldrich EF, Eisenberg HM, Saydjari C, et al. Predictors of mortality in severely head-injured patients with civilian gunshot wounds: a report from the NIH Traumatic Coma Data Bank. *World Neurosurg*. 1992;38(6):418–423.
28. Srinivasan VM, O'Neill BR, Jho D, Whiting DM, Oh MY. The history of external ventricular drainage: historical vignette. *J Neurosurg*. 2014;120(1):228–236.
29. Lovasik BP, McCracken DJ, McCracken CE, et al. The effect of external ventricular drain use in intracerebral hemorrhage. *World Neurosurg*. 2016;94:309–318.
30. Denninghoff KR, Griffin MJ, Bartolucci AA, LoBello SG, Fine PR. Emergent endotracheal intubation and mortality in traumatic brain injury. *West J Emerg Med*. 2008;9(4):184.
31. Aarabi B, Tofighi B, Kufera JA, et al. Predictors of outcome in civilian gunshot wounds to the head. *J Neurosurg*. 2014;120(5):1138–1146.
32. Badjatia N, Carney N, Crocco TJ, et al. Guidelines for prehospital management of traumatic brain injury 2nd edition. *Prehosp Emerg Care*. 2008;12(Suppl. 1).
33. Nathens AB, Cryer HG, Fildes J. The American college of surgeons trauma quality improvement program. *Surg Clin N Am*. 2012;92(2):441–454.
34. Office USGP. 42 CFR 482 - conditions of participation for hospitals. https://www.gpo.gov/fdsys/pkg/CFR-2011-title42-vol5/pdf/CFR-2011-title42-vol5-part482.pdf Accessed on August 20, 2018.