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Patterns of concomitant traumatic brain injury and ocular trauma in US service members

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ABSTRACT

Background Concomitant traumatic brain injury (TBI) and ocular trauma (OT) are caused by the same physical mechanisms, which may complicate therapeutic intervention if screening and evaluation of each condition are not promptly initiated. The aim of this study is to identify concomitant TBI in OT patients and characterize the pattern of those injured service members (SMs) in non-combat environments to assist in the early detection and treatment of both TBI and OT.

Methods Encounters matching the case definitions of TBI and OT for injured SMs were extracted from the Military Health System. Concomitant TBI and OT was identified as patients who were diagnosed with both medical conditions within 30 days. Incidence rates of concomitance were analyzed using a Poisson regression model. The odds of mechanisms and types of OT with concomitant TBI were analyzed using logistic regression models.

Results From 2017 to 2021, there were 71 689 SMs diagnosed with TBI, and 69 358 patients diagnosed with OT. There were 3251 concomitant cases identified. The overall concomitance rate in OT patients was 4.7%. Clinical presentations of concomitant OT had a higher rate of complications. Blast, transport accidents, assaults, alcohol, falls, and sports-related injuries (in decreasing order) were significantly associated with concomitance rates. Compared with closed globe injuries, OT with orbital fractures, rupture, laceration, adnexal periocular injury, and penetrating injury had higher risks of concomitant TBI. For patients with orbital fractures, nearly half (44.1%) sustained a concomitant TBI.

Conclusions A practical approach using temporal proximity of diagnostic data was developed to identify concomitant cases of TBI and OT which presented with more severe injury types than non-concomitant cases. These results indicate OT patients with orbital or open globe injuries sustained from high-impact mechanisms warrant further TBI screening to prompt early detection and treatment.

Level of evidence IV.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Cohort studies have shown that concomitant traumatic brain injury (TBI) was common in ocular trauma (OT) patients from battlefields. However, little is known about the rate and pattern of concomitant TBI in service members who had sustained OT in non-military operations.

WHAT THIS STUDY ADDS

⇒ This study developed a pragmatic approach to identify concomitant cases based on temporal proximity of index diagnoses of TBI and OT using electronic health record data in Military Health System. The patterns of OT types and injury mechanisms associated with concomitant TBI were characterized.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our study provides the important data regarding the increased probability of TBIs when globe ruptures and orbital fractures are present, especially in the setting of high-force impact. Eyecare providers should be aware of those clinical presentations of OT for improvement of timely recognition of concomitant TBI.

INTRODUCTION

Traumatic brain injury (TBI) is a significant health threat to US service members (SMs), with nearly half a million cases identified from 2000 to 2023.[1] The actual number of TBI cases may be much higher. The diagnosis of TBI—mild TBI, in particular—is challenging because injuries may not be clearly visible, and providers often have to rely on self-report or an inquiry of a patient's injury history.[2,3] Failing to diagnose TBI early adversely affects clinical outcomes and rehabilitative success.[4,5] It is essential to commence screening evaluations and testing early to diagnose TBI and initiate treatment addressing associated health concerns and related issues affecting quality of life.

Previous work has shown TBI occurs frequently in ocular trauma (OT) patients sustaining battlefield injuries due to blast exposure.[6] Several studies have published concomitant TBI rates as high as 40% to 66% in SMs with combat-related OT.[7,8] There are little data on concomitant OT and TBI in SMs in non-combat settings, where underlying injury mechanisms often differ from those seen in the combat environment.[9]

In previous cohort studies, patients with concomitant TBI and OT have been identified by asking questions about mechanism(s) of injury and circumstances related to the event. However, this type of observational data is often incomplete or unavailable in the electronic health record (EHR). In this study, a novel approach is presented to identify concomitant TBI and OT cases based on examination of the temporal proximity of relevant diagnoses. The Military Health System (MHS) Data Repository (MDR) was leveraged to characterize patterns of OT associated with concomitant TBI.

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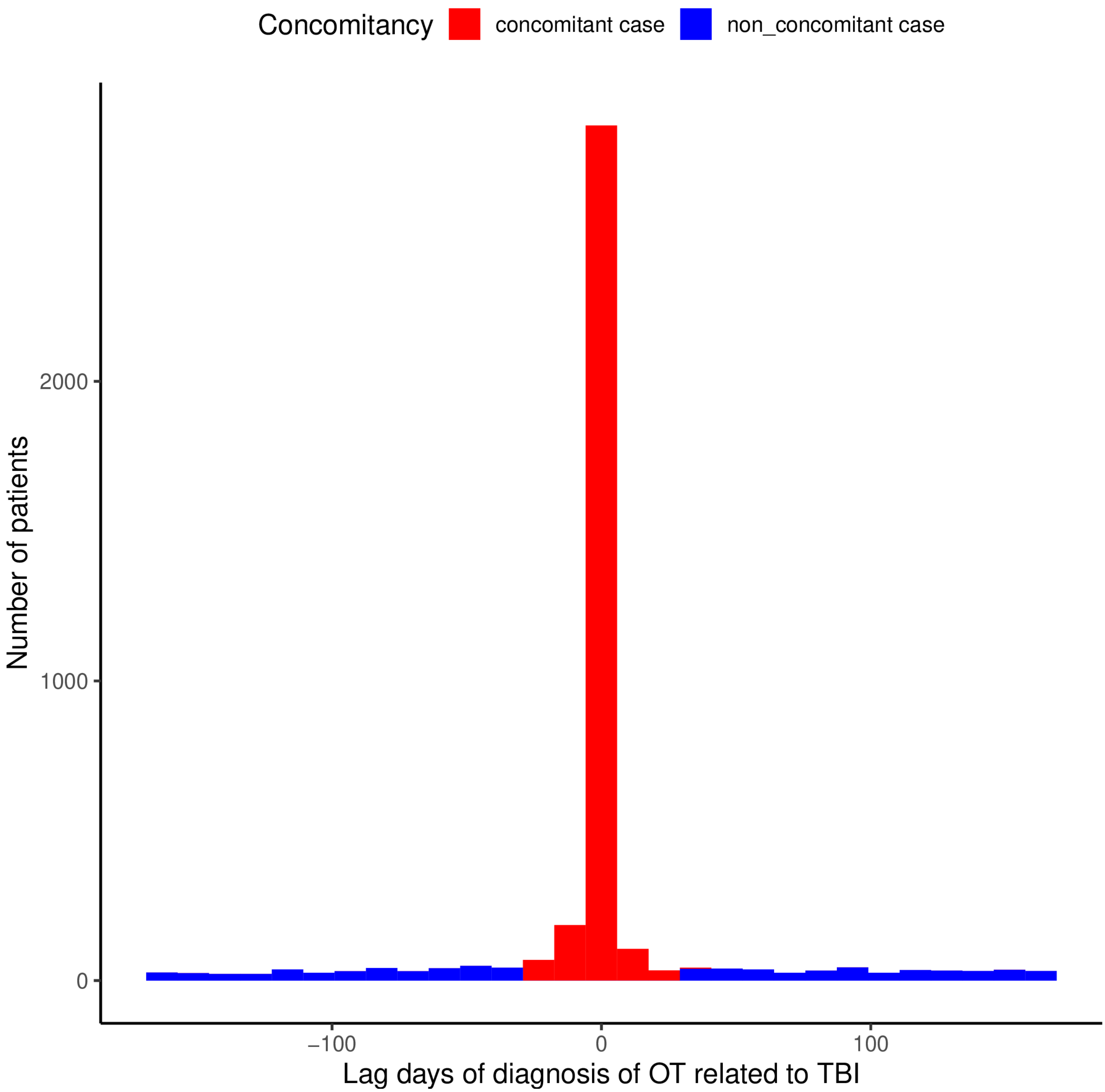

Figure 1 Lag days between index diagnoses of TBI related to OT displaying cases with lag days within −170 to 170 days (concomitant cases are identified in red). OT, ocular trauma; TBI, traumatic brain injury.

Study aims were to: (1) understand factors influencing the occurrence of the concomitant TBI and OT injuries, and (2) provide clinical data in OT patients to assist in the early screening/detection of TBI and improve clinical outcomes.

METHODS

Data

The MDR is a centralized MHS data repository that captures, archives, and distributes MHS data worldwide, including TRICARE beneficiary data. The repository receives and validates EHR data from the Department of Defense's (DoD) worldwide network of more than 260 military healthcare facilities and non-DoD data sources, covering approximately 9.2 million beneficiaries. The MHS Management and Analysis Reporting Tool (MHS MART or M2) is an MDR-derived web-based data mart designed for easy self-service to access enterprise data.

TBI cohort

The case definition of TBI was adopted from a previous definition published by the Armed Forces Health Surveillance Division.[10] To capture patients with newly diagnosed TBI, patients with only historical TBI diagnoses (Z87820, DOD0101, DOD0102, DOD0103, DOD0104, DOD0105) during the 2017–2021 study period were excluded.

Encounter data matching any TBI case definition in any diagnosis field were extracted from M2. Data included both inpatient

Table 1 Average annual numbers and estimated risks of concomitant TBI with OT patients in the US service members during 2017–2021

	Concomitant cases	OT cases	Rate per 100 (95% CI)
Sex			
Male	545	11 159	4.88 (4.48 to 5.28)
Female	79	2213	3.58 (2.81 to 4.35)
Age group			
18–24	367	5587	6.56 (5.91 to 7.21)
25–34	178	4915	3.62 (3.1 to 4.14)
35–44	59	2297	2.59 (1.94 to 3.24)
45–64	20	574	3.54 (2.03 to 5.05)
Service			
Air Force	108	3255	3.32 (2.7 to 3.94)
Army	313	5718	5.47 (4.88 to 6.06)
Marines	105	1756	5.98 (4.87 to 7.09)
Navy	98	2643	3.71 (2.99 to 4.43)

OT, ocular trauma; TBI, traumatic brain injury.

and outpatient SM encounters from direct care (military hospitals and clinics) and purchased care (healthcare of private sectors through TRICARE) facilities. TBI severity was classified (from most severe to least) in groups of penetrating, severe, moderate, and mild TBI.

Ocular injury cohort

Conventionally, the case definition of ocular injury surveillance is based on examining the first diagnosis that matches specified International Classification of Diseases (ICD) codes of ocular injury in the EHR.[11] To mitigate inaccurate diagnosis and misclassification of OT based on the first documented diagnosis in the EHR, the authors developed a unique approach employing a longitudinal evaluation of medical procedures and complications to classify OT into uncomplicated (simple injury without complications and/or surgical operations) and complicated OT (complicated injury with complications and/or surgical operations).[12] Furthermore, types of OT were classified based on examining ICD codes according to Birmingham Eye Trauma Terminology.[13]

Identification of concomitant cases

For patients with diagnosed TBI and OT, concomitant injuries were defined as those caused by the same mechanism(s). This definition excluded cases of primary and secondary injuries which were caused by different mechanisms. It was difficult or impossible to ascertain simultaneity of TBI and OT injury in the EHR, because external causes of injury diagnoses were often not specified or incomplete. Thus, concomitant TBI and OT was pragmatically defined as the diagnoses of both TBI and OT occurring within 30 days of each other. The 30-day window was adopted due to TBI and OT diagnoses often necessitating evaluation by different healthcare providers, despite both injuries occurring from the same mechanism(s).

Statistical analysis

Risks of concomitance rates of TBI with OT were calculated by demographics and service branch. Statistical comparison of concomitance rates between subgroups was conducted based on X^2 statistic. To examine a factor's influence on TBI concomitance, two multivariate logistic regression models were developed to investigate the concomitance of: (1) injury type, and (2) external causes (mechanisms) of OT with adjustment for demographics and service branch. Documented external causes of OT were classified based on modified the Centers for Disease Control and Prevention (CDC) classification.[14] Of note, the possibility existed for a patient to be counted multiple times if he or she had more than one injury type or external cause.

The case identification, classification, and statistical analysis were conducted in R.[15]

RESULTS

From 2017 to 2021, there were 71 689 SMs diagnosed with TBI, and 69 358 patients diagnosed with OT. There were 6404 patients diagnosed with both TBI and OT. The distribution of lag days between the TBI and OT index diagnoses peaked at zero, with 2103 (31.8%) patients diagnosed on the same date (figure 1). 3254 cases of TBI and OT were identified within the −30 to +30-day concomitance lag window, accounting for a concomitance rate of 49.3%. For these patients, the temporal proximity of the diagnosis of TBI was close to the diagnosis of OT, suggesting common mechanisms for these injuries. Of 3254 concomitant cases, 2102 (64.6%) patients were diagnosed with TBI and OT on the same day and 2953 (90.7%) within 1 week.

The overall concomitance rate in OT patients was 4.7%. Males tended to have higher risk of concomitant injuries than females ($\chi^2=348$, df=1, $p<0.01$). The concomitance rate in the age group of 18–24 years old was significantly higher than the concomitance rate in the older age groups ($\chi^2=467.4$, df=3, $p<0.01$), and those in the Army and Marines had higher concomitance rates than those in the Air Force and Navy ($\chi^2=211$, df=3, $p<0.01$) (table 1). The breakdown of concomitance rates by TBI severity, types of OT, gender, age groups and service branch is presented in the online supplemental file 1.

The proportions of TBI severity were statistically significantly different between concomitant TBI and TBI alone ($\chi^2=996.3$, df=3, $p<0.01$). Severe types (penetrating and severe) of TBI had higher proportions than those of TBI without OT cases (table 2). For concomitant TBI, similarly, TBI diagnosed prior to OT tended to be more serious than TBI diagnosed post-OT ($\chi^2=131.6$, df=3, $p<0.01$).

Similarly, concomitant cases had higher proportions of complicated OT (54.3%) than that in non-concomitant OT patients (19.1%). The severity level of TBI was associated with increased rates of complicated OT. Incidence rates of complicated OT increased from 1.72% in mild TBI to 32.18% in penetrating TBI. In contrast, uncomplicated OT rates were relatively constant (1.83–2.97) across the TBI severity level (figure 2).

Compared with closed globe injuries, orbital fractures, eyeball rupture from blunt objects, eyeball laceration from sharp objects,

Table 2 Percent cases of various TBI severity for comparison between concomitant TBI and TBI without OT (above), and TBI prior to OT versus TBI post -OT (below)

	Concomitant TBI (%)	TBI alone (%)
mild	61.0	77.9
moderate	32.4	20.6
penetrating	4.4	0.6
severe	2.3	0.9
	TBI prior OT (%)	TBI post OT (%)
mild	55.8	79.2
moderate	36.4	18.2
penetrating	5.0	1.9
severe	2.8	0.6

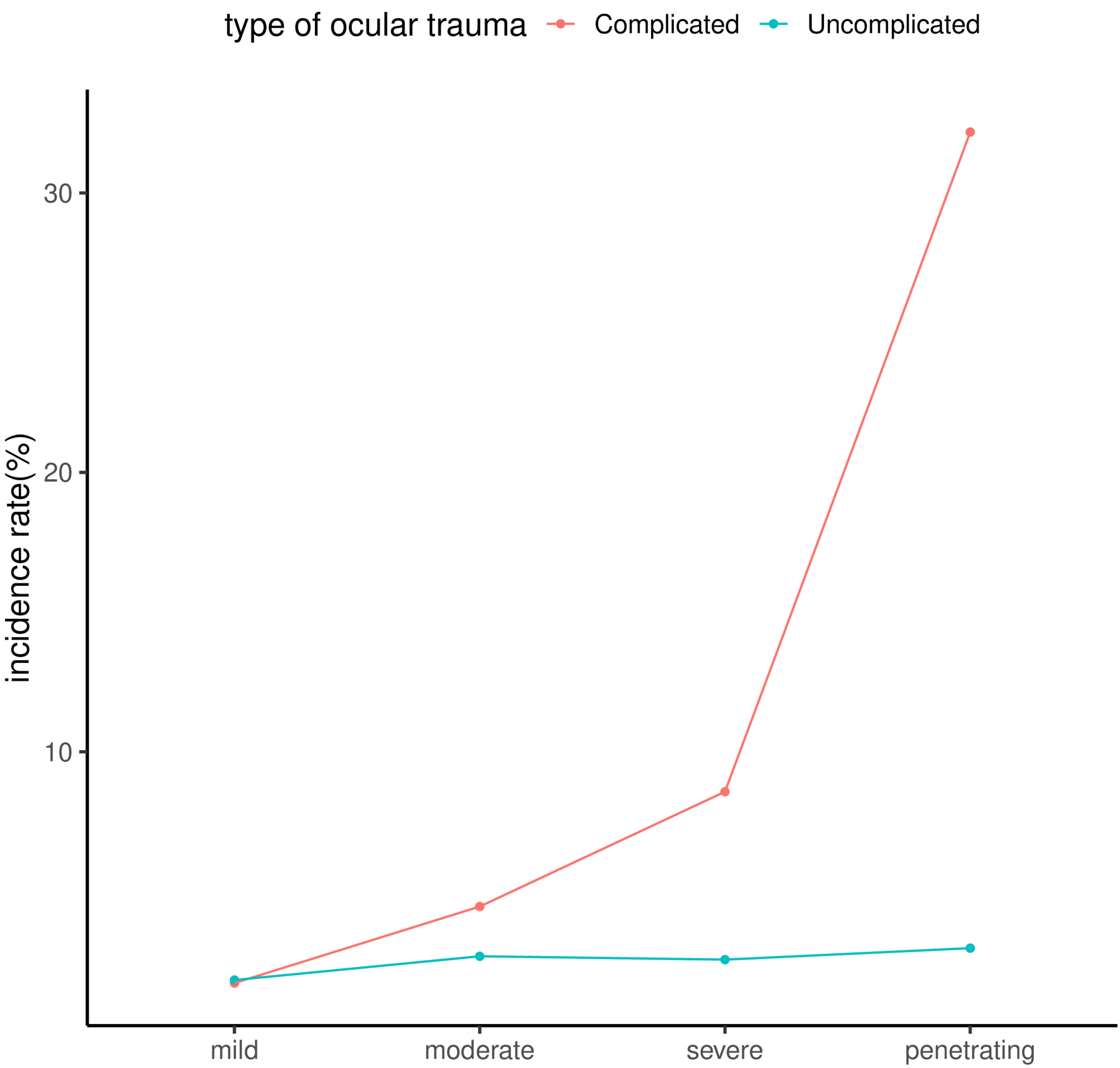

Figure 2 Incidence rate (%) of uncomplicated OT and complicated OT related to TBI severity. OT, ocular trauma; TBI, traumatic brain injury.

adnexal periocular injuries, and eyeball penetration had significantly higher odds of concomitance. The estimated OR in orbital fractures was as high as 43.4 (table 3). Of note, among 2747 cases of orbital fractures, nearly half (44.1%) were associated with concomitant TBI.

In the analysis of causes of OT, external causes occurring in small numbers were grouped into 'other causes' as the default level of comparison. The compliance rate with proper documentation of external causes was modest (54.4%). Blast, transport accident, assault, alcohol, fall, war/conflict, and sports-related causes had significantly higher risks of concomitant TBI compared with the default 'other causes' category (table 3).

DISCUSSION

The identification of concomitant TBI and OT cases in retrospective studies is challenging due to missing or inaccurate EHR documentation describing circumstances and mechanism(s) of injuries. To minimize these limitations, we explored longitudinal diagnostic records to identify concomitant TBI and OT injuries based on temporal proximity of the relevant index diagnoses. Recognizing the diagnosis of TBI and OT often requires specialized examinations by a variety of subspecialists; the adopted span of 30 days accounted for the fact that concomitant TBI and OT can be diagnosed separately and at different times after the injuries. The current approach allowed for the identification of concomitant TBI and OT based on diagnostic data alone. The observed highly clustered pattern of lag days around day 0 indicated the validity of our approach that those identified cases were most likely caused by the same mechanism(s). Although the 30-day criterion was arbitrary and might miss concomitant injuries with diagnoses spanning more than 30 days, a relaxed lag of 60 days or a restrictive 14 days yielded only small changes in

Table 3 Multivariate logistic regression of occurrence of concomitance of TBI and OT by demographics, Sservice branch, types of ocular injury, and external causes

	Estimated OR	Number of patients
Injury type (default: closed globe) 43 733		
Orbit fractures	43.4 (39–48.4)	2747
Eyeball rupture from blunt objects	12.6 (7.6–19.9)	119
Eyeball laceration from sharp objects	7.8 (5.7–10.5)	439
Adnexal periocular injuries	5.3 (4.9–5.8)	22 815
Eyeball penetration	5.3 (3.2–8.2)	241
External cause (default: Other causes) 4382		
Explosion in military operations	10.2 (5.1–19.5)	39
Transport accident	7.8 (6.5–9.3)	1152
Assault	4.9 (4.2–5.8)	2100
Alcohol	4.4 (3.2–6.1)	264
Fall	3.2 (2.7–3.9)	2040
Sports	1.6 (1.3–2)	1623
Burn	1.3 (0.7–2.4)	154
Other military operations	1.3 (0.6–2.5)	106
Exposure to inanimate mechanical forces	0.7 (0.6–0.8)	8549
Exposure to animate mechanical forces	0.1 (0.1–0.2)	1192
Effects of foreign body entering through natural orifice	0.1 (0.1–0.2)	11 712

the number of identified cases, that is, 221 (6.8%) more cases or 155 (4.8%) fewer cases, respectively. Therefore, our results were robust to a reasonable assumption of the lag day.

Patterns of OT in SMs are different among battle and non-battle injury settings. Results of this study reflect the first attempt to document patterns of concomitant TBI and OT of SMs in non-combat environments. Previous studies of a small cohort of combat OT patients showed only closed globe injuries were significantly negatively correlated with concomitant TBI.[7] This study leveraged a large database and was able to identify a suite of significant factors related to the occurrence of concomitant TBI in non-combat settings, mostly non-military operations, for example, transport accidents, assaults, alcohol, and falls.

Compared with the high concomitant TBI rates (>60%) in combat OT patients from Operation Iraqi Freedom and Operation Enduring Freedom,[8] this study shows a low concomitance rate of 4.7% in non-combat environments. The discrepancy in concomitance rates may be attributed to different mechanisms of injury. Combat OT is largely due to blast exposure with sudden, devastating impacts with severe clinical presentation and poor prognosis,[16] and blast exposures accounting for most (89%) of concomitant TBI.[7] The wave of force progression resulting in coup and countercoup presentations—with rapid acceleration and deceleration energies similar to automotive crashes—occurs in both scenarios. In this study, combat-related injuries accounted for a small proportion (0.5%) of OT in SMs. However, blast injuries, despite its small number, ranked the top in risk of TBI concomitancy with OT.

Uncomplicated OT was shown to be relatively unchanged during the spectrum of TBI severity. It was noted that uncomplicated OT, which was based on a single diagnosis in EHR, was subject to misdiagnosis.[17] In contrast, the proportion of complicated OT in which the diagnosis was corroborated by complications or medical procedures increased dramatically for severe and penetrating TBI, indicating simultaneously increased severity for concomitant injuries. In simultaneous traumatic insults to the eye and brain, injury patterns that overcome the natural barrier of the skull have significant impacts to adjacent tissue structures (including the eyes). Conversely, high-force injury can affect deep structures within the orbit, with higher odds of concomitant central nervous system diagnoses. Simple or superficial injuries can induce adnexal and/or lacerated ocular injuries, and orbital injuries disrupting ocular/visual architecture can often result in simultaneous injury to the brain. When complicated OT presents, especially orbital fractures, the need to screen for TBI is clearly warranted.

LIMITATIONS

The study cohort varied in their entrance, follow-up, and exit patterns from clinical care. As a result, identifying concomitant TBI with OT patients based on the recorded diagnoses alone in EHR suffered from inadequate information describing injuries, insufficient follow-ups for injuries occurred close to the end of the study period (2021), or inconsistent date time stamp and diagnostic data quality across MHS. Our criterion of the 30 days for defining the concomitancy of TBI and OT was arbitrary and might miss concomitant cases with longer spans of the relevant diagnoses. Although there were 90.7% defined concomitant cases whose diagnoses of TBI and OT occurred within 7 days, it is not adequate to evaluate the adequacy of the existent TBI screening practices for two reasons. First, there might be failed recognition (false negativity) of TBI due to lack of self-reported cognitive symptoms of patients with mild TBI. Second, it was difficult to discern whether patients with TBI diagnoses beyond 30 days of OT were delayed diagnosed TBI or they might have suffered injuries separately. Chart reviews of the history of injuries might be helpful if these data are available. In addition, documentation of external injury mechanisms was with modest compliance (54.4%) that these reported external causes were representative of the entire group of undocumented cases that require further examination.

CONCLUSIONS

This study developed a pragmatic approach to identify concomitant cases of TBI and OT using EHR data. Identified injury patterns and mechanisms of OT were informative for clinical screening for concomitant TBI presentations where clinicians should be aware of the increased probability of TBI associated with globe ruptures and orbital injuries, especially in the setting of high-force impact. This study reinforces the importance of early screening and diagnosis of TBI to ensure timely treatment that maximizes the potential for optimal clinical outcomes.

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Patient consent for publication Not applicable.

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