Isolated Severe Traumatic Brain Injuries Sustained During Combat Operations: Demographics, Mortality Outcomes, and Lessons to be Learned From Contrasts to Civilian Counterparts

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Background: Severe traumatic brain injuries occurring in the context of modern military conflict are entities about which little has been reported. We reviewed the epidemiology of these injuries from the Joint Trauma Theater Registry (JTTR), contrasting these results with civilian counterparts from the National Trauma Databank (NTDB).

Methods: Isolated severe brain injuries (defined as head abbreviated injury scale [AIS] $\geq$3 and no other body region AIS $>$2) were queried from the JTTR over a period from 2003 to 2007. The demographics and outcomes of these injuries were reviewed. These results were then contrasted to findings of similar patients, age 18 years to 55 years, over the same period from the NTDB using propensity score matching derived from age, gender, systolic blood pressure, Glasgow Coma Scale, and AIS.

Results: JTTR review identified 604 patients meeting study criteria, with a mean age of 25.7 years. Glasgow Coma Scale was $\leq$8 in 27.8%, and 98.0% were men. Hypotension at presentation was noted in 5.5%. Blast (61.9%) and gunshot wound (19.5%) mechanisms accounted for the majority of combat injuries. Intracranial pressure monitoring was used in 15.2%, and 27.0% underwent some form of operative cranial decompression, lobectomy, or debridement. When compared with matched civilian NTDB counterparts, JTTR patients were significantly more likely to undergo intracranial pressure monitoring (13.8% vs. 1.7%; $p < 0.001$) and operative neurosurgical intervention (21.5% vs. 7.2%; $p < 0.001$). Mortality was also significantly better among military casualties overall (7.7% vs. 21.0%; $p < 0.001$; odds ratio, 0.32 [0.16–0.61]) and particularly after penetrating mechanisms of injury (5.6% vs. 47.9%; $p < 0.001$; odds ratio, 0.07 [0.02–0.20]) compared with propensity score-matched NTDB counterparts.

Conclusion: Patients sustaining severe traumatic brain injury during military operations represent a unique population. Comparison with civilian counterparts has inherent limitations but reveals higher rates of neurosurgical intervention performed after penetrating injuries and a corresponding improvement in survival. Many factors likely contribute to these findings, which highlight the need for additional research on the optimal management of penetrating brain injury.

Key Words: Severe traumatic brain injury, Combat, Civilian, Outcomes.

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Traumatic brain injury (TBI) remains a significant problem occurring among combat casualties of Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). Considerable recent attention has been directed toward the effective recognition and treatment for mild TBI occurring as a result of exposure to explosive mechanisms of injury. A significant portion of combat-related TBI patients requiring inpatient care, however, have sustained brain injuries that are moderate to severe in nature.[1] These casualties also constitute challenging care issues encountered in the austere environment present in OIF and OEF.

The treatment of combat-related moderate to severe brain injury continues to evolve. In 2003, the Army Surgeon General mandated development of a Joint Trauma Theater System (JTTS) designed to provide for the optimal care and quality improvement for casualties of OIF and OEF. Subsequently developed JTTS clinical practice guidelines (CPGs) continue to provide all in-theater care providers with best-evidence approaches designed to optimize casualty outcomes in this austere environment. The CPGs cover a wide range of trauma care topics, including the care of brain-injured casualties, and are developed using data from both military and civilian experiences. Accordingly, frequent review of these experiences is necessary to maintain ongoing efforts to optimize outcome after brain injury sustained during combat operations.

The aim of our study is to compare treatments and outcomes of civilian and military severe TBI victims using the National Trauma Databank (NTDB) of the American College of Surgeons and the Joint Trauma Theater Registry

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(JTTR). These databases represent the largest of their type for civilian and military trauma victims, and although possessing their own inherent limitations, provide the best available opportunity to compare treatment and outcomes of patients after severe TBI from these two groups. It is our hope that such a comparison will highlight areas for potential improvement and identify subsequent needs for additional investigation and changes in resource utilization required to continue efforts to optimize outcomes after combat-related TBI in austere environments.

PATIENTS AND METHODS

The Joint Theater Trauma Registry (JTTR), which includes data from 2003 to 2007, and the NTDB version 7.0, which includes data from 2002 to 2006, were used to identify patients aged 18 years to 55 years, sustaining an isolated TBI, defined as head abbreviated injury scale (AIS) of 3 or higher, with the AIS for all the other body regions (chest, abdomen or pelvis, and extremity) <3. Demographic and clinical data including age, gender, mechanism of injury, systolic blood pressure (SBP), and Glasgow coma scale (GCS) on admission were abstracted. In addition, all neurosurgical procedures were identified using the International Classification for Diseases—9th Edition medical procedure codes 01.00 to 05.00. Clinically relevant cut-points were used for the purpose of the analysis. The GCS was stratified into three groups: 3 to 8, 9 to 13, and 14 to 15; hypotension was considered an SBP on admission <90 mm Hg. The primary outcome was mortality.

Statistical Analysis

JTTR Patients

The JTTR patients were stratified into three groups, according to the mechanism of injury: blunt, penetrating (gunshot wounds), and explosive. Basic demographic and clinical data, along with the neurosurgical procedures were compared among groups using analysis of variance. Differences in mortality between groups were then examined, with the blunt trauma patients being the reference group for the purpose of the comparison. To adjust for confounding factors, a logistic regression was used and factors which were different between the three groups at a $p < 0.05$ level were entered in the equation.

JTTR Versus NTDB Patients

Blunt and penetrating injury patients from both databases were then selected, excluding explosion injury patients from the JTTR, because there were no civilian correlates for this injury mechanism available for analysis among NTDB patients. Differences in demographic and clinical characteristics between JTTR and NTDB patients were initially examined using a standard statistical analysis. Means were compared using a Student's t test and proportions were compared through a chi-square test. Because of the observed imbalance in the sample size between the two groups, the JTTR and NTDB patients were matched with the use of a propensity score derived from all available covariates. We assumed that inclusion in the JTTR was randomly assigned with probabilities that depended only on the observed covariates. The propensity score is a measure of the likelihood that a patient would have been entered in the JTTR using the patient's covariate scores. For patients with similar propensity to be included in the JTTR, we compared mortality among the JTTR and NTDB patients.

The propensity score was derived from a logistic regression model in which the outcome was the log-odds to be entered in the JTTR. The covariates used for this model were those available within both databases: age, gender, SBP, GCS on admission, and head AIS. We quantified the model's accuracy by the area under the Receiver Operator Characteristic curve. We then matched each patient in the JTTR to a patient with the closest estimated propensity score in the NTDB. We included in our analysis only those matches that were within 0.00001 of the estimated logit. This method of defining the closeness of a match is referred to caliper matching and is the observational study analog of randomization in clinical trials. After selecting the closest patient in the NTDB, the patient in the JTTR and the matched patient in the NTDB were removed from the sample. If no patient in the NTDB could be found, we removed the JTTR patient from the sample and classified him as "unmatched." We then assessed the balance between the matched groups using a paired-sample t test for means and McNemar test for proportions. Differences in mortality were examined between the two groups and within subgroups of patients including blunt, penetrating, and head AIS 3 to 5. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, Somers, NY) for Windows, version 12.0.

RESULTS

JTTR Patients

A total of 604 patients from the JTTR met inclusion criteria. The mean age was 25.7 years $\pm$ 6.4 years and 98% were men. The majority of these patients sustained an injury as a result of exposure to explosive mechanisms (n = 374, 61.9%), with the remaining sustaining penetrating (n = 118, 19.5%), or blunt (n = 112, 18.5%) trauma. Patients in the penetrating injury group were admitted more frequently with hypotension (SBP <90 mm Hg; 11.0% vs. 4.8% for explosion and 1.8% for blunt; $p = 0.011$; Table 1). The majority of explosion and blunt injury patients were admitted with a GCS score of 14 to 15 (46.0 and 50.9%, respectively), in contrast to penetrating injury patients, the majority of whom were admitted with a GCS score between 3 and 8 (40.7%; $p < 0.001$).

The majority of initial intracranial pressure (ICP) monitor placements (95.6% Level III, 3.3% Level IV, and 1.1% Level V) and operative interventions (87.7% Level III, 8.6% Level IV, and 3.7% Level V) were conducted at Level III facilities. When compared with blunt injury patients, patients in the penetrating and explosion injury groups more frequently underwent neurosurgical interventions (8.9, 34.7, and 29.9%, respectively; $p < 0.001$; Table 2). This difference was noted for craniotomy, craniectomy, brain lobectomy, and skull and brain debridement. There was no significant difference in the use of ICP monitoring between penetrating,

TABLE 1. Comparison of Demographic and Clinical Characteristics Between Blunt, Penetrating, and Explosion Injury Patients in the JTTR

	Total (n = 604)	Blunt (n = 112)	Gunshot Wound (n = 118)	Explosion (n = 374)	*p*
Age (yr; mean ± SD)	25.7 ± 6.4	27.1 ± 7.7	25.1 ± 5.9	25.5 ± 6.0	0.035
Male	98.0% (592/604)	94.6% (106/112)	100.0% (118/118)	98.4% (368/374)	0.010
SBP (mm Hg)					
Normotension (SBP ≥90 mm Hg)	85.3% (515/604)	89.3% (100/112)	76.3% (90/118)	86.9% (325/374)	0.011
Hypotension (SBP <90 mm Hg)	5.5% (33/604)	1.8% (2/112)	11.0% (13/118)	4.8% (18/374)	
Unknown	9.3% (56/604)	8.9% (10/112)	12.7% (15/118)	8.3% (31/374)	
GCS					
3–8	27.8% (168/604)	17.9% (20/112)	40.7% (48/118)	26.7% (100/374)	<0.001
9–13	4.6% (28/604)	4.5% (5/112)	7.6% (9/118)	3.7% (14/374)	
14–15	43.5% (263/604)	50.9% (57/112)	28.8% (34/118)	46.0% (172/374)	
Unknown	24.0% (145/604)	26.8% (30/112)	22.9% (27/118)	23.5% (88/374)	
AIS head					
3	46.5% (281/604)	69.6% (78/112)	24.6% (29/118)	46.5% (174/374)	<0.001
4	30.1% (182/604)	24.1% (27/112)	37.3% (44/118)	29.7% (111/374)	
5	21.0% (127/604)	6.2% (7/112)	34.7% (41/118)	21.1% (79/374)	
6	2.3% (14/604)	0.0% (0/112)	3.4% (4/118)	2.7% (10/374)	

Values are reported as % (n) unless otherwise specified.
p values for means were obtained from analysis of variance.

TABLE 2. Surgical Interventions in JTTR Patients Stratified by Mechanism of Injury

Procedure	Total (n = 604)	Blunt (n = 112)	Gunshot Wound (n = 118)	Explosion (n = 374)	*p*
Any operative intervention	27.0% (163/604)	8.9% (10/112)	34.7% (41/118)	29.9% (112/374)	<0.001
ICP monitoring	15.2% (92/604)	11.6% (13/112)	17.8% (21/118)	15.5% (58/374)	0.414
Craniotomy	7.3% (44/604)	2.7% (3/112)	11.9% (14/118)	7.2% (27/374)	0.028
Craniectomy	10.1% (61/604)	3.6% (4/112)	14.4% (17/118)	10.7% (40/374)	0.020
Brain lobectomy	2.2% (13/604)	0.0% (0/112)	5.1% (6/118)	1.9% (7/374)	0.024
Other brain incision	5.5% (33/604)	0.9% (1/112)	2.5% (3/118)	7.8% (29/374)	0.006
Skull debridement	9.4% (57/604)	2.7% (3/112)	11.9% (14/118)	10.7% (40/374)	0.024
Brain debridement	8.8% (53/604)	0.0% (0/112)	11.0% (13/118)	10.7% (40/374)	0.001

Values are reported as % (n).
p values for means were obtained from analysis of variance.

explosion, and blunt injury mechanisms of injury (17.8, 15.5, and 11.4% respectively; $p = 0.414$).

The overall mortality of JTTR patients was 8.4%. The crude mortality did not differ significantly among the three examined groups (9.8% for blunt, 6.8% for penetrating, and 8.6% for explosion; $p = 1.000$). After adjusting for gender, GCS, SBP, and head AIS, the difference in mortality between blunt and penetrating, and between blunt and explosion injury patients remained insignificant (Table 3).

TABLE 3. Mortality in JTTR Patients Stratified by Mechanism of Injury

	Mortality	*p*	Adjusted* Odds Ratio (95% CI)	Adjusted* *p*
Blunt	9.8% (11/112)	—	1	—
Gunshot wound	6.8% (8/118)	1.000	0.60 (0.19–1.89)	0.385
Explosion	8.6% (32/374)	1.000	0.66 (0.31–1.41)	0.284

* Variables in the equation: gender, GCS groups, SBP groups, and head AIS.
Blunt injury patients were considered as the reference group for the comparison.

JTTR Versus NTDB Patients

A total of 11,029 patients in the NTDB met inclusion criteria. The mean age was 34.7 years ± 11.5 years, 77.6% were men, and 92.8% had sustained a blunt mechanism of injury. These patients were then compared with the subgroup of JTTR patients who had sustained a blunt or a penetrating mechanism of head injury (n = 230). JTTR patients were significantly younger (26.1 ± 6.9 years vs. 34.7 ± 11.5 years; $p < 0.001$), had sustained more frequently a penetrating injury (51.3% vs. 7.2%; $p < 0.001$), and were admitted more frequently with a GCS score between 3 and 8 (29.6% vs. 16.9%; $p < 0.001$; Table 4).

The matching algorithm successfully matched 181 patients from the JTTR with 181 patients in the NTDB within 0.00001 on the propensity score. Overall, 78.7% of the

TABLE 4. Comparison of Demographic and Clinical Characteristics Between JTTR and NTDB Patients Sustaining Blunt or Penetrating Mechanism of Injury

	Unmatched				Matched*		
	Total (n = 12,109)	JTTR (n = 230)	NTDB (n = 11,029)	p**	JTTR (n = 181)	NTDB (n = 181)	p***
Age (yr) mean ± SD	34.5 ± 11.5	26.1 ± 6.9	34.7 ± 11.5	<0.001	26.3 ± 7.1	26.2 ± 7.0	0.319
Male	78.0% (9,430/12,092)	97.4% (224/230)	77.6% (9,206/11,862)	<0.001	96.7% (175)	96.7% (175)	1.000
Mechanism							
Blunt	92.0% (11,141/12,109)	48.7% (112/230)	92.8% (11,029)	<0.001	60.8% (110)	60.8% (110)	1.000
Penetrating	8.0% (968/12,109)	51.3% (118/230)	7.2% (850/11,879)		39.2% (71)	39.2% (71)	
SBP (mm Hg)							
SBP ≥90 mm Hg	86.5% (10,474/12,109)	82.6% (190/230)	86.6% (10,284/11,879)	0.169	86.2% (156)	86.2% (156)	0.317
SBP <90 mm Hg	4.4% (537/12,109)	6.5% (15/230)	4.4% (522/11,879)		6.1% (11)	6.6% (12)	
Unknown	9.1% (1,098/12,109)	10.9% (25/230)	9.0% (1,073/11,879)		7.7% (14)	7.2% (13)	
GCS							
3–8	17.1% (2,074/12,109)	29.6% (68/230)	16.9% (2,006/11,879)	<0.001	32.0% (58)	32.6% (59)	0.317
9–13	7.2% (876/12,109)	6.1% (14/230)	7.3% (862/11,879)		2.8% (5)	2.8% (5)	
14–15	59.8% (7,236/12,109)	39.6% (91/230)	60.1% (7,145/11,879)		43.1% (78)	43.1% (78)	
Unknown	15.9% (1,923/12,109)	24.8% (57/230)	15.7% (1,866/11,879)		22.1% (40)	21.5% (39)	
AIS head							
3	58.2% (7,048/12,109)	46.5% (107/230)	58.4% (6,941/11,879)	<0.001	53.0% (96)	53.6% (97)	0.317
4	31.1% (3,771/12,109)	30.9% (71/230)	31.1% (3,700/11,879)		27.1% (49)	26.5% (48)	
5	10.4% (1,261/12,109)	20.9% (48/230)	10.2% (1,213/11,879)		19.3% (35)	19.3% (35)	
6	0.2% (29/12,109)	1.7% (4/230)	0.2% (25/11,879)		0.6% (1)	0.6% (1)	
Propensity score mean ± SD	0.019 ± 0.041	0.109 ± 0.109	0.017 ± 0.036	<0.001	0.084 ± 0.096	0.084 ± 0.096	0.319

SD, standard deviation.
* Propensity score matching derived from age, gender, SBP groups, GCS groups, and AIS head. Caliper used: 0.00001. Area under the ROC for the model was 0.843.
** p values for means were obtained from Student's t test or Mann-Whitney U test; p values for proportions were obtained from χ^2 or Fisher's exact test.
*** p values for means were obtained from paired-sample t test; p values for proportions were obtained from McNemar test.
Values are reported as % (n), unless otherwise specified.

TABLE 5. Neurosurgical Interventions in JTTR- and NTDB-Matched Patients

	JTTR (n = 181)	NTDB (n = 181)	p
Any operative intervention	21.5% (39)	7.2% (13)	<0.001
ICP monitoring	13.8% (25)	1.7% (3)	<0.001
Craniotomy	6.6% (12)	3.3% (6)	0.238
Craniectomy	8.8% (16)	0.6% (1)	<0.001
Brain lobectomy	2.2% (4)	0.0% (0)	—
Other brain incision	1.1% (2)	1.7% (3)	1.000
Skull debridement	7.7% (14)	2.8% (5)	0.064
Brain debridement	5.0% (9)	1.7% (3)	0.146

p values were obtained from McNemar test.

patients in the JTTR were successfully matched with a patient from the NTDB. The area under the Receiver Operator Characteristic was 0.843 for the overall sample, indicating very good model discrimination between patients in the JTTR and NTDB.

The matched pairs of JTTR and NTDB patients were then compared with respect to neurosurgical interventions and mortality. JTTR patients underwent significantly more neurosurgical monitoring and interventions, compared with the NTDB patients (21.5% vs. 7.2%; $p < 0.001$; Table 5). This difference was mostly attributed to the difference in the proportion of patients undergoing ICP monitoring (13.8% vs. 1.7%; $p < 0.001$).

The matched JTTR patients had a threefold lower overall mortality compared with the NTDB patients (7.7% vs. 21.0%; odds ratio, 0.32; 95% confidence interval, 0.16–0.61; $p < 0.001$; Table 6). There was no difference in mortality in the subgroup of blunt injury patients. However, penetrating injury patients in the JTTR demonstrated an over 10-fold lower mortality rate when compared with the NTDB patients (5.6% vs. 47.9%; odds ratio, 0.07; 95% confidence interval, 0.02–0.20; $p < 0.001$). The difference in mortality between the two groups increased with the increase of the head AIS, from 8.3 versus 6.2% for head AIS of 3 to 5.7 versus 68.6% for head AIS of 5 (Table 6).

DISCUSSION

TBI remains a common component of injury patterns encountered in modern conflict. Although considerable attention has been called to the important issue of mild TBI recognition and treatment, the majority of TBI patients requiring treatment during military operations have sustained severe injuries.[1] Our study suggests that, despite the challenges posed by the austere environments of care inherent to OIF and OEF, the outcome of military severe TBI is lower than that of civilian counterparts. Although the manner in

TABLE 6. Comparison of Mortality in JTTR- and NTDB-Matched Patients

Mortality	Total	JTTR	NTTB	Odds Ratio (95% CI)	p
Overall	14.4% (52/362)	7.7% (14/181)	21.0% (38/181)	0.32 (0.16–0.61)	0.001
Blunt	6.4% (14/220)	9.1% (10/110)	3.6% (4/110)	2.65 (0.81–8.72)	0.454
Penetrating	26.8% (38/142)	5.6% (4/71)	47.9% (34/71)	0.07 (0.02–0.20)	<0.001
AIS head >3	22.5% (38/169)	7.1% (6/85)	38.1% (32/84)	0.12 (0.05–0.32)	<0.001
AIS head 3	7.3% (14/193)	8.3% (8/96)	6.2% (6/97)	1.38 (0.46–4.14)	0.791
AIS head 4	12.4% (12/97)	8.2% (4/49)	16.7% (8/48)	0.44 (0.12–1.59)	0.267
AIS head 5	37.1% (26/70)	5.7% (2/35)	68.6% (24/35)	0.03 (0.01–0.14)	<0.001

p values were obtained from McNemar test.

which these outcomes are achieved is likely multifactorial, there are several advances in modern combat casualty care that have contributed.

The development of a mature JTTS has likely played an important role in optimizing outcome. Civilian literature suggests that the development of advanced trauma systems improves adherence to TBI care guidelines[2,3] and may result in improved mortality[4] and better functional independence after injury.[5] Since JTTS development in 2003, 7 years of considerable wartime experience has resulted in the development of a robust system with active quality improvement mechanisms. These advances have included the development of JTTS CPGs that rely on best-evidence data from both civilian and military experience to establish recommendations for the care of severely injured casualties. The JTTS CPGs, which include guidelines for the care of moderate to severe brain injuries, provide guidance across a complex spectrum of care that spans several continents and includes a multidisciplinary team from several partner nations.

The JTTS CPG specifically dealing with moderate to severe brain injury is largely based on civilian best-evidence practices and the Brain Trauma Foundation (BTF) guidelines.[6–8] Despite the comprehensive efforts of the BTF to develop effective recommendations, the role of invasive monitoring and craniectomy after TBI remain active matters of investigation.[9] Although some groups have proposed the benefits of aggressive policies of decompression,[10,11] these procedures carry appreciable risk for complications.[12] At present, no prospective randomized trial has yet served to adequately assist in the reliable identification of those patients most likely to benefit from ICP monitoring or decompressive procedures after trauma.

Our findings highlight that, despite CPGs based on BTF guidelines, there are considerable differences between military and civilian populations relative to the use of intracranial monitoring and operative neurosurgical interventions. Among matched JTTR- and NTDB-isolated severe TBI patients, we found that military casualties were almost three times more likely to receive a neurosurgical operative intervention (21.5% vs. 7.2%; $p < 0.001$) and were approximately eight times more likely to have an ICP monitor placed (13.8% vs. 1.7%; $p < 0.001$). Although it is impossible to adequately analyze the indication of each of these procedures with our present retrospective registry comparison, there are components of care inherent to modern combat environments that may serve to explain some of these differences. Critical to modern JTTS casualty care has been the use of the Critical Care Air Transport Team.[13,14] The use of this transport modality has provided greater ability to move critically ill casualties across large distances to more advanced care environments. The effects of flight on ICP and TBI outcome, however, have not been fully elucidated.[15] The potential contributions of early transport and aircraft turbulence to secondary TBI remain concerns. The effects of exposing brain-injured patients to aircraft cabin pressures approximating 8,000 foot elevation equivalents is also not completely understood. These factors may influence providers in the combat zone to more readily place invasive monitors and to perform operative decompressions.

There are also a number of other important potential care differences between civilian and military counterparts that limit conclusions that can be based on our findings. Training in self-aid buddy care routinely provided to military members, as well as the close proximity to unit-embedded medics may result in the more rapid delivery of early prehospital care and minimize the effects of hypotension after injury compared with civilian counterparts. Resuscitative strategies using Hextend in the prehospital setting and guidelines for the monitored use of 3% hypertonic saline after severe TBI are also included in the JTTS CPGs but are not routine components of civilian trauma care. Transfusion strategies designed to deliver a higher ratio of fresh frozen plasma to packed red blood cells have demonstrated benefit for the care of combat casualties and are commonly used in the military environment,[16–18] but civilian experience with similar transfusion approaches has been mixed.[19,20] The impact of transfusion ratios specifically on TBI outcomes for either military or civilian populations has not been well examined. The role of hemostatic adjuncts in TBI outcome after hemorrhage is also largely unknown. Factor VIIa has been used in both military[21] and civilian trauma settings, but the optimal utilization of this adjunct is not well defined. At present, there is no reliable evidence from randomized control trials to support the effectiveness of any hemostatic agent in reducing mortality or disability after TBI.[22] The registries used in our study do not adequately record the use of any of the above measures and, therefore, we could not identify potential differences between military and civilian practices or relate them to outcomes.

Perhaps, the most important limitation of this study is our failure to adequately improve understanding of the outcomes associated with explosion-related TBI. Explosive mechanisms account for the majority of military TBIs, but there are, at present, no substantial number of civilian equivalents available for comparison. For this reason, we excluded explosion-related mechanisms from our comparison. In comparing our military population by mechanism, however, we noted that both mortality and the number of neurosurgical procedures performed after explosion-related severe TBI fell between the values recorded for blunt injuries and gunshot wounds. Primary overpressure events, secondary penetrating fragmentation wounds, tertiary blunt injuries, and deceleration forces all play varying roles in the mechanism of explosion-related injury.[23] In reality, explosion-injured military casualties are commonly exposed to a mix of forces, as well as associated penetrating and blunt mechanisms. The variable effects of improvised munitions, differences in shielding between dismounted and mounted personnel, and the potential protective effects of body armor compound the complexity of explosion-related TBI.

Our study demonstrates that mortality of modern military isolated severe TBI may not only be comparable with that of civilian counterparts but also highlights important gaps in our knowledge regarding military TBI. There remains a need for study of explosion-related TBI, for which there is presently no substantial civilian experience. The natural history of this injury pattern must be defined, with consideration given to establishing both short- and long-term outcomes. Present military practices should be examined to analyze whether these interventions contribute to improved outcomes and if they warrant use in civilian TBI care. Additionally, research designed to identify improved protective measures needs to be conducted.

CONCLUSION

Patients sustaining severe TBI during military operations represent a unique population. Comparison with civilian counterparts has inherent limitations but reveals higher neurosurgical procedure rates and an improvement in survival. Among military casualties, many factors likely contribute to these findings, which highlight the need for additional research on the natural history and optimal interventions for severe TBI, and specifically explosion-related TBI.

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DISCUSSION

Dr. Donald D. Trunkey (Portland, Oregon): This was a very well written paper. It's a very provocative paper. I think the statistical package they used is very reasonable.

I'm going to reiterate some of the things that Dr. DuBose outlined. This is a comparison of outcomes between military and civilian brain injury. The JTTR was set up in 2003 and this registry was used to compare that to the National Trauma Databank (NTDB).

The other thing that's critical about this study are the clinical practice guidelines used by the military. These patients were stratified by Glascow Coma Score, three groups, GCS 3 to 8, 9 to 13, and 14 to 15. They were also stratified into blunt, penetrating, and explosive injuries. They then compared these except for the explosive category to the NTDB.

They used a propensity score to compare 181 patients from the JTTR and the NTDB. They came up with a 78.7 percent match and an ROC of .84, which I think is quite good.

The military patients had ICP placements and operative interventions at 87.7 percent at the Level III hospitals, 3.3 percent at the Level IV, and 1.1 percent at the Level V. The overall crude mortality was 9.8 percent for blunt, 6.8 for penetrating, and 8.6 for explosion.

In the matched pairs between the JTTR and the NTDB injured soldiers underwent significantly more neurosurgical interventions when compared to the civilian segment.

Other interesting results showed: 21.5 percent versus 7.2 percent as far as mortality and ICP placement was 13.8 percent versus 1.7 percent.

Most remarkably, the military patients had a three-fold lower mortality when compared to civilian patients and in penetrating injuries it was ten-fold. The difference was not so striking as with the blunt trauma patients. I have some questions.

You state in the manuscript that the civilian experience with military transfusion guidelines are mixed. Is this not due to poor adherence in the civilian community to the guidelines of 1:1:1? You should not deviate from these guidelines in comparative studies.

Explosive mechanisms were not compared in the differences between JTTR and National NTDB. Wouldn't it be reasonable to do such a comparison with our Israeli colleagues?

Third, who did the operative interventions in the Level III, Level IV, and Level V hospitals?

Fourth, in the patients who had a lobectomy, what was their disability following these radical procedures? We know that in children you can take out a lobe up to about 12 years and they will compensate by relearning in the remaining lobe.

In conclusion, your results are impressive and I believe are due to the clinical practice guidelines, including monitoring and aggressive surgical intervention, particularly in the penetrating injuries.

You asked early on why was there a difference in outcome between the military and civilian patients. Despite the Brain Trauma Foundation guidelines in the civilian sector, we're not following our own guidelines. We will continue to have inferior results until we do pay attention to them.

Thank you very much.

Dr. Randall S. Friese (Tucson, Arizona): Friese from Tucson. Thank you very much for a great presentation and I think your work is extremely important.

Data like this should help us get our neurosurgical colleagues to possibly treat these patients more aggressively in the civilian population.

I wanted to ask you, do you think that the availability, the immediate availability of the neurosurgeons in the military environment is what prompted them to be more aggressive?

And, secondly, you described what proportions of procedures were being done. Were they minor procedures? Elevations or debridements? Or were they mostly craniectomies and lobectomies?

Dr. Peter Rhee (Tucson, Arizona): Colonel DuBose, thank you for serving and also thanks to those in uniform here at the meeting.

When I joined the military 27 years ago and read the military textbooks they said for penetrating injury the vast majority (over 95%) need surgery. However, my civilian training taught me that no neurosurgeon operates on penetrating injury to the head.

Then I go to this war and we're doing surgery on a lot of these guys and their survival rates are much better than historically reported. So, the issue is, how do we get this information to the neurosurgical community in order to change therapy and management of penetrating head injuries?

Dr. Charles Wade (Houston, Texas): I would, too, like to commend you for your efforts. I have a simple question. When matching with the civilian population, did you eliminate or include self-inflicted wounds?

Suicide due to gunshot is a major issue that we deal with on a regular basis in Houston that has a very, very poor outcome. It's the biggest group of mortality right now in the United States for the young population with penetrating head injuries. Thank you.

Dr. Joseph DuBose (Baltimore, Maryland): Thank you for the wonderful questions. Dr. Trunkey, thank you for the honor of reviewing our work.

I agree with you, the adherence to one-to-one transfusions may be considerably different between civilian and military settings. The nice thing about the JTTR is that it is very well run. We have some wonderful oversight and I'm sure some of them are in this room.

The JTTS is one system – even though it's geographically spread over a large region, with very tight adherence to one-to-one policies. And I'm certain that that's not the case universally among civilian centers. That's a wonderful question.

The question of the comparing to our Israeli counterparts experience is actually an interesting one that we had not considered. And that may very well be something that we would be very interesting in looking at.

The operative interventions - you inquired who had done these. The majority were done at Level III by neurosurgeons and along the advanced continuum of care to Level IV, Landstuhl Regional Medical Center or in the United States, again by neurosurgical providers.

The providers at the Level III facitilities may actually have been NATO partners, with very different training backgrounds. The British neurosurgeons may have done some of these, or German or Dutch neurosurgical providers - so different training backgrounds but the guidelines overruling all of their actions were consistent.

With regards to your question about the disability associated with lobectomy; this is one of the glaring limitations of our study as we do not have the links to the disability or long term functional outcomes among those that survived to achieve discharge from a level V facility. We are opening some of those pathways to correlate the JTTR with our VA outcome resources for our neuro rehab patients. So we hope to move forward with examining some of that.

And, finally, you asked about following the guidelines of the Brain Trauma Foundation with relation to ICP monitoring and craniectomy. This was very difficult to weed out with this retrospective database registry. We do have a prospective database that we have recently completed and we are presently working on the analysis phase of that. The prospective data set will better help us hone down how many of these patients that had BTF indications for ICP monitor actually had them placed, and how many of these were placed in the absence of indications because people worried about putting them at a C17 up at cabin pressure equivalents of 8,000 feet and wanted to be able to monitor their intracranial pressure. These are questions we just can't answer with our present retrospective analysis.

Dr. Friese, thank you for your comments. I have no doubt the immediate availability of a neurosurgeon plays a key role in the outcomes of these patients.

That's very difficult to look at, however, with a retrospective analysis. It's certainly something that maybe we can tease out a little better with a prospective analysis, particularly the time to intervention may be a critical component that we can examine.

As for the types of procedures done, we did break these out. And I showed some of that data in my presentation. There was a significant portion of patients undergoing debridement due to the fact that these were gunshot wounds, and we list these in the matched tables. The types of procedures did vary but the craniectomy rates were also higher for our combat casualties relative to the NTDB patients.

And, finally, Dr. Rhee, appreciate your comments, although I am still a major and not a colonel just yet. I do appreciate the promotion if you are authorized.

Your question is a wonderful one. How do we change philosophies amongst our neurosurgical colleagues who may have very disparate and different training backgrounds? I have thought that as we start to build more wealth of this literature maybe I need to go to their meetings and initiate those conversations , "draw their fire" and present them with the data that we have – data that I don't think is being adequately shared amongst their circles.

And, finally, Dr. Wade, again, thank you for your comments. We did, for the purpose of this study, include the self-inflicted mechanisms which is always something we struggle with in theater as well as in the civilian practice.

Again, I would like to thank the association for the opportunity to present this work.