Physiological and radiological parameters predicting outcome from penetrating traumatic brain injury treated in the deployed military setting

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ABSTRACT

Introduction Penetrating traumatic brain injury (TBI) is the most common cause of death in current military conflicts, and results in significant morbidity in survivors. Identifying those physiological and radiological parameters associated with worse clinical outcomes following penetrating TBI in the austere setting may assist military clinicians to provide optimal care.

Method All emergency neurosurgical procedures performed at a Role 3 Medical Treatment Facility in Afghanistan for penetrating TBI between 01 January 2016 and 18 December 2020 were analysed. The odds of certain clinical outcomes (death and functional dependence post-discharge) occurring following surgery were matched to existing agreed preoperative variables described in current US and UK military guidelines. Additional physiological and radiological variables including those comprising the Rotterdam criteria of TBI used in civilian settings were additionally analysed to determine their potential utility in a military austere setting.

Results 55 casualties with penetrating TBI underwent surgery, all either by decompressive craniectomy (n=42) or craniotomy±elevation of skull fragments (n=13). The odds of dying in hospital attributable to TBI were greater with casualties with increased glucose on arrival (OR=70.014, CI=3.0399 to 1612.528, OR=70.014, p=0.008) or a mean arterial pressure <90 mm Hg (OR=4.721, CI=0.969 to 22.979, p=0.049). Preoperative hyperglycaemia was also associated with increased odds of being functionally dependent on others on discharge (OR=11.165, CI=1.905 to 65.427, p=0.007). Bihemispheric injury had greater odds of being functionally dependent on others at discharge (OR=5.275, CI=1.094 to 25.433, p=0.038).

Conclusions We would recommend that consideration of these three additional preoperative clinical parameters (hyperglycaemia, hypotension and bihemispheric injury on CT) when managing penetrating TBI be considered in future updates of guidelines for deployed neurosurgical care.

KEY MESSAGES

- ⇒ Penetrating traumatic brain injury is the most common cause of death in current military conflicts, and results in significant morbidity in survivors.
- ⇒ Specific physiological and radiological parameters are associated with worse clinical outcomes and therefore may assist military clinicians to provide optimal care.
- ⇒ This study analysed all emergency neurosurgical procedures performed at a Role 3 Medical Treatment Facility in Afghanistan over a 5-year period.
- ⇒ Hyperglycaemia, hypotension and bihemispheric injury are not currently recommended in current guidelines for deployed neurosurgical care and may be of use in managing such injuries.

INTRODUCTION

Penetrating traumatic brain injury (TBI) is the most common cause of death in current military conflicts, and results in significant morbidity in survivors.[1] This reflects large numbers of high-energy injuries, such as from high-velocity gunshot wounds (GSWs), or energised fragments from improvised explosive devices, grenades or missiles.[2] Evidence-based guidance for military clinicians on the management of TBI in the resource-limited environment is provided for the USA in three Clinical Practice Guidelines,[3–5] and for the UK in the Clinical Guidelines for Operations.[6] Limited evidence exists to assist clinicians in identifying which patients with TBI are most likely to benefit from neurosurgical procedures in the military setting.[1 7–10] Preoperative factors that have been investigated include GCS on arrival,[11] time to treatment[12] and blunt versus penetrating injury.[7] Such factors were determined from retrospective interrogation of the US Department of Defense Trauma Registry (DoDTR),[2] a large database of US military injuries from Iraq and Afghanistan.[13]

The civilian literature describes several additional variables suggestive of a poor prognosis that are not used in current US or UK military guidelines and have not been described in a military setting. These include hypoxia,[14] hyperglycaemia,[15] hypotension,[16 17] hypothermia[14] and hyperthermia,[17 18] and bilateral absent pupillary light reflex with dilated pupils.[14 19] In addition, preoperative CT scans have been used to determine poor prognostic factors, including increased midline shift,[20] bihemispheric injury[21] and larger sizes of blood collection.[22] Most of these physiological variables are not currently recorded in the DoDTR database. The CT scans taken on deployment are not currently transferred to the USA so can only be analysed by clinicians while deployed and not later.

The aim of this paper was to analyse a case series of penetrating TBI treated surgically in a military austere setting and relate clinical outcomes to preoperative physiological parameters and CT features.

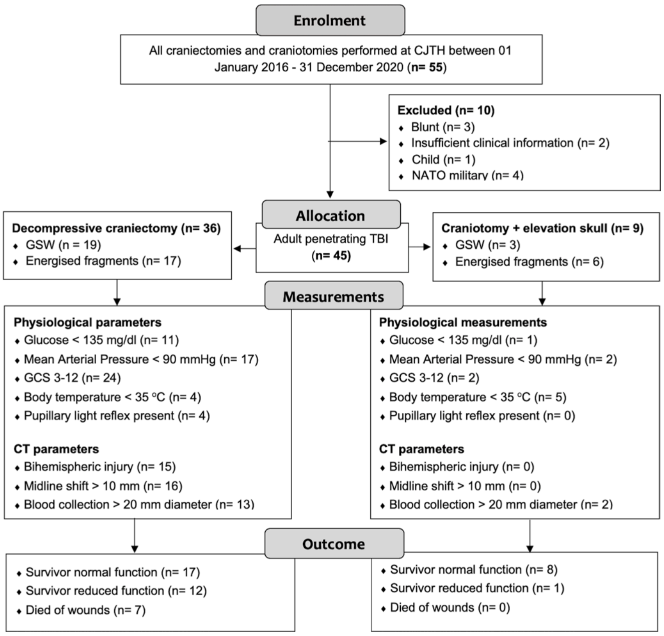

Figure 1 Flow diagram demonstrating variables measured for each type of surgery performed for penetrating head injury. GSW, gunshot wound; TBI, traumatic brain injury.

Table 1 Preoperative physiological variables used to determine odds of death following surgical treatment of penetrating traumatic brain injury

Variable	OR	P value	95% CI
GCS 12 or less	4.561	0.297	0.264 to 78.791
MAP 90 or less	13.387	0.082	0.718 to 249.435
Glucose 135 or more	70.014	0.008	3.0399 to 1612.528
Body temperature 35° and above	2.789	0.501	0.141 to 55.191
Unilateral or bilateral unreactive pupils	2.981	0.556	0.0786 to 113.132

MAP, mean arterial pressure.

METHOD

Patient identification

All patients with penetrating TBI treated surgically at a mature Role 3 Medical Treatment Facility (MTF) between 01 January 2016 and 18 December 2020 were identified from its electronic operating room database. All records prior to this start date had been deleted and are no longer accessible. This end date was chosen as it represents the time when the MTF became as Role 2 and no longer had a neurosurgeon present. During this period, the MTF was responsible for treatment of coalition service personnel, local nationals and other civilian personnel under the rules of eligibility.

Table 2 Preoperative physiological variables used to determine odds of death/survival (dependent on others) versus survivors (independent) following surgical treatment of traumatic brain injury

Variable	OR	P value	95% CI
GCS 12 or less	1.259	0.767	0.273 to 5.810
MAP 90 or less	4.721	0.049	0.969 to 22.979
Glucose 135 or more	11.165	0.007	1.905 to 65.427
Body temperature 35° and above	0.843	0.870	0.108 to 6.543
Unilateral or bilateral unreactive pupils	5.929	0.175	0.452 to 77.798

MAP, mean arterial pressure.

Table 3 Preoperative radiological variables used to determine odds of death following surgical treatment of penetrating traumatic brain injury

Variable	OR	P value	95% CI
Bihemispheric injury	2.918	0.334	0.333 to 25.597
Intraventricular or subarachnoid blood	10.946	0.059	0.917 to 130.688
Epidural haematoma	0.155	0.267	0.005 to 4.152
Compression of the basal cisterns	8.806	0.201	0.314 to 246.835
Midline shift >5 mm	0.861	0.902	0.806 to 9.209

Table 4 Preoperative radiological variables used to determine odds of death/survival (dependent on others) versus survivors (independent) following surgical treatment of traumatic brain injury

Variable	OR	P value	95% CI
Bihemispheric injury	5.275	0.038	1.094 to 25.433
Intraventricular or subarachnoid blood	2.386	0.231	0.575 to 9.897
Epidural haematoma	0.389	0.337	0.056 to 2.675
Compression of the basal cisterns	1.751	0.693	0.108 to 28.170
Midline shift >5 mm	2.134	0.412	0.348 to 13.079

Preoperative variables analysed

The hospital numbers from the operating room database were matched to those from the main deployed (TC2) hospital clinical database and the deployed emergency room database. Together these databases included physiological parameters for each patient on arrival to the MTF and a clinical narrative of the patient's prehospital journey. The following variables were measured, including recognised threshold values: glucose >135 mg/dL,[15] mean arterial pressure (MAP) <90 mm Hg,[16] GCS on arrival 3–12, body temperature <35°C,[18] and unilateral or bilateral pupils unreactive to light.[19] We included all GCS scores but chose a recognised cut-off between mild and moderate brain injury by prognosticating with scores of 3–12 on arrival. Preoperative CT scans were analysed using the deployed MedWeb imaging system using recognised parameters,[20–22] including that described within the Rotterdam classification[23]: midline shift >5 mm,[20] and intraventricular or subarachnoid blood collection diameter >20 mm,[22] compression of the basal cisterns and evidence of an epidural haematoma. Additionally, we analysed bihemispheric damage as this is recognised to be important in penetrating ballistic TBI.[21]

Statistical analysis

Adjusted multiple logistic regression models producing ORs were performed on the preoperative independent variables using three dependent variables representing clinical outcomes: (1) survival with independent function, (2) survival but dependent

Table 5 Radiological parameters according to the Rotterdam system related to GCS on arrival

	Rotterdam score				
GCS	1	2	3	4	5
3–8	7	10	4	1	2
9–12	0	2	0	0	0
13–15	6	7	3	2	0

on others and (3) death during admission. We did not use GCS on discharge as this was not reliably recorded. Reverse stepwise logistic regression was performed with a p value threshold of <0.05 for inclusion in the model. Data analysis was performed using Stata for Mac V.15.1 (StataCorp).

RESULTS

During this period, 55 casualties with penetrating TBI were treated by emergency surgery (Figure 1). Treated penetrating TBI was most commonly from energised explosive fragments (27 of 55, 49%) and GSW (25 of 55, 45%). No significant difference was found in post-surgical mortality from TBI due to GSW compared with energised fragments (OR=0.362, p=0.440). Surgery comprised decompressive craniectomy (n=42) or craniotomy±elevation of skull fragments (n=13). The mean time between operation and discharge from the Role 3 MTF was 52 days.

Physiological parameters

Those casualties with increased glucose on arrival (>135) were more likely to die (OR=70.014, p=0.008, Table 1), and in survivors to be functionally dependent on others on discharge (OR=11.165, p=0.007, Table 2). Both a MAP of <90 mm Hg on arrival and unilateral or bilateral unreactive pupils had increased odds of injury resulting in being functionally dependent on others on discharge (OR=4.721 and OR=5.929, respectively), but only a raised MAP was statistically significant (OR=4.721, p=0.049, Table 2).

CT factors

No preoperative signs on CT scan were found to have a significantly increased odds of death postoperatively (Table 3). Bihemispheric injury was the only sign demonstrated to be associated with an increased odds of being functionally dependent on others (OR=5.275, p=0.038, Table 4). GCS on arrival related to those radiological parameters seen on CT described within the Rotterdam classification[23] is shown in Table 5.

DISCUSSION

Penetrating TBI remains a common injury in current conflicts such as in Afghanistan with large proportions of casualties dying before reaching medical care. Casualties are often stabilised in a Role 2 MTF before aeromedical transportation within the area of operations to a Role 3 MTF for definitive care by a neurosurgeon.[24] Determining how best to manage these casualties in the resource-limited environment can be challenging.[24] Traditional military teaching has been highly dependent on variables such as GCS on arrival, but often by the time they reach Role 3 they have been intubated, and their neurological status at the scene is unknown.[25]

Preoperative hyperglycaemia had increased odds of death from TBI postoperatively and hypotension was associated with increased odds of the casualty being functionally dependent on others on discharge. Nineteen of 45 (42%) of the casualties were still hypotensive on arrival despite resuscitation, likely reflecting that many had sustained severe polytrauma and required long evacuation times prior to arrival at Role 3. Consideration should be made to correction of these potentially modifiable factors prior to surgery if possible. No appearances on CT were found to have increased odds of death from TBI, but bihemispheric brain injury was predictive of being dependent on others at discharge. We would recommend that these three additional preoperative clinical parameters be considered in decision-making and included in any future updates of guidelines for deployed neurosurgical care.[3–5]

The authors recognise several potential limitations to this analysis, primarily reflecting its retrospective nature and small patient numbers resulting in wide CIs. Only a small proportion of casualties were not haemodynamically optimised or were hypothermic, reflecting excellent prehospital care, but may have prevented these variables being used as predictors. Knowledge of these factors potentially in the prehospital setting might have allowed us to better stratify the patients. Reductions in temperature, GCS and MAP may have been reflective of other injuries such as in polytrauma. Additional metabolic parameters such as hyponatraemia were not analysed because the data for this were not reliably recorded in the deployed setting. We would recommend that these missing physiological data be recorded in the future. Although haemoglobin was recorded, being in a military environment, the vast majority of patients had significant fluid resuscitation including blood products in the prehospital setting such that the authors do not feel that analysis of anaemia in our cohort would be of value. We also only had access to the records of patients up to the time of discharge from Role 3, and it may have been that some casualties improved or worsened at a later date. We would recommend that future work be undertaken to prospectively relate the projectile path to outcome as this cannot be done reliably retrospectively without accurate knowledge of impact±exit locations which were rarely described in the deployed clinical records.

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Competing interests None declared.

Patient consent for publication Not required.

Ethics approval This study adhered to the Declaration of Helsinki. Informed patient consent was not required due to the nature of the study. This project was approved as a Performance Improvement initiative by the US Central Command (CENTCOM) Surgeon. It was reviewed by the US Army Medical Research and Development Command's Office of Research Protections, Institutional Review Board Office, and given a Not Research Determination (IRB Office Log Number M-10879).

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