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Management of Penetrating Traumatic Brain Injury: Operative *versus* Non-Operative Intervention

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ABSTRACT

Background: Penetrating traumatic brain injury (pTBI) is the most lethal form of TBI, with mortality rates as high as 90%. This high mortality rate leads many providers to feel that the treatment of pTBI is futile. Contrary to this point of view, several studies have shown that victims of pTBI who present with a Glasgow Coma Scale (GCS) ≥6 have a reasonable chance of a meaningful outcome. This study sought to investigate outcomes of pTBI patients based on GCS score who underwent neurosurgical intervention (craniotomy or craniectomy) and compare them with patients who did not undergo surgical intervention.
Materials and methods: The study represents a secondary analysis of the data that were collected from 2006 to 2016 from 17 institutions as part of a multi-center study, investigating clinical outcomes for adult patients sustaining pTBI and surviving >72 h. Patients were divided into those with GCS 3-5 and those with GCS ≥6. Within these groups, patients were stratified by whether they received surgical intervention, compared with standard non-surgical care. Patient level data (age and gender), clinical data (Injury Severity Score and Abbreviated Injury Score), GCS on admission, post-op infection rates, and outcomes data (mortality, length of stay [LOS], intensive care unit LOS) were collected. Both groups were compared using independent sample *t*-test or chi-squared test.
Results: Seven hundred twenty patients with pTBI were identified over 11 y, out of which 336 (46.7%) underwent surgery. The mean Injury Severity Score and Abbreviated Injury Score on admission were higher in the surgical intervention group than their non-surgical counterpart in patients with a GCS ≥6 ($P < 0.0001$). Patients with GCS of 3-5 with surgical intervention demonstrated a higher survival rate than non-surgical patients ($P < 0.0001$). In the GCS ≥6 group, surgical intervention did not impact near-term mortality. Intensive care unit LOS was significantly longer in the surgical intervention group in patients with

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GCS $\geq$ 6 ($P < 0.0001$) and GCS of 3-5 ($P < 0.0001$), as was total hospital LOS ($P < 0.0001$). Patients with a GCS 3-5 and $\geq$6 who underwent surgical intervention were more likely to develop a central nervous system infection ($P = 0.016$; $P = 0.017$).

Conclusions: Surgical intervention in pTBI patients with GCS 3-5 results in improved mortality but comes at a cost of increased resource utilization in the form of longer LOS and higher infection rate. On the other hand, in patients with GCS $\geq$6, surgery does not provide significant benefits in patient survival. Future prospective studies providing insight as to the impact of surgery on the resource utilization and quality of survival would be beneficial in determining the need for surgical intervention in this population.

Introduction

Traumatic brain injury (TBI), defined as injury to the head resulting from blunt or penetrating trauma,[1] affects approximately 1.7 million people in the United States each year.[2] Penetrating TBI (pTBI) includes a subset of injuries in which a foreign body pierces the skull and dura, entering into the cranial cavity.[3] This is the most lethal form of TBI, with patient mortality between 70% and 90% before hospital arrival.[4,5] Firearm-related injuries are the most common form of pTBI, accounting for over 39,000 deaths in the United States annually,[6] with over half these cases classified as suicides.[3-5,7] Importantly, pTBI incurs a significant healthcare cost—in 2010 alone, the CDC reported over $76 billion attributed to management of pTBI cases.[5]

Management of pTBI patients includes both operative and non-operative interventions. Of patients who are managed non-operatively, treatment goals closely parallel standard resuscitation protocols and interventions. This includes infection control and prevention through debridement and closure of wounds, management of cerebrospinal fluid leaks,[8] and antibiotics—although recent data suggest that the use of prophylactic antibiotics does not have a significant outcome on morbidity and mortality in patients with pTBI.[9] In patients with Glasgow Coma Scale (GCS) 3-5, reduction in intracranial pressure (ICP) is also considered.[4,7,8] Operative intervention in pTBI patients can be rare, partly due to the perception that mortality is high and outcomes are poor. It has been shown that many caregivers for patients with pTBI fall victim to "false pessimism," a cognitive error identified in 1983 by Kaufman *et al.*[10] This hypothesis was tested by Joseph *et al.*[11] from 2007 to 2011 by demonstrating that more aggressive treatment of the most severe pTBI (GCS 3-5) improved survivability from 0% to 23% in this time frame.

Of those who do receive operative intervention, early cranial decompression has been shown to increase survival of pTBI resulting from blast injury in military settings.[12] In a civilian setting, Joseph *et al.*'s[11] study showed that aggressive resuscitation of patients with severe pTBI improved survivability. One of the primary predictive factors of patient survival in this population is GCS at the time of admission.[4,7,13] Mortality associated with a GCS of 3-5 can exceed 90%,[14] with 70%-90% dying prior to reaching the emergency department.[5] Among pTBI patients who reach the emergency department, Aarabi *et al.*[15] found a 61% mortality rate with the remainder having a "good" outcome at 3 y. Despite this, many providers question the use of aggressive management in this population.[16-18] Furthermore, several studies have shown that victims of pTBI who present with a GCS $\geq$6 have a high incidence of survival and reasonable chance of a meaningful outcome.[14,19,20] Current data are limited that assesses mortality in pTBI patients with varying GCS scores stratified by intervention method.

Therefore, the primary objective of this study is to investigate outcomes of pTBI patients based on GCS scores who underwent operative intervention (defined as craniotomy or craniectomy) *versus* those who received standard non-operative care. We hypothesized that a positive survival benefit would be seen in patients with a GCS $\geq$6 who underwent operative intervention, while operative intervention would not improve mortality in patients with a GCS 3-5 on admission.

Materials and methods

This study is a secondary analysis of de-identified data collected from 2006 to 2016 by 17 participating centers of The Eastern Association of Surgery and Trauma. Local Institutional Review Board approval was obtained. In this retrospective chart review, informed consent was not required. Patients greater than age 17 y sustaining pTBI, with documented dural penetration confirmed by computed tomography or operative report, who survived for greater than 72 h were included in this study. Patients without evidence of dural penetration or who survived less than 72 h were excluded, considering these patients likely had lethal injuries with or without surgical intervention.

The primary endpoint was mortality rate in patients with pTBI undergoing operative intervention compared to those undergoing standard non-operative care. Mortality was defined in our study as in-hospital mortality, indicating survival through the current hospital admission, regardless of length of stay (LOS). Patients were divided into those with admission GCS scores of 3-5 or GCS scores $\geq$6. They were then stratified based on operative intervention *versus* standard non-operative care. Operative intervention included craniotomy or craniectomy. Procedures such as simple entry and exit wound closure, irrigation and debridement, and ICP monitoring were not included as operative interventions.

Additional data collected included age and gender, Injury Severity Score (ISS), Abbreviated Injury Score (AIS), post-op central nervous system infection (CNS INF) rates, and hospital and intensive care unit (ICU LOS). CNS INF was determined

Table 1 – Patient demographics stratified by admission GCS score and intervention method.

Demographic	GCS 3-5 ($n = 282$)			GCS ≥6 ($n = 438$)		
	Operative ($n = 122$)	Non-operative ($n = 158$)	P-value	Operative ($n = 214$)	Non-operative ($n = 224$)	P-value
Median age (y)	27.5	34.50	<0.001	29.0	30.0	0.58
Age (mean ± SD)	32.17 ± 12.58	40.21 ± 17.82		33.74 ± 13.99	34.60 ± 14.89	
Male gender, n (%)	102 (83.6%)	130 (82.3%)	0.87	184 (86%)	195 (87%)	0.78

GCS = Glasgow Coma Scale.

by clinical presentation, imaging, and microbiology cultures, and included empyema, meningitis, ventriculitis, or cerebral abscess. GCS 3-5 and GCS ≥6 groups were compared using independent sample t-test or chi-squared tests. A P-value below 0.05 was considered statistically significant.

Results

A total of 720 patients were included in this study. Median age was significantly lower in operative patients in the GCS 3-5 group, at 27.5 y *versus* 34.5 ($P < 0.001$). Patients were predominantly male (Table 1). Table 2 outlines LOS, ICU LOS, infection rate, ISS, and AIS in patients with GCS 3-5 *versus* those with GCS ≥6, stratified by mode of intervention. LOS and ICU LOS were significantly longer after operative intervention in both subsets of patients ($P < 0.0001$). Fourteen of the 122 patients with GCS 3-5 undergoing operative intervention developed a CNS INF (11.5%), compared to 3.9% (6 of 158) in non-operative patients ($P = 0.016$). This relationship was again observed in patients with GCS ≥6, with 7.0% ($n = 15$) of operative patients ($n = 214$) developing infection *versus* 2.2% ($n = 5$) of non-operative patients ($n = 224$; $P = 0.017$). In patients with GCS ≥6, mean ISS (24.33 ± 9.38) and AIS (4.35 ± 0.68) on admission were higher in the operative intervention group than the non-operative group ($P < 0.0001$). Mean ISS and AIS on admission in patients with GCS 3-5 did not reach statistical significance, with a mean ISS of 26.65 ± 10.26 *versus* 28.94 ± 13.68 ($P = 0.126$) and mean AIS of 4.57 ± 0.60 *versus* 4.65 ± 0.91 ($P = 0.402$) in operative and non-operative patients, respectively.

Overall survival rate was 76.3% (549 of 720), with 146 (51.8%) patients with admission GCS of 3-5 surviving. Four hundred three patients with admission GCS ≥6 survived to hospital discharge (92%; Table 3). Of the patients included in our study, 336 (46.7%) underwent surgery, with 43.3% of patients with GCS 3-5 and 48.9% of patients with GCS ≥ 6 to receive operative intervention (Table 4). Patients with GCS 3-5 who underwent operative intervention demonstrated a significantly increased survival rate compared to their non-operative counterparts (82% *versus* 27.8%, $P < 0.0001$). As shown in Figure, in patients with GCS scores 3-5, mortality rate reached 72.2% without operative intervention. This dropped to 18.5% with operative intervention ($P < 0.0001$). Moreover, patients with GCS ≥6 had a 7.5% mortality rate with operative intervention, compared to a rate of 8.5% without, which was not significantly different ($P = 0.72$).

Table 2 – Operative *versus* non-operative intervention and associated variables stratified by admission GCS score.

Variable	Operative ($n = 122$)	Non-operative ($n = 158$)	P-value
GCS = 3-5 ($n = 282$)			
LOS (mean ± SD)	25.31 ± 19.96	8.70 ± 12.26	<0.0001
ICU LOS (mean ± SD)	15.29 ± 11.09	6.00 ± 7.57	<0.0001
Infection rate, n (%)	14 (11.5%)	6 (3.9%)	0.016
ISS (mean ± SD)	26.65 ± 10.26	28.94 ± 13.68	0.126
AIS (mean ± SD)	4.57 ± 0.60	4.65 ± 0.91	0.402
	Operative ($n = 214$)	Non-operative ($n = 224$)	P-value
GCS ≥ 6 ($n = 438$)			
LOS (mean ± SD)	17.05 ± 15.64	10.57 ± 11.92	<0.0001
ICU LOS (mean ± SD)	9.78 ± 9.23	4.60 ± 6.31	<0.0001
Infection rate, n (%)	15 (7.0%)	5 (2.2%)	0.017
ISS (mean ± SD)	24.33 ± 9.38	18.95 ± 9.55	<0.0001
AIS (mean ± SD)	4.35 ± 0.68	3.48 ± 1.26	<0.0001

AIS = Abbreviated Injury Score; GCS = Glasgow Coma Scale; ICU = intensive care unit; ISS = Injury Severity Score; LOS = length of stay; SD = standard deviation.

Table 3 – Percentage of survival in patients with GCS 3-5 *versus* ≥6.

Clinical outcome	GCS 3-5	GCS ≥6	Total
Survival % (*n*)	51.8% ($n = 146$)	92.0% ($n = 403$)	76.3% ($n = 549$)
Deceased % (*n*)	48.2% ($n = 136$)	8.0% ($n = 35$)	23.8% ($n = 171$)
Total (*N*)	282	438	720

GCS = Glasgow Coma Scale.

Discussion

In this retrospective, multi-center study of 720 patients, we found that operative intervention in pTBI patients with admission GCS scores of 3-5 was associated with significantly improved in-hospital mortality. In patients with admission GCS ≥6, however, operative intervention was not associated with improved mortality. ICU LOS, total hospital LOS, and CNS INF rates were significantly higher in patients undergoing operative intervention, regardless of admission GCS scores.

Although this lower in-hospital mortality may be directly related to benefits of operative intervention, it is also possible that GCS 3-5 patients who underwent surgery may have received more aggressive care, with the results confirming Joseph *et al.*'s[11] observations. Our results are not consistent with the previous study by Clark *et al.*,[16] who studied craniocerebral gunshot wounds in a patient sample of 76. They found that no patient presenting with admission GCS 3-5 survived, regardless of operative intervention. This could be attributed to their definition of operative intervention, which included "exploratory surgery and debridement."[16] It is unclear if craniotomy or craniectomy was performed, which was the primary operative interventions in our study.

Although we did not assess for functional outcome at discharge, our results detail the importance of survival in pTBI patients with admission GCS scores 3-5, as several studies have shown that these patients can have meaningful outcomes. In a study of combat pTBI, Weisbrod *et al.*[20] found that 32% of patients with admission GCS 3-5 progressed to functional independence, as defined by GCS ≥ 4 ($P < 0.01$). Promisingly, Zafonte *et al.*[18] found that all patients requiring inpatient rehabilitation after surviving severe pTBI made functional improvement at rehabilitation discharge, regardless of their admission GCS. Patients included in this study presented with GCS 3-8, sustained a pTBI, and were age 16 y or older. This patient population is strikingly similar to ours, leaving us to question if the increased resource utilization required for improved survival in patients with admission GCS 3-5 can be offset by their potential for improved functional outcome at discharge.

Our data showed that patients with GCS ≥6 had an overall mortality rate of 8.0%, compared to 41.8% mortality in patients presenting with GCS 3-5, regardless of intervention method. Several other studies have shown mortality benefit beginning with GCS scores of 6, including Aldrich *et al.*,[14] who found that mortality decreased to 70% from 94% in patients with GCS 3-5. In our study, surgery appeared to have little impact on patients with a GCS ≥6. However, both the ISS and AIS of patients in the operative group were significantly higher; this raises the question of whether the benefit of operation was obscured by more severely injured patients being offered operation. This may also be due to these patients having less elevated ICP and mass effect, two issues that emergent lifesaving cranial surgery addresses.

This current study had several limitations. Although we did observe an increased survival rate in operative patients with admission GCS scores between 3 and 5, we were not able to assess if intervention improves functional outcomes in these patients. It is also unclear if their improved mortality is directly correlated to surgical benefits, or if the increased attention and care by hospital staff during the postoperative period plays a role. As this study was retrospective, we could not follow mortality past hospital discharge. The retrospective nature of this study also allowed for the presence of several confounders that have been shown to have prognostic value in pTBI patients, including coagulopathies,[8] hemodynamic instability,[13] and high ICP.[8] Furthermore, as this study used pre-collected national data, the ability to investigate computed tomography scans was limited. Therefore, our study used admission GCS scores to indicate level of pTBI severity and could not directly assess the extent of intracranial involvement, such as bi-hemispheric or transventricular injury. Additionally, by including only major decompressions (craniotomy or craniectomy) in our operative intervention groups, we are not evaluating for the role that wound closure, irrigation and debridement, or placement of ICP monitoring may have on in-hospital mortality. Future analysis of the

Table 4 – Patients undergoing operative *versus* non-operative management, stratified by GCS score at admission.

Intervention method	GCS 3-5 ($n = 282$)	GCS ≥ 6 ($n = 438$)	Total (*N*)
Operative (*n*)	122	214	336
Non-operative (*n*)	158	224	382

GCS = Glasgow Coma Scale.

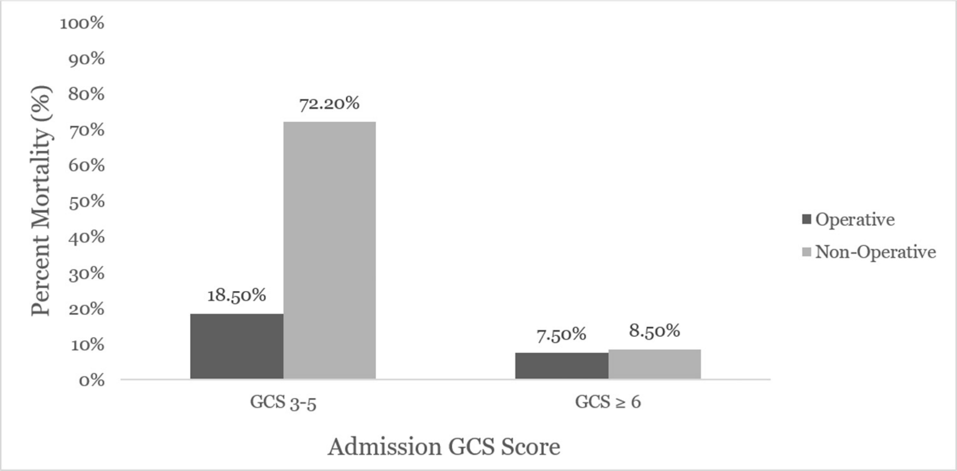

Fig – Percentage in-hospital mortality by intervention.

relationship between ICP monitoring and in-hospital mortality in pTBI patients is recommended.

Conclusions

Our study suggests an association between improved in-hospital mortality and operative intervention in patients with admission GCS 3-5 compared with standard non-operative care. This comes at a cost of increased resource utilization as demonstrated by significantly increased ICU LOS, hospital LOS, and infection rate in operative patients regardless of admission GCS score. Furthermore, the current study did not find a significant improvement in in-hospital mortality after operative intervention for patients with admission GCS ≥6. Therefore, we believe that more robust or prospective studies are needed to evaluate the role for surgery in this population. Additional areas for future research would be to analyze functional outcomes in pTBI patients with major decompressive surgeries *versus* simple wound closure, debridement, and ICP monitoring.

Disclosure

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.

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