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# Outcomes of the Survivors of Combat Related Penetrating Brain Injury in a Tertiary Care Military Facility from a Low to Moderate Income Country

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**Background**: Penetrating brain injury (PBI) is a leading cause of combat mortality but local outcome data is limited. The authors examined combat-related PBI cases to describe patient characteristics and identify clinical and radiologic predictors of functional recovery
**Methods**: This is a retrospective cohort study of military personnel aged 18–56 years with combat-related PBI referred to VLGH-AFPMC between January 2017 to June 2022. The authors collected demographics data, injury mechanism, pre-hospital and transfer details, admission clinical and radiologic findings, treatments, and follow-up outcomes. The Glasgow Outcome Scale (GOS), dichotomized into unfavorable (GOS 1–3) and favorable (GOS 4–5), was used to assess functional status. Associations were tested with Fisher's Exact Test.
**Results**: Thirty-seven patients met inclusion criteria: 31 survivors with follow-up and 6 who died in hospital. All were male; gunshot wounds accounted for 81% of injuries. At a median follow-up of 27 months, among survivors, 74% had a Glasgow Coma Scale (GCS) of 15 and 45% achieved good recovery (GOS 5). Pre-hospital timing measures (evacuation time, interval to surgery, and transfer delays) were not significantly associated with outcome. Favorable outcomes correlated strongly with higher admission GCS ($p < 0.001$), preserved baseline motor function ($p < 0.001$), smaller hemorrhage volume ($p = 0.01$), and injury limited to a single lobe ($p < 0.001$). Unfavorable outcomes were associated with intracranial infection, post-traumatic seizures, and need for multiple surgeries (all $p < 0.001$).
**Conclusion**: Functional recovery after combat-related PBI in this cohort was principally determined by initial neurologic status, injury extent, and subsequent complications The lack of association with pre-hospital timing possibly reflects survivorship bias and incomplete capture of early fatalities.

**Key words**: Penetrating brain injury, early response, traumatic brain injury, low-middle income country

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Penetrating brain injury (PBI) is one of the most severe forms of traumatic brain injury and is associated with high mortality and significant neurological disability[1]. In military settings, PBI commonly results from gunshot wounds and explosive fragments sustained during combat operations. Survivors often require complex neurosurgical management and prolonged rehabilitation. Their functional outcomes depend on multiple injuries and treatment-related factors.

The management of combat-related penetrating brain injury presents unique challenges compared to civilian settings. These include delayed evacuation, limited availability of neurosurgical capability in forward medical units, and logistical constraints in transporting injured personnel to definitive care facilities[2,3]. Timely evacuation and access to specialized neurosurgical care are critical components of military trauma systems and may influence functional outcomes among survivors.

In the Philippine military healthcare system, the Victoriano Luna General Hospital – Armed Forces of the Philippines Medical Center (VLGH-AFPMC) serves as the primary tertiary referral center for neurosurgical care. Military personnel who sustain penetrating brain injuries are referred to this institution from military regional and station hospitals for definitive management, follow-up, and assessment prior to return to duty or medical disposition. This centralized referral pathway provides an opportunity to evaluate the clinical characteristics and outcomes of survivors of combat-related penetrating brain injury.

Local data describing the functional outcomes of survivors of combat-related penetrating brain injury remains limited. Understanding the characteristics, management, and functional outcomes of survivors may

help guide neurosurgical care, rehabilitation planning, and military medical evacuation and referral protocols.

The objective of this study was to describe the demographic characteristics, injury patterns, management factors, and functional outcomes of military personnel who had combat-related penetrating brain injury and were managed at a tertiary military referral center.

## Methods

### *Study Design and Setting*

This was a retrospective cohort study conducted at the VLGH-AFPMC, a tertiary military referral center in Quezon City, Philippines. It serves as the principal neurosurgical referral facility for military personnel who sustain combat-related injuries. Military personnel sustaining penetrating brain injuries are initially stabilized and managed at forward medical units or other designated military treatment facilities. They are subsequently referred to VLGH-AFPMC for definitive or post-operative neurosurgical care, comprehensive follow-up, and formal disposition evaluation prior to return to duty, medical retirement, or separation from military service.

This study described the clinical characteristics, management, and functional outcomes of military personnel who survived combat-related penetrating brain injury and were managed at VLGH-AFPMC.

### *Study Population*

The study included all military personnel aged 18 to 56 years who sustained combat-related penetrating brain injury and were referred to and managed at VLGH-AFPMC between January 1, 2017 and June 1, 2022.

Eligible patients were identified through hospital medical records. Total enumeration sampling was employed, and all patients meeting the inclusion criteria during the study period were included.

Patients were included if they:

- Sustained a penetrating brain injury during combat operations; and
- Were successfully transported to and managed at VLGH-AFPMC for definitive neurosurgical care, post-operative management, follow-up, or disposition evaluation.

Patients were excluded from the functional outcome analysis if they:

- Died prior to being assessed and treated in VLGH-AFPMC
- Had incomplete medical records preventing adequate data extraction; or
- Had insufficient follow-up data to determine functional outcome.

In-hospital deaths were classified as GOS 1 and included in outcome analysis.

### *Data Collection*

Data were collected through retrospective review of medical records, operative reports, imaging records, and outpatient follow-up records. Data collection was carried out from July 1, 2022 to October 1, 2022. Demographic variables recorded included age at the time of injury and sex. Injury characteristics included mechanism of injury (gunshot wound or blast injury), Glasgow Coma Scale (GCS) score at presentation at AFPMC VLGH, pupillary reactivity on presentation, and the presence of associated extracranial injuries. Neuroimaging findings were also documented, including entry and exit wound characteristics, presence of intracranial hemorrhage, skull fractures, and retained bone or metallic fragments. Management variables included the type of surgical intervention performed (such as craniectomy, craniotomy, or wound debridement), timing of surgical intervention, number of surgical procedures performed, requirement for intensive care unit admission, and length of hospital stay.

### *Outcome Measures*

The primary outcome was functional outcome, assessed using the Glasgow Outcome Scale (GOS). Functional outcome was determined at the most recent documented outpatient follow-up.

GOS scores were categorized as follows:

- Favorable outcome: GOS 4 (moderate disability) and GOS 5 (good recovery)
- Unfavorable outcome: GOS 2 (persistent vegetative state) and GOS 3 (severe disability), GOS 1 (death) or deaths that occurred during their hospitalization were also included in the study.

*Follow-up*

Functional outcomes were assessed at routine outpatient neurosurgical follow-up visits as part of standard military medical evaluation and clearance protocols. The most recent documented GOS score during the follow-up period was used for outcome assessment.

*Statistical Analysis*

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 24.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were employed to summarize the dataset, with continuous variables expressed either as mean ± standard deviation or as median with interquartile range, depending on the underlying distribution. Categorical variables were presented as frequencies and percentages.

For inferential analysis, patients were stratified into two groups based on functional outcomes: favorable (Glasgow Outcome Scale [GOS] scores of 4–5) and unfavorable (GOS scores of 1–3). Owing to the relatively small sample size (n = 31) and the categorical nature of the variables, Fisher's Exact Test was utilized to evaluate associations between independent variables and functional outcomes. The variables examined encompassed pre-hospital factors, initial clinical and radiologic characteristics, as well as follow-up clinical parameters and complications. Statistical significance was defined as a p-value of less than 0.05.

No survival analysis was conducted, as the study population consisted exclusively of survivors referred to the tertiary center. Furthermore, multivariable regression analysis was not performed due to the limited sample size and the consequent risk of model overfitting.

*Ethical Considerations*

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. The study was reviewed and approved by the Armed of the Forces of the Philippines Health Service Command – Research Ethics Committee with protocol number 103/12-23.

Patient confidentiality was maintained throughout the study. Identifiable patient information was anonymized, and data were stored securely and accessed only by the investigators.

## Results

A total of 37 patients with PBI were transported to and managed at VLGH-AFPMC between January 2017 and June 2022.

Of these, 31 survived their injuries. Among these, the mean age at injury was 29 years, and all were male. The cohort consisted predominantly of enlisted personnel (28, 90%), with a smaller proportion of officers (3, 10%). Most patients were affiliated with the Philippine Army (28, 90%). In terms of civil status, 18 patients (58%) were single and 13 (42%) were married.

A detailed flow diagram of patient selection and inclusion is presented in Figure 1.

*Prehospital and Injury Characteristics*

Most patients were evacuated from the site of injury to an initial treatment facility within 24 hours (22, 59%). Definitive surgical intervention within 24 hours of injury was achieved in 18 patients (49%). The predominant mechanism of injury was gunshot wounds (30, 81%), with the remaining cases attributed to other penetrating mechanisms, including blast injuries. Medical personnel were present at the scene in 29 cases (94%) as detailed in Table 1.

Injuries were distributed across geographic regions, with a substantial proportion occurring in Mindanao. However, only 12 patients (32%) were transferred to a neurosurgical-capable facility within 24 hours, indicating potential delays in access to specialized care.

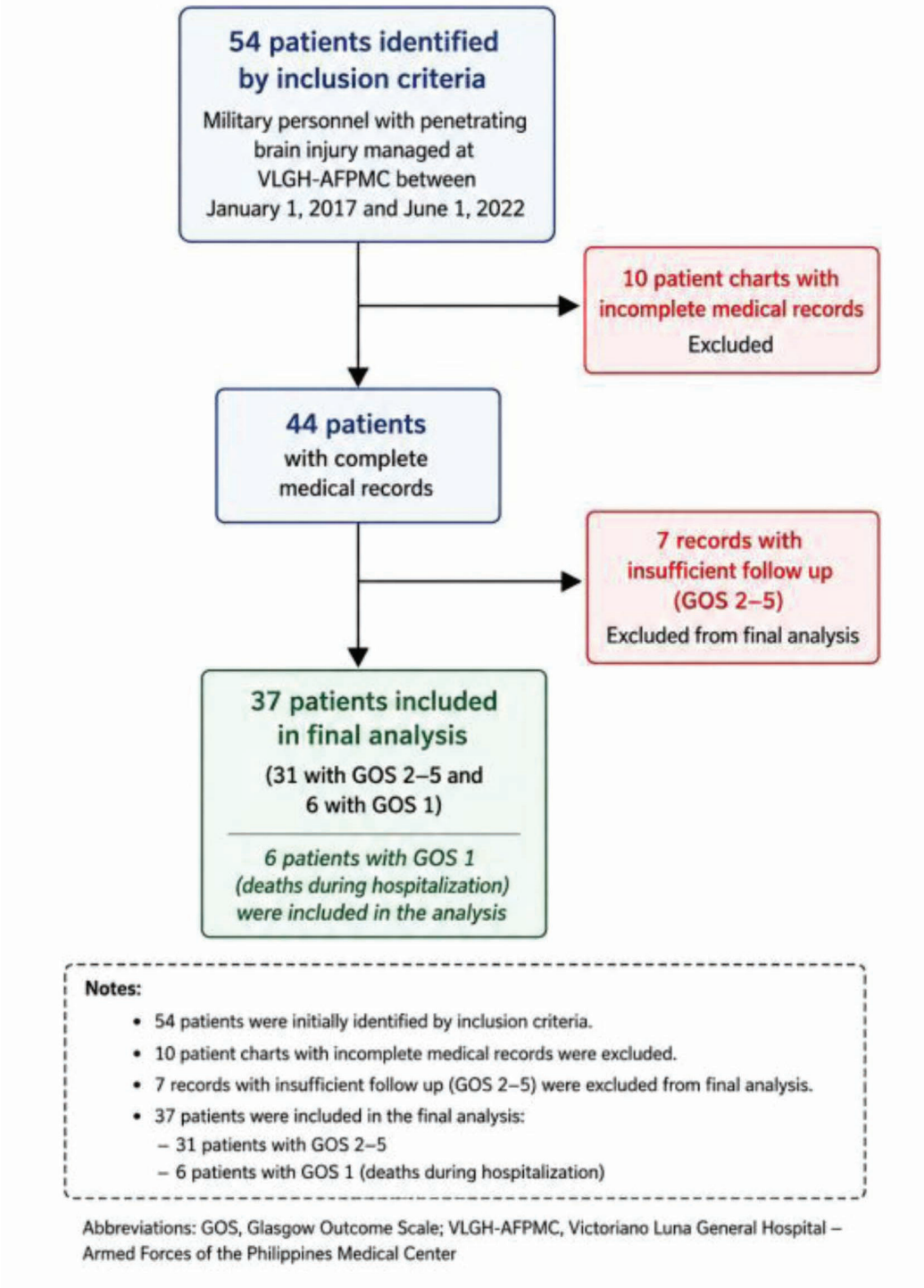


**Figure 1.** Flow diagram of patient selection and inclusion. VLGH-AFPMC, 2017–2022

**Table 1.** Pre-hospital factors and their association with functional outcomes (GOS 1–3 vs GOS 4–5) among survivors of combat-related penetrating brain injury. VLGH-AFPMC, 2017–2022.

| Variable | Category | Total n (%) | GOS 1–3 | GOS 4–5 | p-value | Odds Ratio (95% CI) | Interpretation |
|---|---|---|---|---|---|---|---|
| **Time to Evacuation to Treatment Facility** | 0–24 hours | 22 (59%) | 6 | 16 | 0.728 | 1.17 (0.14–9.90) | Not significant |
| | 25–48 hours | 8 (22%) | 3 | 5 | | | |
| | 49–72 hours | 3 (8%) | 2 | 1 | | | |
| | >72 hours | 4 (11%) | 3 | 1 | | | |
| **Time from Injury to Operation** | 0–24 hours | 18 (49%) | 5 | 13 | 0.743 | 1.06 (0.13–8.50) | Not significant |
| | 25–48 hours | 6 (16%) | 2 | 4 | | | |
| | 49–72 hours | 9 (24%) | 6 | 3 | | | |
| | >72 hours | 4 (11%) | 1 | 3 | | | |
| **Mechanism of Injury** | Bullet | 30 (81%) | 12 | 18 | 0.291 | 0.63 (0.03– 13.37) | Not significant |
| | Explosive fragments | 7 (19%) | 2 | 5 | | | |
| **Type of Encounter** | CPP-NPA | 25 (68%) | 9 | 16 | 0.835 | 1.12 (0.12– 10.21) | Not significant |
| | Abu Sayyaf | 6 (16%) | 2 | 4 | | | |
| | Others | 6 (16%) | 3 | 3 | | | |
| **Medical Aid at Scene** | Present | 29 (94%) | 8 | 21 | 1.000 | 1.13 (0.05– 26.48) | Not significant |
| | Absent | 2 (6%) | 0 | 2 | | | |
| **Geographic Location** | NCR | 3 (8%) | 1 | 2 | 0.183 | 0.33 (0.06–1.87) | Not significant |
| | Luzon | 12 (32%) | 2 | 10 | | | |
| | Visayas | 5 (14%) | 2 | 3 | | | |
| | Mindanao | 17 (46%) | 9 | 8 | | | |
| **Transfer to Neurosurgical Capable Center** | 0–24 hours | 12 (32%) | 3 | 9 | 0.386 | 1.29 (0.26–6.46) | Not significant |
| | 25–48 hours | 4 (11%) | 0 | 4 | | | |
| | 49–72 hours | 9 (24%) | 6 | 3 | | | |
| | >72 hours | 12 (32%) | 5 | 7 | | | |

On initial presentation, 13 patients (35%) had a Glasgow Coma Scale (GCS) score of 15, and 15 patients (41%) demonstrated preserved motor function (MMT grade 4 or 5). Extracranial injuries were present in 23 patients (62%) as summarized in Table 2.

Neuroimaging findings frequently demonstrated intracranial bone fragments (28 patients, 76%) and retained metallic foreign bodies (22 patients, 59%). Hemorrhage volume was less than 30 $cm^3$ in 24 patients (65%), and 19 patients (51%) had injury tracts confined to a single lobe. All patients received prophylactic antibiotic therapy upon admission.

*Treatment and Hospital Course*

All patients underwent surgical intervention (craniectomy, craniotomy, or wound debridement) as indicated. A total of 20 patients (54%) required multiple neurosurgical procedures, reflecting a substantial proportion with complex clinical courses. Cranioplasty had been performed in 20 patients (54%) at the time of latest follow-up as elaborated in Table 3. Encephalomalacic changes were present in all patients on follow-up imaging.

Complications were common: intracranial infection occurred in 15 patients (41%), and post-traumatic seizures developed in 23 patients (63%).

*Follow-up and Functional Outcomes*

The median follow-up duration was 27 months (interquartile range, 17–46 months). At latest follow-up, 23 patients (74%) had a GCS score of 15. Fourteen patients (45%) achieved a Glasgow Outcome Scale (GOS) score of 5, indicating good recovery. Among patients with residual motor deficits, the most common motor strength was MMT grade 4 (12 patients, 39%), reflecting substantial functional improvement compared to initial presentation as shown in Table 3.

**Table 2.** Initial clinical and radiologic characteristics and their association with functional outcomes (GOS 1–3 vs GOS 4–5) among survivors of combat-related penetrating brain injury. VLGH-AFPMC, 2017–2022.

| Variable | Category | Total n (%) | GOS 1–3 | GOS 4–5 | p-value | Odds Ratio (95% CI) | Interpretation |
|---|---|---|---|---|---|---|---|
| **Initial Glasgow Coma Scale** | 15 | 13 (35%) | 0 | 13 | <0.001 | 0.03 (0.00–0.47) | Significant |
| | 14 | 3 (8%) | 1 | 2 | | | |
| | 9–13 | 7 (19%) | 2 | 5 | | | |
| | 5–8 | 11 (30%) | 8 | 3 | | | |
| | 3–4 | 3 (8%) | 3 | 0 | | | |
| **Initial Manual Muscle Testing (Weak Side)** | 0 | 3 (8%) | 3 | 0 | <0.001 | 1.12 (0.18–6.89) | Significant |
| | 1 | 6 (16%) | 5 | 1 | | | |
| | 2 | 9 (24%) | 2 | 7 | | | |
| | 3 | 4 (11%) | 3 | 1 | | | |
| | 4 | 7 (19%) | 1 | 6 | | | |
| | 5 | 8 (22%) | 0 | 8 | | | |
| **Functional Initial MMT (≥4)** | Yes | 15 (41%) | 1 | 14 | <0.001 | 1.12 (0.18–6.89) | Significant |
| | No | 22 (59%) | 13 | 9 | | | |
| **Extracranial Injury** | Yes | 23 (62%) | 11 | 12 | 0.17 | 0.81 (0.17–3.91) | Not significant |
| | No | 14 (38%) | 3 | 11 | | | |
| **Intracranial Bone Fragments** | Yes | 28 (76%) | 12 | 16 | 0.43 | 1.33 (0.35–5.09) | Not significant |
| | No | 9 (24%) | 2 | 7 | | | |
| **Retained Metallic Foreign Body** | Yes | 22 (59%) | 10 | 12 | 0.31 | 0.72 (0.20–2.61) | Not significant |
| | No | 15 (41%) | 4 | 11 | | | |
| **Location of Hemorrhage** | Frontal | 9 (24%) | 0 | 9 | <0.001 | 0.01 (0.00–0.15) | Significant |
| | Temporal | 2 (5%) | 0 | 2 | | | |
| | Parietal | 6 (16%) | 1 | 5 | | | |
| | Occipital | 2 (5%) | 1 | 1 | | | |
| | Infratentorial | 3 (8%) | 1 | 2 | | | |
| | Multiple lobes | 15 (41%) | 11 | 4 | | | |
| **Hemorrhage Size** | <30 cc | 24 (65%) | 5 | 19 | 0.01 | 5.00 (1.19–20.99) | Significant |
| | ≥30 cc | 13 (35%) | 9 | 4 | | | |
| **Injury Tract (Extent of Brain Involvement)** | Single lobe | 19 (51%) | 0 | 19 | <0.001 | 0.01 (0.00–0.15) | Significant |
| | Crosses coronal plane | 13 (35%) | 9 | 4 | | | |
| | Crosses sagittal plane | 3 (8%) | 3 | 0 | | | |
| | Crosses both planes | 2 (5%) | 2 | 0 | | | |
| **Initial Antibiotic Prophylaxis** | Yes | 37 (100%) | 14 | 23 | N/A | — | — |
| | No | 0 (0%) | 0 | 0 | | | |

**Table 3.** Clinical characteristics at last follow-up and their association with functional outcomes (GOS 2–3 vs GOS 4–5) among survivors of combat-related penetrating brain injury. VLGH-AFPMC, 2017–2022.

| Variable | Category | Total n (%) | GOS 2–3 | GOS 4–5 | p-value | Odds Ratio (95% CI) | Interpretation |
|---|---|---|---|---|---|---|---|
| **Manual Muscle Testing** | 1–2 | 9 (24%) | 9 | 0 | <0.001 | 0.01 (0.00–0.07) | Significant |
| | 3 | 7 (19%) | 4 | 3 | | | |
| | 4–5 | 21 (56%) | 1 | 20 | | | Significant |
| **Intracranial Infection** | Yes | 15 (41%) | 11 | 4 | <0.001 | 6.82 (1.52–30.62) | Significant |
| | No | 22 (59%) | 3 | 19 | | | |
| **Retained Bone Fragments** | Yes | 16 (43%) | 10 | 6 | 0.020 | 1.42 (0.36–5.61) | Significant |
| | No | 21 (57%) | 4 | 17 | | | |
| **Retained Metallic Foreign Body** | Yes | 13 (35%) | 9 | 4 | 0.010 | 2.00 (0.38–10.52) | Significant |
| | No | 24 (65%) | 5 | 19 | | | |
| **Need for Multiple Operations** | Yes | 20 (54%) | 14 | 6 | <0.001 | 28.67 (3.88–211.74) | Significant |
| | No | 17 (46%) | 0 | 17 | | | |
| **Cranioplasty Performed** | Yes | 20 (54%) | 13 | 7 | <0.001 | 9.71 (1.67–56.55) | Significant |
| | No | 17 (46%) | 1 | 16 | | | |
| **Post-traumatic Seizures** | Yes | 23 (63%) | 14 | 9 | <0.001 | 11.33 (1.91–67.24) | Significant |
| | No | 14 (37%) | 0 | 14 | | | |

*Comparison of Functional Outcome Groups*

Patients were stratified into two groups based on functional outcome: favorable (Glasgow Outcome Scale [GOS] 4–5) and unfavorable (GOS 1–3). Associations between clinical variables and functional outcomes were analyzed using Fisher's Exact Test, given the small sample size and categorical nature of the data.

Among pre-hospital variables, none of the evaluated pre-hospital or logistical factors demonstrated a significant association with functional outcomes as shown in Table 1. These included evacuation within 24 hours ($p = 0.19$), time from injury to operation ($p = 0.26$), mechanism of injury ($p = 0.69$), type of encounter ($p = 0.88$), presence of medical personnel ($p = 0.52$), geographic location ($p = 0.24$), and time to transfer to a neurosurgical center ($p = 0.09$).

Although early transfer to a neurosurgical-capable facility showed a trend toward improved outcomes, this did not reach statistical significance.

In contrast, several initial clinical and radiologic variables were significantly associated with functional outcomes as detailed in Table 2. A higher Glasgow Coma Scale (GCS) score on admission to the initial treatment facility was significantly associated with favorable outcomes ($p < 0.001$). Similarly, better baseline motor function, as measured by Manual Muscle Testing (MMT), was also significantly associated with improved outcomes ($p < 0.001$). Radiologic characteristics also demonstrated significant associations. Smaller hemorrhage volume ($<30$ cm$^3$) was associated with favorable outcomes ($p = 0.01$). Likewise, injury tracts confined to a single lobe showed a strong association with improved functional recovery ($p < 0.001$).

In contrast, extracranial injuries ($p = 0.17$), intracranial bone fragments ($p = 0.43$), and retained metallic foreign bodies ($p = 0.31$) were not significantly associated with outcomes.

Multiple follow-up and treatment-related variables were significantly associated with functional outcomes as summarized in Table 3. Good motor function at follow-up (MMT grade 4 or 5) was strongly associated with favorable outcomes ($p < 0.001$).

Intracranial infection was significantly associated with poorer outcomes ($p < 0.001$). Similarly, the need for multiple surgical procedures demonstrated a strong association with unfavorable outcomes ($p < 0.001$), suggesting that greater injury severity and treatment complexity negatively impact recovery.

The occurrence of post-traumatic seizures was also significantly associated with poorer outcomes ($p < 0.001$).

Cranioplasty status showed a significant association with outcomes ($p < 0.001$), though this likely reflects underlying injury severity and survivorship factors rather than a direct causal relationship.

Interestingly, the persistence of intracranial bone fragments ($p = 0.02$) and retained metallic foreign bodies ($p = 0.01$) at follow-up were also significantly associated with outcomes, indicating that incomplete clearance of foreign material may correlate with worse recovery or more severe initial injury.

## Discussion

This study represents one of the first local investigations to systematically examine functional outcomes among survivors of combat-related penetrating brain injury (PBI) in a resource-constrained military setting. Whereas much of the existing literature has traditionally emphasized mortality, the present analysis redirects focus toward determinants of functional recovery, integrating both descriptive and inferential approaches to more precisely characterize outcome trajectories in this unique population.

In this cohort, prehospital and logistical variables did not demonstrate significant associations with functional outcomes. Instead, outcomes were primarily driven by initial neurologic status and structural injury characteristics, particularly GCS score, baseline motor function, hemorrhage volume, and extent of cerebral involvement. However, this should be interpreted with caution, as key pre-hospital factors such as hypotension, hypothermia, and other physiological derangements were not consistently documented and were therefore not included

Additionally, the clinical course played a critical role. Complications such as intracranial infection and post-traumatic seizures, as well as the need for multiple surgical interventions, were strongly associated with poorer outcomes. The association between retained

intracranial material and outcomes further suggests that injury severity and completeness of surgical management may influence recovery.

Overall, these findings emphasize that injury severity at presentation and subsequent clinical trajectory, rather than prehospital factors, are the principal determinants of functional recovery in penetrating brain injury within this cohort.

Penetrating brain injury, particularly from gunshot wounds, remains among the most lethal forms of trauma, with reported mortality rates ranging from approximately 60% to as high as 80% in civilian cohorts, and even higher in combat settings[4-6]. In contrast, the present study focuses exclusively on survivors, representing a highly selected subgroup of patients who have already overcome the most critical early phase of injury.

Within this cohort, recorded pre-hospital variables, including time to evacuation, time from injury to surgical intervention, distance to medical facilities, inter-facility transfer intervals, and the presence of medical aid personnel, were not significantly associated with functional outcomes. This observation should not be construed as contradicting established military trauma doctrine, which underscores the importance of rapid evacuation and early surgical intervention. Rather, it likely reflects a cohort limited to survivors, as pre-hospital deaths and early mortalities were not adequately documented and therefore not captured, potentially obscuring the true effect of timely care on overall outcomes.

This finding is more appropriately interpreted in the context of survivorship bias. Patients who experience delays in evacuation or access to definitive care are less likely to survive long enough to be included in tertiary referral cohorts. Consequently, among survivors, the influence of pre-hospital factors may be attenuated, with outcomes instead largely determined by intrinsic injury severity and neurological status at presentation.

*Initial Neurological Status and Injury Severity*

Initial neurological status emerged as one of the most robust predictors of functional outcome in this study. Both admission Glasgow Coma Scale (GCS) scores and baseline motor function, as assessed by Manual Muscle Testing (MMT), demonstrated significant associations with recovery. These findings are consistent with a substantial body of literature identifying early neurological assessment as a cornerstone of prognostication in penetrating brain injury.

Radiologic indicators of injury burden further reinforced this relationship. The location and size of intracranial hemorrhage, as well as the extent of brain involvement along the projectile tract, were all significantly associated with outcome. In particular, the extent of injury tract involvement demonstrated a strong association, highlighting the critical role of anatomical disruption—especially when eloquent or multiple brain regions are affected.

In contrast, the presence of intracranial in-driven bone fragments and retained metallic foreign bodies did not show a significant association with outcome. This suggests that such findings, while radiographically conspicuous, may not independently reflect the severity of underlying parenchymal injury, particularly when appropriate surgical debridement and management are performed.

These findings are congruent with prior reports from both civilian and military cohorts, including data from the United States[7] and conflict settings such as Afghanistan and Eastern Ukraine[8], where lower admission GCS, greater injury burden, and more extensive intracranial involvement have consistently been associated with poorer outcomes.

The post-injury clinical course was likewise a critical determinant of functional outcome. Higher GCS scores and improved motor function at follow-up were strongly associated with favorable recovery, reflecting the dynamic and potentially reversible nature of neurological impairment in this population.

Complications such as intracranial infection and post-traumatic seizures demonstrated significant associations with poorer outcomes, underscoring the importance of secondary injury processes. Intracranial infection remains a well-recognized contributor to morbidity in penetrating brain injury, while post-traumatic seizures may reflect underlying cortical disruption and have been linked to adverse neurological outcomes in prior studies, including those involving missile injuries in wartime settings.

The requirement for multiple surgical interventions was also significantly associated with outcome, likely serving as a surrogate marker for injury complexity and clinical instability. Conversely, the association between cranioplasty and improved functional outcome suggests a potential therapeutic benefit of cranial vault reconstruction. This may be mediated through restoration of cerebral blood flow, normalization of cerebrospinal fluid dynamics, and improvement in cortical function—mechanisms that have been increasingly recognized in neurosurgical literature.

In comparison to high-resource military systems, the Philippine setting presents distinct challenges, including geographic fragmentation, delayed transport due to an archipelagic environment, and limited neurosurgical workforce capacity. Despite these constraints, the present study demonstrates that meaningful functional recovery is achievable among survivors of PBI.

Historical data from the Armed Forces of the Philippines, particularly following the Marawi Siege, have reported mortality rates as high as 92% for penetrating brain injuries[8]. Within this context, the cohort of survivors analyzed in this study represents a select group in whom aggressive surgical management and sustained follow-up care have translated into measurable functional gains.

Although descriptive trends suggest that earlier surgical intervention and expedited transfer may be associated with improved outcomes, these factors did not reach statistical significance in the present analysis, likely due to limited sample size. Nonetheless, these observations remain clinically relevant and are supported by prior reports demonstrating improved outcomes with rapid intervention in selected cases.

The findings of this study have several important implications. Early and accurate neurological assessment (GCS and MMT) should remain central to triage, prognostication, and management planning. Detailed radiologic evaluation of injury burden, including hemorrhage characteristics and trajectory, is essential in guiding surgical decision-making.

Equally critical is the prevention and aggressive management of complications, particularly intracranial infection and post-traumatic seizures, which appear to significantly influence recovery. Efforts to minimize the need for repeated surgical interventions may also improve outcomes, where clinically feasible.

The observed association between cranioplasty and functional recovery further suggests that timely cranial reconstruction should be considered an integral component of rehabilitation strategies.

While rapid evacuation and efficient transport systems remain indispensable for improving survival, the present findings suggest that, among survivors, optimization of neurosurgical care, complication management, and long-term rehabilitation may have a more direct impact on functional outcomes.

Taken together, this study highlights a critical distinction in penetrating brain injury care: factors that determine survival may differ from those that govern functional recovery. Among survivors, neurological status at presentation, extent of intracranial injury, and the subsequent clinical course appear to be the dominant determinants of outcome.

Despite the heterogeneity of injuries and the limited sample size precluding multivariable modeling, these findings provide important baseline data for understanding PBI outcomes in a low- to middle-income military setting and underscore the need for larger, multicenter studies to refine prognostic models and optimize care pathways.

*Limitations*

This study has several important limitations. First, the study population consisted exclusively of patients initially managed at forward medical units who survived the initial injury and were subsequently transferred to the main military referral center. Patients who died at the scene, during transport, or prior to referral were not included. As a result, the study is subject to survivorship and referral bias, and the findings cannot be used to determine predictors of survival or overall mortality among all patients with penetrating brain injury. Rather, the findings apply specifically to survivors who had access to definitive neurosurgical care.

Second, the retrospective design limits control over data completeness and introduces potential information bias. Third, the relatively small sample size limits statistical power to identify independent predictors of functional outcome. Finally, the single-center nature of

the study may limit generalizability to other military or civilian settings.

Future multicenter studies incorporating both survivors and non-survivors are needed to better define predictors of survival and functional recovery in penetrating brain injury, particularly in low- and middle-income countries and resource-limited combat environments.

## Conclusions

In survivors of combat-related PBI, long-term functional outcome after transfer to a tertiary military referral center is largely determined by initial injury severity and neuroanatomic injury. Post-injury course and management factors also meaningfully influenced outcomes. No single independent predictor emerged, likely reflecting sample size and injury heterogeneity. These results establish important baseline data for resource-limited military settings. The study underscores the need for larger multicenter prospective studies that include non-survivors to develop robust prognostic models and inform targeted management strategies in these settings.

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