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# Mortality and Functional Outcome Predictors in Combat-Related Penetrating Brain Injury Treatment in a Specialty Civilian Medical Facility

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**ABSTRACT**

**Introduction**

The combined use of new types of weapons and new types of personal protective equipment has led to changes in the occurrence, nature, and severity of penetrating brain wounds. The availability of modern equipment, methods of treatment, and trained medical personnel in a civilian hospital, as well as advanced specialty medical care, has improved treatment outcomes. There have been a limited number of publications regarding analysis and predictors of treatment outcomes in patients with combat-related penetrating brain injury in contemporary armed conflicts. The purpose of this study was to analyze the results of surgical treatment of patients with penetrating brain injury and to identify significant outcome predictors in these patients.

**Materials and Methods**

This was a prospective analysis of penetrating brain injury in patients who were admitted to Mechnikov Dnipropetrovsk Regional Clinical Hospital, Ukraine, from May 9, 2014, to December 31, 2017. All wounds were sustained during local armed conflict in Eastern Ukraine. The primary outcomes of interest were mortality rate at 1 month and Glasgow Outcome Scale score at 12 months after the injury.

**Results**

In total, 184 patients were identified with combat-related brain injury; of those, 121 patients with penetrating brain injury were included in our study. All patients were male soldiers with a mean age of 34.1 years (standard deviation [SD], 9.1 years). Mean admission Glasgow Coma Scale score was 10 (SD, 4), and mean admission Injury Severity Score was 27.7 (SD, 7.6). Mortality within 1 month was 20.7%, and intracranial purulent-septic complications were diagnosed in 11.6% of the patients. Overall, 65.3% of the patients had favorable outcome (good recovery or moderate disability) based on Glasgow Outcome Scale score at 12 months after the injury. The following were predictors of mortality or poor functional outcome at 1 year after the injury: low Glasgow Coma Scale score on admission, gunshot wound to the head, dural venous sinuses wound, presence of intracerebral hematomas, intraventricular and subarachnoid hemorrhage accompanied by lateral or axial dislocation, and presence of intracranial purulent-septic complications.

**Conclusions**

Generally, combat-related penetrating brain injuries had satisfactory treatment outcomes. Treatment outcomes in this study were comparable to those previously reported by other authors in military populations and significantly better than outcomes of peacetime penetrating brain injury treatment.

## INTRODUCTION

The combined use of new types of weapons and new types of personal protective equipment has led to changes in the occurrence, nature, and severity of penetrating brain wounds.[1] The availability of modern equipment, methods of treatment, and trained medical personnel in a civilian hospital, as well

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as advanced specialty medical care has improved treatment outcomes.[2] There have been a limited number of publications regarding analysis and predictors of treatment outcomes in patients with combat-related penetrating brain injury in contemporary armed conflicts.[3,4] Some of these studies have involved analysis of predictors in a mixed population (combat wounds and wounds sustained by civilians).[5] Most of the literature describes improved principles of medical care,[6–8] influences of intervention type and timing on patient mortality,[9–11] influence of gender[12] and rehabilitation[3] on treatment outcomes. In the civilian population, there is a clear tendency of increased occurrence of penetrating brain injuries, as well as worse treatment outcomes, compared to those data in military populations.[1,13]

In this regard, the purpose of our study was to analyze the results of surgical treatment of patients with combat-related penetrating brain injuries and to identify significant outcome predictors in these patients.

## METHODS

### Design and Data Collection

After institutional review board approval, data were reviewed regarding all patients who were treated in Mechnikov Dnipropetrovsk Regional Clinical Hospital (MDRCH) Ukraine, for combat-related brain injury (wound) between May 9, 2014, and December 31, 2017. All wounds were sustained during local armed conflict in Eastern Ukraine. This was a prospective study with a single center. Study design, including the inclusion criteria, study plan, treatment plan, final goals of treatment, treatment outcome parameters, and statistical analysis methods were established at the beginning of the clinical study.

The main inclusion criterion was the presence of a combat-related penetrating brain injury. In total, 184 patients were identified with combat-related brain injury; of those, 121 patients with penetrating brain injury were included in our study. Thus, penetrating and nonpenetrating brain injuries comprised 65.8% and 34.2%, respectively, of all injuries in the study. Notably, the study included some patients who were delivered to MDRCH in a deep coma (Glasgow Coma Scale [GCS] score at admission[3]). This may have contributed to worse general outcomes than those of other studies. However, this aspect of the study allowed analysis of all living patients delivered to MDRCH and assembly of a complete database to determine the appropriate outcome predictors.

Patients who sustained injuries during military operations in Eastern Ukraine were delivered to MDRCH by air or ground medical vehicles from field military hospitals (FMHs). Medical care in FMHs aimed to ensure airway patency, adequate oxygenation, stable hemodynamics, and bleeding control. Neurosurgical interventions of varying scope in military hospitals were performed in 44 (36.4%) patients. In patients with GCS score of ≤5, only entrance wound bleeding control was performed and retention sutures were applied.

The distance from the site where the injury occurred to the regional hospital ranged from 178 to 361 km (mean, 255.4 ± 62.5 km). The time from injury to delivery to MDRCH ranged from 3 to 219 hours (mean, 21.7 ± 31.5 hours). MDRCH is a 24/7 multidisciplinary medical facility with 1,200 beds, which has three urgent and 22 nonurgent surgical rooms, four resuscitation and intensive care units (42 beds overall), and three neurosurgical departments (120 beds overall). Two of the three neurosurgical departments specialize in the treatment of peacetime neurotrauma (cranial and spinal injuries and wounds). Upon admission to the regional clinical hospital, all patients were examined by anesthesiologists and intensive care physicians, neurosurgeons, surgeons, and traumatologists. If necessary, related specialists were also engaged: vascular surgeons, thoracic surgeons, maxillofacial surgeons, otolaryngologists, and urologists, which enabled the provision of adequate care for patients with combined injuries.[14] Head, neck, chest, abdomen, and lower pelvis helical computed tomography (HCT) scans were performed for all patients. Brain HCT was performed using an Optima CT660 (GE Healthcare, Chicago, IL, USA).

Demographic data were collected, including mechanism of injury, admission Injury Severity Score (ISS), admission GCS score (determined by a neurosurgeon upon patient admission), injury characteristics, and surgical interventions. Glasgow Outcome Scale (GOS) scores for all patients were independently determined at 12 months after the injury by two investigators during inpatient follow-up at that time.

### Outcomes and Statistical Analysis

Evaluation of treatment outcome included analysis of mortality at 1-month after the injury (survived/died) and dichotomous GOS score at 12 months (favorable/unfavorable outcome). Favorable outcome included the following: good recovery or moderate disability (≥4). Unfavorable outcome included severe disability, vegetative state, and death (<4).

Analysis of the relationships between mortality and outcomes in patients with combat-related penetrating brain injury was performed based on multiple groups of variables, including clinical and computed tomographic data, as well as the nature of therapeutic measures implemented. Descriptive statistics were calculated as means with standard deviations or percentages where appropriate. For all variables, Spearman's rank correlation coefficient was used. Significant correlations ($P < 0.05$) were subjected to additional analysis. For numerical (ordinal or continuous) variables, the Mann–Whitney $U$ test was used; for categorical variables, the Fisher's exact test was applied, in accordance with existing recommendations.[15] For statistically significant clinical factors, odds ratios with 95% confidence intervals were used. Statistical significance was set at $P < 0.05$. All data were analyzed using a statistical data processing software package, Statistica 64, version 12.

**TABLE I.** Demographic and Clinical Characteristics of the 121 Patients in the Study Cohort

| Variable | Value |
|---|---|
| Age, years, mean (range) | 34.1 (18–56) |
| Mechanism of injury, *n* (%) | |
| Blast | 101 (83.5) |
| GSWH | 20 (16.5) |
| Admission GCS score, mean (SD) | 10 (4) |
| 13–15 | 42 (34.7%) |
| 9–12 | 32 (26.4%) |
| 6–8 | 27 (22.3%) |
| 4–5 | 11 (9.1%) |
| 3 | 9 (7.4%) |
| Admission ISS, mean (SD) | 27.7 (7.6) |
| Mild to moderate, ISS ≤ 25, *n* (%) | 74 (61.2) |
| Severe to critical, ISS ≥ 26, *n* (%) | 47 (38.8) |
| Injury characteristics, *n* (%) | |
| Epidural hematoma | 8 (6.6) |
| Subdural hematoma | 36 (29.8) |
| Intracerebral hematoma | 66 (54.5) |
| Intraparenchymal contusion | 108 (89.3) |
| Intraventricular hemorrhage | 24 (19.8) |
| Subarachnoid hemorrhage | 41 (33.9) |
| Dural venous sinuses injury | 14 (11.6) |
| Vascular injury | 15 (12.4) |
| Brain stem injury | 4 (3.3) |
| Skull base damage | 41 (33.9) |
| Lateral dislocation | 31 (25.6) |
| Axial dislocation | 24 (19.8) |
| Surgical intervention, *n* (%) | |
| Resection trepanation | 58 (47.9) |
| Osteoplastic trepanation | 23 (19) |
| Decompressive craniectomy | 17 (14) |
| Removal of bone fragments | 87 (71.9) |
| Removal of metallic foreign bodies | 36 (29.7) |
| Skull base plastic repair | 30 (24.8) |
| Inflow-outflow drainage of brain wound | 58 (48.9) |

GCS, Glasgow Coma Scale; GSWH, gunshot wound to the head; ISS, Injury Severity Score; SD, standard deviation.

## RESULTS

### Patient Population

In total, 121 patients aged 18–56 years (mean, 34.1 ± 9.1 years) were included in the study. All patients were male soldiers. Upon admission, consciousness according to GCS score varied from 3 to 15 (mean admission GCS score, 10 ± 4), and patient condition according to ISS varied from 16 to 57 (mean admission ISS, 27.7 ± 7.6) (Table I).

Overall, 47 (38.8%) patients were in a comatose state (GCS score of 3–8) and 9 (7.4%) patients had a terminal state. In 101 (83.5%) patients, wounds were caused by mine blast fragments, whereas wounds in 20 (16.5%) patients were caused by small-arm bullets. The most frequent wounds were nonperforating and ricochet types, which were detected in 73 (60.3%) and 29 (24%) patients, respectively. Penetrating wounds occurred in 14 (11.6%) patients and tangential (gutter) wounds (the pressure waves generated by the bullet fractured the inner table) occurred in 5 (4.1%). Nearly half of the patients (50.4%) were diagnosed with isolated wounds. In total, 55 (45.5%) patients were diagnosed with combined wounds. In those patients, skull and brain wounds were combined with extracranial wounds (face, body, limbs, chest, abdominal cavity, and pelvic organs). A high percentage of combined wounds is associated with a high frequency of use of modern mine blasting devices. Five (4.1%) patients had combined wounds that, in addition to mechanical injuries from the injuring shell, included scalp and face burns of varying severity. These injuries were typically caused by mine explosion in the immediate vicinity of the patient.

Brain computed tomography (CT) most frequently revealed focal concussions of cerebral arteries and intracerebral hematomas. Nearly 1 in 3 patients had massive subarachnoid hemorrhage and skull base (anterior and/or middle cranial fossa) damage, and 1 in 4 patients (25.6%) had signs of lateral dislocation. The average midline shift was 7.5 ± 3.8 mm, and compression or lack of mesencephalic cistern visualization was present in 24 (19.8%) patients.

### Treatment

The overall goals of intensive therapy in the patients were stabilization or improvement of neurological condition; reduced severity of midline shift, based on HCT; maintenance of systolic blood pressure of ≥100 mmHg for patients aged 50–56 years and ≥ 110 mmHg for patients aged 18–50 years; elimination of hypoxia (avoidance of $PaO_2 < 60$ mmHg or $SatO_2 < 90\%$); maintenance of adequate cerebral perfusion pressure (60–70 mmHg); and monitoring and adjustment of intracranial hypertension (≤22 mmHg).[16] Prevention of infections in combat-related skull and brain wounds was performed in accordance with the United States military medicine recommendations on the selection and duration of antimicrobial therapy.[17]

Seventy-seven (63.6%) patients underwent operations in MDRCH. Neurosurgical interventions in hemodynamically stable patients were performed immediately upon admission. For hemodynamically unstable patients, the surgery was postponed until the condition had stabilized. Surgery had the following objectives: stop bleeding, prevent intracranial hypertension, and prevent infectious complications. The "brain" stage of the surgery was performed using an OPMI VARIO 700 microscope (Carl Zeiss, Oberkochen, Germany). ICP measurements were performed using parenchymal sensors on Spielberg's (Hamburg, Germany) REF HDM 26.1/FV500 Brain Pressure Monitor. ICP sensor was installed during the first surgery stage. Follow-up brain HCT was performed for all patients within 24 hours after surgery. Subsequently, the frequency of repeated brain HCTs was based on the behavior of the neurological condition and on dislocation syndrome, compared with previous HCTs.

Analysis of CT scans and intraoperative data allowed elucidation of some pathogenetic mechanisms of combat-related penetrating brain injury. Brain destruction in 85 (70.2%) patients was caused by the injuring projectile (bullet or fragment) itself, as well as by bone fragments that were severed by the projectile. In contrast, brain damage in 32 (26.4%) patients was caused by bone fragments alone when ricochet or tangential wounds occurred, or when a fragment became lodged in the bone. Thus, bone fragments, so-called "secondary injuring projectiles," participated in traumatic brain damage in 117 (96.7%) patients. In perforating, tangent, and ricochet wounds, metal fragments provided damaging force but were not detected in brain wounds. Only 4 (3.3%) patients had explosive skull base fractures with dura mater disruption and varying degrees of brain contusion.

According to brain HCT analysis, 73 (60.3%) patients had foreign metal density bodies (bullets/fragments) in the cranial cavity before surgery; this number was reduced to 29 (24%) patients after surgery. In addition, 117 (96.7%) patients had bone fragments in the cranial cavity before surgery; this number was reduced to 15 (12.4%) patients after surgery. Thus, surgical brain wound treatment resulted in removal of bone fragments and foreign metal density bodies in 84.3% and 36.3% of patients, respectively. This was due to the nature of penetration of such foreign bodies into brain wounds. Injuring projectile penetration, measured from the outer bone plate, was 18–199 mm (mean, 70.6 ± 33.7 mm). Bone fragment penetration was 12–84 mm (mean, 46.1 ± 19.7 mm).

Intracranial purulent-septic complications were diagnosed in 14 (11.6%) patients with combat-related penetrating brain injury: isolated meningoencephalitis in eight patients, meningoencephalitis combined with ventriculitis in three, meningoencephalitis combined with ventriculitis and subdural empyema in two, and recurrent meningoencephalitis complicated by multiple brain abscesses in one. Bacteriological analysis of cerebrospinal fluid (CSF) enabled identification of the pathogen in 12 patients. *Acinetobacter baumannii* was inoculated from CSF in five patients; *Klebsiella pneumoniae* and *Staphylococcus epidermidis* were found in two patients each; *Pseudomonas aeruginosa*, *Enterobacter agglomerans*, and *Enterococcus faecalis* were found in one patient each.

### Mortality and GOS Scores Depending on GCS on Admission

Within 1 month after the injury, 25 patients died; overall mortality was 20.7%. The findings of this study confirm that GCS score on admission is a predictor (Fig. 1 and Table II). Notably, mortality was 44.7% in patients with GCS score of ≤ 8 on admission, whereas it was 5.4% in patients with GCS score of ≥9 on admission ($P < 0.001$). The average GCS score in deceased patients was 5.1 ± 2.68.

Patients' major causes of death were as follows: primary severe brain damage with uncontrolled diffuse brain swelling/edema in 12 (48%) patients, primary severe brain stem damage in 3 (12%) patients, intracranial infection in 7 (28%) patients, systemic infection in 2 (8%) patients, and massive pulmonary thromboembolism in 1 (4%) patient.

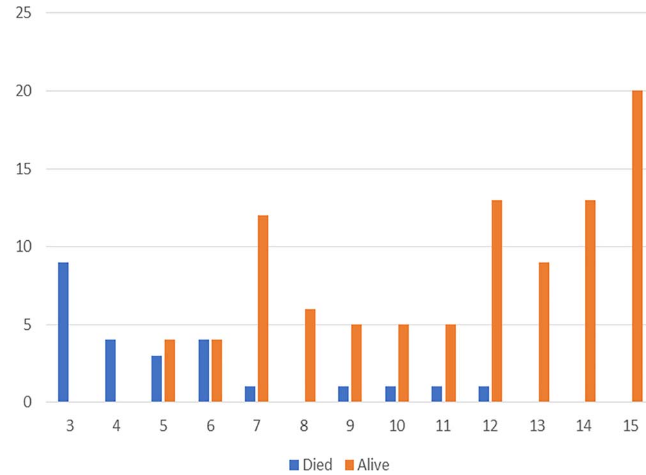


**FIGURE 1.** GCS score vs. treatment outcome at 1 month after the injury.

All nine wounded died with a GCS score of 3 points. The causes of death were primary severe brain stem damage in three and primary severe brain damage with uncontrolled diffuse brain swelling/edema in six. Among seven wounded dead with a GCS score of 4–5, the cause of death was uncontrolled cerebral edema in four, and infectious complications (two and one had intracranial and systemic infections, respectively) in three. Among five wounded dead with a GCS score of 6–8 points, two had uncontrolled cerebral edema, two had infectious complications, and one had massive pulmonary thromboembolism. Furthermore, in four wounded dead with a GCS score of 9–12 points, the main cause of death was intracranial infection. Thus, among patients with a low GCS score, the main cause of death was severe brain damage with uncontrolled edema. In addition, with an increase in the GCS score, infectious complications were the first among the other causes of death.

Favorable outcome (with GOS scores of 4 and 5) at 12 months from the injury was recorded in 79 (65.3%) patients with combat-related penetrating brain injury, whereas unfavorable outcome (with GOS scores of 1–3) was recorded in 42 (34.7%). Overall, 34% and 85.1% patients with GCS scores of ≤ 8 and ≥ 9 on admission had a favorable outcome, respectively, ($P < 0.001$). Average GOS score at 12 months after the injury was 3.64 ± 1.51.

### Predictors of Early Mortality and Long-term Functional Outcomes

Unfavorable predictive factors of mortality at 1 month after the injury and GOS-based functional outcome at 1 year after the injury were as follows: GCS score of ≤ 8 on admission; gunshot wound to the head (GSWH); dural venous sinuses wound; presence of intracerebral hematomas according to brain CT; intraventricular and subarachnoid

**TABLE II.** Mortality at 1 Month and Glasgow Outcome Score at 12 Months After the Injury, Depending on Glasgow Coma Scale Score on Admission

| GCS on admission | Died within 1 month after the injury, *n* (%) of total group size | Favorable outcome based on GOS at 1 year, *n* (%) |
|---|---|---|
| 13–15 | 0/42 (0) | 42/42 (100) |
| 9–12 | 4/32 (12.5) | 21/32 (65.6) |
| 6–8 | 5/27 (18.5) | 14/27 (51.9) |
| 4–5 | 7/11 (63.6) | 2/11 (18.2) |
| 3 | 9/9 (100) | 0/9 (0) |



hemorrhage; injuries accompanied by lateral or axial dislocation; and postoperative purulent-septic complications (Supplemental files).

As expected, patients with GSWH had the highest mortality: 50% of patients with gunshot wound died, whereas only 14.9% of patients with blast injury died. This is related to the speed of the injuring projectile, as well as the kinetic energy transmitted to skull bones and the brain itself. The highest mortality rates were identified in tangential and transient injuries (60% and 42.8%, respectively). In penetrating wounds, mortality was 19.2%, whereas it was only 6.9% in ricochet wounds. The presence of epidural hematomas or skull base damage was not a statistically significant predictor of unfavorable outcome. The presence of subdural hematoma did not affect the rate of positive outcomes at 1 year ($P = 0.09$) and was marginally significant for 1 month mortality ($P = 0.0472$).

In our study, patient age at the time of injury was not a significant predictor of survival ($P = 0.14$, Mann–Whitney U test) or functional outcome based on GOS at 1 year ($P = 0.11$, Mann–Whitney U test). Calculated odds ratios showed that at 1 year after the injury, patients with a GCS score of $\geq 9$ on admission had a favorable outcome with 11-fold greater frequency than those in a coma state (GCS $\leq$ 8) on admission. GSWH patients had an unfavorable outcome at 1 year with 3.6-fold greater frequency than blast injury patients. As expected, GOS-based unfavorable treatment outcomes at 1 year occurred 10-fold more frequently in the presence of purulent-septic complications than in patients without such complications. Mortality at 1 month after the injury was 20-fold more frequent in the presence of axial dislocation (a symptom of temporal-tentorial brain herniation) than in patients without signs of axial dislocation on cerebral HCT (Table III).

## DISCUSSION

In our study, treatment outcomes in combat-related penetrating brain injuries were similar to those previously reported. Notably, in a study by Larkin et al.,[3] mortality rate was 21% and average GOS score at 12 months was 3.8 [SD, 1.56]. However, the results in the present study are better than those reported by Fathalla et al.,[18] who performed a retrospective review of 102 patients with penetrating military missile head injuries in various facilities in northern Sinai between 2011 and 2018. In that study, the mortality rate was 49%; 11.8% of patients had a persistent vegetative state, and 39.2% of survivors had varying degrees of disability at the final follow-up.

Determination of predictors is important, especially when clinical treatment can have a significant impact on those factors. Different studies have revealed a variety of predictors of lethality and unfavorable long-term outcome. Larkin et al.[3] found that admission GCS score $\leq$ 5, GSWH, admission ISS $\geq$ 26, and brain herniation on admission HCT were all associated with worse GOS scores at all time points. Another study[18] identified an anatomical danger zone in which injuries were predictive of mortality. Bilateral dilated fixed pupils and low GCS score on admission were independent predictors of mortality and poor outcome. Tunthanathip et al.[5] found that midline shift and coagulopathy were treatable factors associated with an unfavorable outcome. Hence, in patients with blast-induced traumatic brain injury, reversal of an abnormal coagulogram is necessary as soon as possible to improve clinical outcomes. We conclude that brain shift management needs further study.

Our findings confirm that patients with low GCS score on admission have worse short- and long-term outcomes than those with higher GCS score on admission.[19–21] We also confirmed that patients with penetrating brain injury secondary to gunshot wound in our cohort had worse functional outcomes at all time points than those who had blast penetrating brain injury. One study[3] has shown mortality rates similar to ours in GSWH (41%) and blast penetrating brain injury (14%).

It is generally accepted that treatment outcomes of civilian penetrating brain injuries are significantly worse than those in the military population. In a study of 26,871 civilian patients over a 5 year period, the mortality rate was 43.8%.[13] The incidence of penetrating traumatic brain injury and associated mortality rate gradually increased over the 5 year period. Gunshot wounds were the dominant mechanism of injury (98.6%) in the study. Independent mortality predictors were age, prehospital intubation, suicide attempt, and craniotomy/craniectomy. Several factors can explain higher survival among the military: first, the use of protective gear (eg, helmets, body armor, and goggles) and the occurrence of blast

**TABLE III.** Odds Ratios for Clinical Characteristics Associated with Poor Outcome

| | OR (95% CI) | |
|---|---|---|
| | Mortality at 1 month | Unfavorable outcome based on GOS at 1 year |
| GCS ≤ 8 | 14.1 (4.43–45.1) | 11.1 (4.6–26.7) |
| GSWH | 5.7 (2–16.1) | 3.6 (1.3–9.6) |
| Intracerebral hematoma | 4.4 (1.5–12.5) | 3.5 (1.6–8.0) |
| Intraventricular hemorrhage | 8.4 (3.1–22.9) | 9.1 (3.2–25.6) |
| Subarachnoid hemorrhage | 14.3 (4.8–42.6) | 8.4 (3.6–19.7) |
| Dural venous sinuses injury | 3.5 (1.1–11.2) | 4 (1.3–13.0) |
| Lateral dislocation | 5.9 (2.3–15.3) | 3.2 (1.4–7.4) |
| Axial dislocation | 19.6 (6.6–58.2) | 12.2 (4.1–36.4) |
| Purulent-septic complications | 4.9 (1.5–15.8) | 10.1 (2.7–38.5) |

GCS, Glasgow Coma Scale; GSWH, gunshot wound to the head; OR, odds ratio; CI, confidence interval.

injury as the dominant mechanism of injury.[22–26] In contrast, GSWH causes massive skull and brain destruction because of the high kinetic energy generated by the high speed of injuring projectile (bullet); this is the dominant mechanism of injury in the civilian population.

The present findings confirm the adverse effect of intraventricular hemorrhage on wound treatment outcome. Erdogan et al.[27] noted that ventricular injury, especially involving intraventricular hemorrhage, is an important variable that is predictive of death and morbidity in patients with craniocerebral injuries. Surgical treatment, external ventricular drain, medical interventions, and close follow-up monitoring with CT scans are the major management procedures in such injuries. Many studies have shown the positive effect of decompressive craniectomy on patient survival.[9–11] Postoperative mortality was significantly lower when craniectomy was initiated within 5.33 hours after the injury. Further research to optimize craniectomy timing and mitigate delays is needed.[9] In addition, Ecker et al.[11] showed that in a selected group of patients who underwent bilateral or bicompartmental craniectomy, 60% were independent at long-term follow-up. Patients with bifrontal injury had the best outcome. Systemic infection and cerebrovascular injury were associated with worse outcomes.

## LIMITATIONS

The present study, only those patients included who were delivered to MDRCH for treatment. The study did not include patients who were hospitalized in other Ukrainian hospitals in the acute period; the study also did not include patients who died on the battlefield or prior to delivery to MDRCH, which may have led to better treatment outcomes in our group than might be observed among all soldiers with combat-related penetrating brain injuries. However, as mentioned above, all living patients who were delivered to MDRCH, including those in a terminal state, were entered in the study. Another limitation was that all patients in this study were men who had undergone medical examination before deployment to the theater of operations and who were considered fit for military service based on health condition.

Treatment outcomes could be negatively affected by delay in specialty military care (mean time of delivery to MDRCH was 21.7 ± 31.5 hours after the injury), which is associated with the territorial location of the hospital and tactical situations during military operations. In patients with vital indications for surgery and in patients with delayed evacuation, brain surgeries were performed by neurosurgeons at a military field hospital with minimal technical equipment (36.4% of all neurosurgical interventions). Nonetheless, the availability of a wide range of related specialists in MDRCH allowed for adequate care for associated and combined injuries; the presence of three specialty neurosurgical departments allowed performance of the most comprehensive surgeries possible using advanced equipment.

Prospective analysis within the study enabled collection of all demographic, medical history, clinical, brain HCT, and treatment outcome data of the included patients. In addition, all survivors continued regular medical checkup with follow-up examinations by relevant specialists in MDRCH. GOS score was assessed in-hospital at 12 months after the injury by two independent neurologists; no telephone survey or written questionnaire was used for this purpose.

## CONCLUSIONS

The characteristics of modern weapons and peculiarities of hybrid war in Eastern Ukraine caused a high rate of blast injury (83.5%), as well as associated and combined wounds of other organs and systems (49.6%). More than one-third (38.8%) of all patients with combat-related penetrating brain injury had GCS score ≤ 8 on admission. A high rate of blast injury is associated with uncontrolled use of mortars, artillery weapons, multiple launch rocket systems, and improvised explosive devices. Another peculiarity of military operations in Eastern Ukraine is the rare use of full individual protection (eg, helmets, glasses, and body armor) by soldiers during the first years of the war.

Generally, combat-related penetrating brain injuries had satisfactory treatment outcomes. The rate of mortality was 20.7%, and intracranial purulent-septic complications were diagnosed in 11.6% of the patients. In total, 65.3% of the patients had favorable outcome (good recovery or moderate disability) based on GOS score at 12 months after the injury. The following were predictors of mortality or poor functional outcome at 1 year after the injury: low GCS score on admission; GSWH; dural venous sinuses wound; presence of intracerebral hematomas; intraventricular and subarachnoid hemorrhage accompanied by lateral or axial dislocation; and the presence of intracranial purulent-septic complications.

Improvements in treatment outcomes were observed in relation to reduced time for patient delivery from the battlefield to the place of specialty medical care, improved prevention and treatment of purulent-septic complications, more frequent intracranial pressure monitoring, decompressive craniectomy based on indications, and improved personal protective equipment used by the military.

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