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CONTENTS

EXPERIENCE OF SURGICAL TREATMENT OF COMBAT GUNSHOT BIHEMISPHERIC CRANIOCEREBRAL WOUNDS IN A SPECIALIZED MEDICAL INSTITUTION

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Annotation. *The article discusses approaches to the treatment of combat bihemispheric craniocerebral wounds, the chosen tactics, and surgical techniques in a specific series of 14 clinical cases. Various predictors of poor outcome according to the literature and their statistical significance in a series of cases are considered. Treatment response and complications are presented. Conclusions have been made based on selected treatment approaches and obtained response.*

Key words: *combat trauma, craniocerebral wound, gunshot wound, brain debris, diametrical wound, bihemispheric wound, decompressive craniectomy, Glasgow outcome scale.*

Bihemispheric craniocerebral wounds (BHCW) are one of the most severe brain injuries, in which the trajectory of a wounding projectile crosses the midline. High mortality in this type of combat craniocerebral wounds (CCW) often leads to the fact that the term, BHCW, is associated with an incurable CCW type, which makes the treatment of this pathology a challenge for neurosurgeons and intensive care doctors.

1. High frequency of poor outcomes in bihemispheric CCW is caused by frequent damage to critical neurovascular structures and gross electrolyte disturbances [1]. Various predictors of poor outcome have been identified, the primary of which are: initially low Glasgow coma scale (GCS) score (3 to 4), bilateral fixed mydriasis, arterial hypotension at admission, diabetes insipidus [2–10], and a number of radiological signs.

Conventionally, in the cranial cavity in the Cartesian coordinate system, a geometric center (x=0, y=0, z=0) located at the top of the clinoid plate is identified [8]. Analyzing the relationship of mortality and trajectory of wounding projectiles in the brain matter, the researchers [8] identified the so-called zona fatalis, located 4 cm above the clinoid plate. The passage of a trajectory through this zone almost always led to death. A poor outcome is also associated [2] with the projectile passage through the X, Y, Z planes (passage through the geometric center in sagittal, coronary, and axial planes, respectively), through the posterior cranial fossa [8]. For combat CCW, as a predictor of poor outcome, we proposed an extended zone, the so-called danger zone, the boundaries of which are: cingulate gyrus superiorly, body of the C2 vertebra inferiorly, anterior commissure anteriorly, cerebellar tentorium and posterior cranial fossa posteriorly, and the line connecting the uncus and the claustrum laterally. Another radiological predictor is the "tram-track" sign [2], a presence of a hypo-intensive wound canal surrounded by a hyperdense zone.

2. Active study of various predictors of poor outcome has led to the widespread use of a conservative approach in the treatment of such patients. With a conservative approach in BHCW patients, mortality was 63.9 to 100% [11-13]. As for the treatment experience of both civil and combat BHCW, using an aggressive surgical approach [14, 15] is associated with improved treatment outcomes.

One of the arguments in favor of active tactics in relation to bone fragments is the risk of purulent-septic complications (PSC). Thus, bacteriological studies of bone fragments extracted from a brain wound indicate a high (45–83%, [16]) level of retained bones and bone fragments contamination. Presence of metallic foreign bodies in the cranial cavity does not increase the risks of PSC [16, 17] and there is no unambiguous data on their influence on the development of post-traumatic epilepsy [18], which justifies the tactics of minimal activity in relation to their removal.

3. In combat BHCW, a higher incidence of adverse outcome was identified (85.7%, [12]) compared with civil injuries (50%, [14]). This can be explained by the predominance of high-velocity projectiles in combat wounds and frequent conjoined nature of injuries, which is accompanied by blood loss and shock. Among the civil population, there is a higher mortality in suicides (often committed at point-blank range) and lower mortality in the pediatric population [14]. Tertiary care is also more accessible for civil patients.

Purpose of the study is to analyze the available literature data on this topic and evaluate the selected surgical tactics and immediate treatment outcomes in BHCW patients in our series of clinical cases.

Material and methods. The study includes combat gunshot penetrating craniocerebral wound (GPCW) patients admitted to the Mechnikov` Dnipropetrovsk Regional Clinical Hospital (DRCH) from May 25, 2014 to December 31, 2017 inclusive. All wounds were sustained during local armed conflict in the Eastern Ukraine.

Inclusion criteria were as follows: penetrating craniocerebral wound received in combat conditions, which by its computer tomography (CT) characteristics belongs to the group of bihemispheric injuries, requiring primary surgery or reoperation.

Exclusion criteria were as follows: extremely serious patient condition with a hemodynamic instability (terminal state).

Low value of consciousness level according to Glasgow Coma Scale (GCS) at admission was not an exclusion criterion. To obtain a complete picture, we even included patients with initial GCS score of 3 to 5.

At admission, all patients were examined by anesthesiology and intensive care physicians, neurosurgeons, surgeons, and traumatologists. If necessary, related specialists were also engaged. The consciousness impairment level was assessed according to GCS, condition severity given damage to various body segments was assessed according to the Injury Severity Score (ISS). All patients underwent neurological examination, and multi-slice brain spiral CT, followed by a three plane analysis and 3D reconstruction. According to initial multi-slice brain CT, the following was determined: the nature of brain damage, location, and characteristics of intracranial hematomas; the nature of the wound (bullet/fragment), and the nature of wound channel (blunt, perforating, rebounding, tangential); location, quantity, and nature of wounding projectiles.

The damage in both brain hemispheres caused by wounding projectile intersecting the midline was the CT criterion in BHCW. CCW cases where both hemispheres were injured but the alleged trajectories of wounding projectiles did not cross the midline were considered multiple and were not included in the study.

If there was a suspicion of an injury to large arterial trunks and dural venous sinuses (DVS), cerebral angiography (CAG) was performed.

When planning a surgery, the following brain CT indicators were taken into account:

- presence of mass foci (intracerebral hematoma, brain matter crushing focus, epidural or subdural hematoma);
- involvement of an eloquent area (motor cortex, language zones);
- depth, size, and number of bone fragments and metal foreign bodies;
- wounding projectile trajectory in the cranial cavity, presence of a rebound in the cranial cavity;
- wound canal nature (its three-dimensional orientation); its length, width, and orientation relative to the midline cerebral structures, main arteries, DVS;
- transventricular wound nature (wounding projectile passage through cerebral ventricular system);
- transbasal wound nature (wounding projectile passage through paranasal sinuses, mastoid process, or petrous pyramid);
- severity of lateral/axial dislocation, basal cisterns condition.

All obtained data was added to a patient's clinical record. Based on patient's condition severity and brain CT data, a decision on urgent surgery or intensive therapy until condition stabilization followed by surgical intervention was made. Surgical intervention included the following key steps:

1. entrance and exit wounds treatment;
2. craniotomy/craniectomy/decompressive craniectomy if required;
3. removal of intracranial hematomas;
4. cerebral debridement;
5. installation of an inflow-outflow drainage system for the brain wound/subdural space/ventricular external drainage (if necessary);
6. watertight dural closure using autogenous tissues (periosteum, fascia lata);
7. wound closure;
8. plastic skin defects closure.

Given the bihemispheric nature of the damage, it was necessary, first of all, to determine the need for surgical intervention from two sides. The first intervention was performed on the side with a larger mass lesion, which was assessed by measuring the linear dimensions and volume of the mass focus itself, the presence of lateral brain shift (in mm from the midline). In case of significant mass focus volume contralaterally (its volume in linear measurements/volumetry, indirect signs of mass effect on the surrounding brain structures), an additional contralateral intervention was performed. The purpose of the surgical intervention was: correction of intracranial hypertension (ICH): removal of intracerebral hematoma, brain debris, brain contusion focus, epidural or subdural hematomas, brain wound debridement (removal of bone fragments, foreign bodies, or debris), and intracranial space sealing.

Surgical technique. For brain debridement (BD), we used a Frazier suction cannula with vacuum control. For hemostasis, bayonet-shaped bipolar forceps and a diathermy coagulation device were used. Aspiration and coagulation were accompanied by abundant irrigation of the surgical field with saline solution heated to 37 °C. When treating a wound canal or an extensive crush zone of the brain tissue and contusion foci causing a mass effect, brain debris aspiration and mild removal of partially viable brain tissue (perifocal zone), characterized by increased bleeding and hyperemia, were performed. When working medially and in the eloquent area (e.g. motor zone), BD was limited to brain debris aspiration and, if necessary, low-current punctual coagulation of a bleeding artery.

When BD was performed in the non-dominant hemisphere, it was carried out more aggressively (non-viable tissues were removed more radically, a larger volume of the perifocal zone was removed).

During the BD, bone fragments and superficially located metallic foreign bodies were removed as radically as possible. Deep or remote (on the opposite side) metal foreign bodies were not removed (except for the cases of mass focus formation at the location of a foreign body, which requires removal). In some cases of increased capillary bleeding from the brain parenchyma after the BD, a surgical oxidized cellulose gauze was used for hemostasis. After controlling hemostasis and for sanitation purposes, an inflow and outflow system was installed in the subdural space. One perforated silicone tube, with a diameter of 3 mm (inflow) was installed in the cavity formed in the brain matter, the wound canal, another one subdurally in the frontal direction (outflow) or more proximal of the inflow tube in the wound canal; the tubes were brought out through the skin counterpunctures at a distance of at least 3 to 5 cm from the skin incision. Thereafter, watertight dural closure with autotissues (periosteum, temporal fascia, or fascia lata), bone flap installation, and tight wound closure were carried out. In cases with initially low GCS score and the presence of extensive zones of crushing and brain matter edema with cistern compression, or lateral/axial dislocation, the BD was preceded by the DC: lateral (frontotemporoparietal), or bifrontal/bifrontotemporal.

Postoperative patients remained in intensive care unit. Laboratory indicators were checked several times a day. Follow-up brain CT was performed within 12 hours after the surgery. Additional brain SCT was carried out, if necessary, in each individual case. Glasgow Outcome Scale (GOS) score was assessed at discharge.

Statistical assessment of the study. For statistical processing of the obtained results, we used the dichotomous distribution of Glasgow Outcome Scale (GOS) scores, categorizing them into two groups: good outcome (GOS 4 to 5) and poor outcome (GOS 1 to 3). GOS dependence on various clinical and demographic factors was investigated using a chi-squared/Fisher's test.

All calculations were made in Statistica for Windows, version 10 (StatSoft ® Inc., USA, license No. AXXR505C705306FAN12).

Study results and discussion. The study included 14 male patients. The patients' age was from 19 to 45, avg. 32.3±7.6. Glasgow Coma Scale score at admission ranged from 3 to 12, avg. 5.1±2.7. Blunt wounds (n=9, 64.3%) prevailed. Detailed demographic and key clinical characteristics are shown in Table 1.

Table 1

Key demographic, clinical, and SCT characteristics

Characteristics	N (%)/m±SD (min–max)
Average age, y.o.	32.3±7.6 (19–45)
GCS score at admission	5.1±2.7 (3–12)
ISS score at admission	29.8±7.6 (25–43)
Bullet	4 (28.6)
Shell fragment	10 (71.4)
Isolated CCW	7 (50)
Concomitant CCW	5 (35.7)
Combined CCW	2 (14.3)
Blunt	9 (64.3)
Perforating	5 (35.7)
Diametral	14 (100)
Trajectory through the danger zone	8 (57.1)
Total	14 (100)

**The table contains absolute values (N), arithmetic mean (m) ± standard deviation (SD), with a range of values (min to max) or relative percentage (%) is presented in brackets.*

Initially, 10 (71.4%) patients were operated in our hospital. 2 (14.3%) wounded were re-operated after the surgeries in a stage 1 hospital, performed without brain CT (according to clinical and craniography data). In 2 cases after a surgery in a stage 1 hospital, reoperation was not performed.

Time of patients delivery to our hospital after the injury was 7.6±3.5 (2–16) hours. For the patients operated in a stage 1 hospital, the surgery was carried out within 1–2 hours from the moment of injury. In all cases (n=14), patient transportation to our hospital was carried out by air (helicopter).

Majority (n=10, 71.4%) of patients had traumatic cerebro-spinal fluid (CSF) leakage and brain debris (n=5) at admission, one patient had meningoencephalitis.

According to brain CT, 7 (50%) patients had lateral dislocation of 4 to 18 mm. 7 (50%) patients had signs of axial dislocation.

Most often, craniectomy was performed (n=7, 50%), but 3 patients of those 7 underwent bilateral surgery (a combination of craniectomy with DC (n=2) and craniotomy (n= 1)). 6 (42.8%) patients underwent decompressive craniectomy (DC). In one case, trepanation was not performed during a surgery in a stage 1 hospital (debris, hematoma, and bone fragments were removed through a bone defect formed by the wound). During the surgery, bone fragments and brain debris were removed in all (n=14) patients. In the majority of patients, the surgery ended with inflow and outflow drainage of the brain wound (n=10, 71,4%). Detailed description of the performed surgical interventions is shown in Table 2.

Table 2

Scope of surgical interventions

Surgery stages	One-side surgery, n (total - 11)	Bilateral surgery, n (total - 3)	**Total (14)**
Trepanation type			
Craniectomy	4	3	**7**
Craniotomy	2	1	**3**
Decompressive craniectomy	4	2	**6**
Brain debridement, etc.			
Bone fragments removal from the brain	11	3	**14**
Metallic foreign bodies removal	3	1	**4**
Brain debris removal	11	6	**17**
Intracerebral hematoma removal	9	3	**12**
Skull base plastic repair	3	-	**3**
Inflow and outflow drainage	8	2	**10**

4 patients underwent repeated surgeries (ventriculostomy in hydrocephalus (n=2), bone fragments removal (n=1), or subdural hygromas drainage (n=1).

In 3 patients, bone fragments remained in the brain postoperatively, which in one case required reoperation.

All metal foreign bodies were removed intraoperatively in 4 cases. In 6 (42.8%) patients, metallic foreign bodies remained postoperatively.

3 (21.4%) patients had intracranial purulent complications (meningoencephalitis and ventriculitis), which in all cases (3/3) was accompanied by sepsis and multiple organ dysfunction syndrome (MODS). Mortality in the study group was 42.8% (n=6). All 3 patients with meningitis and MODS died. 2 other patients who died had primary severe brain damage with total cerebral ischemia, one patient had damage to the diencephalic structures along with development of gross electrolyte disturbances.

Almost one fifth of the patients (n=3, 21,4%) had good recovery (GOS 4 to 5). Complications and outcomes are shown in Table 3.

Poor outcome (GOS 1–3) was associated with initially low (3 points) GOS score ($p<0.05$), meningitis ($p=0.025$), and wounding projectile passage through the danger zone ($p=0.006$). Poor outcome in the study was not associated with axial or lateral dislocation ($p>0.3$), which is probably due to timely and fully performed surgery to eliminate such dangerous complication and predominant damage to one hemisphere in the presence of dislocation. No GOS association with other independent variables was found (p>0.05). No intracranial purulent complications association with the duration of inflow and outflow drainage of subdural space, bone fragments left in the brain, ventricular hemorrhage and wound CSF-leakage, or metal fragments in the brain matter was identified.

Table 3

Complications and GOS in the acute period of the CCW.

Complication	GOS 1 (n=6)	GOS 3 (n=5)	GOS 4–5 (n=3)	Total frequency
Meningitis	3	-	-	3 (21.4%)
Ventriculitis	3	-	-	3 (21.4%)
Empyema	1	-	-	1 (7.1%)
Hydrocephalus	1	-	-	1 (7.1%)
Cerebrospinal rhinorrhea	-	1	-	1 (7.1%)
MODS	4	-	-	4 (28.5%)

Discussion. Zona fatalis, as a predictor of poor outcome, is described in the context of civil injuries by a low velocity projectile [6]. As for combat injuries, we primarily deal with a high-velocity projectile as a result of shell explosions. In such fragments, greater kinetic energy leads to the expansion of the damage zone to the brain matter along the wound canal, and therefore it is more advisable, particularly in our opinion, to use the "extended" version of zona fatalis, the so-called danger zone, as Fathalla et al. suggested [4]. Nevertheless, a number of publications [19, 20] indicate that even with the involvement of the danger zone, favorable treatment outcomes are possible.

The mortality rate (42.8%) in our series of cases is comparable with the literature data, where mortality in bihemispheric wounds reaches 82% [11]. Analyzing the causes of mortality it should be noted that two cases with adverse outcome were initially incurable (extensive zones of secondary cerebral ischemia) and in three cases with meningoencephalitis, electrolyte disorders (initially, probably they had diencephalic genesis) and MODS quickly developed. Only one patient had diabetes insipidus.

When determining the indications for surgical treatment, we used a balanced approach — a surgery is performed for the patients with stable hemodynamics, compensated blood parameters (replenished blood loss, etc.) and no signs of spread ischemic changes on brain SCT. Surgical tactics was quite aggressive: wide DC use, active removal of crushed zones of brain matter and, if possible, compromised perifocal zone, the most radical removal of bone fragments. In the study, DC was performed in almost half of the patients (n=6, 42.8%). It is noteworthy that mortality in patients who underwent DC was 33.3% (2/6) (lower than in the entire group), but at the same time, patients with severe neurological disorders predominated among the survivals. 66.7% of the survived patients who underwent DC were deeply disabled (GOS 3).

When brain debridement was performed in the medial sections of the wound canal, manipulations were minimized (washing off debris and blood clots with a saline stream and using low-current only bipolar coagulation) to prevent iatrogenic damage to vital brain structures. In case of blunt wounds in our series, a metal foreign body was only removed if it was necessary to remove the mass focus and the fragment was in close proximity to the surgical area.

Purulent complications developed in 21.4% patients, which also correlates with the literature data [3–5, 7]. Often [2–9, 19], researchers associate PSC with initial wound CSF-leakage or paranasal sinuses wound, but in our series we did not identify reliable predictors of such complications.

Conclusions. 1. Bihemispheric gunshot craniocerebral wounds are characterized by the highest mortality rates compared with other penetrating craniocerebral wounds.

2. Wounding projectile trajectory through zona fatalis or danger zone leads to significant increase of mortality.

3. Combat gunshot bihemispheric craniocerebral wounds are characterized by better treatment response compared with the treatment response of peacetime BHCW.

4. Active surgical tactics in the treatment of BHCW patients with admission GCS score of 5 or higher ensures improvement in treatment outcomes compared with conservative treatment.

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