

# Surgical management of battle gunshot injuries to the dural venous sinuses, combined with brain injury: an analysis of series of observations

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A – research concept and design; B – collection and/or assembly of data; C – data analysis and interpretation; D – writing the article; E – critical revision of the article; F – final approval of the article

## Key words:

combat head injury, venous sinus injury, superior sagittal sinus.

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**The present study aimed** to summarize the literature data about wounds to the dural venous sinus (DVS) and validating the importance of surgery in a series of clinical observations in patients with craniocerebral gunshot wound (CGW) sustained in battles with the DVS wound.

**Materials and methods.** We conducted a retrospective analysis of the clinical records and long-term outcomes in patients who were admitted to our medical center from 05/2014 to 12/2017. The study included soldiers with gunshot DVS wounds sustained in battles, who presented with the Glasgow Coma Scale (GCS) score  $\geq 4$ . Upon admission, damage to the DVS was diagnosed based on spiral computed tomography (SCT) imaging and/or was identified during surgery. All the patients underwent SCT imaging on admission and 12 hours after surgery. When severe damage to the DVS was suspected, cerebral angiography (CAG) was performed. The age, initial GCS score, the Injury Severity Score, location and nature of injuries to the DVS, the location and nature of brain injury, the volume of surgical interventions and the presence of complications in a postoperative period were taken into account. The outcome data included an assessment of the Glasgow Outcome Scale (GOS) in 6 and 12 months.

**Results.** Of 241 patients with CGW sustained in battles, 21 (8.7 %) presented with wounds to the DVS. The average initial GCS score was  $10.0 \pm 3.7$ . Superior sagittal sinus wound was identified in 20 (95.2%) patients and straight sinus wound – in one (4.8 %) patient. Wound to one DVS wall was identified in 15 (68.2 %) cases, wound to two DVS walls – in five (22.7 %) cases, and complete DVS damage (transection) – in two (9.1 %) cases. Twenty (95.2 %) patients presented with DVS wound combined with brain injury: one in the lobe in 10 (47.6 %) patients and  $\geq 2$  lobes in 10 (47.6 %) patients. All the patients underwent surgery. CAG was performed in five (23.8 %) patients. DVS ligation was performed in four (19 %) patients. Five (23.8 %) patients had meningitis, three (14.3 %) patients died. After 6 months, five (23.8 %) patients recovered well (GOS score of 5), 12 (57.1 %) had moderate disability (GOS of 4), and one (4.8 %) had severe disability. The significant factors of good outcome within 6 months after the injury were age ( $P = 0.04$ ) and GCS score on admission ( $P = 0.01$ ).

**Conclusions.** The DVS repair via surgery in case of concomitant brain matter injury must be performed very cautiously because of a high risk of developing hemorrhagic complications due to early use of anticoagulants. The feasibility of surgical DVS repair in case of transection can be assessed in large neurosurgical centers for such pathology management to obtain more data.

## Ключові слова:

бойові поранення голови, вогнепальне черепно-мозкове поранення, пошкодження венозного синуса, верхній сагітальний синус.

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## Хірургічне лікування бойових вогнепальних поранень дуральних венозних синусів, що поєднані з пошкодженням головного мозку: аналіз серії спостережень

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**Мета роботи** – узагальнення наявних даних літератури та обґрунтування правильності обраної тактики лікування в наведеній серії клінічних спостережень у пацієнтів із пораненням дуральних венозних синусів (ДВС) при бойових вогнепальних черепно-мозкових пораненнях (БВЧМП).

**Матеріали та методи.** Виконали ретроспективний аналіз даних медичних карт і віддалених результатів лікування з травня 2014 р. до грудня 2017 р. У дослідження залучили військовослужбовців із БВЧМП із пораненням ДВС із початковим рівнем свідомості за шкалою ком Глазго (ШКГ) 4 бали і більше. Усім пацієнтам здійснили спіральну комп'ютерну томографію головного мозку (ГМ) при надходженні та протягом 12 годин після операції. Якщо виникало припущення про тяжке ушкодження ДВС, виконували церебральну ангіографію (ЦАГ). Враховували вік, початкові значення за ШКГ, значення Injury Severity Score, локалізацію, характер поранення ДВС, локалізацію та характер пошкоджень ГМ, обсяг оперативних втручань, наявність ускладнень у післяопераційному періоді. Результати включали оцінювання за шкалою наслідків Глазго (ШНГ) через 6 і 12 місяців.

**Результати.** Із 241 поранених із БВЧМП у 21 (8,7 %) діагностували поранення ДВС. Середнє значення за ШКГ при надходженні –  $10,0 \pm 3,7$  бала. Поранення верхнього сагітального синуса виявили у 20 (95,2 %) хворих, прямого синуса – в одного (4,8 %). Поранення однієї стінки синуса виявили в 15 (68,2 %) випадках, двох стінок ДВС – у 5 (22,7 %), повне пошкодження ДВС (трансекція) – у двох (9,1 %) випадках. У 20 (95,2 %) випадках поранення ДВС поєднувалося з ушкодженням ГМ. ЦАГ виконали у 5 (23,8 %) випадках. Перев'язку ДВС виконали в 4 (19,0 %) випадках. Менінгіт розвинувся в 5 (23,8 %) випадках. Померли 3 (14,3 %) пацієнти. Гарне відновлення (ШНГ 5 балів) через 12 місяців – у 8 (38,1 %) пацієнтів, помірна інвалідизація (ШНГ 4 бали) через 12 місяців – у 10 (47,6 %). Факторами, статистично значущими для позитивного результату через 6 місяців від часу поранення, були вік хворого ( $p = 0,04$ ) та оцінювання за ШКГ при надходженні ( $p = 0,01$ ).

**Висновки.** Хірургічне відновлення ДВС при одночасному пошкодженні ГМ необхідно виконувати з обережністю через високий ризик геморагічних ускладнень при ранньому застосуванні антикоагулянтів. Доцільність хірургічного відновлення ДВС у разі перетину може бути оцінена у великих нейрохірургічних центрах, які займаються такою патологією, при більшій вибірці.

## Хирургическое лечение боевых огнестрельных ранений дуральных венозных синусов, сочетанных с повреждением головного мозга: анализ серии наблюдений

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**Цель работы** – обобщение имеющихся данных литературы и обоснование правильности выбранной тактики лечения в представленной серии клинических наблюдений у пациентов с ранением дуральных венозных синусов (ДВС) при боевых огнестрельных черепно-мозговых ранениях (БОЧМР).

**Материалы и методы.** Выполнен ретроспективный анализ данных медицинских карт и отдаленных исходов лечения с мая 2014 г. по декабрь 2017 г. В исследование включены военнослужащие с БОЧМР с ранением ДВС с уровнем сознания по шкале ком Глазго (ШКГ) 4 балла и более при поступлении. Всем пациентам выполнена СКТ головного мозга (ГМ) при поступлении в течение 12 часов после операции. При подозрении на тяжелое повреждение ДВС проведена церебральная ангиография (ЦАГ). Учитывали возраст, уровень сознания по ШКГ, значение Injury Severity Score (ISS), локализацию, характер ранения ДВС, локализацию и характер повреждений ГМ, объем оперативных вмешательств, наличие осложнений в послеоперационном периоде. Данные исхода включали оценку по шкале исходов Глазго (ШИГ) через 6 и 12 месяцев.

**Результаты.** Из 241 мужчин с БОЧМР у 21 (8,7 %) диагностировано ранение ДВС. Среднее значение по ШКГ при поступлении –  $10,0 \pm 3,7$  балла. Ранение верхнего сагитального синуса установлено у 20 больных (95,2 %), прямого синуса – у одного (4,8 %). Ранение одной стенки синуса диагностировано в 15 (68,2 %) случаях, двух стенок ДВС – в 5 (22,7 %), полное повреждение ДВС (трансекция) – в 2 (9,1 %) случаях. В 20 (95,2 %) случаях ранение ДВС сочеталось с повреждением ГМ. ЦАГ выполнена в 5 (23,8 %) случаях. Перевязка ДВС выполнена в 4 (19 %) случаях. Менингит развился в 5 (23,8 %) случаях. Умерли 3 (14,3 %) пациента. Хорошее восстановление (ШИГ 5 баллов) через 12 месяцев – у 8 (38,1 %) пациентов, умеренная инвалидизация (ШИГ 4 балла) через 12 месяцев – у 10 (47,6 %). Факторами, статистически значимыми для хорошего исхода через 6 мес. с момента ранения, были возраст больного ( $p = 0,04$ ) и оценка по ШКГ при поступлении ( $p = 0,01$ ).

**Выводы.** Хирургическое восстановление ДВС при сочетанном повреждении ГМ необходимо выполнять с осторожностью из-за высокого риска развития геморрагических осложнений при раннем применении антикоагулянтов. Целесообразность хирургического восстановления ДВС в случае пересечения может быть оценена в крупных нейрохирургических центрах, занимающихся такой патологией, при большей выборке.

**Ключевые слова:**  
боевые  
ранения головы,  
огнестрельное  
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повреждение  
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Gunshot wound to the dural venous sinus (DVS) is a rare and severe complication of battle gunshot craniocerebral wound. Battle gunshot DVS wounds accounted for 4.0–12.4 % of penetrating craniocerebral wounds [1–3]. Approximately 69.6–80.0 % of cases involved superior sagittal sinus (SSS) wounds [3–5].

The unique features of the clinical course and surgical treatment of DVS wounds during World War I were described by Sargent and Holmes, Nutal, and Cushing [1,6,7]. After World War II, Matson described a surgical technique for the different types of DVS injuries in detail [8]. After the Korean War, Meirowsky [4] presented the detailed classification of DVS wounds based on anatomical characteristics, presence of damage in the dura mater, type of injury, combination with intracranial hematomas, and presence of skeletal damages. During subsequent decades, this classification did not change significantly.

Although there have been several military conflicts over the past decades, treatment of battle gunshot DVS wounds are not elucidated fully in modern literature. Earlier studies have only focused on damage to the DVS. When evaluating the outcomes, the authors did not consider combined injury to the brain matter and how combined brain injuries affect the management of DVS wound [3–5].

### Aim

The present study aimed to summarize the literature data about wounds to the dural venous sinus (DVS) and validating the importance of surgery in a series of clinical observations based on the combined approach used for the surgical management of patients with craniocerebral wounds sustained in battles.

### Materials and methods

The institutional review board of Mechnikov Dnipropetrovsk Regional Clinical Hospital approved this study. All patients with war-related gunshot head injury were assessed between May 9, 2014 and December 31, 2017. An informed consent to participate in the study was signed at hospital admission. If the patient had an impaired consciousness on admission to hospital, the consent to participate in the study was signed by his legal representative. In these cases, patients recovering consciousness were asked for an additional consent as soon as feasible.

Wounds were sustained during local armed conflict in the East of Ukraine.

The study included soldiers with an initial Glasgow Coma Scale (GCS) score  $\geq 4$  upon admission to our center and with DVS wound that was confirmed via brain spiral computed tomography (SCT) scan (Astelion, Toshiba, Japan; Hi Speed CT/e DUAL, General Electric, USA), cerebral angiography (CAG) (Integris V3000, Philips, Netherlands; Innova IGS 540, General Electric, USA) and/or surgery. Upon admission, every patient underwent assessment of GCS score and Injury Severity Score (ISS), neurological examination, and multi-slice brain SCT imaging with further analysis using multi-planar and three-dimensional reconstruction (3D reconstruction). Based on the initial brain SCT scan, we determined the characteristics of brain matter injury: one lobe and two or more lobes, transventricular nature of a wound, location and characteristics of intracranial hematomas, nature and degree of sinus damage, and nature of wound (bullet/shell fragment).

Criteria to suspect the injury of the DVS:

– an open wound with a profuse venous bleeding in the projection of DVS (SSS, transverse, sigmoid sinus);

**Table 1.** DVS wounds nature and location; their association with intracranial injuries and volume of surgery

Location of sinus injury	Nature of sinus injury					Nature of intracranial injuries (SCT)					Volume of surgical intervention				
	1 wall	2 walls	1 wall + lacunae	3 walls	Total	Focal contusion/ICH	EDH	SDH	Trans-ventricular	Skull base injury	SDH removal	EDH removal	ICH removal	DC	Skullbase reconstruction
SSS, anterior third	2	3	1	1	7	13	–	3	1	3	3	–	10	3	3
SSS, middle third	4	1	2	–	7	8	2	3	–	–	3	2	6	–	–
SSS, posterior third	4	1	–	1	6	10	–	1	3	–	1	–	8	–	–
Straight sinus	1	–	–	–	1	1	–	–	–	–	–	–	1	–	–
Total, cases	12*	5	3	2	22*	32	2	7	4	3	7	2	25**	3	3

\*: a sigmoid sinus injury; \*\*: 7 patients had bihemispheric brain injury, 3 patients had bilobar injury within one hemisphere; EDH: epidural hematoma, SDH: subdural hematoma, ICH: intracerebral hematoma.

- the presence of bone fragments in the area of DVS (SCT imaging);
- the presence of a skull fracture crossing the place of the external DVS wall attachment to the skull;
- close location or direct contact of the DVS wall with a foreign body (wounding projectile, bone fragment) with / without an intracerebral hematoma formation.

When severe injury to the DVS was suspected, cerebral angiography was performed. All data were added to a patient's clinical record. Based on the severity of a patient's condition and brain SCT data, a decision about urgent surgery or intensive therapy until stabilization of condition followed by a surgical intervention was made. All the patients underwent surgery (craniotomy / craniectomy / decompressive craniectomy) based on indications, surgical debridement of brain wound, removal of intracranial mass (epidural, subdural, and intracerebral hematoma / brain contusion focus), removal of bone fragments, accessible foreign metallic bodies, control of bleeding in the DVS, primary duraplasty, and watertight wound closure. Based on the location and nature of venous sinus damage, defect in the DVS was closed or sinus was ligated. Postoperative patients remained in the intensive care unit. Laboratory indicators were assessed several times a day. Follow-up brain CT scan was performed within 12 h after the surgery. The Glasgow Outcome Scale (GOS) score was evaluated after 6 and 12 months via structured phone interview with patients or their relatives as per guideline [9].

The GCS score in patients upon admission is usually obtained to assess the level of consciousness. However, some of the patients (n = 3) were sedated and underwent tracheal intubation prior to a level 2 transportation. Hence, the level of consciousness upon admission could not be assessed using GCS score. In such cases, GCS score before sedation / intubation was obtained from supporting documents, which might be inaccurate.

To ensure clinically significant GOS score, all the scores were classified as good outcome (4–5) or poor outcome (1–3). The relationship between GOS and categorical variables was determined using the Mann–Whitney U test (Wilcoxon's signed-rank test) and Kruskal–Wallis test (for several independent groups), and a P value ≤0.05 was considered as significant. Spearman's rank correlation coefficient was used to determine the correlation between GOS and various quantitative variables. STATISTICA 10 for Windows (StatSoft © Inc., USA, license No AXXR505C705306FAN12) was used for all analyzes.

## Results

A total of 241 patients were identified, of whom 21 with DVS wounds were included in our study. The average age of the patients was 29 ± 8.5 (range: 18–48) years. All the patients were men. The average follow-up period for the patients who survived was 18 (range: 12–22) months. Regarding the DVS wounds, there were 10 (48 %) cases of multilobar brain damages, 10 (48 %) cases of one lobe damage and one (4 %) patient without brain injury; 17 (81 %) cases of shell fragment wounds, 4 (19 %) cases of bullet wounds; penetrating wound – in 7 (33.3 %) cases, perforating (through-and-through wound) – in 5 (23.8 %) cases, gutter-like wound – in 9 (42.9 %) cases. A non-penetrating injury was identified in one (5 %) case (there was no dura mater injury, and only the outer SSS wall was damaged) and penetrating injury was identified in 20 (95 %) cases. The average GCS upon admission was 10.0 ± 3.7 (range: 4–15). Average ISS score was 26 (range: 17–44). Average time from injury to admission was 14 (range: 2–44) hours.

Most patients (n = 19, 90.5 %) had isolated SSS injury. One patient had straight sinus wound; another patient (n = 1) presented with both SSS and sigmoid sinus wound. Wounds to SSS posteriorly to Rolando's veins entering (middle and posterior third of the SSS) were observed (n = 13). There were four (19 %) patients with combined injuries to the head.

In five cases, cerebral angiography was performed to identify the patency of the sinus and to evaluate the function of collateral vessels.

Table 1 depicts the detailed characteristics of the location and nature of DVS injuries and the association between intracranial wounds and volume of surgical intervention.

If one or two walls of the sinus or lateral lacunae were damaged, Tachocomb® was used or wall defect suturing was conducted to control bleeding. In two cases of transection, sinus ligation was performed more proximally and distally from the area of injury (anterior third of the SSS in the first case and the first part of the posterior third of the SSS in the second case, respectively). In three cases, thrombosis in the posterior third of the SSS and the region of sinus confluence was identified via CAG or surgery (case of injury of the lateral wall of the posterior third of the SSS).

Among 32 focal brain injuries (contusion foci, intracerebral hematomas), in seven cases, the wound was bihemispheric, and three patients had multilobar injury in one hemisphere. A total of 25 mass lesions in 19 patients were evacuated, and the remaining seven brain contusions had no clinically significant mass effect and were not removed.

The most severe intracranial damages were diagnosed in cases of injury in the anterior third of the SSS. Bilateral intracerebral hematomas were removed in three patients, and the presence of massive cerebral edema with axial or lateral dislocation required decompressive craniectomy (DC) (bifrontal in two cases, left-sided in one case) if this was the case. Injury in the anterior cranial fossa base required plastic repair of the skull base in two of these cases.

None of the patients who underwent anterior cranial fossa plastic repair was diagnosed with nasal cerebrospinal fluid (CSF) leaks. In one case, bifrontal DC caused encephalomeningitis, which was treated later with antibiotics.

Intracranial purulent-septic complications were observed in 5 (23.8 %) patients. Meningitis associated with ventriculitis in three cases) was diagnosed along with transbasal injury when paranasal sinuses were damaged ( $n = 1$ ), in cases of transventricular injury ( $n = 3$ ) and in case of systemic infection ( $n = 1$ ). In all these cases ( $n = 5$ ), CSF lumbar drainage was performed. After CSF draining, one patient developed multiple organ dysfunction syndrome with fatal outcome.

Of the seven patients with penetrating injuries, foreign metallic bodies were removed in three patients. However, to avoid an additional brain matter injury, the bodies were left inside in four patients.

The average duration of intensive care unit (ICU) stay was  $12.1 \pm 10.9$  (range: 2–42) days. The average GCS at discharge was  $14.4 \pm 0.7$  (range: 13–15).

After 6 and 12 months, five (23.8 %) and eight (38.1 %) patients, respectively, had a good recovery (GOS of 5). Moderate disability (GOS of 4) was observed in 12 (57.1 %) and 10 (47.6 %) of patients after 6 and 12 months, respectively. Only one (4.8 %) patient with severe disability (GOS of 3) underwent follow-up after 6 months, and none of the patients were in vegetative state (GOS of 2) during the follow-up period. Therefore, from 6 to 12 months postoperatively, four patients had a good outcome based on the GOS. Mortality was observed in 14.3 % ( $n = 3$ ) of patients.

DC ( $n = 3$ ) was associated with good outcome (GOS of 4 after 6 months).

The most significant factor ( $P = 0.01$ ) of good outcome after 6 months with positive correlation was the initial GCS score. The negative correlation between age and good outcome after 6 months was also identified ( $P = 0.04$ ).

The data provided in Tables 2 and 3 show the GOS score after 6 and 12 months and its correlation with various clinical indicators.

## Discussion

Gunshot wound in the DVS sustained during a battle may be a life-threatening. Meticulously described clinical picture of the SSS injuries [1,6,7] is typical. Cushing used staples or sutures to stop bleeding in the DVS wounds [1]. After World War II, Matson provided detailed recommendations relating to the DVS defect closure depending on a wound location and nature [8] as well as bleeding management. If suturing was inefficient, he closed small sinus wall defects with thrombin-soaked gelatin sponge or fragment of muscle tissues. The fragments of the autoperiosteum and dura mater were also used for the same purpose [2,4]. The use of a special hemostatic sponge (Tachocomb / Tachosil)

**Table 2.** Relationship between clinical indicators and GOS score after 6 months and 12 months

Indicator	6-month GOS score			12-month GOS score		
	Number of patients (%)		P	Number of patients (%)		P
	1–3	4–5		1–3	4–5	
Number of patients	4 (19.0)	17 (81)		3 (14.3)	18 (85.7)	
Time between injury and admission, hours						
0–12	4 (19.0)	9 (42.9)		3 (14.3)	10 (47.6)	
>12	0	8 (38.1)		0	8 (38.1)	
			<b>0.17</b>			<b>0.25</b>
ISS						
0–25	3 (14.3)	15 (71.4)		3 (14.3)	15 (71.4)	
>25	1 (4.8)	2 (9.5)		0	3 (14.3)	
			<b>0.29</b>			<b>0.36</b>
Type of wound						
Bullet	1 (4.8)	3 (14.3)		1 (4.8)	3 (14.3)	
Shell fragment	3 (14.3)	14 (66.6)		2 (9.5)	15 (71.4)	
			<b>0.74</b>			<b>0.5</b>
Presence of CSF leakage (initially)	4 (19.0)	13 (61.9)	0.52	3 (14.3)	14 (66.7)	0.6
CNS infection	3 (14.3)	2 (9.5)	0.12	2 (9.5)	3 (14.3)	0.31
Systemic infection	1 (4.8)	0		0	1 (4.8)	
Injury of 1 brain lobe	0	10 (47.6)		0	10 (47.6)	
Injury of 2 or more brain lobes	4 (19)	6 (28.6)		3 (14.3)	7 (33.3)	
			<b>0.27</b>			<b>0.07</b>
Injury of 1/3 of SSS	0	7/20 (35)		0	7/20 (35)	
Injury of 2/3–3/3 of SSS	3/20 (15)	10/20 (50)		3/20 (15)	10/20 (50)	
			<b>0.18</b>			<b>0.18</b>

**GOS:** Glasgow Outcome Scale; **SSS:** Superior sagittal sinus; **ISS:** Injury Severity Score.

**Table 3.** 6- and 12-month GOS score and several average values (range) of clinical indicators

Indicator	6-month GOS score				12-month GOS score			
	Average (range)		r	P	Average (range)		r	P
	Poor outcome (1–3)	Good outcome (4 or 5)			Poor outcome (1–3)	Good outcome (4 or 5)		
Age (years)	37.8 (26–48)	26 (18–41)	-0.44	0.04	32 (26–48)	26 (18–48)	-0.42	0.05
Evacuation time, hours	8.7 (7–12)	14.8 (2–44)	-0.03	0.87	8.7 (7–12)	14.5 (2–44)	-0.002	0.99
Admission GCS score	5.3 (4–12)	10.9 (6–15)	0.53	0.01	5.3 (4–7)	11 (6–15)	0.51	0.02
Discharge GCS score	13	14.5 (13–15)	-0.06	0.11	–	14.4 (13–15)	0.8	0.6
ISS	29.7 (25–44)	25.2 (17–30)	-0.16	0.48	25	26.2 (17–44)	0.18	0.4
ICU stay time, days	17.5 (7–17)	10.7 (2–42)	-0.3	0.18	10.3 (7–17)	12.3 (1–42)	-0.1	0.65

**GOS:** Glasgow Outcome Scale; **ISS:** Injury Severity Score; **ICU:** Intensive Care Unit.

was effective [10]. In our study, Tachocomb was used to stop bleeding in 16 (72.7 %) cases of the DVS wound in 1–2 walls of the sinus. Most complications occur if three DVS walls (transection) were damaged or if there was an elongated damage to two DVS walls and the DVS repair or its ligation (tamponade) was considered. Despite the idea [11] that SSS ligation in the anterior third is dangerous and may cause venous infarction, it is generally accepted that the procedure is associated with a low occurrence of neurological complications. However, the presence of dominant venous reflux from the frontal lobes to the anterior third of the SSS in 25 % cases, based on [12], may

cause severe complications with a high probability. In cases of SSS injury posteriorly to the veins of Rolando (i.e., middle and posterior third of the SSS), the SSS repair is preferable, its ligation typically considered as a high risk of developing venous infarction and worsening of neurological condition. The risk of brain disorder was proven experimentally [13]. However, the absolute number of fatalities caused by the SSS occlusion posteriorly to the veins of Rolando and confluence area has not been yet described in the literature. Apparently, good outcomes of thrombosis / occlusion at this level are associated with the individual anatomy of anastomotic veins – both key veins (Labbé and Trolard) and anatomical variants (e.g., falcine sinus [14]). Moreover, described cases of SSS injury from the times of Sargent and Holmes with a typical clinical picture included patients who did not undergo intensive therapy for severe traumatic brain injury, that is currently included in a standard protocol [15].

In case of the SSS transection or extended two-wall injury, the sinus repair can be performed by a graft insertion [2,3,5]. In terms of the anatomic sinus repair, this is a perfect technical solution. However, several significant challenges are evident: 1) Such intervention requires sufficient technical preparation. A surgeon must be experienced and skillful at vessel suturing. 2) Appropriate microsurgical instruments and surgical optics (which are rather difficult to obtain in case of urgent intervention) must be available. 3) For an effective anastomosis, it is necessary to ensure the patency of the distal and proximal DVS ends; in case of thrombosis, the patency can be recovered with clot extraction procedure. For clot extraction, Fogarty catheter can be used. It is also recommended for the temporary obturation of the DVS lumen. However, such procedure may be traumatic due to the presence of trabeculas in the SSS lumen, and it subsequently causes thrombosis in the SSS. 4) Applying anastomosis to prevent thrombosis requires the injection of heparin derivatives [16,17], inevitably increasing the risk of hemorrhagic progression of brain tissue damages and worsening neurological outcome. 5) The vessel suturing technique itself requires releasing the DVS edges, appropriately shaping them for applying the vessel suture (skeletization, refreshing the edges), inevitably leading to additional damage to the surrounding brain tissue and bridging veins adjacent to the DVS transection area in cases of combined brain tissue injury.

When applying veno-venous anastomosis, the autovenous graft should be used [3,5,16,17]. It is not advisable to use synthetic graft due to a high occurrence of thrombosis [16]. The use of autovenous graft requires immediate injection of anticoagulants (at the start of a surgery). Recent studies [18,19] on about the risk of hemorrhagic progression of mass brain lesions in case of the early administration of low-molecular-weight heparins reported its safety in cases of stable CT image, but patients with a high risk of hemorrhagic progression were often excluded from the studies. In our series, patients with combined brain injury mostly had a high risk of hemorrhagic progression. The intracerebral mass lesions were removed in 25 cases (18 patients), and that is why the early use of anticoagulants was extremely risky.

In our opinion, the disadvantages and risks in the process of anastomosis application during the DVS transection outweigh its advantages.

All (23.8 %) patients with infectious complications had penetrating injury caused by foreign bodies in the cranial cavity and severe brain tissue destruction. The occurrence of infectious complications and mortality were consistent with the results of more extensive studies [20].

Based on different data, the DVS wound mortality rate is 7–79 % [1,3–5]. It is challenging to identify the causes of mortality in our series with venous drainage disorder. However, all three fatal cases (14.3 %) were associated with injury in the posterior third of the DVS. One patient was admitted to our hospital with a GCS score of 4, and he presented with symptoms, such as intracranial hypertension and intracerebral hematoma. The causes of mortality were secondary ischemic brain changes. Damage to the SSS wall was identified intraoperatively. The second patient had multiple organ dysfunction syndrome as observed during CSF drainage. In the third case, the cause of death was undetermined. The patient was alert but suddenly his heart arrested. Out of four (19.0 %) patients with obstruction in the posterior third of the SSS (1 ligation, 3 thromboses), two (50 %) survived. One patient had temporary vision impairment (the GOS of 5 after 6 months, transection and ligation in the posterior third of the SSS), and the other patient had persistent visual impairment and temporary hemiparesis (the GOS score of 4 after 6 months).

Surgery was performed less aggressively to treat brain matter (debridement) according to mass effect based on brain SCT data, extension of brain matter damage, location of injuries, and patient's condition. We removed devitalized brain matter, intracerebral hematomas, and perifocal brain tissue partially based on the injured area function. If the function of the brain area was significantly affected, debridement was cautiously performed. In case of combined injuries of the brain matter and the DVS, we stopped a sinus bleeding and then performed a debridement (excluding the case of straight sinus wound when bleeding could only be stopped after the removal of intracerebral hematoma).

Notably, DC was performed rarely (n = 3, 30 %) in severely injured patients (the initial GCS of 4–8, n = 10) despite information in the literature (18) showing that DC was performed in 78% of cases. We obtained good functional outcomes. All the patients had the GOS score of 4 after 6 months. As our hospital is a multidisciplinary center and place of final and complete treatment for patients with severe injuries, we used less aggressive injury management techniques that were different from commonly accepted ones for wartime severe penetrating injury [16,21].

We obtained generally good outcomes due to quick transportation of patients with an average injury-to-hospitalization time of  $13.7 \pm 10.3$  hours (range: 2–44 hours) and the provision of appropriate treatment.

The present study had several limitations. First, it had a small sample size. Second, it was a retrospective study. Third, there were insufficient medical data before admission to our hospital.

## Conclusions

1. If severe DVS injury is suspected, cerebral vessel CAG or SCT-AG should be performed before surgery to evaluate the patency of the DVS and peculiarities in the anatomy of veins draining into the DVS as well as

the presence of anastomotic veins. If anastomotic veins are observed, performing urgent DVS ligation is less risky. Otherwise, surgical repair is preferred.

2. In case of the DVS injury combined with venous drainage disorder (thrombosis and DVS occlusion), management for hypertension should be more aggressive being that intracranial hypertension worsens the venous drainage disorder.

3. DVS repair (grafting) via surgery in case of concomitant brain matter injury must be performed very cautiously because of a high risk of developing hemorrhagic complications due to necessity of early using of anticoagulants, which may worsen neurological outcome.

4. Finally, the feasibility of surgical DVS repair in case of transection can be assessed in large neurosurgical centers for such pathology management to obtain more data.

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