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Research Article



Use of navigation technologies in the installation of external ventricular drainage in patients with severe combined traumatic brain injury

V.I. Badalov, P.K. Tyulikov, V.S. Mityunina, M.I. Spitsin, K.E. Korostelev,
K.V. Tyulikov, R.V. Yarmoshuk, V.S. Zhukov, I.H. Ismailov

Kirov Military Medical Academy, Saint Petersburg, Russia

Abstract

The study investigated the possibilities and effectiveness of surgical navigation in the installation of external ventricular drainage in patients with severe combined traumatic brain injury. In total, 41 patients were examined, and in those with urgent indications during the first period of traumatic illness, external ventricular drainage was installed (up to 2 days). All patients were divided into the main group ($n = 14$) and control group ($n = 27$). In the main group, external ventricular drainage was installed using surgical navigation. The control group underwent surgery without surgical navigation. According to the treatment results of the main group, the use of surgical navigation during the introduction of ventricular drainage significantly increased the accuracy of its installation and reduced the number of complications and rechecks. The accuracy of ventricular drainage installation was improved by 35%. Thus, out of 13 drainage installations, 12 (92.3%) had an optimal position, and 1 had a satisfactory position because its tip had a deviation of 2 mm; however, this drainage did not require re-examination, performing its function. Moreover, in the control group using the classical “free hand” technique, out of 21 cases with drainage installed, only 12 (57.1%) had an optimal position, 9 (42.9%) drains were rechecked because of deviation from the specified trajectory over 3 mm, and 4 (19%) required repeated rechecking ($p = 0.039$). The main causes of errors and complications of the surgical treatment of patients with craniocerebral injuries are related to the difficulties in installing ventricular drainage, namely, inaccurate positioning of the drainage tip, placement of the drainage in the brain substance at a distance from the planned point (28.6%), the drainage is going beyond the ventricular system of the brain (14.3%), re-drainage during the operation (44.4%), which often (42.9%) leads to incorrect introduction of the drainage into the ventricular system of the brain. Thus, the application of the navigation technology technique when installing drains into the ventricular system of the brain is very effective in the treatment of patients with severe combined traumatic brain injury. This innovative technique for ventricular drainage in severe combined traumatic brain injury will reduce the frequency of errors and complications associated with repeated drains, which is fundamentally important in unstable patients with multiple traumas. The navigation system allows for accurate installation of the drainage to the planned location from the first attempt.

Keywords: ventricular drainage; intracranial pressure; ventricle of the brain; severe combined trauma; surgical navigation; traumatic brain injury; free hand technique; polytrauma; traumatic illness.

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Научная статья

Применение навигационных технологий при установке наружного вентрикулярного дренажа у пациентов, страдающих тяжелой сочетанной черепно-мозговой травмой

В.И. Бадалов, П.К. Тюликов, В.С. Митюнина, М.И. Спицын, К.Е. Коростелев, К.В. Тюликов, Р.В. Ярмошук, В.С. Жуков, И.Х. Исмаилов

Военно-медицинская академия имени С.М. Кирова, Санкт-Петербург, Россия

Резюме

Исследованы возможности и эффективность применения хирургической навигации при установке наружного вентрикулярного дренажа у пациентов при тяжелой сочетанной черепно-мозговой травме. Обследован 41 пострадавший, которым проводилась установка наружного вентрикулярного дренажа по срочным показаниям в первый период травматической болезни (до 2 сут.). Все пострадавшие были разделены на две группы: основную — 14 человек и контрольную — 27 человек. Пациентам основной группы установка наружного вентрикулярного дренажа выполнялась с применением хирургической навигации. Пациентам контрольной группы операция выполнялась без нее. По результатам лечения пострадавших основной группы было доказано, что применение хирургической навигации при введении вентрикулярного дренажа значительно повышает точность его установки и снижает количество осложнений и перепроведений. Точность установки вентрикулярного дренажа была улучшена на 35 %. Так, из 13 операций по установке дренажей 12 (92,3 %) имели оптимальное положение, положение 1 дренажа было расценено как удовлетворительное, так как его кончик имел отклонение в 2 мм, но данный дренаж не потребовал перепроведения, выполняя свою функцию. При этом у пострадавших контрольной группы с использованием классической техники «свободной руки» из 21 случая установленного дренажа лишь 12 (57,1 %) имели оптимальное положение, 9 (42,9 %) дренажей были перепроведены в связи с отклонением заданной траектории свыше 3 мм, а 4 (19 %) дренажа потребовали повторного перепроведения, $p = 0,039$. Основными причинами ошибок и осложнений хирургического лечения пострадавших при черепно-мозговых повреждениях являются сложности при установке вентрикулярного дренажа, а именно неточное позиционирование кончика дренажа, размещение дренажа в веществе головного мозга на удалении от запланированной точки (28,6 %), выход за пределы желудочковой системы головного мозга (14,3 %), многократное перепроведение дренажа в ходе операции (44,4 %), что часто (42,9 %) приводит к некорректному введению дренажа в желудочковую систему головного мозга. Таким образом, применяемая методика навигационных технологий в лечении больных, страдающих тяжелой сочетанной черепно-мозговой травмой, при установке дренажей в желудочковую систему головного мозга весьма результативна. Данная инновационная методика при проведении вентрикулярного дренирования при тяжелой сочетанной черепно-мозговой травме позволяет снизить частоту ошибок и осложнений, связанных с повторными проведениями дренажей, что принципиально важно у нестабильных пострадавших с политравмой. Навигационная система позволяет точно, с первой попытки установить дренаж в запланированную локацию.

Ключевые слова: вентрикулярный дренаж; внутричерепное давление; желудочек головного мозга; тяжелая сочетанная травма; хирургическая навигация; черепно-мозговая травма; техника «свободной руки»; политравма; травматическая болезнь.

Как цитировать

Бадалов В.И., Тюликов П.К., Митюнина В.С., Спицын М.И., Коростелев К.Е., Тюликов К.В., Ярмошук Р.В., Жуков В.С., Исмаилов И.Х. Применение навигационных технологий при установке наружного вентрикулярного дренажа у пациентов, страдающих тяжелой сочетанной черепно-мозговой травмой // Вестник Российской военно-медицинской академии. 2023. Т. 25, № 3. С. 413–421. DOI: <https://doi.org/10.17816/brmma430289>

INTRODUCTION

In the mortality status of the populations of economically developed and developing countries, injuries rank third after cardiovascular diseases and malignant neoplasms. In Russia, injuries among people of working age, in terms of the total economic and medical–social damage, rank first in the overall mortality structure (52%) [1, 2]. The social significance of injuries is associated with the high disability level of patients (up to 25%–45%) [3].

Severe combined trauma (SCT) [4], particularly trauma including the craniocerebral region, is the most significant among injuries [5, 6]. Among severe combined injuries, traumatic brain injury (TBI) accounts for 42%–69%, and the severity of the condition in such patients is due to both TBI and extracranial injuries [7]. Mutual aggravation and subclinical presentation are the main characteristics of combined injuries; therefore, the difficulty in diagnosing and treating patients increases [8]. Because of emergency resuscitation measures and surgeries to eliminate the life-threatening consequences of injury, brain surgery may be delayed, which leads to worse treatment outcomes [9, 10].

Owing to the lack of uniform protocols and algorithms for treating severe combined TBI, peculiarities of diagnostic techniques, and individual course of the traumatic disease (TD), a significant probability of errors remains in the diagnosis of complications. The introduction of new technologies for treating patients with severe TBI will improve the results and reduce the number of errors and complications.

For example, the installation of ventricular drainage in the case of hypertension-dislocation syndrome (HDS) and impaired cerebrospinal fluid dynamics in the brain, due to inaccuracy in positioning, often require multiple reinstallations using the classical technique of introducing a “free hand” along anatomical landmarks, which is well described in the literature [11]. The feasibility of using navigation during emergency surgeries for intracerebral hemorrhage has been proven [12, 13].

Thus, the use of navigation systems for treating patients with severe combined TBI can significantly improve their treatment outcomes. Currently, no data exist in the literature on the use of the discussed technology for treating patients with severe TBI, which determined the relevance of this study.

This study aimed to analyze the possibilities and efficiency of surgical navigation to improve results when installing external ventricular drainage in patients with severe combined TBI.

MATERIALS AND METHODS

The clinical study was based on data on the treatment of 41 patients with combined TBI who underwent installation

of external ventricular drainage in the military field surgery clinic of the S.M. Kirov Military Medical Academy between 2012 and 2019. Surgical interventions were performed according to urgent indications during the first period of traumatic illness (up to 2 days). All patients were divided into two groups, where the main and control groups included 14 and 27 patients, respectively. External ventricular drainage was installed in the main group using surgical navigation, whereas the control group underwent surgery without it. A comparative analysis of the ventricular drainage installation with and without navigation was performed. The identified groups practically did not differ in the major region of damage, severity, and nature of brain injury (Tables 1 and 2).

In most cases, the major region of damage in both groups with combined TBI was the head area (78.6% and 77.8%, respectively). Among morphological changes in the brain, contusion lesions with HDS were most often diagnosed in 50% of the patients in the main group and 48.2% in the control group. Intraventricular hemorrhages with tamponade were noted in 21.4% of the patients in the main group and 22.2% in the control group.

The consciousness level was determined using the Glasgow coma scale (GCS), where most of the patients in the main and control groups were in a state of coma (≤ 8 points), namely, 13 (92.9%) and 24 (88.9%) patients, and 1 (7.1%) and 3 (11.1%) patients were in a state of stupor (8–10 GCS points), respectively. Moreover, 11 (78.6%) and 20 (74.1%) patients of the main and control groups had open head injuries, and TBI of a penetrating nature was registered in 9 (64.3%) and 17 (63%) patients of the main and control groups, respectively. Severe brain contusions were noted in 12 (85.7%) and 17 (63%) patients in the main and control groups, respectively.

Characteristics of surgical interventions in the main group with severe combined TBI. Ventricular drainage was installed in 13 (92.9%) patients to monitor the level of intracranial pressure (ICP) for timely correction; 11 out of 13 installed drains had built-in ICP monitoring sensors. Decompressive trepanations were performed in 4 (28.6%) patients for the evacuation of intracranial (meningeal and intracerebral) hematomas.

The indication for installation of ventricular drainage (with ICP control sensors) was the need to control ICP in patients with severe TBI ($n = 13$; 3–8 GCS points) with pathological changes on computed tomography (CT), namely, intracerebral hematomas ($n = 4$), foci of contusion ($n = 3$), cerebral edema with HDS ($n = 5$), and intraventricular hemorrhages with tamponade of the ventricular system with blood ($n = 3$). Surgeries such as infratemporal decompressions were performed for patients with persistent lateral dislocation syndromes and persistent intracranial hypertension ($n = 9$).

Table 1. Distribution of the patients in both groups according to the primary damage
Таблица 1. Распределение пострадавших обеих групп по ведущему повреждению

Region	Group			
	main		test	
	<i>n</i>	%	<i>n</i>	%
Head	11	78.6	21	77.8
Chest	1	7.1	1	3.7
Abdomen	0	0	2	7.4
Combination of regions	2	14.3	3	11.1

Table 2. Distribution of the patients in both groups according to the nature of morphological changes in the brain
Таблица 2. Распределение пострадавших обеих групп по характеру морфологических изменений головного мозга

Nature of brain damage	Group			
	main		test	
	<i>n</i>	%	<i>n</i>	%
Epi-/subdural hematomas	2	14.3	4	14.8
Contusion lesions + HDS	7	50.0	13	48.2
Intracerebral hematomas	2	14.3	4	14.8
Intraventricular hemorrhages	3	21.4	6	22.2

Note: HDS. hypertension-dislocation syndrome.
Примечание: ГДС — гипертензионно-дислокационный синдром.

In the treatment of patients, drains from Codman “Neuro Monitor” (USA) were used. External drainage was performed with caution in patients with mass effect because of the risk of developing paradoxical dislocation syndrome with increased pressure gradient (*n* = 2). In 12 (85.7%) patients with combined TBI in the group using surgical navigation, cerebral ventricular drainage was performed according to urgent indications in period 1 of TD. In period 2 of TD, 1 (7.1%) drainage system was installed because of an increase in HDS. After drain placement, a follow-up CT was performed in the first 24–48 h (mean 32.2 ± 3.2 h) for the assessment of the drain position and compliance with preoperative planning.

The main group also underwent surgeries on adjacent organs and systems, and surgeries were most often performed (78.6%, *n* = 11) to arrest ongoing external bleeding. Because of the life-threatening consequences of chest trauma (e.g., continuing intrapleural bleeding and tension pneumothorax), 7 (49.8%) patients underwent puncture and drainage of the pleural cavities.

Characteristics of surgical interventions in the control group with severe combined TBI. In this group, various morphological manifestations of brain damage, such as contusive lesions of the brain with edema and HDS, were noted in 48.2% of cases. Intraventricular hemorrhages

were registered in 22.2% of the cases, accompanied by tamponade of the brain ventricular system. Compression of the brain by epidural/subdural hematomas was detected in 14.8% of cases. The degree of loss of consciousness varied from stupor (44.4%) to deep coma (55.6%). For urgent indications, 20 (74.1%) patients of the total number of cases underwent surgeries to arrest continuous bleeding. Because of the life-threatening consequences of injuries, 10 (37%) patients underwent puncture and drainage of the pleural cavities.

Ventricular drains were installed according to the generally accepted technique at Kocher’s point. This procedure is considered “blind” because it is performed according to anatomical surface landmarks. Inaccuracies in the drainage location and its repeated reinstallations are the main problems in the application of this technique.

Both groups with severe combined TBI underwent whole-body CT. For the main group, preoperative planning and intraoperative assistance were performed using a surgical navigation stand model “iNtellect ENT Navigation” (Stryker, USA). Head CT parameters were as follows: slice thickness of 1–2 mm, series consisting of 70–200 images, Gantry angle of 0°, position of anatomical landmarks such as ears, tip of the nose (should not be pressed or deformed), and the region

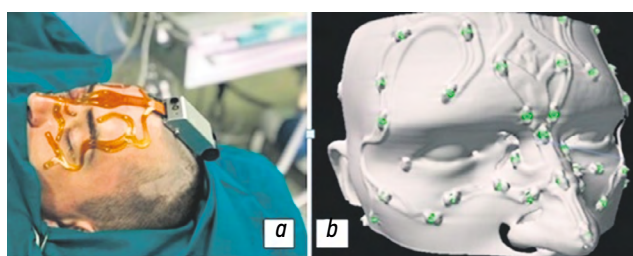


Fig. 1. 3D model of the head injury zone: *a* — registration using an overhead mask (chip with infrared radiation sensors); *b* — facial reconstruction

Рис. 1. Построение 3D-модели зоны повреждения головы: *a* — регистрация с помощью накладной маски (микросхема с датчиками инфракрасного излучения); *b* — реконструкция лица



Fig. 2. Registration with X-ray-contrast markers: *a* — radiopaque markers built on a computed tomography image; *b* — schematic representation of the location of markers on the head

Рис. 2. Регистрация с рентгенконтрастными маркерами: *a* — рентгеноконтрастные маркеры, отстроенные на компьютерно-томографическом изображении; *b* — схематическое изображение расположения маркеров на голове

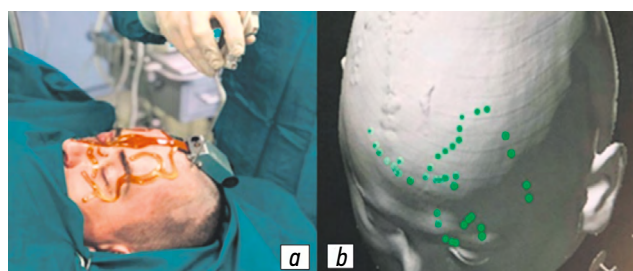


Fig. 3. Additional marks on the surgical intervention area: *a* — registration of anatomical landmarks; *b* — target points applied by the pointer

Рис. 3. Дополнительные точки-метки на области хирургического вмешательства: *a* — регистрация анатомических ориентиров; *b* — точки-мишени нанесенные пойнтером

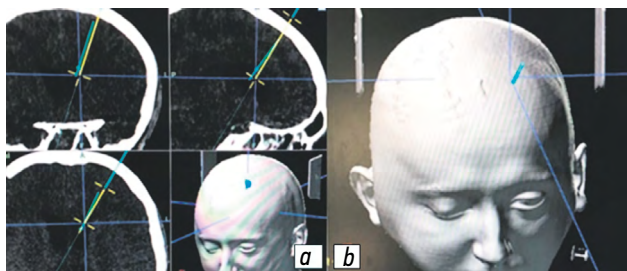


Fig. 4. 3-D model of the patient's head with entry points and a target point: *a* — direction vector of the stiletto; *b* — entry point

Рис. 4. 3D-модель головы пострадавшего с точками входа и точкой-мишенью: *a* — вектор направления стилета; *b* — точка входа

of study including the maxilla and calvarium. Radiopaque markers were used to accurately construct a 3D model of the scanned area.

After downloading, CT data were transferred to the media selector, images were previewed, and a 3D model of the damage zone was constructed. After preoperative planning, automatic registration was performed using an overhead mask (Fig. 1).

A registration method using radiopaque markers was also used (Fig. 2). To increase image accuracy, additional marking points were applied to the surgical site using a pointer (Fig. 3).

After establishing the reference points, a target point (damage zone) and an entry point on the head surface were created, and the access trajectory was determined (Fig. 4).

The instrumentation was registered and validated using trackers and infrared sensors preinstalled on basic navigation instruments. The instrument was conjugated with the tracker in relation to the reference ("zero") point, which was rigidly associated with the region of interest (Fig. 5).

After registration, the surgical instrument was identified in real time on a monitor screen, after which it was linked to the site of the planned surgical intervention. The device generating the infrared radiation was located

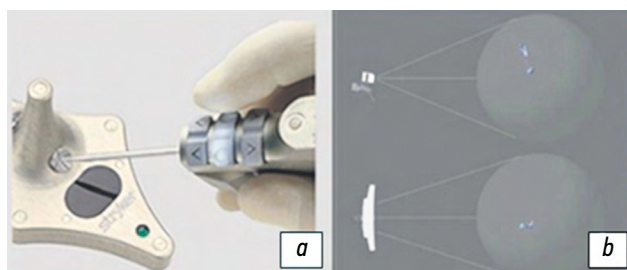


Fig. 5. Registration of the toolkit: *a* — tracker registration; *b* — registered tracker in the navigation tracking camera field; *c* — registration of the start tracker

Рис. 5. Регистрация инструментария: *a* — регистрация трекера; *b* — зарегистрированный трекер в поле следящей камеры навигации; *c* — регистрация стартового трекера



near the patient's head. After the skin incision and making a trephine opening (Kocher's point) using an active drain installation device (Fig. 6), under continuous triplanar control of the direction of movements, the drainage was installed at the planned point.

Statistical analysis was performed using MS Excel (Microsoft Corp., USA) and Statistica 10 (StatSoft Inc., USA) application package. The sample size was not previously calculated. Nominal data were compared using Pearson's χ^2 test. When analyzing four-field tables with an expected phenomenon in at least one cell of < 10 , the χ^2 criterion was calculated with the Yates correction, which reduces the probability of a type 1 error. In cases where the number of expected findings in any of the table cells was < 5 , Fisher's exact test was used to assess the level of significance of differences. The numerical characteristics of time (installation of drainage and time of the start of surgical intervention) are given with an indication of the mathematical expectation and its mean-square deviation ($M \pm MSD$).

The study was approved by the ethics committee of S.M. Kirov Military Medical Academy (Protocol No. 261 of March 22, 2022).

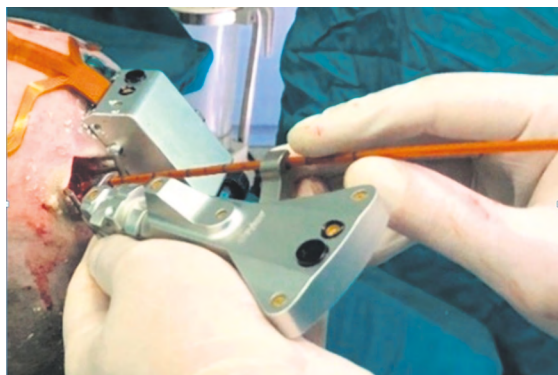


Fig. 6. Active device with adaptive tip

Рис. 6. Активное устройство с адаптивным наконечником

RESULTS AND DISCUSSION

Installation of drainage with an ICP control sensor using navigation in patients with severe combined TBI. An increase in ICP, which required the installation of a sensor and subsequent monitoring, was detected in 11 (78.6%) patients of the main group. They received conservative interventions aimed at drug protection of the brain substance and ICP reduction. This technique enabled us dosed decompression of the brain by removing cerebrospinal fluid. Drainage was used to wash away and evacuate blood in the case of intraventricular hemorrhages.

After CT, study data were immediately transferred to the navigation system because of changes in the brain, such as edema swelling, displacement of the midline structures, HDS, and formation of contusion foci in the brain (brain shift); thus, the intervention was started immediately after preoperative planning, with an average time interval of 17.6 ± 3.7 min. To assess accuracy and complications, a control CT was performed 24–48 h after drainage installation. The accuracy of drainage positioning was assessed using the classification by U.K. Kakarla, L.J. Kim, and S.W. Chang et al. [14]. Thus, with navigation support, the installed drains had an optimal position in 92.3% of the cases.

Comparison of ventricular drainage installation with and without navigation. The position of drains with ICP control sensors was assessed based on the position of their tips in the brain structures, compared with preoperative planning, and was divided into three accuracy classes (Table 3).

The main group had 13 drains installed in the ventricular system of the brain. The control CT detected one drain in the parietal position of the lateral ventricle with a slight deviation from the planned preoperative planning point, whereas the remaining 12 drains were installed in the optimal position. On day 2, due to a decrease in the amount of

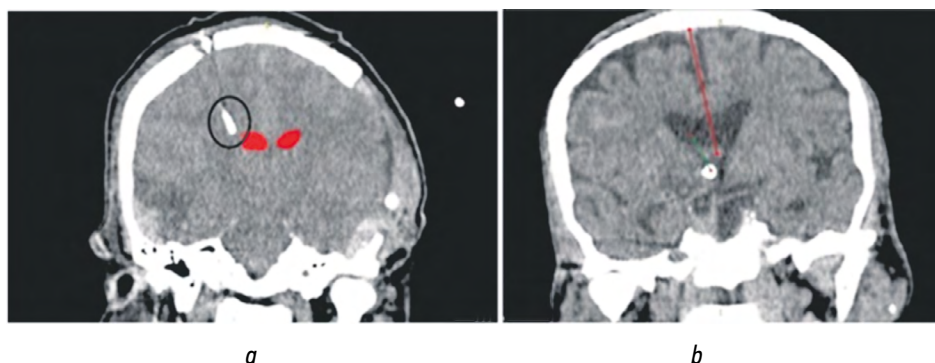


Fig. 7. Installation of drains outside the ventricular system of the brain: *a* — the tip of the drainage is located in the brain substance of the frontal lobe near the edge of the anterior horn of the lateral ventricle; *b* — the end of the drainage is located in the projection of the Monroe hole

Рис. 7. Установка дренажей за пределами желудочковой системы головного мозга: *a* — кончик дренажа расположен в веществе головного мозга лобной доли вблизи края переднего рога бокового желудочка; *b* — кончик дренажа расположен в проекции отверстия Монро

Table 3. Accuracy of the installation of drains into the ventricular system of the brain in the study groups, abs (%)
Таблица 3. Точность установки дренажей в желудочковую систему головного мозга в исследуемых группах, абс. (%)

Drain tip position	Group		<i>p</i>
	main	test	
Grade 1 Optimal (anterior horn of the lateral ventricle, including the apex of the third ventricle)	12 (85.7)	12 (44.4)	0.02
Grade 2 Satisfactory (lateral ventricle, corpus callosum, and longitudinal cerebral fissure)	1 (7.1)	6 (22.2)	0.01
Grade 3 Unsatisfactory (brainstem, cerebellum, internal capsule, basal ganglia, thalamus, and basal cisterns)	0	3 (11.1)	0.05
Reinstallation of drainage	1 (7.1)	9 (33.3)	0.047
Complications	0	4 (14.8)	0.04

cerebrospinal fluid in the main group, one drain was reinstalled. After removal, fibrin clots were identified in the drainage lumen.

Control CT of the control group with installed ventricular drains detected nine cases of incorrect installation. That is, 6 (44.4%) cases, according to the level of deviation, were “satisfactory” according to the classification by U.K. Kakarla, L.J. Kim, S.W. Chang, et al. [14], and in 3 (11.1%) cases, the level of deviation was “poor”. Three drainage systems classified as “poor” and one as “satisfactory” were replaced because their tips were outside the ventricular system (Fig. 7). Reinstallation was complicated by hemorrhage in two cases and infectious ventriculitis in two more cases.

Thus, navigation technologies used for treating patients with severe combined TBI are very effective when installing drains in the ventricular system of the brain. This innovative technique for performing ventricular drainage in severe combined TBI reduces the incidence of errors and complications associated with repeated drainage, which is fundamentally important in patients with unstable status and polytrauma. The navigation system can be used to accurately install drainage in the planned location at the first attempt. Importantly, no surgery-associated complications occurred in the postoperative period. In patients with severe TBI, when the surgeon encounters difficulties when performing drainage (swelling, HDS, compression of the ventricles, and displacement of the midline structures), this intervention should be performed with navigation assistance.

CONCLUSIONS

1. In the general structure of severe combined injuries, TBI accounts for 42%–69%, and the severity of the condition of such patients is related to both TBI and extracranial injuries.

Given the lack of uniform protocols and algorithms for treating severe combined TBI, peculiarities of diagnostic techniques, and individual course of TD, a significant probability of errors remains in the diagnosis of complications.

2. The installation of ventricular drainage for HDS and in cases of impaired cerebrospinal fluid dynamics in the brain due to inaccurate positioning often requires multiple reinstallations.

3. The use of navigation technologies when installing drains in the ventricular system of the brain enables accurate installation of the drain at the planned location during the first attempt. This significantly improves the treatment outcomes in these patients and reduces the number of surgery-associated complications in the postoperative period.

ADDITIONAL INFORMATION

Authors' contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study.

The contribution of each author: V.I. Badalov — general concept development, research design, data analysis, surgical treatment, diagnostic studies; P.K. Tyulikov — data collection and processing, literature review, article writing; V.S. Mityunina — data collection and processing, literature review, article writing; M.I. Spitsyn — general concept development, research design, data analysis, surgical treatment, diagnostic research; K.E. Korostelev — development of a general concept, research design, data analysis, surgical treatment, diagnostic research; K.V. Tyulikov — development of a general concept, research design, data analysis, surgical treatment, diagnostic research; R.V. Yarmoshuk — data analysis, surgical treatment; writing an article; V.S. Zhukov — data

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исследования; П.К. Тюликов — сбор и обработка данных, обзор литературы, написание статьи; В.С. Митюнина — сбор и обработка данных, обзор литературы, написание статьи; М.И. Спицын — разработка общей концепции, дизайн исследования, анализ данных, хирургическое лечение, диагностические исследования; К.Е. Коростелев — разработка общей концепции, дизайн исследования, анализ данных, хирургическое лечение, диагностические исследования; К.В. Тюликов — разработка общей концепции, дизайн исследования, анализ данных, хирургическое лечение, диагностические исследования; Р.В. Ярмошук — анализ данных, хирургическое лечение; написание статьи; В.С. Жуков — сбор и обработка данных, обзор литературы, написание статьи; И.Х. Исмаилов — сбор и обработка данных, обзор литературы, написание статьи.

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AUTHORS INFO

***Ismail H. Ismailov**, cadet; Researcher ID: ISS-0771-2023; ORCID: 0009-0000-0582-0575; e-mail: ismailov.iskh@mail.ru

Vadim I. Badalov, MD, Dr. Sci. (Med.), professor; ORCID: 0000-0002-8461-2252; Scopus Author ID: 6504224287; Researcher ID: V-1487-2017; eLibrary SPIN: 9314-5608; e-mail: vadim_badalov@mail.ru

Pavel K. Tyulikov, cadet; ORCID: 0009-0006-1669-7836; Researcher ID: ISS-0816-2023

Vladislava S. Mityunina, cadet; ORCID: 0009-0008-7703-7908; Researcher ID: ISB-6351-2023

Maxim I. Spitsin, MD, MD, Cand. Sci. (Med.); ORCID: 0000-0002-2059-7399; Researcher ID: ISS-0739-2023; eLibrary SPIN: 5303-7104

Konstantin E. Korostelev, MD, Cand. Sci. (Med.); ORCID: 0009-0009-1321-9363; Researcher ID: ISS-1011-2023; eLibrary SPIN: 8004-0658; e-mail: neuro-koro@mail.ru

Konstantin V. Tiulikov, MD, Cand. Sci. (Med.); ORCID: 0000-0002-4700-889X; Researcher ID: ISS-0358-2023; eLibrary SPIN: 6047-9941

Roman V. Yarmoshuk, surgeon; ORCID: 0000-0002-8270-4903; Researcher ID: ISS-0755-2023; eLibrary SPIN: 1928-0023; e-mail: ryarmoshuk@inbox.ru

Vladimir S. Zhukov, cadet; ORCID: 0009-0006-1027-2474; Researcher ID: ISS-0762-2023

ОБ АВТОРАХ

***Исмаил Халиллаевич Исмаилов**, курсант; Researcher ID: ISS-0771-2023; ORCID: 0009-0000-0582-0575; e-mail: ismailov.iskh@mail.ru

Вадим Измаилович Бадалов, д-р мед. наук, профессор; ORCID: 0000-0002-8461-2252; Scopus Author ID: 6504224287; Researcher ID: V-1487-2017; eLibrary SPIN: 9314-5608; e-mail: vadim_badalov@mail.ru

Павел Константинович Тюликов, курсант; ORCID: 0009-0006-1669-7836; Researcher ID: ISS-0816-2023

Владислава Сергеевна Митюнина, курсант; ORCID: 0009-0008-7703-7908; Researcher ID: ISB-6351-2023

Максим Игоревич Спицын, канд. мед. наук; ORCID: 0000-0002-2059-7399; Researcher ID: ISS-0739-2023; eLibrary SPIN: 5303-7104

Константин Евгеньевич Коростелев, канд. мед. наук; ORCID: 0009-0009-1321-9363; Researcher ID: ISS-1011-2023; eLibrary SPIN: 8004-0658; e-mail: neuro-koro@mail.ru

Константин Владимирович Тюликов, канд. мед. наук; ORCID: 0000-0002-4700-889X; Researcher ID: ISS-0358-2023; eLibrary SPIN: 6047-9941

Роман Викторович Ярмошук, хирург; ORCID: 0000-0002-8270-4903; Researcher ID: ISS-0755-2023; eLibrary SPIN: 1928-0023; e-mail: ryarmoshuk@inbox.ru

Владимир Сергеевич Жуков, курсант; ORCID: 0009-0006-1027-2474; Researcher ID: ISS-0762-2023

* Corresponding author / Автор, ответственный за переписку