

DOI: <https://doi.org/10.63769/1683-3295-2026-28-1-43-57>

# Frameless neuronavigation in surgery of distal cerebral aneurysms

**Contacts:**Elena Stanislavovna  
Ryzhkova  
[rzhckowa.elena@yandex.com](mailto:rzhckowa.elena@yandex.com)E.S. Ryzhkova<sup>1,2</sup>, V.A. Lukyanchikov<sup>3,4</sup>, I.V. Senko<sup>5</sup>, T.A. Shatokhin<sup>3,4</sup>, D.V. Khovrin<sup>1</sup>,  
V.A. Dalibaldyan<sup>2</sup>, M.V. Sinkin<sup>2</sup>, Z.A. Barbakadze<sup>2</sup>, Z.A. Kulov<sup>3</sup>, A.A. Grin<sup>2</sup>, V.V. Krylov<sup>3,4</sup><sup>1</sup>Moscow City Hospital named after S.S. Yudin, Moscow Healthcare Department; 4 Kolomensky Proezd, Moscow 115446, Russia;<sup>2</sup>N.V. Sklifosovsky Research Institute for Emergency Medicine, Moscow Healthcare Department; 3 Bolshaya Sukharevskaya Sq., Moscow 129090, Russia;<sup>3</sup>Russian Center of Neurology and Neurosciences; 80 Volokolamskoye Shosse, Moscow 125367, Russia;<sup>4</sup>Department of Fundamental Neurosurgery, Faculty of Continuing Professional Education, N.I. Pirogov Russian National Research Medical University, Ministry of Health of Russia; 1 Ostrovityanova St., Moscow 117513, Russia;<sup>5</sup>Federal Center for Brain and Neurotechnology, Federal Medical and Biological Agency of Russia; Bld. 10, 1 Ostrovityanova St., Moscow 117513, Russia

**Aim.** To compare results of surgical treatment of patients with distal aneurysms of the middle cerebral and pericallosal arteries who underwent surgery with frameless neuronavigation and without it.

**Materials and methods.** The study was performed at the N.V. Sklifosovsky Research Institute for Emergency Medicine, Russian Center of Neurology and Neurosciences, Moscow City Hospital named after S.S. Yudin between January 1<sup>st</sup> 2009 and December 31<sup>st</sup> 2023. Analysis included 45 patients with distal aneurysms of the pericallosal and middle cerebral arteries. Taking into account surgical technique, the patients were divided into 2 groups: the 1<sup>st</sup> group ( $n = 21$ ) included patients who underwent surgery with frameless neuronavigation; among them 10 (47.6 %) patients had distal aneurysms of the middle cerebral artery, 11 (52.4 %) patients had distal aneurysms of the pericallosal artery. The 2<sup>nd</sup> group ( $n = 24$ ) included patients who underwent surgery without frameless neuronavigation; among them 10 (41.7 %) patients had distal aneurysms of the middle cerebral artery, 14 (58.3 %) patients had distal aneurysms of the pericallosal artery.

**Results.** The use of frameless neuronavigation helps in the search for distal aneurysms during the main stage of the surgery, decreases time between dissection and clipping of a distal aneurysm ( $p = 0.0001$ ), decreases operative time ( $p = 0.0001$ ) but requires more time for access planning ( $p = 0.008$ ). Frameless neuronavigation helps to determine optimal size and location of craniotomy for the most direct and safe trajectory to the distal aneurysm ( $p = 0.008$ ), decreases the risk of intraoperative injury of the frontal sinus ( $p = 0.025$ ). Patients, in whom distal aneurysm clipping was performed using frameless navigation, had lower rate of neurologic deficit ( $p = 0.0001$ ), postoperative ( $p = 0.025$ ) and systemic ( $p = 0.005$ ) complications, repeat surgeries ( $p = 0.002$ ).

**Conclusion.** The use of frameless neuronavigation decreases search time for distal aneurysms and operative time, allows to decrease craniotomy area and prevent intraoperative injury of the frontal sinus, statistically significantly decreases the risk of postoperative neurologic deficit, and improves clinical outcomes.

**Keywords:** frameless neuronavigation, distal aneurysm, middle cerebral artery, pericallosal artery

**For citation:** Ryzhkova E.S., Lukyanchikov V.A., Senko I.V. et al. Frameless neuronavigation in surgery of distal cerebral aneurysms. *Neyrokhirurgiya = Russian Journal of Neurosurgery* 2026;28(1):43–57.

DOI: <https://doi.org/10.63769/1683-3295-2026-28-1-43-57>

## BACKGROUND

Among all cerebral aneurysms, the incidence of distal ones is 10 % [1–5]. Distal aneurysms are typically small in size and have a thin wall as well as are irregular in shape and lack a formed aneurysm neck. These factors increase the risk of intraoperative rupture and create the difficulties

in intraoperative visualization due to difficult-to-reach locations, narrow surgical corridor, absence of anatomical landmarks and variability in vascular anatomy, requiring additional surgical solutions [1–3, 6]. An effective option in distal aneurysm surgery is the use of frameless neuronavigation (FN).

**Aim of study** – to analyze the results of surgical treatment of patients with distal aneurysms of the middle cerebral (MCA) and pericallosal (pCA) arteries, operated with and without the use of FN.

**MATERIAL AND METHODS**

A multicenter retrospective study of current practice included 45 patients with distal aneurysms of the pCA and MCA, operated on at the Sklifosovsky Research Institute of Emergency Care, the Scientific Center of Neurology, and the Yudin City Clinical Hospital from January 1, 2009, to December 31, 2023. Based on the surgical treatment method, all patients were divided into 2 groups.

The 1st group ( $n = 21$ ) included patients in whom clipping of the distal aneurysm was performed using FN: 10 (47.6 %) patients with distal aneurysms of the MCA and 11 (52.4 %) with distal aneurysms of the pCA. Among these patients were 12 women and 9 men; and 7 (33.3 %) patients in this group had multiple aneurysms.

The 2nd group ( $n = 24$ ) included patients in whom distal aneurysm clipping was performed without the use of FN: 10 (41.7 %) patients with distal MCA aneurysms and 14 (58.3 %) with distal pCA aneurysms. Among these patients were 17 women and 7 men; 9 (37.5 %) patients in this group had multiple aneurysms. The localization of distal aneurysms in the groups is shown in Fig. 1.

In the 1st group, 16 patients (76.2 %) were admitted with a ruptured aneurysm, 4 (19 %) without aneurysm rupture, and 1 patient (4.8 %) had mass effect signs. In the 2nd group, 21 patients (87.5 %) were admitted with a ruptured aneurysm, and 3 (12.5 %) without aneurysm rupture.

Among patients with rupture in the 1st group, fully conscious was observed in 12 patients (75 %), moderate confusion in 3 (18.7 %), and severe confusion in 1 (6.3 %). In the 2nd group, fully conscious was observed in 15 patients (71.4 %), moderate confusion in 3 (14.3 %), and severe confusion in 3 (14.3 %). Sopor and coma were not observed in both groups.

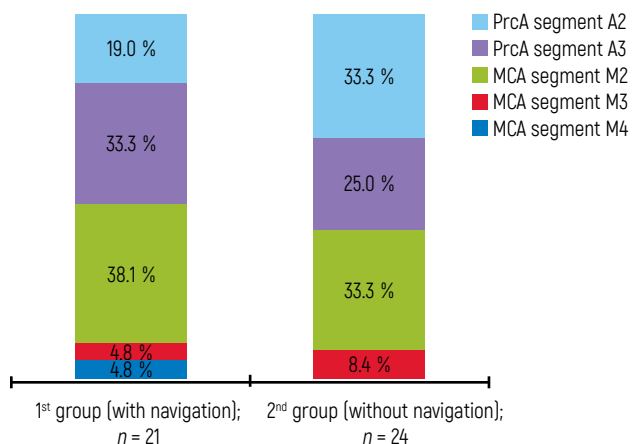


Fig. 1. Distribution of distal aneurysms per segments in the territories of the middle cerebral (MCA) and pericallosal (PrCA) arteries

Analyzing the brain computed tomography (CT) data according to the Fisher classification, the following types of hemorrhages were identified in the 1st group: type I – in 5 (23.8 %) patients; type II – in 5 (23.8 %); type III – in 5 (23.8 %); type IV – in 6 (28.6 %). In the 2nd group, the following types of hemorrhages were revealed: type I – in 3 (12.5 %) patients; type II – in 1 (4.2 %); type III – in 9 (37.5 %); type IV – in 11 (45.8 %) (Fig. 2).

In the 1st group, parenchymal hemorrhage with a volume of 7–41 cm<sup>3</sup> was detected in 5 (31.3 %) patients; subdural hematoma with a volume of 5 cm<sup>3</sup> – in 1 (6.3 %) case; intraventricular hemorrhage (IVH) with a volume of 1 cm<sup>3</sup> at admission – in 2 (12.5 %) patients.

In the 2nd group, parenchymal hemorrhage with a volume of 5–64 cm<sup>3</sup> was detected in 9 (42.9 %) patients; subdural hematoma with a volume of 21 cm<sup>3</sup> – in 1 (4.8 %) case; IVH with a volume of 0.5–4 cm<sup>3</sup> – in 7 (33.3 %) patients.

An ischemic area with a volume of 74 cm<sup>3</sup> according to brain CT was detected only in 1 (4.8 %) patient of the 1st group.

Brain midline shift in the 1st Group was detected in 2 patients (12.5 %) at admission and ranged from 3 to 11 mm. In the 2nd group, brain midline shift was detected in 2 patients (9.5 %) and ranged from 3 to 5 mm. Brain axial shift was observed only in 2 patients (12.5 %) in the 1st group.

Cerebral edema at admission was revealed in 4 patients (25 %) in the 1st group: perifocal – in 2 (12.5 %), diffuse – in 2 (12.5 %). In the 2nd group, cerebral edema was detected in 8 patients (38 %): perifocal – in 4 (19 %), diffuse – in 4 (19 %). Occlusive hydrocephalus was not observed in both groups.

At admission, both groups did not statistically differ by the following parameters: the aneurysm localization ( $p = 0.694$ ), the disease course ( $p = 0.443$ ), the intracerebral hematomas (ICH) volume ( $p = 0.529$ ), intraventricular hemorrhage (IVH) volume ( $p = 0.889$ ), brain midline shift ( $p = 0.667$ ), the severity of patients' condition according to the Hunt–Kosnik scale ( $p = 0.529$ ), severity of

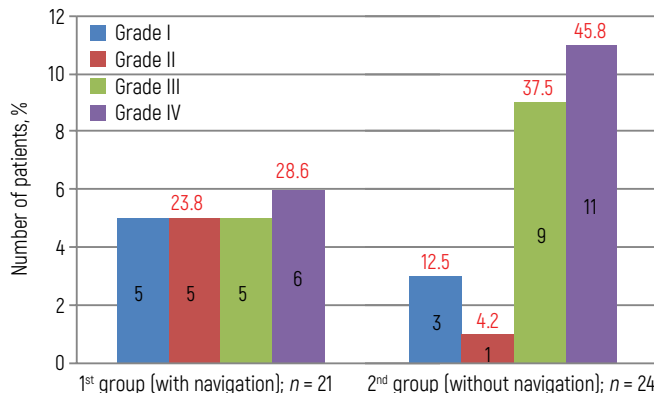


Fig. 2. Distribution of the patients per Fisher grade of subarachnoid hemorrhage

hemorrhage according to Fisher scale ( $p = 0.156$ ), as well as the timing of surgical treatment ( $p = 0.796$ ).

#### Methodology of registration and preoperative planning using frameless neuronavigation

Preoperative CT angiography data of patients in DICOM format was transferred to the navigation station software. Hereafter the aneurysm dome, neck, and parent artery as well as branches arising from the aneurysm dome (if present) and adjacent arteries of the A2-A3 and M2-M3 segments, as well as the frontal sinus were marked on axial, coronal, and sagittal CT angiography scans (Fig. 3).

Preoperatively this made it possible to determine the optimal size and location of the craniotomy, taking into account the localization and trajectory of the approach to the aneurysm, as well as the adjacent anatomical structures – the sagittal sinus and frontal sinuses (Fig. 4).

During forming the bone flap with the usage of sterile FN, the boundaries were re-determined, as well as the optimal size and location of the craniotomy, taking into account the projection of the distal aneurysm and the adjacent anatomical structures – the frontal sinuses, the superior sagittal sinus (Fig. 5).

Before opening the dura mater, the location and trajectory of approach to the distal aneurysm as well as the distance to it, and the location of the venous sinus tributaries were determined in case of distal pCA aneurysms. This minimized the subarachnoid dissection and intraoperative impact on surrounding brain structures during approach to the distal aneurysm (Fig. 6).

The main microsurgical stage was performed in accordance with standard microsurgical technique for this pathology.

All patients ( $n = 20$ ) with distal MCA aneurysms underwent neurophysiological monitoring during surgery, including recording of somatosensory evoked potentials and transcranial motor evoked potentials.

#### Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics v.26. Quantitative indicators were assessed for normal distribution using the Shapiro–Wilk test. In the absence of a normal distribution, quantitative data were described using the median (Me) and the lower and upper quartiles ( $Q_1$ – $Q_3$ ). Mann–Whitney tests were used to compare groups based on quantitative variables.

To compare groups by categorical variable, four-field and multi-field contingency tables were performed, and the results were analyzed using the Pearson  $\chi^2$  test or Fisher's exact test. The Wilcoxon signed-rank test and McNemar's test were used to analyze the frequency of one-sided changes in quantitative and binary nominal variables before and after treatment.

Binary logistic regression was used to create a predictive model. Factors selection was performed by elimination using the Wald test. Differences between the compared groups were considered statistically significant at  $p < 0.05$ .

## RESULTS

### Comparison of surgical treatment methods in groups

To compare surgical treatment methods between groups, the following parameters were included in the analysis: duration of the main surgical stage, total duration of surgery, skin incision length, craniotomy area, intraoperative frontal sinus injury, and blood loss volume. Statistically significant differences were found when comparing these parameters using the Mann-Whitney test (Table 1).

In the 1<sup>st</sup> Group (with FN), distal aneurysms were found and clipped in all cases (median time 95 [80–100] min). In 3 patients with multiple aneurysms, distal aneurysms were clipped in the 2<sup>nd</sup> turn; clipping time ranged from 95 to 150 min (Fig. 7).

In the 2<sup>nd</sup> group (without FN), distal aneurysms were clipped in 21 (87.5 %) patients (median time 160 [140–210] min); in 3 cases, distal aneurysms were not found. In 3 patients with multiple aneurysms, distal aneurysms were clipped in the 2<sup>nd</sup> turn. In 1 case, a catheter was inserted into the interpeduncular cistern before clipping. In these cases, the time of the main surgical stage ranged from 140 to 225 min (see Fig. 7).

In the 1<sup>st</sup> Group (with FN), the median total duration of surgery was 165 [135–195] min. In 4 patients, several aneurysms were clipped during the surgery; the total duration of surgery ranged from 150 to 270 min. In the 2<sup>nd</sup> group (without FN), the median total duration of surgery was 240 [207.5–297.5] min. In 4 clinical cases 2–3 aneurysms were clipped simultaneously; the total duration of surgery ranged from 210 to 335 min (Fig. 8).

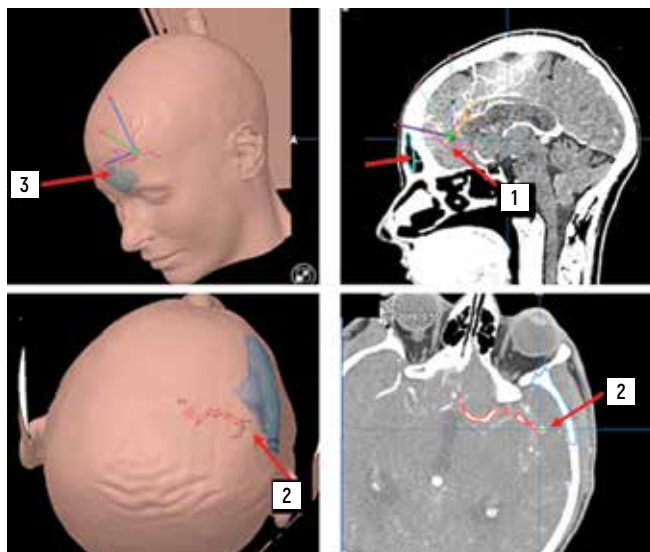


Fig. 3. View from the Brainlab navigation station's monitor: 1 – saccular aneurysm of the A3 segment of the pericallosal artery; 2 – saccular aneurysm of the M3 segment of the middle cerebral artery; 3 – frontal sinus

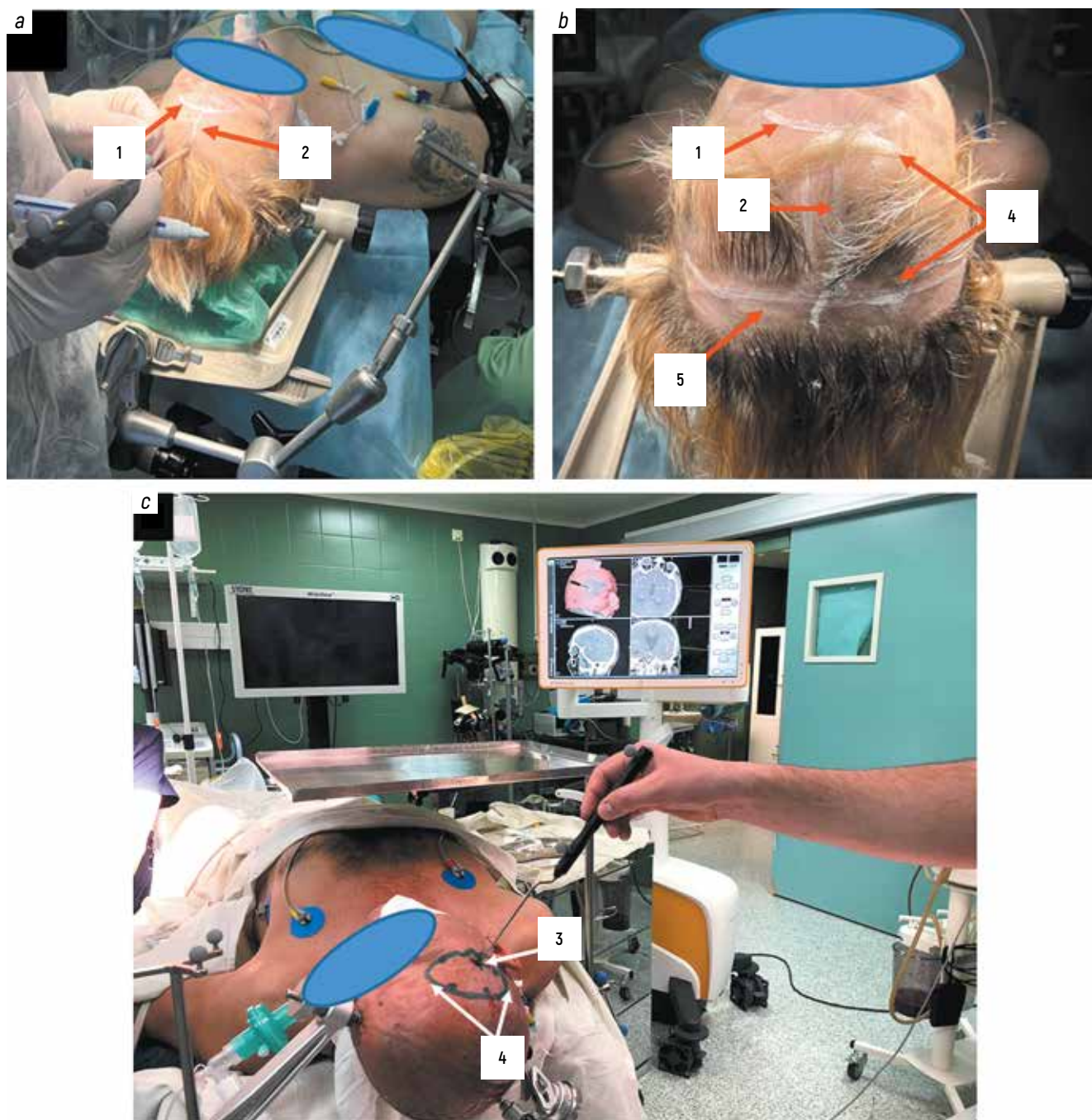


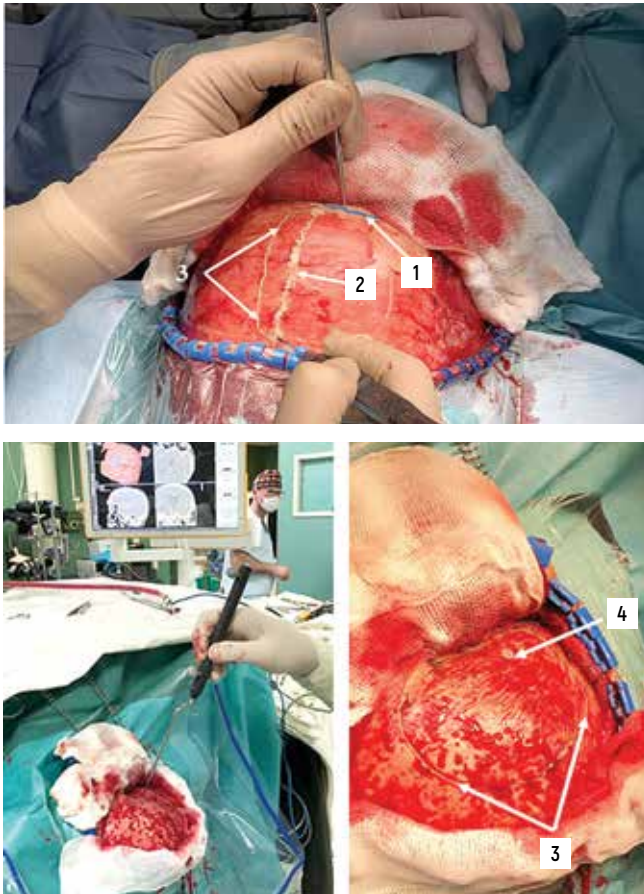
Fig. 4. Intraoperative photos. Stage of preoperative planning of access to distal aneurysms of the pericallosal artery [a, b] and middle cerebral artery [c] using frameless navigation: 1 - projection of the superior wall of the frontal sinus; 2 - projection of the sagittal sinus; 3 - projection of a distal aneurysm of the middle cerebral artery; 4 - assumed craniotomy; 5 - skin incision

In the 1<sup>st</sup> Group (with FN), osteoplastic craniotomy was performed in all cases. The median craniotomy area was 42 [31–47] cm<sup>3</sup>.

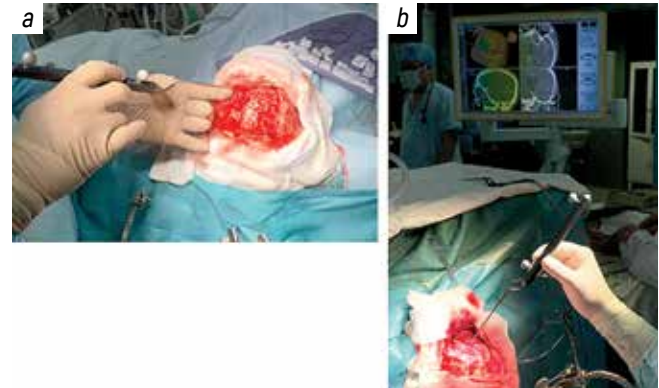
In the 2<sup>nd</sup> group (without FN), decompressive craniotomy was performed in 2 cases (8.3 %), and osteoplastic craniotomy was performed in the remaining 22 (91.7 %) patients; the median craniotomy area was 51 [46–68] cm<sup>3</sup> (Fig. 9). In 1 case, a re-operation was performed, during which

a new access was created using FN for optimal approach to the distal MCA aneurysm (Fig. 10).

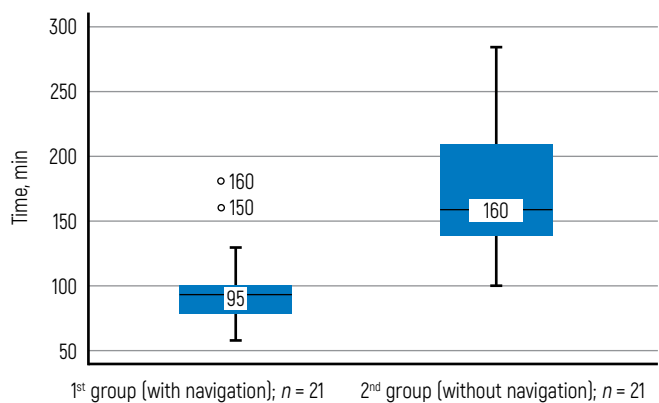
In the 1<sup>st</sup> Group (with FN), bicoronal soft tissue incision was performed in 9 (42.9 %) cases, and an arcuate incision (median length 18 [16–21] cm) in 12 (57.1 %) cases. In the 2<sup>nd</sup> group (without FN), bicoronal soft tissue incision was performed in 8 (33.3 %) cases, and an arcuate incision (median length 19 [15–27] cm) in 16 (66.7 %)



**Fig. 5.** Intraoperative photos. Stage of planning of the size and location of craniotomy using frameless navigation: 1 – superior wall of the frontal sinus; 2 – projection of the sagittal sinus; 3 – assumed craniotomy; 4 – projection of a distal aneurysm of the middle cerebral artery



**Fig. 6.** Intraoperative photos. Refinement of the projection, access trajectory and distance to a distal aneurysm of the pericallosal (a) and middle cerebral (b) arteries



**Fig. 7.** Duration of the main stage of surgery (from the start of surgery to clipping of a distal aneurysm) in the groups

**Table 1.** Comparison of 2 techniques of surgical treatment in the groups

Показатель Characteristic	1 <sup>st</sup> group (with navigation); n = 21		2 <sup>nd</sup> group (without navigation); n = 24		p
	Median [Q <sub>1</sub> -Q <sub>3</sub> ]	Min-max	Median [Q <sub>1</sub> -Q <sub>3</sub> ]	Min-max	
Duration of the main stage of surgery, min	95 [80-100]	60-160	160 [140-210]	100-290	0.0001*
Operative time, min	165 [135-195]	100-275	240 [207.5-297.5]	165-430	0.0001*
Craniotomy area, cm <sup>2</sup>	42 [31-47]	14-84	51 [46-68]	34-98	0.008*
Length of skin incision	18 [16-21]	12-29	19 [15-27]	12-30	0.434
Blood loss volume, mL	200 [100-200]	100-300	200 [200-300]	50-500	0.130

\*Differences are statistically significant ( $p < 0.05$ ).

cases. In 1 (4.2 %) case, during a re-operation for distal MCA aneurysm clipping, the skin incision was adapted for optimal approach to the aneurysm (Fig. 11).

Thus, in the 1st group, FN significantly reduced the duration of the main surgical stage ( $p = 0.0001$ ) and the total duration of surgery ( $p = 0.0001$ ), as well as decreased the craniotomy area ( $p = 0.008$ ). No statistically

significant differences were found in the volume of blood loss ( $p = 0.130$ ) and the length of the skin incision ( $p = 0.434$ ). The absence of differences in the skin incision length between the groups in this case is due to the preference among overwhelming majority of neurosurgeons to adapt skin incisions for possible decompressive craniotomy (Fig. 12).

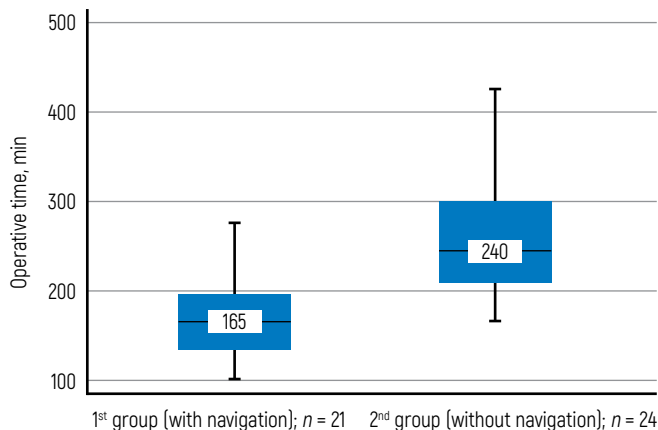


Fig. 8. Operative time in the groups

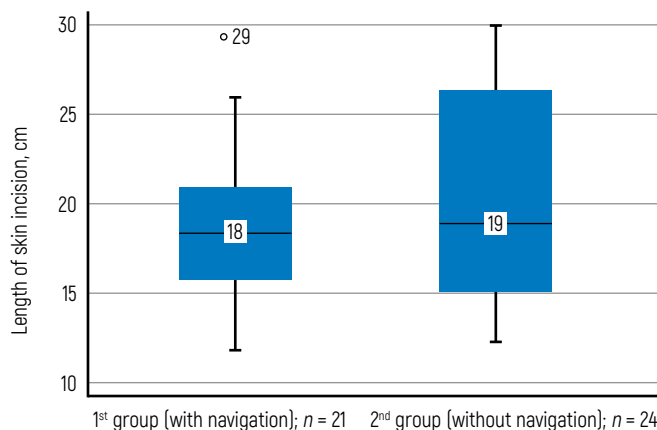


Fig. 11. Length of skin incision in the groups

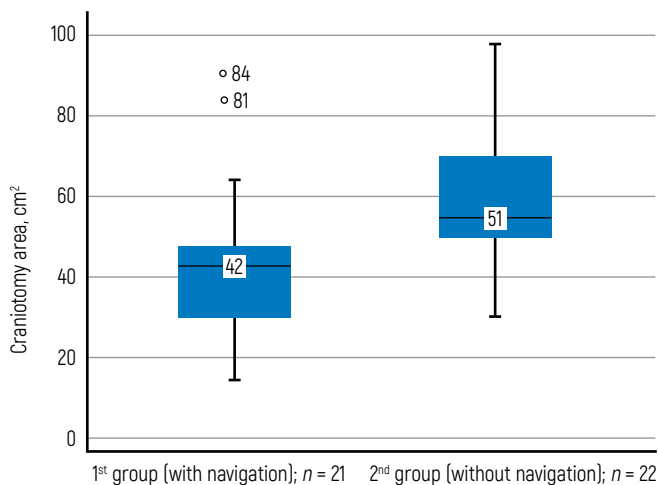


Fig. 9. Craniotomy area in the groups

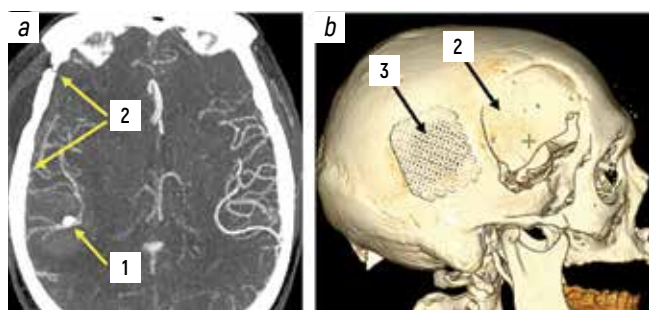


Fig. 10. Postoperative photos of a patient: a - computed angiography, axial projection (after 1st surgery); b - 3D reconstruction of computed tomography of the brain (after 2nd surgery): 1 - distal aneurysm of the M3 segment of the right middle cerebral artery; 2 - craniotomy [1st surgery]; 3 - resection trephination, cranioplasty [2nd surgery]

Intraoperative frontal sinus injury during surgery in the 1st group (with FN) occurred in 1 case (4.8 %) during craniotomy in the parasagittal frontal region and was caused by a technical error – displacement of the FN during approach formation. In the 2nd group 2 (without FN),

8 (33.3 %) cases of frontal sinus injury were observed during craniotomy in the parasagittal frontal region ( $n = 5$ ) and pterional craniotomy ( $n = 3$ ) (Fig. 13).

When comparing the incidence of intraoperative frontal sinus injury depending on the surgical technique, statistically significant differences were obtained ( $p = 0.025$ ). Frontal sinus injury was more common in the 2nd group (without FN) (Fig. 14).

#### Comparative analysis of surgical treatment results

To compare postoperative outcomes between the surgical treatment groups, the following parameters were included in the analysis: volume of intraparenchymal hemorrhage (IPH), ischemic area, and the degree of brain midline shift. These parameters were measured using brain CT scans.

In the 1st group (with FN), IPH occurred in 7 (33.3 %) cases (median volume 14 [6.5–19.5] cm<sup>3</sup>). In all cases, the hematomas were parenchymal. In one case, the hematoma volume in the postoperative period was 25 cm<sup>3</sup> and was due to the patient's concomitant aggravating diseases – thrombocytopenia, idiopathic thrombocytic purpura (Fig. 15).

In the 2nd group (without FN), intracranial hematomas occurred in 11 (45.8 %) cases (median volume 12 [5.5–17.5] cm<sup>3</sup>). In 10 cases, the hematomas were parenchymal; in 1 case, parenchymal and subdural hematomas with a total volume of 40 cm<sup>3</sup> were detected.

We assessed the dynamics of hematoma volume depending on the treatment method. In the 1st Group (with FN), the volume of the IPH was completely removed in 3 cases postoperatively, decreased in 3 cases (42.9 %), and was newly detected in 4 cases (57.1 %). No statistically significant changes in the dynamics of the IPH volume before and after surgery were found ( $p = 0.541$ ).

In the 2nd group (without FN) the postoperative volume of the IPH was completely removed in 2 cases, decreased in 4 (36.4 %), increased in 2 (18.2 %), IPH was detected

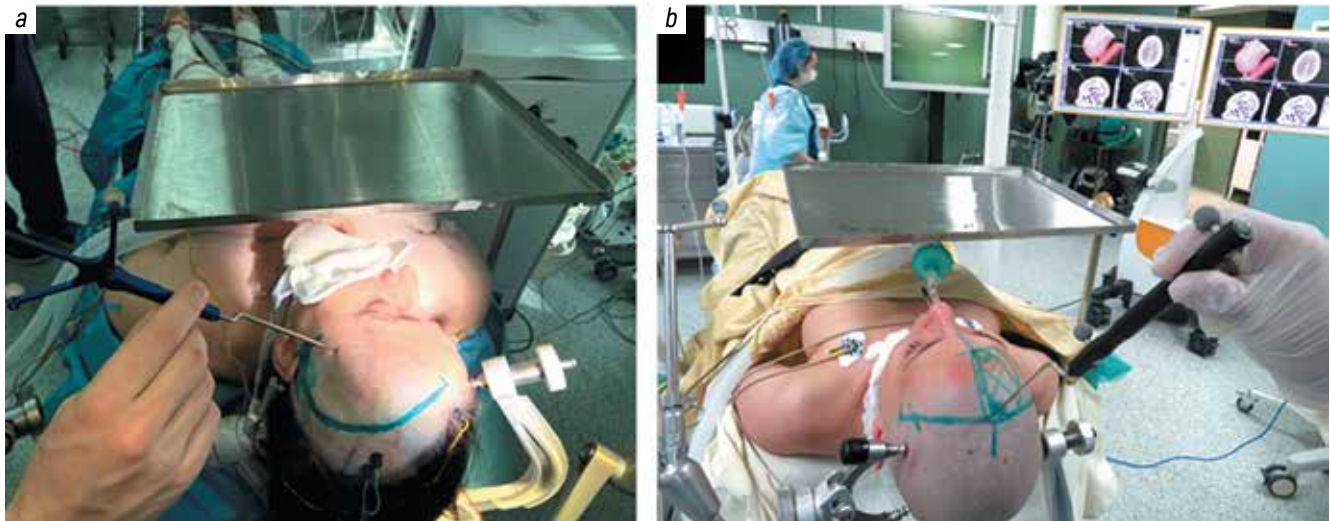


Fig. 12. Types of skin incisions for distal aneurysm access: a – middle cerebral artery, curved incision; b – pericallosal artery, Zutter incision

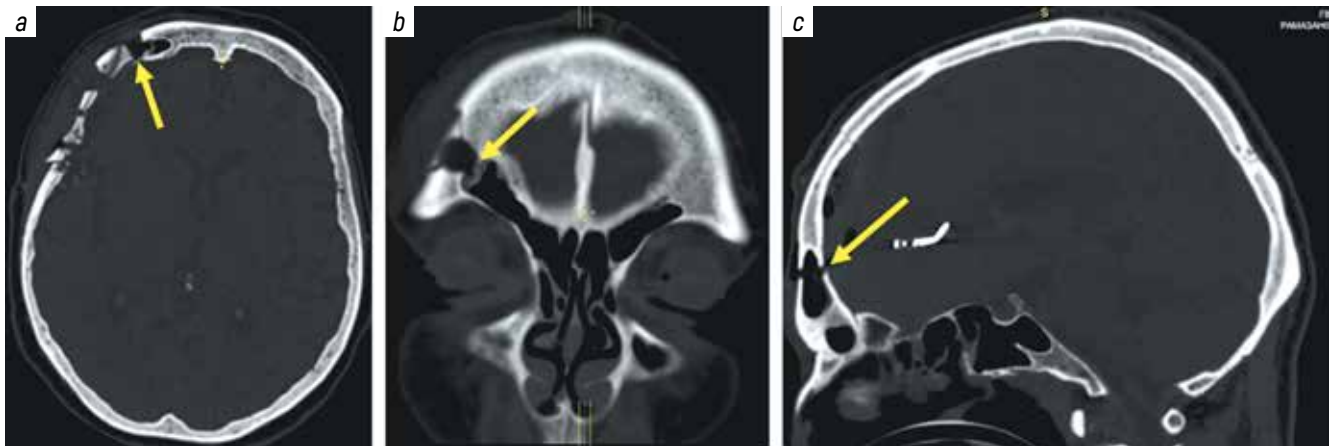


Fig. 13. Results of computed tomography of the brain the postoperative period: examples of frontal sinus injury during pterional craniotomy (a, b), craniotomy in the parasagittal frontal area (c). Arrow points at an open frontal sinus

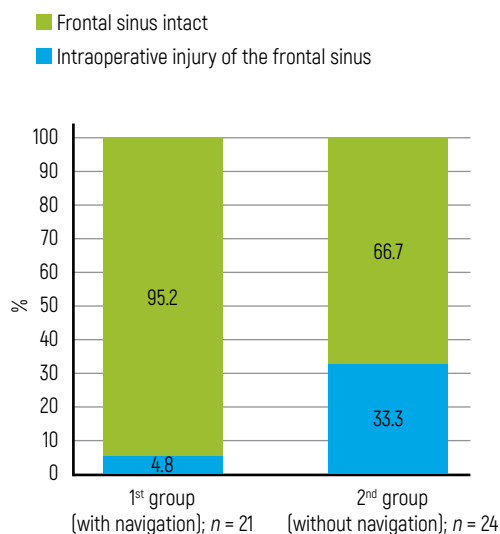


Fig. 14. Intraoperative injuries of the frontal sinus in the groups

for the first time in 4 (36.4 %) cases postoperatively, and the hematoma volume did not change in 1 (9.0 %) patient. No statistically significant changes in the dynamics of the IPH volume were found ( $p = 0.433$ ).

The dynamics of IPH volume in both groups before and after surgery are shown in Fig. 16.

In the 1<sup>st</sup> group, no new cases of IVH were observed postoperatively. The baseline IPH volume in the 1<sup>st</sup> group patients ( $p = 0.317$ ) and the 2<sup>nd</sup> group patients ( $p = 0.076$ ) did not change statistically significantly.

In the 1<sup>st</sup> group (with FN) the ischemic area according to brain CT increased in 1 (4.8 %) case, and was detected for the first time in 2 (9.5 %) patients (median volume – 90 [54–93] cm<sup>3</sup>). No statistically significant changes in the dynamics of ischemic area were detected ( $p = 0.109$ ). In 1 case, according to brain CT, an ischemic area in the surgical site with a volume of 18 cm<sup>3</sup> was detected (Fig. 17, a).

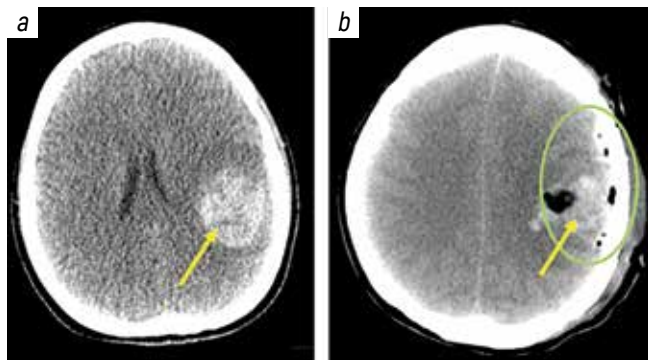


Fig. 15. Results of computed tomography of the brain before (a) and after (b) surgery. Arrow points at an intracerebral hematoma, outline shows surgical zone

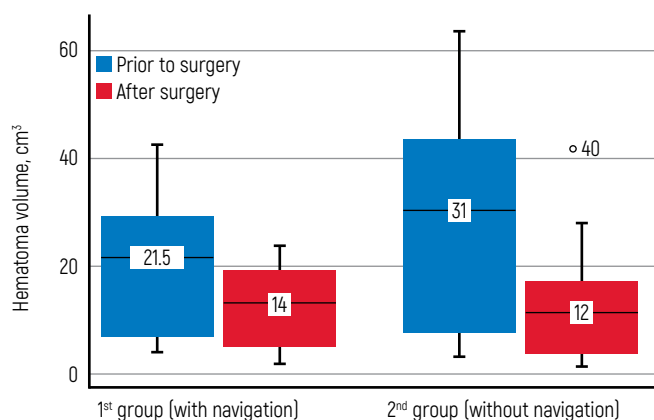


Fig. 16. Dynamics of hematoma volume in the groups before and after surgery per the results of brain computed tomography

In one case of a patient with a FN displacement, brain CT revealed an area of edema-ischemia in the surgical site with hemorrhagic infiltration accounts in total to 90 cm<sup>3</sup> (Fig. 17, b). In one case of a patient with a concomitant disease (thrombocytopenia, idiopathic thrombocytic

purpura), brain CT revealed an increase of the edema-ischemia area from 41 to 96 cm<sup>3</sup> (Fig. 17, c).

In the 2<sup>nd</sup> group (without FN) ischemia was detected for the first time in 12 (50.0 %) patients (median volume – 22 [13.5–77.5] cm<sup>3</sup>) (Fig. 18). These changes according to brain CT data were statistically significant ( $p = 0.002$ ).

In the 1<sup>st</sup> Group (with FN) brain midline shift occurred in 5 (23.8 %) cases (median shift – 5 [4–7] mm). According to brain CT data, brain midline shift decreased in 1 case (20 %), increased in 1 patient (20 %), and was revealed for the first time in 3 cases (60 %). These changes were statistically insignificant ( $p = 0.138$ ). Brain axial shift before and after surgery occurred in 2 cases.

In the 2<sup>nd</sup> group (without FN), brain midline shift occurred in 9 (37.5 %) cases (median shift – 5 [4–5] mm). In 1 case, brain midline shift regressed, in 1 case (11.1 %) it increased, and in 8 (88.9 %) patients it was revealed for the first time. These changes are statistically significant ( $p = 0.04$ ). Brain axial shift was not revealed before surgery according to brain CT data; however, it occurred in 3 (12.5 %) cases postoperatively; these changes are statistically insignificant ( $p = 0.25$ ). The dynamics of displacement of the brain midline shift in the groups before and after surgery are presented in Fig. 19.

#### Description and analysis of surgical outcomes in patients with distal aneurysms

To analyze the surgical treatment outcomes, the following parameters were studied: level of consciousness according to the Glasgow Coma Scale (GCS) after surgery, neurological deficit, postoperative and systemic complications, re-operation incidence, the number of days in intensive care unit and in hospital, treatment outcome.

The comparison of patients' levels of consciousness according GCS revealed statistically significant differences between the groups ( $p = 0.013$ ). These differences were explained by the higher frequency of fully conscious

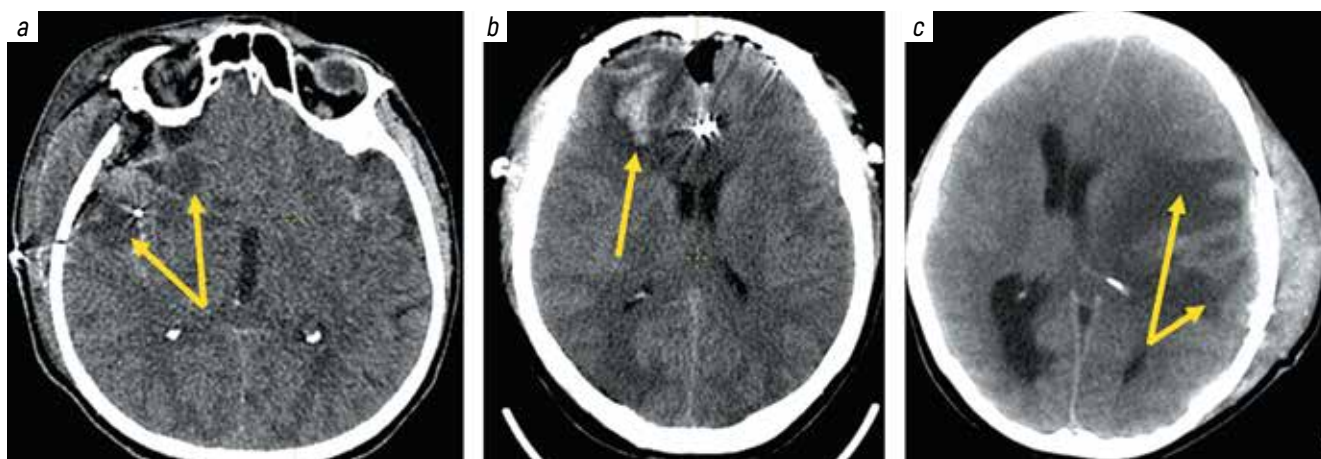


Fig. 17. Results of brain computed tomography after surgery, axial projection: a – area of ischemia in the surgical zone, volume 18 cm<sup>3</sup>; b – area of edema-ischemia in the surgical zone with hemorrhagic soak, volume 90 cm<sup>3</sup>; c – growth of edema-ischemia area from 41 to 96 cm<sup>3</sup>. Arrows point at areas of ischemia

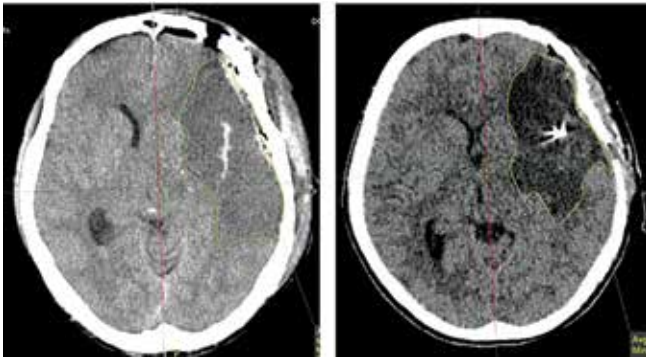


Fig. 18. Results of brain computed tomography after surgery, axial projection. Areas of ischemia are outlined

in the 1<sup>st</sup> group (with FN) compared to severely impaired consciousness among patients in the 2<sup>nd</sup> group 2 (without FN) ( $p = 0.023$ ). The results are presented in Table 2.

The incidence of new focal neurological deficits in the postoperative period in the 1<sup>st</sup> Group 1 (with FN) increased from 19 % to 23.8 %. In four cases, neurological deficits remained unchanged, and in one case the new one was detected. These changes across the group were statistically insignificant ( $p = 1.000$ ).

In the 2<sup>nd</sup> group (without FN) the incidence of new neurological deficits after treatment increased from 12.5 % to 54.2 %. In 3 cases (12.5 %) neurological deficits worsened after surgery; in 10 cases (41.6 %) the new ones were detected and manifested as decreased consciousness, motor impairments ranging from 0 to 4 points, sensor and motor aphasia, and visual impairments. These changes in the postoperative group were statistically significant ( $p = 0.002$ ).

When comparing the two groups in terms of the incidence of new neurological deficits, the statistically significant differences were found ( $p = 0.0001$ ). The incidence of new neurological deficits was statistically significantly higher in the 2<sup>nd</sup> group (without FN) compared to the 1<sup>st</sup> group 1 (with FN).

We created a predictive model to determine the likelihood of developing a new neurological deficit in the postoperative period based on various factors using binary logistic regression. The final model included factors such as surgical technique, cerebral angiospasm, ischemia, and ICH:

$$P = 1/(1 + e^{-z}) - 100 \%;$$

$$z = -21,33 + 3,95X_{\text{angiospasm}} - 5,94X_{\text{treatment method}} + 2,53X_{\text{ischemia}} + 3,35X_{\text{ICH}}, \quad (1)$$

where  $P$  is the probability of developing a new neurological deficit in the postoperative period (%);  $X_{\text{angiospasm}}$  is the development of severe angiospasm in the postoperative period (0 – absence, 1 – presence);  $X_{\text{treatment method}}$  is the surgical technique (1 – FN, 2 – routine method

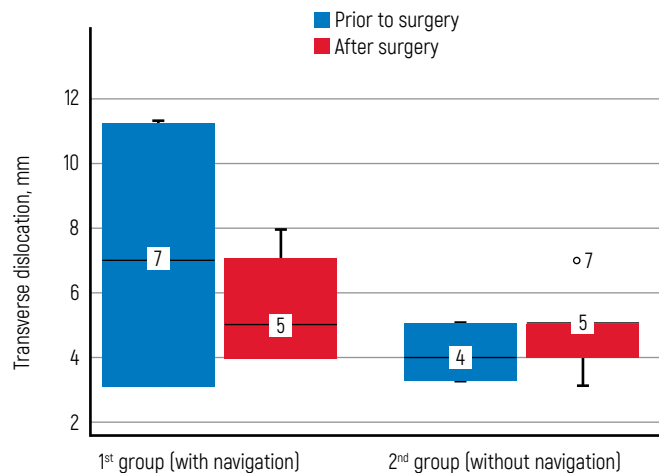


Fig. 19. Dynamics of transverse dislocation of midline structures per brain computed tomography before and after surgery

without FN);  $X_{\text{ischemia}}$  is ischemia in the postoperative period (0 – absence, 1 – presence);  $X_{\text{ICH}}$  – intracerebral hemorrhage (0 – absence, 1 – presence).

The resulting regression model is statistically significant ( $p = 0.0001$ ). The characteristics of each factor included in the model are presented in Table 3.

The threshold value of the logistic function  $P$  was determined using the ROC curve analysis method (Fig. 20).

The area under the ROC curve was  $0.95 \pm 0.03$  (95 % confidence interval 0.9–1.0). The probability of developing a new neurological deficit  $P$  at the cut-off point was 35.1 %. At  $P \geq 35.1$  %, a high risk of detecting a neurological deficit was determined, and at  $P < 35.1$  % – a low risk. The sensitivity and specificity of the model (1) at this cut-off value were 85.7 and 86.7 %, respectively.

Postoperative complications included new-onset and postoperative worsening of ICH, ischemia, brain midline shift, cerebral angiospasm, and cerebral edema. For ease of comparison, these indicators were combined into the category of “postoperative complications”.

If any of the listed symptoms appeared or worsened, the patient was considered as a case of postoperative complication. A comparison of the incidence of postoperative complications between the groups yielded statistically significant differences ( $p = 0.025$ ). The incidence of postoperative complications in the 1<sup>st</sup> group 1 (with FN) was significantly lower than in the 2<sup>nd</sup> group (without FN) – 47.6 % and 83.3 %, respectively. The results are presented in Table 4. The distribution of postoperative complications between the groups is shown in Fig. 21.

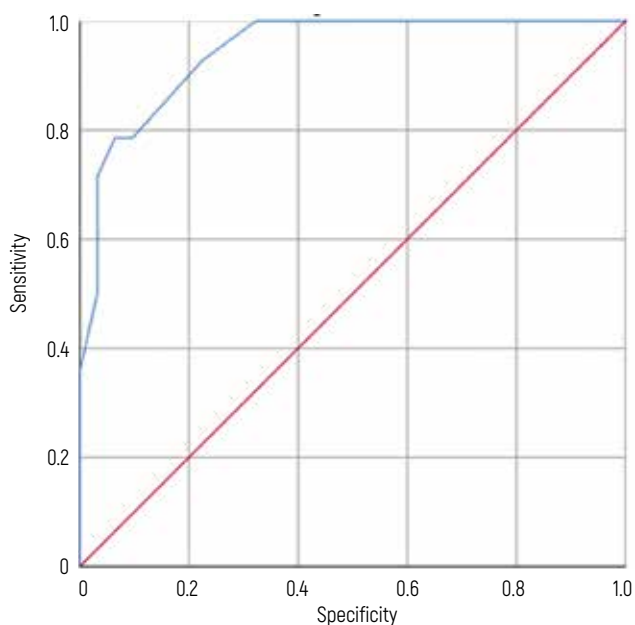
When comparing the incidence of systemic complications in the postoperative period in the groups, statistically significant differences were revealed ( $p = 0.005$ ). The incidence of systemic complications was significantly lower in the 1<sup>st</sup> group (with FN) compared to the 2<sup>nd</sup> group (without FN) – 14.3 and 58.3 % respectively. The results are presented in Table 5. The distribution of systemic complications in the groups is shown in Fig. 22.

**Table 2.** Results of comparison of patient data per consciousness level in the postoperative period, n (%)

Consciousness level	1 <sup>st</sup> group (with navigation); n = 21	2 <sup>nd</sup> group (without navigation); n = 24	p
1. Full consciousness	19 (90.4)	10 (41.6)	0.013; $p_{1-4}, 5, 6 = 0.023$
2. Moderate obtundation	1 (4.8)	4 (16.7)	
3. Deep obtundation	0	3 (12.5)	
4. Stupor	1 (4.8)	4 (16.7)	
5. Moderate coma	0	2 (8.3)	
6. Deep coma	0	1 (4.2)	

**Table 3.** Characteristics of the relationship between model predictors (1) and probability of neurologic deficit (P) in the postoperative period

Predictor	Univariate analysis		Multivariate analysis	
	Odds ratio; 95 % confidence interval	p	Odds ratio; 95 % confidence interval	p
Surgical technique	23.64; 2.72–205.56	0.004	379.6; 3.87–37 277.1	0.011
Cerebral angiospasm in the postoperative period	7.5; 1.83–30.73	0.005	52.1; 1.65–1646.82	0.025
Ischemia in the postoperative period	7.5; 1.83–30.73	0.005	12.5; 0.8–180.27	0.063
Intracerebral hematoma	7.2; 1.75–29.48	0.006	28.4; 1.21–665.64	0.038



**Fig. 20.** ROC curve characterizing the relationship between probability of new neurologic deficit and prognostic function value (1)

The re-operation was performed in 1 case (4.8 %) in the 1<sup>st</sup> Group 1. Decompressive craniotomy was performed due to postoperative worsening cerebral edema-ischemia and brain midline shift (see Fig. 17, c).

In the 2<sup>nd</sup> group, decompressive craniotomy was performed in 20.8 % ( $n = 5$ ) of cases, external ventricular drainage and ventriculoperitoneal shunt were placed 3d in 8.3 % ( $n = 2$ ) cases, repeated clipping of the distal MCA aneurysm using FN was performed in 4.2 % ( $n = 1$ ) cases, secondary surgical debridement of the postoperative wound was performed in 4.2 % ( $n = 1$ ), revision of the surgical wound for removal of ventriculoperitoneal shunt in 4.2 % ( $n = 1$ ), revision of the surgical wound for removal of a non-traumatic acute subdural hematoma with a volume of 200 cm<sup>3</sup> in 1 patient (4.2 %). The frequency of re-operations was statistically significantly higher in the 2<sup>nd</sup> group ( $p = 0.002$ ).

When comparing the groups by the duration of postoperative treatment in the intensive care unit, statistically significant differences were revealed ( $p = 0.011$ ). Patients in the 1<sup>st</sup> group (with FN) spent fewer days in the intensive care unit than patients in the 2<sup>nd</sup> Group (without FN). There were no statistically significant differences in the duration of hospital staying ( $p = 0.119$ ) between the groups (Table 6).

The lethality incidence in the postoperative period was statistically significantly higher in the 2<sup>nd</sup> group 2 (without FN) compared to the 1<sup>st</sup> group ( $p = 0.023$ ). When comparing the rate of outcome according to the 5-point Glasgow Outcome Scale (GOS), statistically significant differences were found between both groups ( $p = 0.0001$ ). These differences were explained by the higher rate of good postoperative

recovery of patients in the 1<sup>st</sup> group (with FN) compared to the 2<sup>nd</sup> group, where severe disability, vegetative state, and death occurred (Table 7).

**DISCUSSION**

Taking into account the atypical localization of distal aneurysms (deep location and lack of anatomical landmarks during approach), the best results in surgical treatment can be achieved by using FN.

The first studies devoted to the FN use in surgery of distal aneurysms described small patient samples. The authors noted the advantages and convenience of using FN in clipping distal aneurysms; however, the surgical results were not analyzed [7–13].

The first description of the surgical treatment results was published by T. Toyooka et al. in 2017. The authors compared the results of surgical treatment in 2 groups of patients: the main group ( $n = 35$ ), where aneurysm clipping was performed using FN, and the control group ( $n = 41$ ), where a routine surgical treatment technique was used.

According to the authors, the time of the main stage of the operation and the size of the supraorbital craniotomy did not differ in the two groups; only the size of the pterional craniotomy differed. However, the authors did not provide statistical analysis of the obtained results, and among the entire sample, only 2 patients had a distal aneurysm [14].

W. Dai et al. retrospectively analyzed the treatment outcomes of 112 patients with distal aneurysms, divided into two groups: a study group ( $n = 51$ ), where clipping was performed using a FN, and a control group ( $n = 61$ ) with a routine surgical technique. The two groups of patients did not differ in gender, age, severity of condition at admission, and aneurysm location.

When analyzing the results of surgical treatment, no statistically significant differences were found in the duration of surgery ( $p = 0.340$ ) and the volume of blood loss ( $p = 0.274$ ). The time of hospital stay in the main group was shorter than in the control group ( $8.12 \pm 2.12$  days *versus*  $8.99 \pm 1.87$  days, respectively;  $p = 0.023$ ). Also, no statistically significant differences were found in the severity of the patients' condition in the groups in the postoperative period according to the National Institutes of Health Stroke Scale (NIHSS) ( $p = 0.136$ ) and the Glasgow Outcome Scale (GOS) ( $p = 0.401$ ) [15].

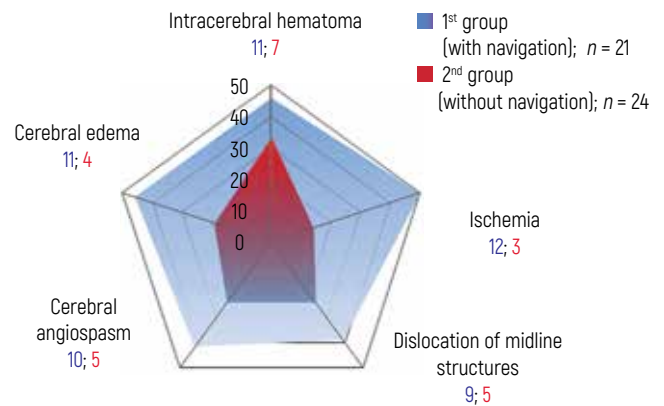
S. Han et al. retrospectively analyzed the treatment results of 139 patients with distal aneurysms, of which 03 were operated on using a routine surgical technique, and 36 patient with the usage of FN. No statistically significant differences were found in the time of hospital stay in both groups ( $17.5 [16–21]$  days *versus*  $18 [15–22]$  days, respectively;  $p = 0.761$ ), the volume of blood loss ( $370 [280–460]$  ml *versus*  $430 [310–610]$  ml, respectively;  $p = 0.045$ ), or the severity of the patient's condition in the postoperative period according to the modified Rankin scale ( $p = 0.157$ ).

**Table 4.** Postoperative complication rate in the groups ( $p = 0.025$ ),  $n$  (%)

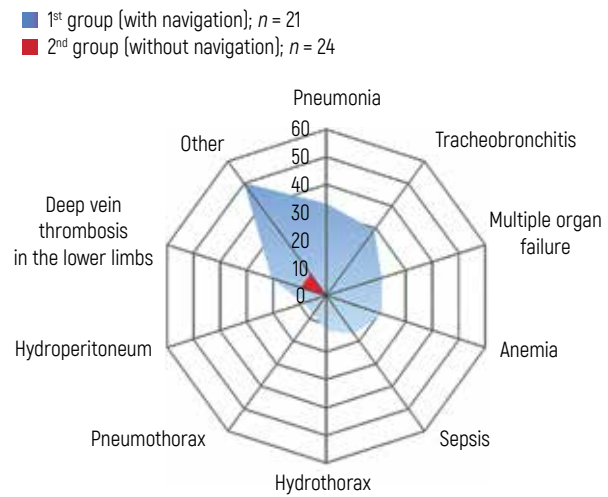
Postoperative complications	1 <sup>st</sup> group (with navigation); $n = 21$	2 <sup>nd</sup> group (without navigation); $n = 24$
Present	10 (47.6)	20 (83.3)
Absent	11 (52.4)	4 (16.7)

**Table 5.** Systemic complication rate in the groups in the postoperative period ( $p = 0.005$ ),  $n$  (%)

Systemic complications	1 <sup>st</sup> group (with navigation); $n = 21$	2 <sup>nd</sup> group (without navigation); $n = 24$
Present	3 (14.3)	14 (58.3)
Absent	18 (85.7)	10 (41.7)



**Fig. 21.** Distribution of postoperative complications in the groups,  $n$



**Fig. 22.** Distribution of systemic complications in the groups

**Table 6.** Results of comparison of duration of treatment in the ICU and inpatient facility in the postoperative period

Characteristic	1 <sup>st</sup> group (with navigation); n = 21		2 <sup>nd</sup> group (without navigation); n = 24		p
	Median [Q <sub>1</sub> –Q <sub>3</sub> ]	Min–max	Median [Q <sub>1</sub> –Q <sub>3</sub> ]	Min–max	
Number of days in ICU	2 [1–7]	1–22	9 [2–24.5]	1–101	0.011*
Number of days in inpatient facility	18 [12–23]	9–70	19.5 [16–45.5]	10–101	0.119

\*Differences are statistically significant ( $p < 0.05$ ).

The authors noted statistically significant differences in the duration of the main stage of the operation in the groups (49 [42–53] min *versus* 79 [63–84] min, respectively;  $p < 0.001$ ), which was significantly shorter while using FN [16].

In our study, statistically significant differences were revealed for the following parameters: the duration of the main stage of the operation ( $p = 0.0001$ ), total time of the operation ( $p = 0.0001$ ), craniotomy area ( $p = 0.008$ ), frequency of frontal sinus injury ( $p = 0.025$ ), severity of the patient's condition according to the GOS in the postoperative period ( $p = 0.0001$ ) and duration of treatment in intensive care ( $p = 0.011$ ).

Despite controversial research results and a small number of studies devoted to the analysis of surgical treatment of distal aneurysms, we consider FN to be

a useful tool in the neurosurgeon's arsenal, allowing for minimal invasiveness and maximum safety, improving surgical outcomes, and reducing the risk of death and severe disability in patients in the postoperative period.

### CONCLUSION

The usage of FN reduces the time to locate the distal aneurysm and the duration of surgery, allows for a smaller craniotomy area, prevents intraoperative damage of the frontal sinus, statistically significantly reduces the risk of developing new postoperative neurological deficits, and improves clinical outcomes. This technique also significantly reduces the risk of re-operations, the time of intensive care unit stay in the postoperative period, and the risk of developing systemic complications.

## References

- Krylov V.V. Surgery of cerebral aneurysms. V. 2. Moscow: Novoe Vremya, 2011. P. 516. (In Russ.).
- Nussbaum E., Madison M., Goddard J. et al. Peripheral intracranial aneurysms: management challenges in 60 consecutive cases. *J Neurosurg* 2009;110(1):7–13. DOI: 10.3171/2008.6.JNS0814
- Rodriguez-Hernandez A., Zador Z., Rodriguez-Mena R., Lawton M. Distal aneurysms of intracranial arteries: application of numerical nomenclature, predilection for cerebellar arteries, and results of surgical management. *World Neurosurg* 2013; 80(1–2):103–12. DOI: 10.1016/j.wneu.2012.09.010
- Hernesniemi J., Tapaninaho A., Vapalahti M. et al. Saccular aneurysms of the distal anterior cerebral artery and its branches. *Neurosurgery* 1992;31(6):994–9. DOI: 10.1227/00006123-199212000-00002
- Wu C., Sun Z., Wang F. et al. Surgical managements of peripheral intracranial aneurysms. *Zhonghua Yi Xue Za Zhi* 2014;94(9): 698–700. (In Chinese).
- Senko I.V., Krylov V.V. Microsurgical treatment of distal cerebral aneurysms. *Neyrokhirurgiya = Russian Journal of Neurosurgery* 2016;(1):98–103. (In Russ.).
- Albert F.K., Wirtz C.R., Forsting M. et al. Image guided excision of a ruptured feeding artery “pedicle aneurysm” associated with an arteriovenous malformation in a child: case report. *Comput Aided Surg* 1997;2(1):5–10. DOI: 10.1002/(SICI)1097-0150(1997)2:1<5::AID-IGS3>3.0.CO;2-3
- Melgar M.A., Zamorano L., Jiang Z., Guthikonda M. Three-dimensional magnetic resonance angiography in the planning of aneurysm surgery. *Comput Aided Surg* 1997;2(1):11–23. DOI: 10.1002/(sici)1097-0150(1997)2:1<11::aid-igs4>3.0.co;2-q
- Raabe A., Beck J., Rohde S., Berkefeld J. Three-dimensional rotational angiography guidance for aneurysm surgery. *J Neurosurg* 2006;105(3):406–11. DOI: 10.3171/jns.2006.105.3.406
- Kim T., Joo S., Lee J. et al. Neuronavigation-assisted surgery for distal anterior cerebral artery aneurysm. *Minim Invasive Neurosurg* 2007;50(3):140–4. DOI: 10.1055/s-2007-985151
- Lee S.H., Bang J.S. Distal middle cerebral artery M4 aneurysm surgery using navigation-CT angiography. *J Korean Neurosurg Soc* 2007;46(6):478–80. DOI: 10.3340/jkns.2007.42.6.478
- Kil J.S., Kim D.W., Kang S.D. Navigation-guided keyhole approach for unruptured intracranial aneurysms. *Korean J Cerebrovasc Surg* 2011;13(3):244–8.
- Hermann E.J., Petrakakis I., Götz F. et al. Surgical treatment of distal anterior cerebral artery aneurysms aided by electromagnetic navigation CT angiography. *Neurosurg Rev* 2015;38(3):523–30. DOI: 10.1007/s10143-015-0611-9

14. Toyooka T., Otani N., Wada K. et al. Head-up display may facilitate safe keyhole surgery for cerebral aneurysm clipping. *J Neurosurg* 2017;129(4):883–9. DOI: 10.3171/2017.5.jns162692
15. Dai W., Ling H., Sun Y. et al. The comparison of neuronavigation combined with CT three-dimensional angiography vs. CT angiography in the guidance of clipping treatment in distal intracranial aneurysm surgery: a retrospective clinical study. *Ann Transl Med* 2022;10(10):572. DOI: 10.21037/atm-22-1749
16. Han S., Qin X., Zhang W. et al. Advantages of computed tomography-based navigation in clipping distal anterior cerebral artery aneurysms: a retrospective cohort study. *Quant Imaging Med Surg* 2023;13(12):8326–35. DOI: 10.21037/qims-23-671

**Authors' contributions**

E.S. Ryzhkova: study design, data collection, statistical analysis, participation in surgeries, article writing;  
V.A. Lukyanchikov, V.V. Krylov: study design, participation in surgeries; scientific editing;  
I.V. Senko: obtaining data for analysis, participation in surgeries;  
T.A. Shatokhin, D.V. Khovrin, V.A. Dalibaldyan, M.V. Sinkin, Z.A. Barbakadze, Z.A. Kulov, A.A. Grin: participation in surgeries.

**ORCID of authors**

E.S. Ryzhkova: <https://orcid.org/0000-0002-5009-3669>  
V.A. Lukyanchikov: <https://orcid.org/0000-0003-4518-9874>  
I.V. Senko: <https://orcid.org/0000-0002-5743-8279>  
T.A. Shatokhin: <https://orcid.org/0000-0002-2864-9675>  
D.V. Khovrin: <https://orcid.org/0000-0002-7081-3766>  
V.A. Dalibaldyan: <https://orcid.org/0000-0002-5993-3310>  
M.V. Sinkin: <https://orcid.org/0000-0002-1339-8519>  
Z.A. Barbakadze: <https://orcid.org/0000-0003-3835-4317>  
Z.A. Kulov: <https://orcid.org/0009-0009-4955-0234>  
A.A. Grin: <https://orcid.org/0000-0003-3515-8329>  
V.V. Krylov: <https://orcid.org/0000-0001-5256-0905>

**Conflict of interest.** The authors declare no conflict of interest.

**Funding.** The study was performed without external funding.

**Compliance with patient rights and principles of bioethics.** The study protocol was approved by the local ethics committee of the Russian Medical Academy of Continuous Professional Education of the Ministry of Health of Russia. The study was retrospective. The patients gave written informed consent to the publication of his(their) data.