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In accordance with the resolution of the Higher Attestation Commission of the Ministry of Education and Science of the Russian Federation, the Problems of Neurosurgery named after N.N. Burdenko was included in the List of Leading Peer-Reviewed Journals and Periodicals issued in the Russian Federation where the main results of Candidate and Doctor Theses are recommended to be published.

Topics to be covered in our next issue:

- Treatment of pituitary adenomas
- Accessing the posterior cranial fossa in the lying position
- Navigation systems in neurosurgery
The Principles for Choosing a Surgical Technique for Patients with Acute Cerebral Aneurysm Rupture


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The article describes the principles for choosing a surgical technique for patients with cerebral aneurysms during acute subarachnoid hemorrhage. The principles were developed based on the experience gained at the Burdenko Neurosurgical Institute. Microsurgical and endovascular treatment options are considered.

Keywords: vascular neurosurgery, aneurysm, subarachnoid hemorrhage, acute period, microsurgical and endovascular treatment, treatment choice principles.

Currently, microsurgical and endovascular techniques form the basis for cerebrovascular surgery. These methods are most widely used in treatment of patients with cerebrovascular aneurysms. At the same time, these directions are competing, which can lead to misguided use, or, on the contrary, non-use of a particular method. Meanwhile, numerous publications testify to the fact that neither microsurgery, nor endovascular surgery alone can solve all the complex problems of surgical treatment of patients with aneurysm rupture [1—8]. In this connection, the search for the best treatment options and ways of co-operation between different methods is still a topical issue.

Currently, N. N. Burdenko Neurosurgical Institute (NSI) has two closely cooperating vascular departments (endovascular and microsurgical), which constantly discuss the tactics of treatment of individual patients and treatment outcomes in general. Treatment of patients with cerebrovascular aneurysms in acute hemorrhage stage is one of the most difficult areas in this work, since, apart from the general indications for a particular type of treatment, which is mainly based on topographic and anatomical features of aneurysms, these patients also have a number of factors that should be considered, when choosing a method of aneurysm exclusion. These include the severity of patient’s state, vasoconstriction, extent of hemorrhage, the presence and volume of intracerebral hematoma (ICH), etc.

The study was aimed at discussing the principles for choosing a surgical technique in patients with acute cerebral aneurysms rupture based on the experience gained at the N. N. Burdenko NSI.

During the period from 1995 to 2015, a total of 894 patients with acute cerebral aneurysm rupture were operated on at the N. N. Burdenko NSI. During this period, some changes occurred in treatment of acute patients. The algorithm of examination of patients with subarachnoid hemorrhage (SAH) has become a standard (Fig. 1). The principles of differential selection of patients for surgery have been implemented, admitting the possibility of refusing the surgery in extremely serious patients and delayed operations in Hunt-Hess grade III—IV patients with progressive vasoconstriction during the period from day 4 to day 7 after SAH [9].

The principles of postoperative intensive care in the acute period of SAH have been significantly modified. Currently, invasive monitoring of intracranial pressure (ICP) is a stringent requirement in patients with risk of intracranial hypertension. Along with the absolute ICP values, the cerebral perfusion pressure (CPP) is evaluated. Maintaining the target values of CPP of not lower than 60—70 mm Hg has become an essential criterion during resuscitation. Monitoring of system oxygenation values, electrolyte homeostasis, and hemoglobin level plays an essential role in management of intensive care patients.

Technological innovations are of key importance. The repertoire of direct vascular neurosurgery was augmented with modern microscopes characterized by higher resolution and more reliable methods of arterial permeability monitoring, including contact Doppler, flowmetry, and microscopic modules for fluorescent video angiography. Endovascular surgery tools have been significantly improved. Coils and stents became more widely used in aneurysm occlusion.

In a sense, endovascular angioplasty with verapamil also came up to expectations in patients with complicated vasoconstriction [10]. It was noted that the efficacy of the method is higher when the treatment is applied at an early stage of vasoconstriction, prior to the formation of ischemic lesions.

All these factors put together contributed to improved values of postoperative mortality: from 11.2%...
Based on the results of direct and endovascular surgery for aneurysms in the acute period of SAH, the criteria that must be considered when choosing the surgical technique have been defined.

The main criteria for selecting the surgical treatment of patients with cerebral aneurysms in the acute stage of SAH are as follows.

**Topographic and anatomical features of aneurysm**

1. Small to medium sized aneurysms of the ophthalmic segment of the internal carotid artery (ICA) are subject to endovascular occlusion with coils. Microsurgical technique under direct control of the cervical carotid arteries and application of intravascular blood aspiration techniques is the method of choice in the case of large and giant aneurysms of the ICA.

2. Aneurysms of the supraclinoid portion of the ICA, proximal and distal (peripheral) aneurysms of the medial cerebral artery and anterior communicating arteries are in most cases excluded from the circulation using microsurgical technique. Endovascular interventions for aneurysm occlusion with coil or occlusion of the artery with aneurysm are considered in special cases, where, for whatever reasons, direct intervention is not possible.

3. All aneurysms of the stem and bifurcation of the basilar artery, as well as aneurysms of the posterior cerebral artery should be excluded using endovascular technique (aneurysm occlusion using coils with or without stent-assistance). Microsurgical clipping of these aneurysms is considered only in special cases, where, for whatever reasons, endovascular intervention is impossible.

4. Aneurysms of the vertebral artery located at the mouth of the posterior inferior cerebellar artery (PICA) and peripheral aneurysms of the PICA are most often excluded using microsurgical clipping, while in the case of other aneurysms of the intracranial portion of the vertebral artery located proximal and distal to the mouth of the PICA, endovascular surgical technique is advisable.

**Number of aneurysms.** Time-urgent exclusion of the bleeding aneurism is the basic principle in management of patients with multiple cerebral aneurysms in the acute stage of SAH. Bleeding aneurism must be excluded using the most appropriate microsurgical or endovascular technique. The decision on the possibility of exclusion of all aneurysms from the circulation, either in a single-stage operation or in several stages, including combination of microsurgical and endovascular interventions, is made individually in each case.

When operating on patients with bilateral aneurysms of the anterior portions of the circle of Willis, surgeons should avoid doing pterional bilateral cranietomy as a single-stage surgical intervention, since the surgical trauma of both frontal lobes is more poorly tolerated by patients in the acute period of SAH.

The severity of patient's condition. The factors determining the risk of unfavorable outcome are well known and have been repeatedly discussed in the literature \[9, 11—15\]. These primarily include the severity of vasospasm and cerebral edema, the presence and volume of intracerebral hematoma (ICH), the time elapsed since the hemorrhage. The combination of these factors determines the severity of patient's condition as assessed on the Hunt-Hess scale or the scale of the World Federation of Neurosurgical Society (WFNS).

Our clinical experience shows that indications for surgical treatment of patients with single cerebral aneurysms in the acute stage of SAH, either compensated (Hunt-Hess grade I—II) or sub-compensated (Hunt-Hess grade III) (Fig. 2) are the most straightforward. Most of these patients should be operated on without delay, regardless of the time elapsed since the SAH. The choice of the method of aneurysm exclusion from the circulation depends primarily on its location and size. The algorithm of surgical treatment of patients with

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**Fig. 1.** The algorithm of examination of patients with non-traumatic SAH approved at the N.N. Burdenko NSI.
multiple cerebral aneurysms in the acute stage of SAH, corresponding Hunt-Hess grades I—III, can also be clearly formulated (Fig. 3). In this case, the sequence of aneurysm exclusion after exclusion of the ruptured aneurysm is determined by their localization in accordance with the anatomic and surgical classification of multiple cerebral aneurysms.

**Anatomic and surgical classification of multiple cerebral aneurysms.**

1. Multiple ipsilateral aneurysm of the anterior portions of the circle of Willis (aneurysms of one carotid system).
2. Multiple bilateral aneurysms of the anterior portions of the circle of Willis (aneurysms of two carotid system).
3. Multiple aneurysms of one carotid and one vertebrobasilar system.
4. Multiple aneurysms of two carotid systems and one vertebrobasilar system.

Development of algorithm for choosing a surgical treatment of patients with single and multiple cerebral aneurysms with complicated SAH, Hunt-Hess grades IV and V, is much more problematic issue (Fig. 4). The severity of clinical condition of these patients may be due to massive SAH and ventricular hemorrhage, acute hydrocephalus, ICH, vasospasm, cerebral ischemia, and cerebral edema. Direct surgical intervention under these conditions is associated with increased traumatization of edematous brain and worsening of vasoconstriction. In these cases, endovascular surgery, which eliminates additional traumatic factors, seems to be a method of choice. Obviously, endovascular surgery may be performed only when there is no ICHs, whose volume requires their removal. Endovascular occlusion is advantageous even in cases where anatomical conditions do not enable complete exclusion of the aneurysm. Under these conditions, partial occlusion of the aneurysm may reduce the risk of re-rupture and provides conditions for the safe conservative treatment [7]. Radical microsurgical intervention can be carried out as the second stage during the cold period after stabilization of patient’s condition. In patients with multiple aneurysms, the number of possible clinical situations is so great that any schematic representation is extremely complicated, and therefore fussiness of these schemes makes their use in everyday clinical work impossible. The indisputable fact is that exclusion of unruptured aneurysms should be carried out only after improvement and stabilization of the patient’s condition.

**Conclusion**

When drawing up the guidelines on choosing a surgical technique in patients with aneurysms in the acute stage of SAH, we followed the rules developed at the N.N. Burdenko NSI, which reflect the common viewpoint of microsurgical and endovascular department.

In our view, the treatment regimens used in patients with acute cerebral aneurysm rupture and discussed in this article can be considered as preliminary algorithms or prototypes of algorithms. At the same time, we guarded against direct copying of foreign standards and advisory protocols. Our viewpoint is based on comparable results of surgical treatment of patients with acute cerebral aneurysm rupture in foreign clinics and neurosurgical departments in our country.
Fig. 3. Selecting treatment technique for patients with Hunt-Hess grade I—III multiple brain aneurysms.
Fig. 4. Treatment of patients with Hunt-Hess grade IV—V cerebral aneurysms.

One or multiple aneurysms were detected

- SAPH with hematoma that needs to be removed
  - Removal of hematoma, clipping of bleeding aneurysm, intracranial pressure sensor, external decompression*
  - Radical aneurysm exclusion in a cold period*, cranioplasty*

- SAH
  - SAPH with hematoma that does not need to be removed. With or without a mild IVH.
  - External ventricular drainage

- SAPH with hematoma that does not need to be removed. With a massive IVH
  - Endovascular occlusion of bleeding aneurysm (total/subtotal), ICP sensor, external decompression*

- Age >65 years, decompensation of somatic diseases, extensive ischemic lesions, Hunt-Hess grade V in patients without hematoma that needs to be removed
  - ICP sensor, intensive care
  - Satisfactory control of ICP (<30 mm Hg)
  - Resistant intracranial hypertension (>30 mm Hg)
  - Symptomatic therapy
The use of the aforementioned principles is justified in clinics that have proper microsurgical and endovascular units and deal with treatment of brain aneurysms.

Of course, the algorithms presented in this article are not dogmatic and there are some factors that can amend the choice of surgical technique in certain cases. At the same time, the variety of clinical and anatomical situations and exceptions that are permissible in some cases do not contradict our core principles and, we believe, justify the most feasible current trend in treatment of patients with aneurysmal SAH.

Authors declare no conflict of interest.

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Commentary

It is very easy to comment on such an article: the authors expressed their attitude to the choice of treatment technique in patients with cerebral aneurysm rupture, which is not much different from a widely recognized tactics and is very similar to the provisions of generally accepted advisory protocols. So I could finish at this point.

However, if we ask the only question “Why?”, when considering each statement in the article, then writing comments becomes impossible due to enormous volume required for the response. For example, Fig. 1 shows the algorithm for examination of patients with non-traumatic SAH. In the case of SAH, authors recommend angiography (direct, CT, MRI). The question arises, what type of angiography should be used? Whether the choice of examination method depends on the timing of hemorrhage or its anatomical shape? What is to be done, if direct angiography detects no aneurysm: CT angiography or additional direct angiography? Whether MR angiography is sufficient to make decision on the need for surgery? In which cases is CT advantageous compared to direct angiography? Whether collateral blood flow should be examined during angiography in the case of trapping? Why re-examination should be carried out in a month, rather than two or six months? Do all patients need follow-up examination and what method should be selected during the re-examination: direct angiography, CT angiography, or MRI?

And so on for each point discussed in the article, without any exception: multiple aneurysms, severity of patient’s condition, time of surgery, vasospasm, location of aneurysms, aneurysm size, endovascular surgery, microsurgery, or combined treatment, intraoperative monitoring of aneurysm exclusion from circulation, organization of the work of the multidisciplinary team, interaction with neurologists and so forth.

Therefore, the article is perceived as a good plan for writing a large monograph on the cerebral aneurysm surgery, where the authors could describe their ideas in detail. This was already discussed with the first author of the article.

Given the active development of aneurysm surgery in Russia (in 2015, almost 6 thousand patients were operated on for brain aneurysms) and emergence of a large number of active young neurosurgeons, who master aneurysm surgery, the publication of this work would be very helpful.

V.V. Krylov (Moscow, Russia)
Results of Deconstructive Endovascular Surgery in Treatment of Large and Giant Intracranial Aneurysms


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Objective. To clarify the indications for deconstructive endovascular surgery in patients with large and giant intracranial aneurysms and to evaluate short-term and long-term postoperative outcomes. Material and methods. The study was based on a retrospective analysis of the treatment results in 50 patients with large (15—25 mm) and giant (more than 25 mm) intracranial aneurysms, aged from 18 to 75 years; who were treated at the Burdenko Neurosurgical Institute in 2002—2014. The patients underwent a balloon occlusion test (BOT) in various modifications before stationary occlusion of the carrier artery. For vascular occlusion, we used detachable latex balloon catheters (33 cases) and microcoils (17 cases). The condition of patients in the pre- and postoperative period was assessed by using the modified Rankin Scale. Results. There were no deaths due to occlusion of the internal carotid artery (37 patients). Postoperative complications occurred in 5 patients. On the basis of BOT, revascularization surgery involving placement of an extra-intracranial microanastomosis (EICMA) was performed in 6 cases. In more 4 cases, EICMA was placed in the early postoperative period due to developing signs of ischemia. Two of 7 patients underwent occlusion of both vertebral arteries (VAs) in the vertebrobasilar basin, which led to fatal outcomes. One more patient died of aggravation of brainstem compression after VA occlusion. There was no worsening of neurological symptoms among survivors. There were no deaths and persistent neurological disorders upon occlusion of branches of the main cerebral arteries, starting with the first order arteries (6 patients). Thirty one patients (66%) were followed-up in the period from 1 to 104 months. There were no deaths associated with artery occlusion. Two patients experienced delayed ischemic disorders. Conclusion. Occlusion of the carrier artery should be performed in a carefully selected group of BOT-negative patients. This surgery can be indicated for aneurysms with a complicated configuration, the topographic and anatomical features of which exclude reconstructive surgery.

Keywords: giant intracranial aneurysm, occlusion of carrier artery, balloon occlusion test.

Over the past decades, endovascular treatment of large (15—25 mm) and giant (more than 25 mm) intracranial aneurysms has gradually replaced direct surgery associated with a high risk of postoperative complications and mortality. Endovascular treatment is usually characterized by a low rate of adverse outcomes [1, 2]. Since the introduction of a balloon catheter technique by F.A. Serbinenko in the early 1970s, deconstructive surgery has been the only technique for endovascular treatment of large and giant aneurysms for a long time [3]. Improvement and invention of new endovascular tools and devices (coils with various stiffness and configuration, compliance balloons, intracranial and flow-diverting stents) have led to implementation and continuous development of reconstructive techniques for endovascular treatment of aneurysms [4].

Over the past 20 years, about 60 patients with large and giant intracranial aneurysms have annually undergone both direct and endovascular surgery at the Burdenko Neurosurgical Institute. A reconstructive intervention is used in the vast majority of endovascular operations. However, in some cases, a deconstructive intervention can become the method of choice. Therefore, it is necessary to have an idea about the indications, implementation techniques, and outcomes of these operations.

In this paper, we present the results of deconstructive surgery in the treatment of large and giant aneurysms of the carotid and vertebrobasilar territories.

The study objective was to clarify the indications for deconstructive endovascular surgery in patients with large and giant intracranial aneurysms and to evaluate short-term and long-term postoperative outcomes.

Material and Methods

The study is based on a retrospective analysis of outcomes in 50 patients with large (15—25 mm) and giant (more than 25 mm) intracranial aneurysms, aged 18 to 75 years, who underwent treatment at the Burdenko Neurosurgical Institute in the period from 2002 to 2014. The male/female ratio was 1.0 : 2.8 (13 males, 37 females). The vast majority of patients (28 people) were aged 41—60 years: 4 patients were under the age of 20 years; 13 patients were aged 21 to 40 years; 5 patients were older than 60 years. The mean age was 44.5 years.

Fifty patients were diagnosed with 5 large and 45 giant aneurysms. In 6 patients, 10 aneurysms of various sizes were additionally found, which required endovascular or direct surgical interventions. Thus, 60 aneurysms were discovered in 50 patients. The
localization of large and giant aneurysms is presented in Figure 1.

The disease was asymptomatic in 3 patients. Intracranial hemorrhages occurred in 7 patients; 1 of the patients underwent surgery in the acute period. The mean time from hemorrhage in patients operated on in the cold period was 8.5 months (from 1 to 35 months). A pseudotumoral course of the disease occurred in 38 patients (2 of them had transient ischemic attacks (TIAs)). Another 2 patients had epileptic seizures.

In most cases, patients were selected for parent vessel occlusion if possible reconstructive surgery was declined. An angiographic examination and endovascular surgery were performed by means of digital subtraction angiography (AG) using an Axiom Artis BA (Siemens) angiographic projection system with roadmap navigation. All patients underwent preliminary AG with a collateral circulation test and a balloon occlusion test (BOT). Initially, patients with carotid territory aneurysms underwent measurements of the linear blood flow velocity (LBFV) in the middle cerebral artery (MCA) using transcranial Doppler (TCD) ultrasonography or electroencephalography (EEG) with short-term occlusion of the ipsilateral common carotid artery (CCA) in the neck. Since 2003, TCD- and EEG-based mobile monitoring has been used in the operating room during temporary balloon occlusion of the internal carotid artery (ICA).

Endovascular surgery was performed through the transfemoral approach under local infiltration anesthesia. After puncture of the femoral artery, bolus heparinization was performed (5,000 U of intravenous heparin). The indications for additional administration of heparin were determined based on the activated clotting time. The target value was maintained at a level of $\geq 200$ s. During AG, the condition of the circle of Willis was assessed. Then, the BOT was performed using a non-detachable latex balloon catheter. Within 15 min, we monitored changes in the neurological status and simultaneously recorded changes in LBFV or bioelectric potentials. Stationary (permanent) occlusion of a vessel was performed if the neurological status was unchanged, and the blood flow was compensated (according to TCD), or if there were no EEG changes typical of early ischemia (negative test). Occlusion was performed using a detachable balloon catheter (DBC) GOLDBAL (Balt, France) or GDC and TARGET (Stryker, USA) and AXIUM (Covidien, EV3, USA) coils.

In the case of hypoplasia or lack of communicating arteries as well as a positive BOT, patients underwent preventive revascularization surgery involving placement of an extracranial-to-intracranial (EC-IC) bypass. This surgery was required in 6 cases. In another 4 cases, an EC-IC bypass was performed in the nearest postoperative period after developing signs of ischemia.

A total of 52 vessels were occluded (two patients underwent occlusion of both vertebral arteries (VAs)). For occlusion of a parent vessel, we used a DBC in 33 cases, coils in 17 cases, a DBC and coils in 1 case, and coils with a preplaced stent in 1 case. The results were evaluated during control AG immediately after occlusion of the artery. Aneurysmal occlusion was considered total if there was no direct and retrograde (through collaterals) contrast enhancement of the aneurysm. The condition of patients before (Fig. 2) and after surgery was evaluated by using the modified Rankin scale (mRs), except 2 patients who were operated on in the acute period of subarachnoid hemorrhage (SAH).

![Fig. 1. The distribution of aneurysms across the vascular territories.](image)

Footnote: ACA — anterior cerebral artery; MCA — middle cerebral artery; VBT — vertebrobasilar territory; cav — cavernous segment of the internal carotid artery; supract — supratrochoid segment of the internal carotid artery; paract — paracarotid segment of the internal carotid artery; PCA — posterior cerebral artery; VA — vertebral artery; BA prox — proximal segment of the basilar artery; BA trunk — trunk of the basilar artery.
Results

A procedure for evaluating collateral cerebral circulation

Several parameters were used to evaluate collateral cerebral circulation. First of all, the anatomical integrity of the Willis circle was assessed according to the data of multi-slice computed tomography AG, magnetic resonance imaging AG, and selective cerebral AG. To evaluate the anatomical integrity of the anterior communicating artery, we performed catheterization and contrast enhancement of the contralateral ICA and direct projection imaging with occlusion of the ipsilateral CCA in the neck; to evaluate the posterior communicating artery (PCOM), we conducted catheterization of one of the vertebral arteries (VAs) (usually, the left artery) and AG in the lateral projection with occlusion of the ipsilateral CCA in the neck. If VA occlusion was suspected, it was necessary to evaluate the condition of both PCOMs. For this, we performed angiography of the VA with consequent occlusion of both CCAs in the neck.

To assess the functional significance of an occluded vessel, different BOT variants were used: temporary occlusion with TCD monitoring of LBFV in the ipsilateral MCA; temporary occlusion with EEG monitoring of hemispheric bioelectrical activity or somatosensory evoked potentials; temporary occlusion with controlled hypotension; temporary occlusion with monitoring of the neurological status only.

The procedure of BOT with controlled hypotension was based on a double occlusion test: at normal blood pressure (BP) indicators and at systolic blood pressure decreased by 20 mm Hg (in the absence of neurological symptoms). The test was considered negative if the neurological status was unchanged, and changes in auxiliary neurophysiological indicators (LBFV or EEG) corresponded to compensation.

Results of deconstructive surgery in the carotid territory

Of 37 patients with ICA aneurysms, 4 patients had anatomically well-developed communicating arteries and an intact carotid-ophthalmic anastomosis. These patients did not undergo BOT. BOT with TCD monitoring was performed in 19 patients, with EEG monitoring in 3 patients, and with controlled hypotension in 4 patients.

Two patients lacking one of the communicating arteries and with low contrast enhancement of the other underwent preventive placement of an EC-IC bypass, without BOT. In the remaining 5 cases, a BOT was performed only with monitoring of the neurological status: in 2 patients, due to the lack of an ultrasound window; in 3 patients, due to a critical narrowing of the ICA lumen caused by marked aneurysm-induced compression, which led to the development of collaterals in the distal vasculature.

Based on the BOT results, ICA occlusion in 5 patients was performed after preliminary placement of an EC-IC bypass. There was no worsening of ischemic neurological symptoms in any of these cases. In 2 cases, the decision to perform EC-IC bypass was made based on the anatomical features of the Willis circle (absence or hypoplasia of the communicating arteries). Despite preliminary revascularization surgery, ischemic complications developed in the territory of interest in one of these cases. After permanent occlusion of the ICA, 4 patients with a negative BOT developed ischemic complications in the ipsilateral territory (transient ischemic attack, small stroke). In 2 cases, ischemic complications developed upon a negative BOT with TCD monitoring (LBFV reduction less than 30% and no focal neurologic symptoms within 15 min); in 2 other cases, ischemic complications developed upon monitoring of the neurological status only (no neurologic symptoms within 15 min). Three of these patients underwent revascularization surgery in the early postoperative period; they had partial (2 patients) and complete (1 patient) recovery of the neurological status to the time of discharge from the hospital.

Thus, a total of 10 revascularization operations were performed: 7 preventive operations and 3 operations in the early period after artery occlusion due to ischemic complications.

BOT variants and the time of revascularization surgery are presented in the Table.

There were no deaths among patients with large and giant aneurysms in the carotid territory in the early postoperative period. According to the mRs data, clinical symptom deterioration associated with a change in the patient’s state (one grade shift in all cases) occurred in 5 (13.5%) patients.

![mRs-based assessment of the preoperative condition of patients.](image)
Results of deconstructive surgery in the vertebrobasilar territory

This group included 7 patients with large, giant, or fusiform aneurysms (3 patients had distal VA aneurysms; 3 patients had proximal basilar artery (BA) and vertebral confluence aneurysms; 1 patient had BA megadolichoectasia). Three patients with distal VA aneurysms underwent ipsilateral VA occlusion distal to the ostium of the posterior inferior cerebellar artery (PICA), without BOT. In 2 cases, aneurysms were thrombosed in the early postoperative period without any complications. The condition of 1 patient with a thrombosed aneurysm and increased brainstem compression deteriorated sharply on the 5th day after surgery, and the patient died on the 8th day.

One patient with a giant aneurysm of the proximal third of the BA underwent basilar artery occlusion proximal to the aneurysm, with a preliminary BOT and recording of somatosensory evoked potentials. The circulation in the basilar territory occurred bilaterally through well-developed PCOMs (Fig. 3).

The aneurysm was thrombosed in the early postoperative period. There were no complications in this case. In 2 other cases, we performed staged occlusion of both VAs at intervals of 1 and 6 months. In both cases, a BOT and assessment of the neurological status were performed. Both patients died in the early postoperative period. In the first case, the aneurysm ruptured on the 4th day; in the second case, worsening of brainstem symptoms due to increased brainstem compression by the thrombosed aneurysm occurred suddenly on the 3rd day after surgery. Death due to disturbed brainstem circulation occurred on the 8th day.

The patient with BA megadolichoectasia underwent occlusion of one VA, with a preliminary BOT and evaluation of the neurological status. The postoperative period was without complications. There were no changes in the size of a contrasted aneurysmal cavity.

Therefore, mortality after deconstructive surgery in patients with large and giant aneurysms of the vertebrobasilar territory amounted to 42.8%. There were no persistent neurological complications in survived patients.

Results of deconstructive surgery for aneurysms of branches of major arteries, starting with the first order vessels

In this group, 4 patients were diagnosed with PCA aneurysms (P1 segment — 2 patients; P2 segment — 1 patient; P3 segment — 1 patient); 1 patient had a MCA M3 segment aneurysm; 1 patient had an aneurysm of the A1 segment of the anterior cerebral artery. Therefore, aneurysms were located at the level of the circle of Willis (P1 and A1) in 3 cases; in the other cases, aneurysms were located on the distal arteries (P2, P3, M3). It should be noted that BOT in peripheral vessels is often impossible due to a small length and diameter of a parent artery. In these cases, we performed the occlusion test using temporary artery occlusion with a coil, without its detachment from a pusher. The reliability of this test is low because total artery occlusion with a single coil is not always possible. The main requirement for performing stationary occlusion of a parent vessel in this group was the presence of well-developed cortical anastomoses (for vessels distal to the circle of Willis) or the integrity of the circle of Willis in the case of more proximal aneurysms.

A complication (TIA) occurred in 1 case (during occlusion of an MCA M3 segment aneurysm) 30 min after surgery. After increasing systolic BP by 15—20 mm Hg, the symptoms regressed. BP was maintained at this level for 2 days. Then, after lowering BP to the patient’s normal level, TIA did not recur. There were no deaths in these patients.

Long-term results of deconstructive surgery

The follow-up period in 31 (66%) patients ranged from 1 to 104 months (mean, 42.7 months). A control evaluation of 23 patients was performed using neuroradiological studies: MRI — 15 patients, SCT — 2 patients, and selective cerebral AG — 6 patients. In 8 patients, only clinical data were collected. The data of control studies are shown in Figures 4 and 5.

One patient with a peripheral aneurysm (P3 segment) who was operated on in the acute period of SAH (H–H II) died. The patient died of pneumonia at another hospital (according to relatives; there was no medical documentation) one month after discharge. Figure 6 presents the clinical picture in 31 patients in the long-term postoperative period.

Discussion

Large and giant cerebral arterial aneurysms usually manifest themselves by compression of surrounding structures. Direct surgical exclusion of these aneurysms is associated with a high risk of complications [1]. Occlusion of large and giant aneurysms with coils, including application of assisting techniques, does not lead to regression of existing clinical symptoms. In this case, aneurysm recanalization occurs quite often [5]. Before the introduction of flow-diverting stents (FDSs), parent artery occlusion was the main endovascular treatment of these aneurysms. Currently, this technique is used for aneurysms where FDSs are not applicable for various reasons (anatomical and topographic parameters, contraindications to the use of double antiplatelet therapy, long-term arterial damage, etc.). This is evidenced by the fact that half of patients of the presented group underwent surgery during active use of FDSs at our institute (from 2009 to 2014).

Parent artery occlusion that is performed without careful pre-selection of patients is accompanied by a high risk of death and severe ischemic complications [6]. In 1911, R. Matas [7] proposed a test with temporary CCA
occlusion in the neck to identify patients who can tolerate ICA occlusion. In 1974, F.A. Serbinenko [3] proposed for the first time selective catheterization of the ICA and its temporary occlusion with a balloon of his own design. At present, technical implementation of this idea has undergone significant changes, but it is still widely used in deconstructive surgery.

One of the most common techniques to assess collateral circulation during temporary ICA occlusion is monitoring of LBFV in the ipsilateral MCA. W. Sorteberg and co-authors [8] published the results of a study of 33 patients during a BOT and TCD monitoring of LBFV in the MCA. The authors indicated a safe level for reducing LBFV by 20—30%. In our work, we used this approach in 19 cases. In 3 (15.8%) cases, the test was false-negative: if the MCA circulation during BOT was decreased by less than 30%, ischemic complications developed during the first day after deconstruction. It should be noted that intraoperative monitoring of LBFV during BOT has a number of limitations. These include: a poor ultrasound window or its absence; the occurrence of a giant aneurysm in the location area, which complicates reliable imaging of the MCA; discomfort to the awake patient lying in a forced position on the operating table, with a helmet on the head. In some cases, even small head movements lead to a sensor displacement and a loss of the signal. This creates additional difficulties for assessing blood flow compensation in patients with borderline indicators.

In 1990, F.A. Serbinenko and co-authors [9] published the results of treatment in 9 patients with ICA giant aneurysms who underwent, based on the EEG data, revascularization surgery. The authors indicated the absence of deaths and postoperative complications. In our series of patients, we used EEG monitoring during BOT in 3 cases. In 1 case, the test was positive, and the patient underwent revascularization surgery with placement of an EC-IC bypass. However, the procedure involving BOT and EEG also has some disadvantages. These include artifacts due to interference created by devices present in the modern operating room. Some publications indicate the possibility of false-negative results reducing the reliability of the test [10]. For this reason, we actually did not use EEG together with the test. K. Kato and co-authors [11] published the results of ICA occlusion using a procedure for evaluating pressure in a vessel during BOT. The authors compared pressure in an occluded vessel at a site distal to the occlusion level with systemic BP. They demonstrated that safe stationary ICA occlusion should be performed at a pressure difference less than 50%. However, J. Kelly and co-authors [12] indicated the lack of a correlation between pressure in distal segments of an artery after its

<table>
<thead>
<tr>
<th>BOT variant</th>
<th>Number of patients</th>
<th>Positive BOT</th>
<th>Preliminary EC-IC bypass</th>
<th>Ischemia</th>
<th>Subsequent EC-IC bypass</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOT with TCD</td>
<td>19</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>BOT with EEG</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>BOT with hypotension</td>
<td>4</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>BOT — neurological status only (sufficient collateral blood flow in the circle of Willis and carotid-ophthalmic anastomosis)</td>
<td>4</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>BOT — neurological status only (no ultrasound window)</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>No BOT (critical ICA stenosis)</td>
<td>3</td>
<td>—</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>No BOT (no collaterals)</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>37</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>3</td>
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</tbody>
</table>

**Fig. 3.** 3D reconstruction of the vertebrobasilar and carotid territories after occlusion of both VAs in a female patient with a giant aneurysm of the proximal segment of the BA.

**Lateral view.** A balloon catheter is placed into the VA distal to the PICA ostium; blood flow in the VA is preserved (indicated by arrows). The blood supply to the BA and its branches occurs from the carotid territory through the PCOM (indicated by arrows)
occlusion and changes in EEG. In this case, both positive (a difference of more than 50% in the absence of changes in EEG) and false-negative (a pressure difference of less than 50% in the presence of changes in EEG) results were observed. We did not use this procedure in our work.

Some studies have used more sophisticated and expensive procedures to determine tolerance to permanent occlusion of the ICA. The most common of these are BOT with $^{99m}$Tc single-photon emission computed tomography (SPECT) or Xe$^{133}$ perfusion CT [13]. At the first stage, the patient undergoes a BOT and evaluation of the neurological status. If the test is negative, a balloon is deflated, and the patient is transferred to a room where SPECT or perfusion CT are performed. Then, the balloon in the ICA is inflated, and the test is repeated with simultaneous SPECT evaluation of cerebral blood flow. However, T. Origitano and co-authors [14] indicated the presence of delayed (>72 h) ischemic complications for a negative BOT with SPECT (22% of false-negative tests). We also did not use this procedure in our work.

BOT with controlled hypotension is a simple and reliable procedure that is used very widely. Its advantages include no need to move the patient to another room for performing the second stage of the test and to inflate a balloon uncontrollably. T. Hassan [15] published outcomes in 25 patients with large and giant intracranial aneurysms who were treated using this procedure. A high-flow bypass was performed in positive test patients during normotension; an EC-IC bypass was performed in positive test patients during hypotension. The author indicated the absence of deaths and one thromboembolic complication. M. Labeyrie and co-authors [16] showed the efficacy of this procedure in the treatment of 56

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**Fig. 4.** Treatment-associated changes in hemodynamics and sizes of aneurysms.

**Fig. 5.** Aneurysm size reduction after deconstructive surgery.  
a — MRI of a patient with a giant aneurysm of the paraclinoid segment of the right ICA; b — MRI 20 months after right ICA occlusion.

**Fig. 6.** Clinical picture in the long-term postoperative period (n=31).
patients with large, giant, and fusiform infraclinoid aneurysms. Thromboembolic complications occurred in 5.5% of cases; there were no deaths. In our series, we used this procedure in 4 patients. There were no false-negative or false-positive results. Also, there were no complications and deaths.

Of particular interest are numerous publications devoted to the use of another relatively simple procedure for assessing the tolerance to permanent occlusion of the ICA [17]. It is based on determining the symmetry of vein filling in both hemispheres. After temporary occlusion of the ICA with a second catheter (via a second femoral approach), a contralateral ICA is catheterized, and AG in the frontal projection is performed. If the difference in the rate of vein filling in the ipsilateral hemisphere is <2 s, the test is considered negative. However, this procedure also has disadvantages. For example, during contrast enhancement of a contralateral ICA, there may be false-positive results (the difference in the rate of venous phase contrast enhancement in the hemispheres is more than 2 s) that are caused by competing blood flow through the PCOM. This leads to partial washout of a contrast agent and a delay in the venous phase. However, some authors consider it necessary to rely on this indicator because the risk of complications associated with “unnecessary” revascularization surgery (EC-IC bypass) is lower than the risk of ischemic complications in the case of a false-negative test.

Perhaps, there were patients with false-positive tests in our group. These may be patients who underwent revascularization surgery based on the TCD, EEG, and AG data. The reliability of this statement can not be tested because retrospective analysis has its limitations. However, greater concern is caused by false-negative BOT results. They demonstrate inadequacy of most of the existing procedures for assessing the tolerance to ischemia. Given our own results and the literature data, we consider a combination of 2 BOT procedures — evaluation of the symmetry of venous phase timing and the use of controlled hypotension — as the most effective approach for planning of ICA occlusion.

Consequences of treatment of vertebrobasilar territory aneurysms should receive particular attention. R. Leibowitz and co-authors [18] published the results of treatment in 13 patients with fusiform aneurysms of the vertebrobasilar territory: there were no clinically significant complications; mortality was 31%; an advantage was observed in patients who had no contrast enhancement (in particular, retrograde) of an aneurysm after artery occlusion — these effects were observed for aneurysms located proximal to the vertebral confluence. Their data correlate with our findings that outcomes are better in the case of proximal aneurysms. M. Sluzewski and co-authors [19] published the results of treatment in 6 patients with giant aneurysms of the VA and BA. In all cases, bilateral occlusion of the VA was performed. Mortality was 50%. In our series, mortality was 42.8%. All these facts demonstrate that patients with vertebrobasilar territory aneurysms are the most complex category of patients, and the results of treatment in them are much worse than those in patients with carotid territory aneurysms.

R. Blanc and co-authors [20] described delayed complications after parent artery occlusion, which were caused by increased compression of surrounding structures. The authors indicated aggravation of symptoms due to rapidly developing thrombosis of the aneurysmal cavity. In some cases, thrombosis of the aneurysm may trigger the mechanism of aseptic inflammation in the aneurysm wall. This factor, along with the mechanical effect of a thrombus on a thinned aneurysm wall, may lead to aneurysm rupture [21]. Most likely, this phenomenon (rupture of a thrombosed aneurysm of the vertebral confluence on the 4th day after bilateral VA occlusion) occurred in one of our cases. To reduce the risk of these complications, the authors recommend drug therapy that is used upon placement of a FDS (administration of hormones and non-steroidal anti-inflammatory drugs in the postoperative period) and also placement of several coils into the cavity of giant aneurysms before parent artery occlusion, which may reduce the volume of a forming thrombus. The last provision is controversial because the presence of coils in an aneurysm will then prevent a decrease in the aneurysm volume and regression of the existing symptoms.

Deconstructive surgery for peripheral aneurysms has some peculiarities. Guiding a balloon catheter followed by an occlusion test is often impossible because of a small artery diameter. D. Eckard and co-authors [22] recommend an amytal test instead of a BOT. Of 8 cases, false-positive test results were obtained in 3 patients; however, artery occlusion was performed with minimal or no neurological deficit. A number of authors [23, 24] do not recommend the amytal test because of its low reliability. We also did not use this test and relied on the angiographic data (the presence and degree of development of cortical and leptomeningeal anastomoses).

Comparison of neuroradiological and clinical data in the long-term period reveal a clear correlation among thrombosis of an aneurysm, a decrease in its size, and an improvement in the clinical picture. Therefore, if an aneurysm can still be contrast-enhanced after proximal occlusion of a parent artery, trapping (endovascular or combined) of the aneurysm should be performed. However, it is worth noting that some aneurysms have dense calcified walls. In these patients, recovery or improvement of lost functions is less frequent. In our patients without regression of clinical symptoms, aneurysm walls were dense in most cases. In these situations, it seems logical to consider direct excision of a thrombosed aneurysm that exerts a mass effect on surrounding structures. This surgery is not always
possible, for which reason the relevant reports are rare [25, 26].

Conclusion

Currently, despite the achievements of endovascular reconstructive surgery in the treatment of large and giant intracranial aneurysms, deconstructive endovascular surgery is still in demand. This surgery is indicated for aneurysms with a complex configuration, the topographic and anatomical features of which exclude reconstructive surgery (impossibility of catheterization of a parent vessel above the aneurysm level, extensive injury to the parent vessel) or direct surgery.

To avoid ischemic complications in the early and long-term postoperative periods, the compensatory capabilities of collateral blood flow in the territory of interest should be carefully examined before stationary occlusion of a parent vessel.

ICA occlusion should be performed in BOT-negative patients under controlled arterial hypotension if the symmetry of the venous phases in the hemispheres is less than 2 s. VA occlusion distal to the PICA can be performed in BOT-negative patients under hypotension. Occlusion of one of the VAs in the case of aneurysms located proximal to the PICA ostium is possible in BOT-negative patients with sufficient retrograde blood flow in the contralateral VA under controlled hypotension. Occlusion of both VAs, even in the case of well-developed PCOMs, is associated with the highest risk of severe ischemic complications.

The decision on parent artery occlusion in the case of peripheral aneurysms should be made depending on the presence and degree of development of cortical arterial anastomoses from adjacent vascular territories.

If the residual aneurysmal cavity can still be contrasted in the long-term period after parent artery occlusion, trapping of the aneurysm should be performed — additional distal occlusion of the artery using a direct or endovascular technique.

Authors declare no conflict of interest.

REFERENCES


Treatment of patients with large and giant intracranial aneurysms still remains a challenge. The problem of choosing a treatment technique remains unsolved because the modern literature lacks clear protocols for managing these patients. This may be microsurgery with clipping and excision of the aneurysm body under conditions of intravascular blood aspiration or endovascular surgery with the use of coils and stents. There may be different combinations of microsurgical and endovascular techniques, but the main requirement for exclusion of these aneurysms from blood flow remains preservation of blood flow in the aneurysm-bearing vessel! Unfortunately, this can not always be achieved using both direct and endovascular surgery. In recent decades, endovascular surgery has increasingly replaced direct surgery. The search for methods to preserve the parent vessel lumen in the case of large and giant aneurysms led, at the turn of the 21st century, to the creation of new endovascular devices — flow-diverting stents, but also raised a number of other issues, in particular those related to compliance with the antithrombotic protocol. Currently, despite the achievements of endovascular reconstructive surgery in the treatment of large and giant aneurysms, deconstructive endovascular surgery still occupies a certain niche. This is the subject of this article.

The article analyzes (retrospective analysis) treatment of 50 patients, mainly with giant ICA aneurysms, at the Burdenko Neurosurgical Institute (2002—2014). Of particular interest are procedures for assessing the functional significance of collateral cerebral circulation, such as the balloon occlusion test (BOT) used in our work in the 1990s and improved at the present time (BOT + controlled hypotension). However, postoperative ischemic complications associated with a lack of collateral circulation still persist. This may be associated with a low efficiency of brain perfusion monitoring under BOT conditions as well as with inadequately active implementation of high-flow bypasses in deconstructive endovascular surgery in patients with giant aneurysms.

The article is topical and, undoubtedly, deserves publication in a dedicated journal. It would also be useful to analyze outcomes in similar patients treated by deconstructive and reconstructive endovascular surgery using flow-diverting stents.

V.A. Lazarev (Moscow, Russia)
Tactics of Surgical Treatment in Patients with Unruptured Asymptomatic Cerebral Aneurysms


Burdenko Neurosurgical Institute, Moscow, Russia

Objective. To clarify the indications for surgical treatment and the principles for choosing a surgical technique for patients with unruptured asymptomatic aneurysms (UAAs), based on the results of direct and endovasal operations performed at the Burdenko Neurosurgical Institute and on the literature data. Material and methods. The study included 694 UAA patients (481 females (69.3%) and 213 males (30.7%)) operated on at the Burdenko Neurosurgical Institute in the period from 1997 to 2013. The patient's age ranged from 1 to 74 years (mean age, 48.3 years). Multiple aneurysms were in 126 (18.2%) patients. Anterior circle of Willis aneurysms were in 92.8% of cases. Among these, internal carotid artery (ICA) aneurysms (46.3%) and middle cerebral artery (MCA) aneurysms (30.8%) were predominant. Microsurgical and endovascular interventions on aneurysms were performed in 665 (95.8%) patients.

Results. Complete aneurysm exclusion was achieved in 94.8% of cases. A pronounced neurological deficit developed in 8 (1.2%) patients, and a moderate neurological deficit developed in 62 (9.3%) patients. Postoperative mortality was 0.5%.

Conclusion. Surgical treatment of UAAs is associated with low disability and mortality rates. All UAAs need to be operated on, especially in young and middle age patients, if surgery is technically possible, and there are no concomitant diseases contraindicating the intervention. The choice of an UAA exclusion technique is made based on the general principles of surgical treatment of cerebral aneurysms. At present, the method of choice is endovascular surgery for most cases of vertebrobasilar basin and ICA aneurysms and a microsurgical intervention for anterior cerebral artery and MCA aneurysms.

Keywords: cerebral aneurysm, asymptomatic aneurysm, subarachnoid hemorrhage.
surgical treatment of UAA patients enabled developing certain recommendations on the treatment tactics for this disease [7—19].

Among many factors affecting the choice of surgical treatment and a particular surgical technique, a generalized experience in surgery for UAAs as well as comparison of the results of direct and endovascular interventions for this disease are of great importance [8, 10, 17, 19].

The aim of this study was to clarify the indications for surgical treatment and the principles for choosing a surgical technique for UAA patients, based on the results of direct and endovascular operations performed at the Burdenko Neurosurgical Institute and on the literature data.

Material and Methods

The study included 694 UAA patients (481 (69.3%) females and 213 (30.7%) males) aged 1 to 74 years (mean age, 48.3 years) who were hospitalized to the Burdenko Neurosurgical Institute for surgery in the period from 1997 to 2013. Multiple aneurysms were present in 126 (18.2%) patients. A total of 869 aneurysms were identified.

The criterion for inclusion of patients in the study was the absence of specific manifestations of the underlying disease: 1) instrumentally confirmed hemorrhage (lumbar puncture, CT, MRI); 2) a typical clinical picture of SAH in medical history; 3) clinical and neuroradiological signs of ischemic circulatory disorders in the parent artery territory; 4) focal symptoms due to the aneurysm influence on the surrounding brain structures (pseudotumoral course).

When defining the indications for surgery, we have relied on our own experience and criteria proposed in various publications because, to date, there are no common standards for indications for UAA surgery [13, 17, 19]. For this reason, we have first assessed the anatomic and topographic features of the aneurysm (size, shape, location, presence and number of diverticula), its surgical accessibility, multiplicity of aneurysms, as well as a number of other factors (age, hypertensive disease and other somatic pathology in medical history, family history of intracranial hemorrhage, hereditary autosomal dominant polycystic kidney disease, Marfan syndrome, Ehlers-Danlos syndrome, concomitant AVM, carotid artery stenosis, smoking). In 106 (15.9%) cases, the indication for aneurysm surgery was the presence of pathology requiring surgical correction (brain tumor, BCA stenosis, cardiovascular diseases — atherosclerotic cardiovascular disease, aortic aneurysm, congenital and acquired heart defects, etc.).

Apart from these objective criteria, we allowed for the patient’s attitude towards proposed surgery. UAA patients were explained the benefits and risks of proposed surgery. Operative interventions for aneurysms were performed in 665 (95.8%) of 694 patients. In 29 (4.2%) patients, surgery was not performed for different reasons: 1) refusal of surgery in 8 patients; 2) death of 2 patients after angiography (in one case, a 75-year-old male patient with severe BCA atherosclerosis developed ischemic stroke in the VBT during an examination; in another case, a female patient with a giant VA aneurysm and angiospasm after angiography developed thrombosis of the aneurysm and VA and ischemia of the brainstem); 3) spontaneous aneurysm thrombosis in 1 patient; 4) a high risk of surgical intervention in 12 patients and the inability to completely exclude the aneurysm from blood flow in 6 patients.

Direct microsurgical and endovascular operations were used. The microsurgical approach was used for 527 (62.6%) aneurysms. Two hundred seventy five (32.7%) aneurysms were treated by endovascular surgery. In 18 (2.7%) cases of multiple UAAs, staged surgical treatment was performed using microsurgical and endovascular techniques.

The method for UAA exclusion was chosen based on the general principles of cerebral aneurysm surgery, with allowance for the anatomic and topographic features of aneurysms and condition of the BCA.

The results of surgical treatment were assessed using technical and clinical parameters.

The term “technical” means the used surgical treatment options — clipping, occlusion of the aneurysm cavity with coils, reinforcement of the aneurysm wall with surgical gauze, etc. To assess the completeness of aneurysm exclusion during microsurgery, we used intraoperative visual control (often with video recording of surgery) and postoperative angiography (in complex situations). During endovascular surgery, we performed control cerebral angiography at the end of surgery. Among patients in whom flow-diverting stents were used, repeated control angiography was performed in 40% of cases at 3 to 29 months after surgery.

Clinical results of surgical treatment were evaluated using the Glasgow outcome scale (GOS) in all patients at discharge from the Burdenko Neurosurgical Institute.

Results

The number of UAA patients is steadily growing, demonstrating particularly rapid growth in the last 5 years (Fig. 1).

Diagnostics of UAA

The indications for angiographic examination of patients are presented in Table 1.

Various headaches were the most frequent cause to seek medical advice. In most patients, headache was chronic — 47.3% of cases. The intensity of pain varied from weak to strong. Most often, the pain was localized in the cervico-occipital or frontotemporal region, spreading to the orbital region. Many patients were weather-
sensitive. In some cases, the pain was migraine-like. Headaches could be isolated or accompanied by nausea, head noises, and dizziness. A sudden headache was observed less frequently. Acute symptoms (acute headache, nausea, unconsciousness) occurred in 67 (9.6%) patients.

Comorbidities (pathology of the cardiovascular system, respiratory organs, kidneys and urinary systems, etc.) occurred in 302 (43.5%) patients. Stenosis and occlusion of the BCA were detected in 35 (2.5%) patients. Comorbid vascular diseases of the CNS were found in 17 patients (2.5%) patients (AVM in 7 patients, cavernous angioma in 6 patients, and a dural arteriovenous fistula in 4 patients).

We paid particular attention to hypertensive disease in medical history because it is one of the pathogenetic factors of cerebral aneurysm development. HD was present in 296 (43%) patients, which slightly exceeded the disease prevalence in the population (30%) [20]. Thirty-five percent of patients were smokers.

Almost in all patients, aneurysms were initially diagnosed by MRI-AG or SCT-AG.

Characterization of aneurysms. The number and structural features of aneurysms

Totally, 694 hospitalized patients had 869 aneurysms: 775 saccular aneurysms, 60 fusiform aneurysms, and 34 aneurysmal protrusions. The last were detected in patients with multiple asymptomatic aneurysms. Therefore, saccular aneurysms predominated (89.2%).

Upon assessing aneurysms during microsurgery, most aneurysms (77%) had very thinned walls (Fig. 2). One third of aneurysms had diverticula, both in the aneurysmal neck region and in the aneurysmal body and dome regions (Fig. 3). In 13.7% of cases, the parent artery and/or aneurysm walls were atherosclerotic altered (Fig. 4 and 5). The signs of partial thrombosis of the aneurysm cavity were observed in 8.4% of cases. Most often, these were peripheral fusiform or eccentric-fusiform aneurysms.

Often, they had a denser wall, with a tendency for partial thrombosis.

Aneurysm location. ICA (46.3%) and MCA (30.8%) aneurysms predominated in the study cohort. The data on the aneurysm location are presented in Table 2.

Aneurysm size. Medium and small aneurysms predominated (73.4% of cases). The size distribution of aneurysms is given in Table 3.

Surgical treatment and its technical results. A total of 802 UAA interventions were performed in 665 patients. Types of surgical interventions are presented in Table 4.

In our series, direct microsurgery was more often used for ACA and MCA aneurysms, and endovascular interventions were predominantly used for VBT and proximal ICA aneurysms (Table 5). Complete exclusion of aneurysms was achieved in 93% of cases of direct microsurgery and in 77.5% of cases of endovascular surgery, which is consistent with the literature data [10, 21—23].

Clinical outcomes of interventions. The postoperative condition of most patients remained at the preoperative level. Deterioration occurred in 73 (10.9%) patients. Of these, 62 (9.3%) patients developed a moderate neurological deficit (GOS IV), and 8 (1.2%) patients had persistent severe neurologig symptoms (GOS III). Three (0.5%) patients died. The outcomes of surgical treatment are given in Table 6.

Lethal outcomes after endovascular interventions (2 cases) were associated with an intraoperative aneurysm rupture. One patient with a large supraclinoid ICA aneurysm died after microsurgery due to postoperative thrombosis of the ICA and development of ischemia, edema, and dislocation of the brain.

Ischemic cerebral circulatory disorders were the most common cause of neurological impairments; they were detected in 64.8% of complicated patients. In the case of microsurgical treatment of paraclinoid ICA aneurysms, the rate of visual impairments (up to unilateral amaurosis) amounted to 5.7%.
The causes of ischemic cerebral circulatory disorders associated with surgery were different. In microsurgical operations, cerebral ischemia was most often associated with exclusion of small arterial branches and stenosis of the parent artery. In endovascular interventions, ischemia was caused by thromboembolic complications and thrombosis and stenosis of the parent artery. Tables 7 and 8 present the causes of complications after microsurgical and endovascular interventions, respectively.

Therefore, 11 (1.7%) patients had adverse outcomes (GOS I—III) after surgery.

**Discussion**

The introduction of minimally invasive neuroimaging techniques has led to an increase in the number of UAA patients. An analysis of the causes to conduct non-invasive angiography in our group demonstrated that they were similar to those reported in the literature [24, 25] and had a comparable rate. The most common cause was headache. It affected 47.3% of patients. Headache was usually chronic and less often paroxysmal. Some authors [25, 26] believe that chronic or paroxysmal headache may be a predictor of hemorrhage from an aneurysm. In some cases, aneurysm hemorrhage, especially the first one, is known to be accompanied by minimal neurologic symptoms, which often results in an incorrect clinical diagnosis. Certain difficulties arise when headache is differentiated as a symptom of hypertensive disease or a sign of subclinical SAH. In our opinion, in these situations, it is mandatory to exclude hemorrhage using neuroimaging or lumbar puncture.

The results of UAA interventions, which were obtained during the study, demonstrated that operations had low complication and death rates. A stable state after surgery (recovery) was achieved in 89% of patients. A moderate neurological deficit developed in 9.3% of cases; deep disability occurred in 1.2% of cases. Postoperative lethality was 0.5% (Table 6). This level is incomparable with the outcomes of surgery in the acute period of aneurysmal hemorrhage and is lower than those of surgery in the long-term period after SAH. To compare outcomes, we used the treatment outcomes from the Burdenko Neurosurgical Institute for patients operated on in the acute [5] and long-term periods of hemorrhage [27] (Fig. 6).

According to other large series of studies [8—10, 13, 15, 17], the rate of postoperative complications in UAA patients varies from 2.7 to 21%, and postoperative mortality is 0—7%. For example, according to the prospective ISUIA data (1,591 patients), mortality and disability in the next 30 days after surgery amounted to 1.8 and 12%, respectively, and reached 2.7 and 10.1%, respectively, after 1 year [8]. According to T. Raaymakers [15] (2,460 patients), mortality and disability were 2.6 and 10.9%, respectively.

![Fig. 2. Intraoperative image.](<image source>)

A thin-walled UAA of the MCA bifurcation.
In choosing the optimal way to exclude an aneurysm, apart from the general rules (anatomic and topographic features of aneurysms, BCA condition, comorbidities, etc.), experience of a surgical team and facilities of a hospital are of great importance. Microsurgical and endovascular techniques have almost the same rate of complications, but they differ in the degree of radicalness, which is higher for microsurgery, as well as in economic costs, which should be taken into account when choosing a treatment option [17, 19, 23].

The main causes of unfavorable outcomes in our series, regardless of the aneurysm location, were ischemic complications associated with either exclusion/stenosis or thromboembolism of arterial branches. The rate of complications, including clinically significant ones, is generally higher for direct surgery, while postoperative mortality is slightly higher for endovascular surgery. Given the non-comparability of groups by various parameters, the latter fact requires further analysis.

In some cases, complications develop, which are pathognomonic for a certain location. For example, visual acuity impairments are typical of paraclinoid ICA aneurysms. They are most often associated with a mechanical impact on the optic nerve during surgery (traction trauma, compression of the nerve by a clip or coils). In direct surgery, these impairments occur more often (in 5.7% of cases), despite performing manipulations aimed at their prevention (mobilization of the nerve by dissecting a reduplication of the dura over the optic nerve canal or resection of the optic canal roof). These data indicate that endovascular interventions should be considered as the method of choice for UAs of the paraclinoid segment of the ICA. Similar recommendations were also suggested by other researchers [28, 29].

The rate of intraoperative aneurysm ruptures in our series was 1.6%, which was significantly lower than that for surgery in the acute and long-term SAH periods. For example, according to the Burdenko Neurosurgical Institute data [30], the rate of intraoperative aneurysm ruptures is 24.1% and 8.2% for surgery in the acute and long-term periods, respectively.

Among the factors affecting the outcome of surgery, we have distinguished the following ones: 1) the anatomic and topographic features of the aneurysm; 2) atherosclerotic changes in the walls of cerebral arteries and aneurysms; 3) the structural feature of the lateral cerebral fissure (tight adherence of the frontal and temporal lobes); 4) unpredictable increased bleeding of the brain tissue, the preconditions for which were absent during a preoperative examination that revealed normal coagulation values.
In our opinion, treatment outcomes may be improved by:

1) thorough postoperative analysis of complications of anatomic aneurysm features, identification of signs of atherosclerotic cerebral arteries, and assessment of the patient’s somatic status;

2) an optimal surgical technique (endovascular or microsurgical);

3) hydrodissection of the lateral cerebral fissure;

4) acute dissection of the fissures in the presence of adhesions;

5) excellent technical skills of surgeons;

6) compliance with the protocol for prevention of thromboembolic complications of endovascular surgery.

According to our data and the data of numerous publications [7—10, 15—17, 31], the elderly age, comorbidities, large aneurysms, a hard-to-reach or VBT location, and a complex aneurysm configuration worsen the prognosis of surgery.

The main problem of managing UAA patients is to define the indications for surgery. The annual risk of rupture of an incidental aneurysm is demonstrated to be quite low, but given the life span of a patient with an identified UAA, it constantly increases and reaches a considerable value of up to 30.3% at 30 years after diagnosis [14]. In addition, an accurate prediction of an aneurysm rupture in a particular patient is an almost insoluble problem. However, when planning surgery, it is necessary to assess a risk of postoperative complications, up to severe ones, because they develop in patients who have not had any clinical disease symptoms affecting their quality of life.

Therefore, when planning treatment for the patient, the goal is to compare the risk of an aneurysm rupture and its consequences with the risk of postoperative complications.

The need to determine the risk of an aneurysm rupture prompted us again to address an extremely wide range of issues related to the etiology and pathogenesis of aneurysms, and primarily to study factors predictive of hemorrhage. On the basis of this study we distinguished the following several groups of the factors.

1. Individual patient-dependent factors

Many authors consider gender to be a risk factor for the formation and rupture of aneurysms [10—12, 14, 31]. According to the literature data [10, 12, 13, 31], females predominate among UAA patients. In our series, the number of females was also significantly higher than that of males: 69.3 and 30.7%, respectively. At the same time,
females slightly predominated among patients with SAH from an aneurysm [1, 2]. More frequent detection of UAs in females is probably associated with the fact that females more frequently seek medical advice for non-specific symptoms.

According to the literature data [6, 10], the mean age of patients with unruptured aneurysms ranges from 56 to 62 years. In our series, the mean age was 48.3 years. Analyzing the effect of gender and age indices, N. de Rooji et al. [32] revealed a high risk of SAH in males aged 25 to 45 years and in females aged 55 to 85 years. In our opinion, these findings should be considered in determining the tactics of treatment.

Certain diseases are associated with ruptured and unruptured aneurysms: polycystic kidney disease with autosomal dominant inheritance, fibrotic dysplasia, and coarctation of the aorta. Association of aneurysms with other diseases, such as tuberous sclerosis, Marfan disease, neurofibromatosis, moyamoya disease, Ehlers-Danlos syndrome, and hereditary hemorrhagic telangiectasia, is less obvious [16, 19].

Many researchers have proven that family history of the disease, cigarette smoking, and hypertensive disease increase the risk of not only developing but also rupturing the aneurysm [14, 16, 19].

In our opinion, the patient’s reaction to detection of an aneurysm and a discussion of the management tactics are important in making a decision on choosing a treatment option. The neurosurgeon should inform in detail the patient and patient’s relatives about the disease, surgical options, and risks of surgical treatment. In this case, it is necessary to assess the degree of the patient’s anxiety. For example, a study by Japanese researchers demonstrated that the risk of an aneurysm rupture in the early period after detection of a UAA was higher than that expected on the basis of aneurysm characteristics [8—12, 14, 16, 17].

### Table 5. Type of surgery depending on the aneurysm location

<table>
<thead>
<tr>
<th>Location</th>
<th>Procedure</th>
<th>microsurgical</th>
<th>endovascular</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICA</td>
<td></td>
<td>133</td>
<td>221</td>
</tr>
<tr>
<td>MCA</td>
<td></td>
<td>255</td>
<td>4</td>
</tr>
<tr>
<td>ACA</td>
<td></td>
<td>135</td>
<td>5</td>
</tr>
<tr>
<td>BA and its branches</td>
<td></td>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>VA and its branches</td>
<td></td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>527</td>
<td>275</td>
</tr>
</tbody>
</table>

### Table 6. Outcomes of surgery in UAA patients

<table>
<thead>
<tr>
<th>GOS score</th>
<th>Microsurgery (n=424), %</th>
<th>Endovascular surgery (n=241), %</th>
<th>Total, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I — death</td>
<td>1 (0.2)</td>
<td>2 (0.8)</td>
<td>3 (0.5)</td>
</tr>
<tr>
<td>II — vegetative state</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>III — severe deficit</td>
<td>7 (1.9)</td>
<td>1 (0.4)</td>
<td>8 (1.2)</td>
</tr>
<tr>
<td>IV — moderate deficit</td>
<td>49 (1.7)</td>
<td>13 (5.4)</td>
<td>62 (9.3)</td>
</tr>
<tr>
<td>V — good recovery</td>
<td>367 (86.5)</td>
<td>225 (93.3)</td>
<td>592 (89)</td>
</tr>
<tr>
<td>Total</td>
<td>424 (100)</td>
<td>241 (100)</td>
<td>665 (100)</td>
</tr>
</tbody>
</table>

### Table 7. Causes of complications of microsurgery

<table>
<thead>
<tr>
<th>Complications</th>
<th>Total, abs. (%)</th>
<th>Clinically significant complications, abs. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exclusion or stenting of an important artery</td>
<td>29 (6.8)</td>
<td>25 (5.9)</td>
</tr>
<tr>
<td>Cranial nerve injury</td>
<td>14 (3.3)</td>
<td>14 (3.3)</td>
</tr>
<tr>
<td>Traction brain injury causing an intracerebral hematoma</td>
<td>9 (2.1)</td>
<td>7 (1.6)*</td>
</tr>
<tr>
<td>Intraoperative aneurysm rupture</td>
<td>8 (1.9)</td>
<td>2 (0.5)</td>
</tr>
<tr>
<td>Traction brain injury</td>
<td>6 (1.4)</td>
<td>5 (1.2)</td>
</tr>
<tr>
<td>Subdural hematoma</td>
<td>1 (0.2)</td>
<td>1 (0.2)*</td>
</tr>
<tr>
<td>Major artery thrombosis</td>
<td>1 (0.2)</td>
<td>1 (0.2)</td>
</tr>
<tr>
<td>Massive bleeding during simultaneous tumor resection</td>
<td>1 (0.2)</td>
<td>1 (0.2)</td>
</tr>
<tr>
<td>Total</td>
<td>69 (16.3)</td>
<td>57 (13.2)</td>
</tr>
</tbody>
</table>

Footnote. * — exploration of the wound and removal of a hematoma were performed in 5 cases. ** — exploration of the wound and removal of a hematoma were performed.
2. Anatomic and topographic characteristics of aneurysms

Many authors consider the size and location of aneurysms as risk factors for aneurysm rupture [7—9, 11, 12, 17].

The risk of an aneurysm rupture grows as the aneurysm size increases. However, there is no single concept of the critical size. According to various data, the size ranges from 5 to 10 mm in diameter [7—9, 11, 12, 17, 31]. The minimal risk of hemorrhage was found in patients with aneurysms of less than 5 mm. As the aneurysm size increases, the five-year cumulative risk of a rupture grows from 2.6% for medium and large aneurysms to 40% for giant aneurysms [8]. In our opinion, given the fact that small aneurysms prevail among ruptured aneurysms, an aneurysm of any size should be considered as a potential source of hemorrhage. In this case, the aneurysm shape should also be considered (typical saccular, fusiform, or eccentric fusiform aneurysm, the presence of diverticula, etc.).

Many authors have proposed using the dome/neck width ratio (aspect ratio) as a prognostic factor [33]. In 80% of ruptured aneurysms, this indicator is more than 1.6.

Multilobed aneurysms are at a higher risk of rupture than single-lobed aneurysms [10]. Diverticula occur in 40% of ruptured aneurysms and in 9% of UAAs [16].

Recently, many researchers have studied and compared the hemodynamic and geometric characteristics of ruptured and unruptured asymptomatic aneurysms [34, 35]. Mathematical modeling uses SCT-AG data for developing functional aneurysmal models to analyze the dynamic characteristics of blood flow in the aneurysm cavity and to determine parameters that are predictors of aneurysm enlargement and rupture. In our opinion, these studies will probably provide objective criteria for assessing the risk of an aneurysm rupture.

Periodical examination of the aneurysm condition is important during conservative management of the patient. Aneurysm enlargement is a prognostically unfavorable factor.

In our series, ICA (>46%) and MCA (>30.8%) aneurysms predominated in UAAs. The reverse situation was observed for ruptured aneurysms where aneurysms of the ACA and AComA, ICA, and MCA accounted for 46.2%, 27.5%, and 17.6% of cases, respectively, [5] (Fig. 7).

According to the literature data [1, 2], the rupture rate of midline aneurysms is also significantly higher than that of ICA and MCA aneurysms: the rupture rate is more than 59% for AComA aneurysms and more than 66% for basilar artery aneurysms. These data provide an additional argument in favor of surgical treatment of midline UAAs. Among ICA aneurysms, the highest rupture rate is typical of aneurysms of the PComA ostium. An analysis of sizes of ruptured aneurysms depending on their location revealed that sizes of ACA and AComA, pericallosal artery, ICA, PComA, and VBT aneurysms at the time of rupture were much smaller than sizes of ruptured MCA aneurysms [17].

![Fig. 6. Comparison of adverse outcomes of surgical treatment in UAA patients and patients operated on in the acute (AP) and cold (CP) periods of SAH (according to the Burdenko Neurosurgical Institute data).]

### Table 8. Causes of complications of endovascular surgery

<table>
<thead>
<tr>
<th>Complications</th>
<th>Total, abs. (%)</th>
<th>Clinically significant complications, abs. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebral thromboembolism</td>
<td>5 (2.1)</td>
<td>4 (1.6)</td>
</tr>
<tr>
<td>Intraoperative aneurysm rupture</td>
<td>5 (2.1)</td>
<td>2 (0.8)</td>
</tr>
<tr>
<td>Parent artery occlusion</td>
<td>4 (1.6)</td>
<td>4 (1.6)</td>
</tr>
<tr>
<td>Major artery thrombosis</td>
<td>3 (1.2)</td>
<td>3 (1.2)</td>
</tr>
<tr>
<td>Aneurysm thrombosis with mass-effect</td>
<td>2 (0.8)</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Coil migration</td>
<td>2 (0.8)</td>
<td>—</td>
</tr>
<tr>
<td>Arterial dissection</td>
<td>2 (0.8)</td>
<td>—</td>
</tr>
<tr>
<td>Arterial perforation</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Parent artery suboclusion</td>
<td>1 (0.4)</td>
<td>1 (0.4)</td>
</tr>
<tr>
<td>Total</td>
<td>25 (10.4)</td>
<td>16 (6.6)</td>
</tr>
</tbody>
</table>
It should be noted that most studies on identification of risk factors for aneurysm rupture and the significance of these factors are those with moderate (IV—V) levels of evidence. It is almost impossible to accurately evaluate the contribution of each of the factors to the event of aneurysm rupture, although there have been attempts to develop aneurysm hemorrhage risk scales [36].

The results of the International Study of Unruptured Intracranial Aneurysms (ISUIA), which were published in 1998, disputed the reasonability of preventive surgery for UAAs [9]. However, the study had significant methodological errors, and most neurosurgeons were skeptical of its results [12, 16, 31]. The criticism was directed towards the process of retrospective cohort selection and a comparison between prospectively obtained morbidity data and a very low rupture rate of aneurysms selected for non-surgical treatment in a historical cohort. For example, in the historical group where the authors studied the risk of an aneurysm rupture, there were 41% of patients with cavernous ICA aneurysms versus 27% of patients with the same pathology in a second group where outcomes of surgical treatment were studied.

Like many other researchers [7, 13, 16], we believe that favorable outcomes of UAA treatment necessitate screening for cerebral aneurysms in risk groups. These groups include the following patients:

1) relatives (first degree of kinship) of patients with ruptured aneurysms;
2) young smokers (in particular, females) with hypertensive disease and nonspecific neurological symptoms (headache, eye pain, neck pain, transient ischemic attacks, etc.);
3) individuals with hereditary connective tissue diseases (autosomal dominant polycystic kidney disease, Marfan syndrome, Ehlers-Danlos syndrome type IV, coarctation of the aorta, etc.).

**Conclusion**

Therefore, there are no standards for management of UAA patients at present. This is associated with the inability to accurately predict the UAA behavior and with a certain risk of surgical complications.

Using the literature data and our own experience, we have defined the recommendations for managing UAA patients.

1. Surgical treatment is indicated for UAAs of more than 5 mm in diameter. In the presence of UAAs less than 5 mm in diameter, with the structure typical of a saccular aneurysm, and risk factors (midline location, VBT, diverticula, family history, etc.), surgery is indicated if exclusion of the aneurysm from blood flow is technically possible, and there are no absolute contraindications for surgery.

2. In the case of atypical aneurysms (aneurysmal protrusions, infundibular and hemispheric dilations of arteries) of less than 5 mm in diameter and in the absence of risk factors for rupture (midline location, VBT, diverticula, family history, etc.), dynamic follow-up with annual non-invasive angiography are recommended. Surgical treatment is recommended in cases of aneurysm enlargement and development of diverticula.

3. A technique for exclusion of an unruptured asymptomatic aneurysm is chosen based on the general principles of surgical treatment of cerebral aneurysms. At present, the method of choice is endovascular surgery for most VBT and ICA aneurysms and microsurgery for ACA and MCA aneurysms.

**Authors declare no conflict of interest.**
REFERENCES


17. Komotar RJ, Mocco J, Solomon RA. Guidelines for the surgical treatment of unruptured intracranial aneurysms: the first annual. Lawrence pool me-
The authors presented a retrospective analysis of complex (surgical and endovascular) treatment of unruptured asymptomatic aneurysms (UAAs) in 694 patients, which was performed in one institution, beginning with 1997. Treatment of UAA patients still remains a challenge for vascular neurosurgeons. It is important that treatment of these patients should be performed in dedicated centers that provide both direct surgery and endovascular treatment.

The authors treated 665 patients. The microsurgical approach was used for 527 aneurysms. The endovascular approach was used in treatment of 275 aneurysms. Neurological worsening, mainly mild, occurred in 9.3% of cases. Mortality was 0.5% (3 patients). In 2 cases, patients died after endovascular surgery.

The present study is very topical nowadays when widely used neuroimaging diagnoses a growing number of patients with UAAs and other vascular pathologies. In this case, aneurysmal hemorrhage may have catastrophic consequences. Therefore, preventive treatment for unruptured aneurysms should be considered in the presence of risk factors for rupture, which were comprehensively described and evaluated in this study. Summing up their results, the authors presented recommendations for the management of UAA patients, which should be used in everyday practice.

In practice of the Neurosurgical Department of the Russian Medical Academy of Postgraduate Education, we have often observed UAAs. In recent years, in UAA patients, given the absence of hemorrhage consequences in the form of edema and intracranial hypertension, we have used minimally invasive keyhole surgery, often in a combination with endoscopic assistance. This approach reduces surgical trauma due to small accesses, minimum use of a retractor, and decreased postoperative pain syndrome and associated complications that are sometimes associated with classical approaches.

The work will undoubtedly be interesting for vascular neurosurgeons; therefore, it can be recommended for publication in the journal Problems of Neurosurgery named after N.N. Burdenko.

V.A. Lazarev (Moscow, Russia)
Surgical Treatment of «Mirror» Aneurysms of the Internal Carotid Artery


Federal Center of Neurosurgery, Novosibirsk, Russia

Background. A relatively high incidence of “mirror” aneurysms of the anterior cerebral circulation in neurosurgical practice necessitates generalization of experience of using different surgical approaches. The choice of treatment usually reflects the number of surgical stages. Material and methods. Forty-nine patients (19 males and 30 females) with mirror aneurysms of the anterior cerebral circulation underwent one- and two-step surgery at the Novosibirsk Federal Center of Neurosurgery in 2013—2015. The total number of bilateral aneurysms was 51 couples (102 aneurysms). The patients’ age ranged from 19 to 66 years (mean age, 47.1±11.6 years). Most of the patients (47) underwent elective surgery; 2 patients were operated on in acute subarachnoid hemorrhage. Results. Sixty-nine microsurgical operations and 19 endovascular interventions were performed during the main step. Microsurgery alone was used in 34 cases; endovascular surgery alone was performed in 6 cases; a combination of the techniques was used in 9 cases. Ten patients underwent one-step surgery, and 39 patients underwent two-step surgery. The radicalness of surgery amounted to 94.1% for the microsurgical technique and 83.3% for the endovascular technique. The excellent and good functional outcome (modified Rankin scale, 0—2) was achieved in 46 (93.9%) patients, and the poor outcome (mRs, 3—5) was observed in 3 (6.1%) patients. Conclusion. Generalization of the results indicates that one-stage surgery is preferable in the treatment of mirror cerebral aneurysms. However, the two-stage approach remains important and, in the case of certain anatomical peculiarities, is the only possible treatment. A combination of microsurgical and endovascular techniques improves clinical outcomes in treatment of mirror aneurysms of the anterior part of the cerebral arterial circle.

Keywords: mirror cerebral aneurysm, bilateral cerebral aneurysms, surgical treatment of aneurysms, combined treatment of aneurysms, multiple cerebral aneurysms.

“Mirror” intracranial aneurysms are a subgroup of coupled (bilateral) multiple intracranial aneurysms located in the same segments of the carotid basins. The incidence of “mirror” aneurysms does not exceed 5% of the number of patients with intracranial aneurysms, although in the structure of multiple aneurysms they constitute 9.4 to 36% according to the data of different authors [1—3]. In women, “mirror” aneurysms are more common, the ratio of women and men with “mirror” aneurysms is 3.1:1.5 [4]. The incidence of “mirror” aneurysms located in the anterior cerebral circulation exceeds that of “mirror” aneurysms located in the posterior sections, and amounts to 98% (only 2% of cases are localized in the vertebrobasilar basin). The most common (34%) localization of bilateral aneurysms is the middle cerebral artery (MCA), slightly more rarely (32%) they are located in the ophthalmic segment of the internal carotid artery (ICA). Their incidence in communication segment of the ICA is 16%, in the cavernous segment, 13%, in the segment of the anterior cerebral — anterior connective arteries, 3%. According to the literature [1], the frequency of ruptures of “mirror” aneurysms does not differ from that for “non-mirror” ones and is 3.0 and 2.8%, respectively.

The rate of detection of intracranial aneurysms, including asymptomatic ones, has significantly increased with the widespread introduction of multispiral computed tomography of cerebral arteries (MSCT-angiography) and selective digital subtraction cerebral angiography (CAG) into the medical practice. The development of endovascular and improvement of microsurgical methods has expanded the options for their treatment. The choice of only one or a combination of methods for treatment of bilateral aneurysms requires careful analysis of clinical and radiologic presentation in each individual case. The possibility of conducting one-stage surgery or a need for a multi-stage approach, as well as the order of the “surgical attack” for each aneurysm, is defined by anatomical and morphological characteristics and available treatment methods.

The paper presents an analysis of the efficacy and safety of treatment of patients with “mirror” aneurysms, performed in the Department of Vascular Surgery of the Federal Center of Neurosurgery (Novosibirsk), as well as the experience of using staged treatment and combinations of surgical techniques for this pathology.

Materials and Methods

In the period from March 2013 to October 2015, 49 patients (19 men and 30 women) with “mirror” (bilateral) aneurysms were operated at the Novosibirsk Federal Center of Neurosurgery. The mean age of patients was 47.1±11.6 years. A total of 113 aneurysms were identified in the study group, of which 102 (51 couples) were “mirror” aneurysms. In 2 out of 49 cases, there were 2 couples of aneurysms. Six patients with bilateral aneurysms had 11 unpaired asymmetric aneurysms with other localizations. “Mirror” aneurysms were located in the cavernous...
section of the ICA in 4 (8.2%) cases, in the ophthalmic segment, in 16 (32.7%) cases, in the supraclinoid segment, in 5 (10.1%) cases, and in MCA in 24 (49.0%) (Table 1).

Miliary aneurysms were detected in 2 (2.0%) patients, normal size aneurysms, in 91 (89.2%), large aneurysms, in 3 (2.9%), giant ones, in 6 (5.9%). Remarkably, 4 out of 6 pairs of aneurysms featuring one giant aneurysm were localized in the ophthalmic segment and 2 in the cavernous segment of the ICA.

A total of 23 patients had an episode of confirmed subarachnoid hemorrhage of varying severity; at admission, most of them (21 patients) were in the cold period. One patient was admitted in the acute period of hemorrhage (grade II on the Hunt—Hess scale) and in 1 case an aneurysmal rupture occurred during the hospitalization at the diagnostic stage.

In other cases, the reason for the examination was nonspecific symptomatology. Aneurysm ruptures were equally often observed on the right and left (11 cases each) ones. In 1 patient, the debut was a rupture of an unpaired aneurysm (in anterior connective artery).

Preoperative planning was performed based on clinical and anamnestic presentation, visualization data (selective CAG, MSCT/MRI angiography of brachycephalic and cerebral arteries, brain MRI with SWI sequence), findings of specialists in the related fields (neurologist, ophthalmologist, anesthesiologist, vascular surgeon).

During the treatment, the aneurysm with verified rupture or the one with the largest size of the pair was clipped first. The one-stage surgery was the method of choice in case of anatomical feasibility of contralateral access for microsurgical operation without increasing surgical risk. The one-stage endovascular surgery was carried out by inserting micro-spirals into the aneurysm cavity without using assisting techniques (Fig. 1). In all other cases, preference was given to the two-stage approach, using either the initial approach (Fig. 2) or a combination of methods during the second surgery (Fig. 3). The time interval between the stages was determined by the patient’s condition after the first surgery, except for cases with paramedical reasons for the delay, and averaged 12.7 days.

In the early postoperative period, all patients underwent control neuroimaging (selective CAG or MSCT angiography), evaluation of their neurological status, and examination by a neurologist.

The functional outcome was assessed using the modified Rankine scale (mRs). Excellent and good outcomes corresponded to assessment of the neurological status of 0 to 2 points, poor, of 3 to 5 points on mRs. Long-term outcomes were evaluated after 6 and 12 months at a follow-up examination in the clinic of the Novosibirsk Federal Center of Neurosurgery, or in the form of correspondence consultations through the website of the center (based on MRI/MSCT-tomograms, selective cerebral angiograms).

The Raymond scale was used to assess the radicality of aneurysm exclusion:
Raymond I, complete occlusion of the aneurysm;
Raymond II, filling the cervical part of the aneurysm;
Raymond III, residual filling of the aneurysm.

Results

A total of 95 surgeries were performed (88 main stage surgeries, 2 surgeries to install flow stents for recanalized aneurysms, 5 surgeries for complications in the early postoperative period). A total of 10 patients were selected for the one-stage approach, and 39 were selected for the two-stage approach. The distribution of treatment methods among these groups of patients is presented in Table 2.

The analysis of clinical cases revealed higher number of microsurgical operations (6 cases) than endovascular operations (1) in cases of uncombined treatment. This can be attributed to localization of the aneurysm

![Table 1. Characteristics of the study group](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of patients/aneurysm</td>
<td>49/113</td>
</tr>
<tr>
<td>Men/women</td>
<td>19/30</td>
</tr>
<tr>
<td>Average age, years</td>
<td>47.1±11.6 (19—66)</td>
</tr>
<tr>
<td>The number of couples of aneurysms localized in different segments of the ICA:</td>
<td></td>
</tr>
<tr>
<td>Cavernous</td>
<td>4</td>
</tr>
<tr>
<td>Ophthalmic</td>
<td>16</td>
</tr>
<tr>
<td>Supraclinoid</td>
<td>5</td>
</tr>
<tr>
<td>MCA</td>
<td>24</td>
</tr>
<tr>
<td>Patients with a history of rupture</td>
<td>23</td>
</tr>
<tr>
<td>Without rupture</td>
<td>26</td>
</tr>
<tr>
<td>By size:</td>
<td></td>
</tr>
<tr>
<td>Miliary (up to 3 mm)</td>
<td>2 (2.0%)</td>
</tr>
<tr>
<td>Conventional (3—14 mm)</td>
<td>91 (89.2%)</td>
</tr>
<tr>
<td>Large (15—25 mm)</td>
<td>3 (2.9%)</td>
</tr>
<tr>
<td>Giant (over 25 mm)</td>
<td>6 (5.9%)</td>
</tr>
</tbody>
</table>
predominantly in those segments of the ICA (supraclinoid section, MCA) that are available for direct and contralateral clipping. In our cohort of patients, aneurysms of this localization amounted to 91.9% of cases. Types of surgery are presented in Table 3. Eight patients underwent clipping of both “mirror” aneurysms using contralateral access. A total of 26 patients underwent 52 (59.1%) two-stage clipping surgeries, and 9 patients, two-stage combinations of clipping with endovasal procedure (18—20.5% of surgeries). In microsurgery (69 operations), aneurysms were clipped in 64 (92.8%) cases. Reconstruction of the ICA lumen by

![Fig. 1](image1.png)

*Fig. 1. a — MSCT-angiograms visualizes “mirror” aneurysms of the ophthalmic segments of both ICA; b — control selective angiogram. Arrows indicate aneurysms occluded using micro-spirals.*

![Fig. 2](image2.png)

*Fig. 2. An example of two-stage clipping of “mirror” aneurysms of M1 segments branches of both MCA. a — preoperative 3D reconstruction of MSCT angiogram (arrows indicate aneurysms); b — postoperative 3D reconstruction of MSCT-angiograms.*

![Fig. 3](image3.png)

*Fig. 3. An example of combined treatment. a — 3D reconstruction of the MSCT angiogram after the microsurgical stage of clipping of aneurysm of the supraclinoid section of the right ICA, right MCA. Functioning aneurysm of the supraclinoid section of the left ICA; b — selective subtraction angiogram after the occlusion of the aneurysm of the supraclinoid section of the left ICA using a flow-guided stent.*
imposing fenestrated clip on the wide neck of a giant aneurysm was performed in 1 case. Creation of a high-flow anastomosis between the external carotid artery (ECA) and M2 segment of MCA followed by trapping of a giant aneurysm was performed in 3 cases. One patient underwent establishment of low-flow extra-intracranial microanastomosis (EICMA) of a double barrel type followed by endovascular trapping of the giant aneurysm. In endovascular interventions, the technique of aneurysm embolization with detachable micro-spirals was used in 11 cases, including 6 operations using stentile balloon assistance. Occlusion of an aneurysm with the help of a flow-directing stent was performed in 7 cases during the primary surgery. In 1 patient, the occlusion of an aneurysm-supporting vessel was performed using detachable micro-spirals in combination with a microsurgical revascularization operation.

Radicality of microsurgical treatment amounted to 94.1%. In 1 case, control CAG in the long-term period revealed contrasting of the cervical part after clipping of the aneurysm of the ophthalmic segment. It required installation of a flow-directing stent in the projection of the aneurysm which allowed to achieve radical treatment. In the group of patients undergoing endovascular treatment, the group of aneurysms occluded with the help of flow-directing stent deserves special mention. All cases in this group had good stagnation of the contrast medium to varying degrees, but long-term period CAG data are required to assess the radicality. In the group of patients with aneurysms occluded using embolization with micro-spirals, the radicality after the first stage was 83.3%, according to the control long-term CAG. A patient with Raymond II type of radical exclusion further underwent occlusion of an aneurysm with a flow-guided stent.

**Complications**

In our group, 5 (5.6%) patients had complicated course of postoperative period. In 4 (5.8%) cases the complications occurred in the microsurgical treatment group. The quantitative characteristics of the functional outcomes are presented in Table 4.

In one case, thrombosis of ICA was observed after reconstructing the lumen of the supporting vessel by clipping the wide neck of a giant aneurysm of the ophthalmic segment with fenestrated clips using proximal control of blood flow in the neck. A decompressive craniotomy for cerebral edema was performed in the early postoperative period. The patient was discharged after a long treatment with a poor functional outcome (mRs 5).

In one case, the early postoperative period was complicated by acute subdural and intracerebral hematomas of the left temporal lobe with dislocation and edema of the brain. This occurred against the background of anticoagulant therapy after the establishment of a high-flow shunt between the ECA and M2 segment of the MCA and trapping of a giant aneurysm of the cavernous segment of the left ICA. A decompressive craniotomy and removal of hematomas were performed as emergency treatment option. The patient was discharged after an intensive treatment with a poor functional outcome (mRs 4).

In one case, a giant aneurysm ruptured in the ophthalmic segment of the ICA at the diagnostic stage.

---

### Table 2. Distribution of treatment methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Microsurgical</th>
<th>Endovascular</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-stage (patients)</td>
<td>8</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Two-stage (patients)</td>
<td>26</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Total patients/surgeries</td>
<td>34/60</td>
<td>6/10</td>
<td>9/18</td>
</tr>
</tbody>
</table>

### Table 3. Types of surgical interventions in the presented group of patients

<table>
<thead>
<tr>
<th>Method</th>
<th>Number of surgeries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clipping</td>
<td>64</td>
</tr>
<tr>
<td>Reconstruction of the lumen of the supporting vessel by clipping a wide neck with a fenestrated clip</td>
<td>1</td>
</tr>
<tr>
<td>Creation of high-flow bypass shunt, aneurysm trapping</td>
<td>3</td>
</tr>
<tr>
<td>Occlusion with micro-spirals</td>
<td>5</td>
</tr>
<tr>
<td>Microcirculation occlusion using assisting technique</td>
<td>6</td>
</tr>
<tr>
<td>Installation of a flow-directing stent into the aneurysm position</td>
<td>7</td>
</tr>
<tr>
<td>Creation of low-flow anastomosis followed by trapping with micro-spirals</td>
<td>1</td>
</tr>
<tr>
<td>Occlusion of the supporting vessel with micro-spirals</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 4. Assessment of outcomes using mRs scale

<table>
<thead>
<tr>
<th>The mRs scale</th>
<th>mRs 0 — excellent</th>
<th>mRs 1—2 — good</th>
<th>mRs 3—5 — poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients (%)</td>
<td>45 (91.9)</td>
<td>1 (2)</td>
<td>3 (6.1)</td>
</tr>
</tbody>
</table>
during the selective CAG. The repeated rupture of the aneurysm was diagnosed intraoperatively prior to the dissection of the dura. Due to the development of cerebral edema the surgery was limited to the establishment of EICMA. Few days later after stabilization of the condition, the patient underwent clipping of a giant aneurysm of the ophthalmic segment by fenestrated clips using intravascular aspiration of blood from the ICA at the cervical level. A few days later, an aneurysm of the opposite carotid basin was embolized using with microspiral. Subarachnoid hemorrhage caused constrictive-stenotic arteriopathy resulting in secondary ischemic impairments that spread to both hemispheres of the brain. A chemical and balloon angioplasty was performed. After a long period of intensive therapy, the patient was transferred to a rehabilitation hospital with a poor functional outcome (mRs 5).

In one other case, visual disturbances appeared after clipping aneurysm of the ophthalmic segment of the ICA. At the time of discharge, the functional outcome was satisfactory (mRs 2).

In the group which underwent endovascular treatment, there was no deterioration in the assessment of functional outcomes. However, it should be noted that all cases of complex and giant aneurysms were treated using microsurgical clipping. In one (4.8%) case, a complication of endovascular treatment was pulsating hematoma in the inguinal region, which required surgical suturing of the walls of the common femoral artery and did not affect the functional outcome of the underlying disease.

Discussion

The choice of surgical tactics is an urgent task in the treatment of cerebral aneurysms. The decision on the number of stages and choice of methods for surgery of bilateral aneurysms can affect the radicality of the aneurysm occlusion, as well as the risk of intraoperative complications. In our work, we adhered to the generally accepted principles of treating aneurysms [5] by first attempting to exclude the aneurysm with verified history of hemorrhage from the blood stream. In the absence of hemorrhage, the surgery was first performed on an aneurysm of a larger size or an aneurysm that had any symptoms. The publication back in 1977 of G. Yasargil’s report on the use of contralateral access for clipping of “mirror” aneurysms of the carotid-opthalmic segment made the one-stage microsurgical approach to bilateral aneurysms widespread [6]. Nowadays, aneurysms of the normal size located in the ophthalmic or supraclinoid segments of the ICA, as well as in the M1 segment of the MCA, are considered to be accessible for contralateral approach without increasing the surgical risk [7, 8]. However, despite the feasibility of using one-stage microsurgical approach, its appropriateness should be discussed in each specific case. For example, according to the team of authors in the Burdenko Neurosurgical Institute, the one-stage treatment of multiple aneurysms using the contralateral approach is significantly inferior to the multi-stage approach in terms of radicality (79 and 92%, respectively) [6]. In our series, we also had observed lower radicality for the one-stage microsurgical approach (93.7%) compared to the two-stage one (98.1%). The presence of one of the signs of a “complex” aneurysm and the likelihood of the need for revascularization played the decisive role in selection of candidates for the two-stage microsurgical or combined treatment [9]. One of the main factors contributing to the increased surgical risk is the large and gigantic size of the aneurysm [10, 11]. In our series, all complications that led to poor functional outcomes occurred in the group of patients who had one giant aneurysm in a pair. Improvement in endovascular technique expanded surgical capabilities for treatment of “mirror” aneurysms. Under certain conditions, flow-directing stents represent a worthy alternative to microsurgical operations. For example, their effectiveness can reach 74—92% with 0—12% frequency of complications [12—15]. It is possible to use them to treat “mirror” aneurysms either as the main method, or in combination with microsurgical operations. Taking into account that assistive techniques in endovascular treatment are associated with 1.4—20% risk of ischemic complications [12—14], they were only used in surgeries conducted in different carotid basins as a part of the two-stage approach. There were no ischemic complications in the endovascular group of patients.

Conclusions

The work presents a series of observations of patients with a rare subgroup of multiple aneurysms of the brain, “mirror” aneurysms of the anterior arterial circle of the brain. The number of stages of surgical treatment was determined based on the clinical-x-ray individually in each case. The success of the one-stage treatment depended to a large extent on the level of experience of the surgical team.

Authors declare no conflict of interest.
REFERENCES


Commentary

The following aspects should be considered in choosing the tactics and method of clipping an aneurysm of the cerebral vessels: the clinical course of the disease (history of hemorrhage or pseudotumorous course of the disease), the anatomical and morphological characteristics of the aneurysm and the number of aneurysms. The tactics of surgical interventions are constructed based on these aspects. Of course, there are many other factors that should be taken into account (age, somatic status, concomitant diseases, etc.), but the three factors listed above are the main ones that define the indication for microsurgical or endovascular interference to treat an aneurysm. According to the experience of the Burdenko Neurosurgical Institute team, aneurysm of the trunk and bifurcation of the basilar artery and aneurysm of the carotid-opthalmic segment of the internal carotid artery (ICA), which did not manifest as spontaneous subarachnoid hemorrhage, shall be treated by endovascular occlusion with micro-spirals (with or without stent assist). Aneurysms of the supraclinoid segment of the ICA and the posterior inferior cerebellar artery can be operated using either endovascular or microsurgical techniques, while aneurysms of the MCA bifurcation and the anterior aneurysms of the anterior connective artery are largely excluded from the blood stream by microsurgical clipping of the aneurysm neck. These data is based on the clinical experience of the two vascular units (a non-randomized study) and is important, since it is confirmed by the analysis of the treatment outcomes.

In this article, a group of authors presented their experience of surgical treatment of 49 patients with bilateral aneurysms of the anterior sections of the Willis circle. Different variants of surgical intervention have been considered: two-stage, one-stage (single-stage operations with clipping of both aneurysms, using contralateral approaches) and combined surgical interventions involving both microsurgical and endovascular techniques. The experience obtained in the Burdenko Neurosurgical Institute shows that preference should be given to two-stage surgical interventions, since even moderate injuries of both frontal lobes during one-stage surgeries involving bilateral trepanation are poorly tolerated by patients, leading to
major disruptions of cognitive functions (especially in acute and subacute period of cerebral aneurysm rupture). If the anatomical and morphological features of the aneurysms, the position of the chiasmus and optic nerves, and the state of the patient’s brain (absence of edema) allow one to clip both aneurysms ipsi-contralaterally from one pterional access, this option may be considered the most preferable. Combinations of endovasal and microsurgical interventions are very important. In the first stage, the bleeding aneurysm should be excluded, especially if the surgical treatment is supposed to be divided into two stages. Such operations should be performed in specialized neurosurgical clinics.

From personal experience, I can add that the bilateral aneurysms of MCA can be considered convenient enough for occlusion from the contralateral access. In aneurysms of MCA bifurcation, the direction of the aneurysm bottom is not as important as the configuration of the aneurysm sac. Contralateral access creates conditions for proximal control of the MCA trunk prior to manipulation of the aneurysm and direct access to the aneurysm neck. In this case, the configuration of the aneurysm sac becomes important. For example, aneurysms of hemispherical form require modeling of the neck with a weak current using bipolar coagulation and a technically complex imposition of the clip, which is difficult to perform from contralateral access.

The article is interesting and useful for experienced and even more for new neurosurgeons of the newly created regional vascular centers from different cities of the country, who are very actively attacking the issue of surgical treatment of patients with aneurysms of the brain.

Sh.Sh. Eliava (Moscow, Russia)
The Modern Role of Microsurgery in Treatment of Large and Giant Aneurysms of the Internal Carotid Artery

O.D. SHEKHTMAN, SH.SH. ELIAVA, S.B. YAKOVLEV, Yu.V. PILIPENKO, AN.N. KONOVALOV

Burdenko Neurosurgical Institute, Moscow, Russia

Introduction. Large (1.5—2.5 cm in diameter) and giant (>2.5 cm) aneurysms of the internal carotid artery (ICA) are still among the complex neurosurgical pathologies in terms of microsurgery. In recent years, endovascular techniques for treatment of paraclinoid aneurysms, in particular, ICA reconstruction using flow-diverting stents, has become a priority. However, surgery of flow stents has a number of limitations and therefore the choice of treatment is individual in each case. Objective. The study was aimed at analyzing the results of direct surgery in patients with large and giant aneurysms of the ICA and determining the role and place of modern microsurgical techniques in the treatment of this vascular disease. Material and methods. The study included 260 patients with large and giant ICA aneurysms who were operated on at the Burdenko Neurosurgical Institute using microsurgical techniques during the period between 2001 and 2015. The mean age of patients was 45.1 years. The male/female ratio was 1:2.5. One hundred sixty four (63.1%) patients were operated on after hemorrhages, of whom 15 (5.7%) patients were operated on in the acute period; 69 (26.5%) patients had pseudotumoral course of the disease; 9 (3.5%) patients had mixed course of the disease; aneurysms were incidentally found in 18 (6.9%) patients. Aneurysm location was as follows: paraclinoid aneurysms were observed in 158 (60.7%) patients, supraclinoid aneurysms — in 77 (29.6%) patients, and ICA bifurcation aneurysms — in 25 (9.6%) patients. Microsurgical clipping was performed in 228 (87.7%) patients, including 158 (60.7%) patients, where an intravascular blood aspiration technique was used. Aneurysm trapping using a flowmetry probe was performed in 16 patients, with formation of vascular anastomoses — in 4 (1.5%) cases. In 16 (6.2%) patients, interventions were completed by gauze strengthening. We performed a comparative analysis of the results of endovascular treatment of paraclinoid aneurysms reported in recent publications and obtained in the present series. Results. Treatment outcomes (Glasgow Outcome Scale) were favorable (Grade 4—5) in 224 (86.2%) patients and satisfactory in 29 (11.1%) patients. Two patients (0.7%) developed diencephalic (electrolyte) disturbances that were successfully corrected using replacement therapy. Mortality was 2.7% (7 patients); treatment completeness was 94.3%. Comparison with the literature data demonstrated comparable results for both treatment techniques. Conclusion. Microsurgical techniques for treatment of large and giant ICA aneurysms are the methods of choice in complex non-standard cases, where endovascular treatment is ineffective or contraindicated. Planning of microsurgical treatment should include the possibility of revascularization surgery. Treatment of these patients should be carried out at large specialized centers having appropriate expertise and facilities.

Keywords: giant aneurysm, surgical treatment of aneurysms, clipping, intravascular blood aspiration, flow-diverting stent.

Abbreviations:
ICA — internal carotid artery
IBA — intravascular blood aspiration
CT — computed tomography
FDS — flow-diverting stent
SCT-AG — spiral computed tomography angiography
CCAG — cerebral carotid angiography
EICMA — extra-intracranial microvascular anastomosis

Large (1.5—2.5 cm in diameter) and giant (>2.5 cm) aneurysms of the internal carotid artery (ICA) are still among the complex neurosurgical pathologies in terms of microsurgery [1,2]. Complexity of surgical treatment is associated with both the large size of aneurysms, cohesion of their walls with the base, proximity of functionally important structures (optic nerve, chiasm, diencephalic region), and the need for highly delicate dissection of these aneurysms in order to preserve vision and blood flow in the ICA branches and perforating arteries. Practical experience shows that successful surgical outcomes can be achieved in large specialized, well-equipped clinics with specialists having appropriate expertise. At the Burdenko Neurosurgical Institute, large and giant aneurysms of the internal carotid artery are diagnosed in 50—60 patients per year [3].

In recent years, endovascular techniques of treatment for paraclinoid aneurysms, in particular ICA reconstruction using flow-diverting stents, have become a method of choice. S.B. Yakovlev et al. [4] demonstrated that such operations are technically quite simple, minimally invasive, characterized by high radicality and good functional outcomes. However, flow-diverting stent surgery has some limitations, for example, it is not...
applicable in the case of acute aneurysm rupture or in patients who have contraindications to administration of dual antiplatelet therapy. Further, it is worth noting that the availability of endovascular surgery is significantly limited by its high cost.

Obviously, the choice of treatment is individual in each case. But how to make this choice? What anatomical and clinical factors should be kept in mind when using direct surgery in patients with large paraclinoid aneurysms? In this paper, the authors analyzed treatment outcomes in a series consisting of 260 patients and represented their view of the problem.

Material and methods

The study included 260 patients with large (1.5—2.5 cm), and giant (more than 2.5 cm) ICA aneurysms, who were operated on using microsurgical technique at the Burdenko Neurosurgical Institute in 2001—2015. The median age was 45.1 years, male to female ratio was 1:2.5. In size, large aneurysm were diagnosed slightly more often (57.7%) than giant ones (42.3%) (Table 1).

Hemorrhage was the most common manifestation of the disease, 164 (63.1%) cases. Pseudotumorous type was observed in 69 (26.5%) patients and mixed type occurred in 9 (3.5%); aneurysm were occasionally detected in 18 (6.9%) patients (Table 2).

A total of 164 patients had hemorrhage, 15 of them were operated on in the acute period of SAH. Condition of 4 patients corresponded to grade I of the Hunt—Hess severity scale, 4 patients — grade II, 4 — grade III, 2 — grade IV, and 1 — grade V.

In 44 (16.9%) patients, paraclinoid aneurysm was detected in combination with aneurisms located in other sites: 33 patients had 2 aneurysms, 6 — 3 aneurysms, 5 — 4 aneurysms. These patients underwent stage-by-stage combination treatment.

All patients underwent a complex examination including CT scan or MRI of the brain in order to assess the condition of the aneurismal wall and the degree of thrombosis of the aneurysm, and SCT angiography and/or selective subtraction angiography in order to assess angioarchitectonics of the aneurysm and collateral. Preoperative preparation also included examination by neurologist, ophthalmologist and electroencephalography. According to their location, aneurysms were subdivided into paracclinoid (wide neck, ICA segment is difficult to differentiate), supraclinoid (aneurysm neck is located distal to the mouth of the PCA), and bifurcation of the ICA (the neck is located near to ICA bifurcation) (Table 3).

The types of aneurisms in terms of location of the aneurysmal dome with respect to the ICA stem and optic nerve (classification by Sh.Sh. Eliava [7, 8]) are shown in Table 4.

Microsurgical intervention was planned based on the following data.

1. Neuroimaging (aneurysm size, neck width, arrangement of the dome with respect to the ICA and the optic nerve, the degree of thrombosis, wall density and atherosclerotic changes, location of the branches of the PCA, superficial temporal artery (STA), etc., displacement of the optic nerve, the size and location of the anterior clinoid process and so forth.).

2. SCT/MR angiography or selective angiography (size of the ICA and its branches, arrangement of the arteries with respect to the aneurysm, collateral blood flow in the PCA and ACA).

3. Neurological status (hemorrhage and its terms, focal neurological deficits, visual/oculomotor disorders and time of their occurrence).

In 60.7% of cases, intravascular retrograde blood aspiration (IBA) technique was used for the aneurysmal sac decompression during separation and clipping. In cases, where the aneurysm clipping was impossible or was associated with a high risk of ischemic complications, trapping operation with revascularization using the wide anastomosis or EICMA were planned. For these patients, additional preparations are required, in particular, balloon occlusion test in order to evaluate collaterals and Allen test to assess the possibility of harvesting as a radial artery donor.

Direct IBA technique includes separation of the ICA, common carotid artery (CCA), and external carotid artery (ECA) through the linear skin incision on the neck followed by blood aspiration through the 16-18G cannula inserted into the lumen of the cervical portion of the ICA with underlying trapping. Endovascular IBA was performed in a similar way using a double-lumen balloon catheter placed into the ICA lumen under fluoroscopic guidance. During fractional aspiration steps, blood was collected to bags with heparin and transfused to the patient at the end of the operation. In cases, when long-term ICA exclusion and aneurysm relaxation were not required, cervical ICA was temporarily excluded without aspiration. More detailed information on IBA technique can be found in our earlier publications [9].

In the case, where aneurysm clipping was impossible, we considered the option of permanent ICA exclusion (aneurysm trapping). Anatomically “correct” form the circle of Willis vessels with intact collaterals was a prerequisite for trapping. The decision whether to perform trapping was made based on the positive flowmetric test, where the blood flow in the MCA was evaluated using the flowmeter at the baseline and during occlusion test. Decrease in the blood flow by no more than 20% as compared to the baseline value was considered as compensated blood flow [10]. In the case of individual (atypical) structural forms of the circle of Willis vessels (aplasia or hypoplasia of the anterior cervical artery (ACeA) or PCA), the surgery was planned...
in such a way to enable separation of the superficial temporal artery to form EICMA.

The types of operations in the study group are shown in Table 5.

Patients were examined at discharge by ophthalmologist and neurologist, functional outcome was assessed on the Glasgow Outcome Scale (GOS).

**Results**

In most patients, aneurysm was successfully clipped (223 patients, 85.7%), including 25 (9.6%) cases where ICA lumen was formed. In 12 cases, the operation was completed with aneurysm trapping, in 4 patients, aneurysm trapping was preceded by fistulization (3 — EICMA, 1 — wide anastomosis). In 16 cases, the aneurysms were reinforced with gauze. Completeness of surgical treatment was 94.3%.

Direct (open) IBA technique was used in 133 patients, endovascular IBA with balloon catheter was used in 26 cases. Proximal fractional exclusion of the cervical ICA without blood aspiration was used in 13 cases. In 7 patients, IBA has been ineffective to achieve relaxation of the aneurysmal sac due to the narrowed cervical portion of the ICA caused by atherosclerosis or hanging down aneurysmal walls.

The following are clinical cases of successful exclusion of paraclinoid aneurysms. Patient S., 41 years old, was admitted with the diagnosis of giant (2.8 cm) paraclinoid (medial) aneurysm of the left ICA (subacute period). Aneurysm was excluded using the IBA technique with 3 tunnel clips accompanied by formation of the ICA lumen (Fig. 1).

The second case presents patient P., 46 years old, with a giant (3.2 cm) aneurysm of the ICA, with aneurismal neck expanding from the distal portion of the ICA to bifurcation. Willis circle was disunited (aplasia

<table>
<thead>
<tr>
<th>Table 1. General characteristics of the study group patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of patients</td>
</tr>
<tr>
<td>Males : Females</td>
</tr>
<tr>
<td>Mean age, years</td>
</tr>
<tr>
<td>Aneurysms size, n (%)</td>
</tr>
<tr>
<td>Giant (&gt;2.5cm)</td>
</tr>
<tr>
<td>Large (1.5—2.5 cm)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Table 2. Clinical presentation of the disease</th>
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<tbody>
<tr>
<td>Hemorrhage</td>
</tr>
<tr>
<td>Acute SAH</td>
</tr>
<tr>
<td>Hunt–Hess severity scale</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td>IV</td>
</tr>
<tr>
<td>V</td>
</tr>
<tr>
<td>Cold period of SAH</td>
</tr>
<tr>
<td>Pseudotumorous course</td>
</tr>
<tr>
<td>Mixed course</td>
</tr>
<tr>
<td>Asymptomatic course</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Distribution of aneurysms according to their location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paracclinoid</td>
</tr>
<tr>
<td>Supraclinoid</td>
</tr>
<tr>
<td>Bifurcation</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4. Anatomic types of aneurisms in the study group patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type (location)</td>
</tr>
<tr>
<td>Anterior (superior)</td>
</tr>
<tr>
<td>Posterior (inferior)</td>
</tr>
<tr>
<td>Lateral</td>
</tr>
<tr>
<td>Medial</td>
</tr>
<tr>
<td>Fusiform</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
of A1 segment on the right). Surgical treatment included formation of wide bypass anastomosis with giant aneurysm trapping (Fig. 2).

In the following case, surgery for clipping of giant (2.5 cm) aneurysm with IBA was planned in a 52 years old patient K. with rapid progressive loss of vision in both eyes. Intraoperative flowmetry has shown that temporary exclusion of the ICA leads to significant (40% compared to the baseline) decrease in blood flow in the MCA. We applied protective EICMA, and then aneurysm was successfully clipped and opened followed by thrombus extraction (Fig. 3).

Clipping under conditions of aneurism rupture was carried out in 31 (11.9%) patients. Bleeding from the cavernous sinus during clinoid process resection occurred in 1 case. In the early postoperative period, clip migration (creep) from the aneurysmal neck accompanied by hemorrhage occurred in 1 case, which required revision and re-clipping. In 18 patients, operation was completed by extended external decompression of the skull with duraplasty; in another 8 patients, external decompression was performed later due to progressive cerebral edema.

Worsening of the neurologic status in the early postoperative period was observed in 72 (27.7%) patients and included mainly visual (hemianopsia) and motor (hemiparesis) disorders. Complications were caused by ischemic (dishematic) lesions of the brain due to temporary exclusion of the arteries, mechanical injury during aneurysm separation, and insufficient blood flow in the perforating arteries during aneurysm clipping (Table 6). The appearance or worsening of the visual deficit in the form of reduced visual acuity and field of view limitations was observed in 63 (24.2%) cases, oculomotor disorders (third cranial nerve palsy) in 28 (10.7%) patients, focal symptoms in the form of the combination of motor, sensory, speech, and mental disorders were observed in 25 (9.6%) patients.

In general, favorable treatment outcomes (GOS score 4—5) were obtained in 224 (86.2%) cases, satisfactory —29 (11.1%) cases (Table 7). In 2 (0.7%)
patients, diencephalic (electrolyte) disturbances were detected, which were successfully corrected using replacement therapy. Mortality was 2.7% (7 patients). In 6 cases, death was caused by brain edema due to massive ischemia. In 1 case, patient died due to progressive multiorgan failure with underlying meningitis and septicemia.

Discussion

The term “paraclinoid aneurysm” was first used by S. Nutik [11] in 1978 to describe large aneurysms, formed near to the mouth of the ophthalmic artery. The international literature suggests several classifications of paraclinoid aneurysms of the intracranial segment of the ICA. Classification suggested by H. Batjer et al. [12], which classifies the aneurysm with respect to the branches of the ICA, is most often used one. In 1996, prof. Sh.Sh. Eliava proposed a simplified classification that describes 4 types of paraclinoid aneurysms with respect to the wall of the ICA, which is involved in formation of aneurysms: superior, medial, inferior, and lateral ones. In our view, this classification is more viable in terms of surgery, since it assumes a certain typical arrangement of the optic nerve (e.g., in the case of medial aneurysms, optic nerve is always located above the aneurysm, and in the case of superior aneurysms, below it), and certain “standard” approach to aneurysm exclusion (medial aneurysms are typically clipped using tunnel clips with formation of ICA

Table 5. Types of surgery in the study group patients

<table>
<thead>
<tr>
<th>Surgery type</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>abs.</td>
</tr>
<tr>
<td>Microsurgical clipping</td>
<td>228</td>
</tr>
<tr>
<td>Clipping with IBA</td>
<td>158</td>
</tr>
<tr>
<td>Clipping with cervical clamping of the ICA</td>
<td>30</td>
</tr>
<tr>
<td>Strengthening with gauze/Omnex adhesive</td>
<td>16</td>
</tr>
<tr>
<td>Trapping</td>
<td>12</td>
</tr>
<tr>
<td>Trapping + anastomosis</td>
<td>4</td>
</tr>
</tbody>
</table>

Fig. 2. a — CCAG visualized a giant partially thrombosed aneurysm of the right ICA; b — surgery was carried out to form a wide-lumen anastomosis; c — permeability of the latter was confirmed by indocyanine green video angiography; d — aneurysm trapping was then carried out; e — postoperative selective staining of the right ICA demonstrated good filling of the ipsilateral PCA system; f — right MCA system supplied by anastomosis.
Up to 1990s, the surgery of large and giant paraclinoid aneurysms included deconstructive operations, clipping and ligation of aneurysms, which was associated with rather high risk of postoperative complications (22.7%) and mortality (4.1—13.0%), according to V.A Lazarev [13]. In 1990, H. Batjer and D. Samson [14] were the first who described the technique of retrograde blood aspiration from the cervical ICA aimed at exclusion of the paraclinoid giant aneurysms, which significantly improved treatment outcomes. At the Burdenko Neurosurgical Institute, such an operation was for the first time carried out in 1995. This study includes 260 patients, who were operated on for the last 15 years (2000—2015); earlier patients were excluded due to the lack of comprehensive data.

Despite the continuous evolution of endovascular tools, microsurgical treatment remained the treatment of choice for paraclinoid aneurysms, since it is characterized by high radicality and reliability. Endovascular occlusion with microcoils often requires stent-assistance and administration of antiplatelet agents. Moreover, accumulated follow-up data showed that large aneurysms are characterized by relatively high incidence of recanalization (17.2—29%) and reoperations (23%), while morbidity and mortality were similar to those in direct microsurgery [15—18].

In our series, microsurgical clipping of aneurysms was performed in 93.8% of patients, palliative intervention (strengthening with gauze), in 16 (6.2%) patients. The reasons for unsuccessful interventions were as follows: IBA inefficiency due to cervical ICA atherosclerosis, dense or soldered walls of the aneurysm (7 patients), aneurysm invasion of the cavernous sinus (2), partial thrombosis (3), and combination of factors (4). Nine of sixteen patients were subsequently sent for endovasal treatment, 6 patients were left under medical care, and 1 patient died due to repeated hemorrhage.

The factors that reduce the radicality of surgery and increase the risk of complications include atherosclerosis, calcification and thinning of the aneurysmal walls (rupture often occurs at the point where wall changes from dense to thin), giant size, fusiform structural type, the presence of blood clots, aneurysmal invasion of the cavernous sinus, cohesion of the functionally important small arteries (PCA and perforating arteries) with the aneurysm and base, acute hemorrhage, and decompensated collateral blood flow [9, 19]. According to our experience, the use of IBA technique facilitates...

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**Fig. 3.** The series of spiral CT angiography detected a giant paraclinoid aneurysm in superior position and aplasia of A1 segment on the right (a). Intraoperative flowmetry (b) showed decrease in the volumetric blood flow in the right MCA during experimental exclusion of the cervical ICA from 33 to 20 ml/min. After application of protective EICMA, (c) blood flow in the MCA increased to 29 ml/min, and aneurysm was successfully clipped and opened (d). According to the control CCAG, aneurysm was completely excluded, EICMA (arrow) is well contrasted (e, f).
Table 6. Type of postoperative neurological disorders

<table>
<thead>
<tr>
<th>Postoperative neurological loss</th>
<th>Number of patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual</td>
<td>63 (24.2)</td>
</tr>
<tr>
<td>Oculomotor</td>
<td>28 (10.7)</td>
</tr>
<tr>
<td>Focal deficit</td>
<td>25 (9.4)</td>
</tr>
<tr>
<td>Motor</td>
<td>19 (7.3)</td>
</tr>
<tr>
<td>Speech</td>
<td>8 (3.0)</td>
</tr>
<tr>
<td>Sensory</td>
<td>3 (1.1)</td>
</tr>
<tr>
<td>Mental disorders</td>
<td>6 (2.3)</td>
</tr>
</tbody>
</table>

Table 7. GOS functional outcomes in the study group patients

<table>
<thead>
<tr>
<th>GOS outcomes</th>
<th>Number of patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>135 (51.9)</td>
</tr>
<tr>
<td>4</td>
<td>89 (34.3)</td>
</tr>
<tr>
<td>3</td>
<td>29 (11.1)</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>7 (2.7)</td>
</tr>
<tr>
<td>Total</td>
<td>260</td>
</tr>
</tbody>
</table>

aneurysm separation and clipping phase, improving the effectiveness of microsurgical treatment.

The incidence of complications, in particular ischemic circulatory disorders, can be reduced due to delicate microsurgical technique, fractional mode of temporary artery clipping, and the use of modern blood flow control techniques (contact Doppler, indocyanine green video angiography, neuromonitoring of motor potentials, etc.). In the case of acute intraoperative thrombosis of the branches, intraarterial fibrinolytics can be used [20].

In cases, where aneurysm clipping is impossible, the option of destructive operation (trapping) is considered. Aneurysm trapping is a “rescue operation”, which should be used in desperate situations. Typically, paraclinoid aneurysm trapping is carried out by cervical clipping of the ICA or intracranial clipping immediately proximal to the aneurysm and distal to the aneurysm, preserving blood flow in the PCA and anterior ciliary artery. Accumulated experience shows that deconstruction of the ICA is associated with high risk of complications and should be performed only after evaluation of collateral blood flow. This study can be carried out intraoperatively using a flowmeter, as described in our previous report [21].

Our experience can largely predict the prospects of aneurysm clipping, when planning the operation. In the cases, where the standard approach may be ineffective, the possibility of revascularization using low-flow (EICMA) or high-flow anastomosis should be provided. The choice of revascularization method and anastomosis type depends on cerebral perfusion deficit, collaterals, and patient’s clinical condition [22, 23].

Visual disorders were the most common neurological complications in the studied series. Deterioration of visual field or oculomotor functions was observed in nearly ¼ of operated patients. These values agree with data of similar international publications (4—30%) and does not vary from year to year [24]. High risk of damage to the cranial nerves is due to the complex anatomy of the parasellar region, the need for manipulation near to the optic nerve, resection of the anterior clinoid process, and other mechanical and thermal traumatic factors. Resection of the roof of the optic canal and anterior clinoid process and incision of the falciform ligament prior to aneurysm separation contributes to prevention of visual disorders. Decompression of the aneurysmal sac can improve vision in the postoperative period. It is worth noting that our follow-up analysis in 2013 has shown that long-existing visual disorders have a slight tendency to recovery, regardless of surgical technique [25].

According to the literature [24], vision impairment occurs after endovascular treatment of giant aneurysms approximately at the same rate, 4—25%. This is due to preservation of mass effect of thrombosed aneurysm, although there were cases in our practice, where visual function improved, apparently due to clot retraction and decrease in the aneurysm volume. Surgery for revascularization and deconstruction of the ICA provides high radicality along with low incidence of complications. According to recent publication by Y. Ishishita et al. [26], in the series of 38 patients with large and giant aneurysms of the ICA that were excluded after application of wide anastomosis, radicality was 100% and complications occurred in 5.2% of patients. Mechanical injury of the optic nerve during aneurism trapping operations with revascularization is minimal and they are the method of choice in cases where it is essential to preserve vision. When using trapping, surgeon can open an aneurysm, remove thrombotic mass, and thus perform decompression of the optic nerve and chiasm. In these operations, there is no need for nerve separation from the aneurysm and resection of bone structures.
We present a series of large and giant aneurysms operated using microsurgical techniques, which is the largest of all published studies. Favorable surgical outcomes were obtained in 224 (86.2%) operated patients, mortality was 2.7%, which can be considered as quite good result compared to the literature data.

Nevertheless, since flow-diverting stents appeared in the repertoire of endovascular surgery, the trend to the use of this minimally invasive technique has become apparent in recent years.

FDS surgery is not complication-free: neurological disorders resulting from treatment occur in 3.5—23.1% of patients, bleeding — 0.5—5.8%, ischemic (embolic) disorders — 4.1—13.5%, surgical mortality is 3.4—5.8% [4, 27, 28]. However, in general, these values are lower compared to direct surgery.

It should be noted that FDS placement is an arterial wall reconstruction surgery, and the results obtained at the end of the procedure are intermediate. Aneurism thrombosis occurs during the first months; in 25.7% of patients, it occurs during 6 months, according to F. Briganti et al. [27]. Surgical outcomes are evaluated at least in 6 months, and most surgeons evaluate them in 12 months. According to the literature, the incidence of partial occlusion is highly variable, accounting for 7.9—21.0%. Late parenchymal hemorrhage, occurring several months after FDS installation, a rare (1.8—10.0%) complication that should be studies. Pathogenesis of these complications is not clear and specialists suggest that formation of ischemic lesions with hemorrhage is caused by microembolism of the materials of catheters, autoimmune transformation of the thrombosed artery wall, etc.

Table 8 summarizes the effectiveness of different treatments of large and giant aneurysms based of recent multicenter trials, meta-analysis, and large series.

Endovascular surgery should be considered as a primary treatment option in patients with unruptured aneurysms, elderly patients (>65 years), as well as in the cold period of SAH. In the acute stage, as well as in the case of pseudotumorous clinical course, especially when vision is affected, microsurgery should be considered. Our experience shows that in large, specialized neurosurgical centers, complex operations for paraclinoid aneurysms can be performed with good functional outcomes. Revascularization surgeries are worthy of special attention, since they prevent some consequences that involuntarily arise during clipping.

### Conclusion

Surgical treatment of large and giant parac linoid aneurysms is a challenging problem at the intersection of two specialties. Treatment plan is determined by a number of clinical factors and must be the result of collegiate work of doctors and strictly individual approach to each patient. Endovascular treatment is the method of choice in patients with large and giant aneurysms of the internal carotid artery, while microsurgical techniques can be helpful in complex, non-standard cases, where

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Number of patients, aneurisms</th>
<th>Trial type</th>
<th>Operations</th>
<th>Radicality, %</th>
<th>Complications, %</th>
<th>Neurological deficit, %</th>
<th>Mortality, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. Kallmes, 2015</td>
<td>793, 906</td>
<td>Multicenter, retrospective</td>
<td>FDS</td>
<td>—</td>
<td>0.5—13.5</td>
<td>7.8—23.1</td>
<td>5.8</td>
</tr>
<tr>
<td>F. Briganti, 2015</td>
<td>1482, 1704</td>
<td>Meta-analysis</td>
<td>FDS</td>
<td>81.5</td>
<td>—</td>
<td>3.5</td>
<td>3.4</td>
</tr>
<tr>
<td>W. Brinjikji, 2013</td>
<td>1451, 1654</td>
<td>Meta-analysis</td>
<td>FDS</td>
<td>74—76</td>
<td>2—6</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>N. McLaughlin, 2013</td>
<td>656, 702</td>
<td>Meta-analysis</td>
<td>Stent, coils</td>
<td>71.9, reoperations — 15.3%</td>
<td>5.3</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>S. Yakovlev, 2015</td>
<td>210, 220</td>
<td>Retrospective series</td>
<td>FDS</td>
<td>80</td>
<td>5.7</td>
<td>4.9</td>
<td>2.5—3.3</td>
</tr>
<tr>
<td>S. Arustamyan, 2015</td>
<td>37, 55</td>
<td>Retrospective series</td>
<td>Stent, coils</td>
<td>90</td>
<td>5.5</td>
<td>10.7</td>
<td>3.5</td>
</tr>
<tr>
<td>M. Park, 2016</td>
<td>70, 73</td>
<td>Retrospective series</td>
<td>Coils</td>
<td>87.8, reoperations — 23.1%</td>
<td>—</td>
<td>8.3</td>
<td>0</td>
</tr>
<tr>
<td>V. Lazarev, 1995 (revised)</td>
<td>212</td>
<td>Retrospective series</td>
<td>Deconstr. balloon, EICMA</td>
<td>82.9</td>
<td>22.7</td>
<td>—</td>
<td>4.1—13</td>
</tr>
<tr>
<td>B. Colli, 2013</td>
<td>95, 106</td>
<td>Retrospective series</td>
<td>Clipping</td>
<td>93.8</td>
<td>—</td>
<td>37.9</td>
<td>11.6</td>
</tr>
<tr>
<td>D. Fulkerson, 2009</td>
<td>134, 157</td>
<td>Retrospective series</td>
<td>Clipping with endovasc. IBA</td>
<td>79.5</td>
<td>12—35.3</td>
<td>5.7—12.5</td>
<td>1.1—17.6</td>
</tr>
<tr>
<td>Present series</td>
<td>260, 320</td>
<td>Retrospective series</td>
<td>Clipping with IBA</td>
<td>93.8</td>
<td>—</td>
<td>27.7</td>
<td>2.7</td>
</tr>
</tbody>
</table>
The authors of this article thoroughly covered the role and place of microsurgical treatment of large-sized (large and giant) aneurysms of the internal carotid artery (ICA), based on the experience accumulated at the Burdenko Neurosurgical Institute, which includes 260 patients treated during 15 years. Large and giant aneurysms of the ICA discussed in the article belong to the so-called “complex aneurysms”. Despite the rapid development of endovascular techniques, surgery of these aneurysms still remains one of the major problems of the vascular neurosurgery and always requires thorough preoperative preparation and individual approach to the choice of the methods of aneurysm exclusion from the circulation, including combined interventions.

Currently, there is no common classification of complex aneurysms, but a number of reputable neurosurgeons (L. Hacein-Bey [1], L. Sekhar [2], R. Hanel and R. Spetzler [3], N. Andaluz [4]) determined several parameters being the prognostic factors of technical difficulties both in microsurgical treatment and endovascular procedures. These parameters include the wide aneurysmal neck (dome-to-neck ration less than 1.5 or aneurysm neck diameter more than 4 mm) or lack of the aneurysmal neck (fusiform, fusiform-saccular, blister-like aneurysms), pronounced atherosclerotic changes in the neck, thrombosis of the aneurysmal cavity, functionally important arteries connected to the dome or neck of the aneurysm, dissecting aneurysms, giant aneurysms, aneurysm located at the cavernous or ophthalmic segment of the internal carotid artery, aneurysms of the vessels of the vertebrobasilar system, collateral circulation insufficiency, previous microsurgical or endovascular intervention in this aneurysm, cohesion of the aneurysmal sac with the surrounding nervous structures and bones of the skull base.

The article is of undoubted interest, since it is complex paraclinoid aneurysms of the ICA that are currently considered as primary candidates for endovascular treatment, while microsurgical interventions are used only in those aneurysms that can not be excluded from the circulation using stents and coils, which obviously pose certain technical difficulties, when manipulating with the aneurysm and increased risk of adverse outcome.

The article deals with the selection of surgical treatment based on assessment of collateral circulation as measured using various neuroimaging methods and balloon occlusion test. Particular attention is paid to the use of intravascular blood aspiration technique, which facilitates manipulation of large and giant ICA aneurysms. The algorithm for selecting the type of revascularization intervention (low-flow or high-flow bypass shunt) based on intraoperative flowmetric test is described in detail.

Although the first in Russia experience of revascularization interventions in these aneurysms was described in the early 1990s (F.A. Serbinenko, 1990 [5]), these operations (especially, high-flow bypass surgery), are not currently widespread in the Russian Federation despite their undoubted importance (V.I. Matveev, 2009 [6]; V.V. Krylov, 2011 [7]; V.V. Krylov, 2013 [8]; A.V. Duboboy 2014 [9]). Therefore, this article will be interesting to all neurosurgeons involved in surgery of cerebrovascular aneurysms.

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REFERENCES


Extracranial ICA aneurysms are a rare pathology. They account for 1—2% of all extracranial carotid artery lesions [1—4] and 0.8—4% of aneurysms of other peripheral vessels [5, 6]. In a Texas Heart Institute study involving 7,394 patients with aorta and peripheral artery aneurysms who were operated on at the center in the period from 1960 to 1995, 67 (0.9%) patients were diagnosed with ICA aneurysms [7]. A.V. Gavrilenko et al. [2] analyzed experience of surgical treatment in 1,836 patients and revealed extracranial ICA aneurysms in 31 (1.7%) patients.

According to most authors [8—10], the main causes for the development of carotid artery aneurysms are atherosclerosis, fibromuscular dysplasia, and traumatic arterial injury. Aneurysms of this location are primarily associated with the risk of ischemic cerebrovascular diseases (CVDs) such as TIA and ischemic stroke due to distal embolism from the aneurysm cavity. Arterio-arterial embolism in this pathology is a consequence of blood flow turbulence in the aneurysm cavity and removal of thrombotic masses from the aneurysmal sac. In addition, the aneurysm, as aneurysms of other locations, may be thrombosed [1, 11]. N. Winanslow who studied the natural course of carotid aneurysms in 124 patients (which were described before 1936) found that the mortality from thrombosis, distal embolism, and rupture in this pathology was 71%. According to R. Busuttil et al. [12], ischemic CVD episodes occurred in 50% of patients. Other authors [13, 14] reported that the CVD rate was 43—74%, with TIA occurring twice as often.

Given the risk of stroke and high mortality in this pathology, various surgical options were proposed. The main task of surgical treatment is prevention of thromboembolism. Since the first procedure performed by A. Cooper [7] in 1805, ligation of the vessel was the only surgical treatment. This surgery was accompanied by a major stroke or death in 20—40% of cases [14, 15]. At present, resection of an ICA aneurysm with replacement of the artery or end-to-end bypass is performed in most cases [1, 2, 4, 11, 14—16]. Reconstructive surgery reduces the rate of acute cerebrovascular disease (ACVD) and lethality to 4—10% [3, 9]. The greatest difficulties occur in surgery for distal ICA aneurysms. According to some authors [17, 18], distal extracranial ICA aneurysms develop in the case of pathological deformity of the carotid arteries due to severe dysplasia of the vascular wall. In many cases, aneurysms are complicated by the presence of thrombotic masses in the cavity of the aneurysmal sac. The literature [1, 11, 17, 18] describes single cases of open surgery for these lesions, but with aneurysms being located more proximally. The development of endovascular surgery in recent years has extended the capabilities of surgeons in choosing surgical options for treatment of ICA aneurysms. However, the literature [19—22] has reported single or small number cases of endovascular grafting for this pathology. The use of stent-grafts in the carotid arteries is associated with the risk of intima dissection and arterial thrombosis and may not always be technically implemented because of artery kinking. However, in recent years, there have been reports of the successful use of high-flow EC-IC bypasses in the treatment of complex intracranial ICA aneurysms [23]. Being experienced in such procedures, we used this technique in the treatment of distal extracranial ICA aneurysms.

The article describes the experience of successful surgical treatment of distal extracranial ICA aneurysms associated with pathological kinking of the artery.
Material and Methods

In 2015, 3 patients diagnosed with pathological ICA kinking and a saccular aneurysm in the distal C1 segment underwent surgery at the Department of Vascular Neurosurgery of the Novosibirsk Federal Center of Neurosurgery. All patients were aged 62—63 years. In medical history of all patients, there were signs of cerebrovascular disease in the MCA territory on the side of an affected ICA: ischemic stroke in 2 cases and repeated TIAs in 1 case. The patients underwent osteoplastic craniotomy, creation of a high-flow extracranial bypass between the ECA and M2 MCA segment, and proximal ligation of the C1 segment of the ICA.

When choosing a surgical treatment option, we considered, along with common clinical examination data, the data of duplex scanning of the brachiocephalic arteries (DS BCA), transcranial dopplerography (TCDG), multislice computed tomography angiography (MSCT angiography), and magnetic resonance imaging (MRI) of the brain. According to the DS BCA data, all patients were diagnosed with ICA deformity in the form of pathological tortuosity of various types, with the linear velocity of blood flow (LVBF) of 150 to 230 cm/s. According to the ultrasound data, aneurysmal enlargement was found only in 1 case. More complete information was obtained by MSCT angiography of the extra- and intracranial arteries, which revealed pathological kinking of varying severity in the distal ICA in all cases. In 2 cases, saccular aneurysms of 8 and 12 mm in size, with partial thrombosis of the aneurysmal sac, were detected at the atlantoaxial joint level (Fig. 1).

In 1 case, the site of an intimal tear with fusiform enlargement of the distal ICA was found above an aneurysm.

Operations were performed under general anesthesia. At the first stage, the common carotid artery (CCA) bifurcation was isolated using a standard approach. Simultaneously, radial artery harvesting was performed. The mean bypass length was 22.5 cm. The proximal segment diameter was 2.5 to 3.4 mm, and the distal segment diameter was 2.1 to 3.1 mm. After craniotomy, the M2 MCA segment was isolated, and temporary clips were applied to it. Then, a longitudinal arteriotomy of the M2 MCA segment and a distal end-to-side anastomosis with the distal radial artery were performed (Fig. 2). Clips were removed from the MCA. The mean time of MCA occlusion ranged from 35 to 44 min. The bypass was passed through a preauricular subcutaneous tunnel or under the zygomatic arch to a wound on the neck.

After ECA occlusion, a proximal end-to-side anastomosis was performed between the initial portion of the ECA and the graft (Fig. 3). After removal of clamps, blood flow in the graft and MCA was monitored using dopplerography, flowmetry, and indocyanine green angiography.
green videoangiography (ICG-VA), with temporary occlusion of the ICA in the ostial region (Fig. 4). If adequate blood flow in the intracranial arteries was preserved, the ICA was ligated in the ostial region, and operative wounds were sutured. All patients underwent MSCT angiography of the extra- and intracranial vessels on the 1st postoperative day (Fig. 5). In the immediate hours after surgery, the extracranial ICA was thrombosed up to the level of the ophthalmic artery origin, without development of neurologic symptoms (Fig. 6).

There were no surgical complications. Patients were discharged in a satisfactory condition on the 8th—10th day after surgery; they were recommended antiplatelet therapy. On follow-up examination at 3, 6, and 9 months, all patients were in satisfactory condition, without worsening of the neurological status. According to control DS BCA and MSCT angiography, bypass patency was preserved in all cases.

**Discussion**

Many authors have indicated that extracranial ICA aneurysms should be operated regardless of the presence of symptoms [2, 17]. The greatest difficulties arise in surgery for distal ICA aneurysms associated with pathological kinking of the artery. In patients of our small series, aneurysms were located close to the entrance to the skull. Based on our own experience with endovascular and open surgery for extracranial ICA aneurysms [24], we considered it rational to refuse conventional surgery and apply another surgical treatment. When reviewing the literature, we found no data on high-flow EC-IC bypass surgery in patients with distal ICA aneurysms associated with pathological kinking. There are reports on the use of this surgery for treatment of complex cerebral aneurysms [23, 25]. We extrapolated the well-proven technique used for treatment of complex intracranial aneurysms to patients with distal extracranial ICA aneurysms. We consider this surgery to be less traumatic and safer for the patient because it avoids a complex approach to an altered site of the artery, including transection of the sternocleidomastoid muscle and posterior belly of the digastric muscle, resection of the styloid process, and displacement of the mandible. Modifications of the approach to the distal ICA, which are described in the literature, are also very traumatic. For example, to access skull base aneurysms, E. Rosset et al. [3] used opening of the external auditory canal, resection of the styloid process, and resection of the mastoid process. U. Fish et al. [26] described an approach to the ICA siphon by subtotal petrosectomy, a forward displacement of the facial nerve, and obliteration of the middle ear cavity. However, this case was accompanied by a high rate of complications, primarily injury to the cranial nerves. Our surgical technique is not routine. This surgery should be performed by surgeons with appropriate
experience. Also, careful selection of patients and an analysis of the capabilities of alternative treatment techniques are required. Our experience demonstrates that volumetric blood flow through bypass (up to 250 mL/min according to flowmetry) provides adequate blood supply to the brain after surgery. The results of our operations and the absence of neurological and local complications confirmed the correct choice of surgical treatment in these patients.

**Conclusion**

The use of high-flow EC-IC bypass surgery for treatment of patients with distal extracranial ICA aneurysms associated with pathological kinking of the artery is an alternative to existing surgical treatments. Despite its technical complexity, it avoids the complications typical of endovascular and open surgery. Further research and implementation of this procedure to practice will extend the capabilities of surgeons in the treatment of various pathologies of extra- and intracranial vessels.

Authors declare no conflict of interest.

**REFERENCES**


The authors set the goal to use one of the surgical interventions for distal extracranial internal carotid artery aneurysms, namely the creation of an extra-anatomic high-flow vascular anastomosis between the external carotid artery and the M2 segment of the middle cerebral artery.

Indeed, false extracranial ICA aneurysms are a rare pathology. As evidenced in the literature, they are associated with the risk of cerebral microembolism, which makes the problem challenging.

According to the literature, ligation of extracranial ICA aneurysms is one of the most common mentioned techniques of surgical treatment, along with resection of aneurysms with subsequent reconstruction of the artery as well as endovascular placement of stents.

The authors describe technical difficulties associated with surgical correction of distal extracranial ICA aneurysms during both direct surgery with resection of the artery and endovascular stenting, especially in the case of an ICA aneurysm associated with pathological deformity of the artery.

The Material and Methods section describes the results of surgical treatment of 3 patients at the Novosibirsk Federal Center of Neurosurgery. The authors indicate a low informative value of ultrasound in the diagnosis of distal aneurysms and a high informative value of MSCT. They describe the technique for placing an extracranial-intracranial vascular anastomosis, with a follow-up period of 9 months.

The main goal of treatment of extracranial internal carotid artery aneurysms is to prevent thromboembolic complications. Flow-replacement bypass surgery is a rather traumatic procedure associated with a high percentage of complications in the postoperative period. When developing indications for this surgery, particular attention should be paid to assessing the system of collateral brain circulation, up to performing test endovascular balloon occlusion of the ICA. Gross ICA deformity associated with a distal extracranial ICA aneurysm has developed for many years, and during this time, the collateral brain system has usually adapted to reduced blood flow in the altered ICA. The exceptions are different forms of an open circle of Willis. In the case of a well developed collateral system, flow-replacement bypasses can be thrombosed in the long-term postoperative period. The classic variant of an EC-IC bypass (between a branch of the temporal artery and the cortical branches of the MCA), including a double one, should not be disregarded. The procedure, being less invasive, may have a compensatory effect on brain hemodynamics in the case of subcompensated collateral circulation.

In the description of a sufficiently short follow-up (9 months), the authors do not provide the parameters for bypass functioning in the postoperative period (volumetric blood flow through the bypass), which complicates assessment of the bypass efficacy.

In general, the article by V.E. Guzhin and co-authors is of great interest for neurosurgeons dealing with pathology of the major cerebral arteries, demonstrating the successful use of flow-replacement extracranial-intracranial bypasses. However, it should be remembered that these procedures should have strict indications and be performed by neurosurgeons with sufficient experience in this surgery.

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Perfusion Criteria of EICMA Efficacy in Patients with Symptomatic Occlusion of the Internal Carotid Artery

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Burdenko Neurosurgical Institute, Moscow, Russia

Objective. The study is aimed at investigating changes in cerebral perfusion in patients with unilateral internal carotid artery occlusion before and after surgical revascularization of the brain, depending on the clinical efficacy of surgical treatment. Material and methods. The study included 60 patients with unilateral ICA occlusions, who underwent formation of an extra-intracranial microvascular anastomosis (EICMA). All patients were subjected to CT perfusion study before and after cerebral revascularization. Additionally, the degree of neurological deficit was evaluated before surgery and during follow-up period (3 and 8—10 months) using the NIHSS score. Results. All patients were divided into 3 groups, depending on the outcome of surgical treatment: objective improvement (43 patients), no changes (14 patients), and worsening of clinical symptoms (3 patients). In each group, absolute and relative perfusion parameters (MTT, CBV, and CBF) were analyzed to identify the perfusion criteria of the efficacy of EICMA. Significant relationship between clinical efficacy of EICMA and baseline perfusion deficit and its change after formation of anastomosis was found. Conclusion. Formation of EICMA is an effective treatment for patients with symptomatic ICA occlusion and increased blood transit time in the hemisphere ipsilateral to occlusion by more than 40% compared to that on the opposite side provided that perfusion is recovered in more than one region of the MCA territory (as assessed on the ASPECTS scale).

Keywords: cerebral ischemia, ICA occlusion, CT perfusion, revascularization.

Surgical formation of extra-intracranial microvascular anastomosis (EICMA) was included in the repertoire of vascular neurosurgery in 1968, but its role in the treatment of patients with chronic cerebral ischemia caused by arterial occlusion in the carotid territory is still disputable. It is difficult to predict the outcome of surgical revascularization of the brain and, and therefore there are no clear indications to this operation, which is one of the reasons for mixed attitude to this operation. Analysis of the outcomes of EICMA surgery performed at Burdenko Neurosurgical Institute over the past 15 years (404 operation) demonstrated objective improvement in the postoperative neurological status in an average of 53% of cases [1]. Furthermore, criteria that should be considered to improve the efficacy of EICMA surgery in patients with the consequences of complete ischemic stroke have been identified; patient’s age, the nature of the clinical course of chronic cerebral ischemia, time elapsed since the development of circulatory disorders, and hemodynamic efficacy of EICMA are the most important of them [1]. Changes in the cerebral hemodynamics is one of the most important factors determining the prognosis of symptomatic arterial occlusion in the carotid territory [2]. Clinical implementation of available modern methods to assess cerebral perfusion enables more detailed investigation of preoperative and postoperative changes in the cerebral blood flow and thereby clarifies the role of hemodynamic factors in predicting the efficacy of EICMA [3, 4].

This article focus on the analysis of cerebral perfusion changes in patients before and after surgical revascularization of the brain in order to identify perfusion-related criteria of the effectiveness of this operation.

Material and methods

The study included 60 patients with unilateral symptomatic arterial occlusion in the carotid territory, who underwent EICMA surgery on the side of occlusion. The age of patients ranged from 27 to 67 years, averaging 51.3 years.

In most patients, clinical presentation included the consequences of ischemic stroke on the side of internal carotid artery (ICA) occlusion (2.16±0.67 on the Rankine scale), a total of 53 (87%) patients. Transient neurologic symptoms in the form of frequent transient ischemic attacks (TIAs) or small ischemic stroke were detected in 7 (13%) patients.

All patients underwent duplex scanning of the brachycephalic arteries (Philips SONOS 5000) verified using spiral computed tomography angiography (SCT angiography) (GE Healthcare) in order to confirm arterial occlusion in the carotid territory. In most cases (55 patients), chronic cerebral ischemia was caused by ICA occlusion. Five patients were diagnosed with occlusion of the middle cerebral artery (MCA). Along with the damaged arterial territory, we also assessed all brachycephalic and major cerebral arteries. The study included patients with only one damaged carotid territory and without hemodynamically significant changes in the territory of the contralateral ICA and vertebral arteries.

The severity of cerebrovascular insufficiency was assessed by initial complex neurosonologic examination, including the assessment of the linear blood flow velocity (BFV) in the MCA, blood flow direction in the opthalmic artery, and calculation of cerebrovascular reactivity index during hypercapnic test (ratio of the BFV
in the MCA during breath holding for more than 20 seconds to the baseline BFV value).

Decision on surgical revascularization of the brain was made on the basis of known ultrasonic criteria of cerebrovascular insufficiency, such as decreased BFV distal to occlusion by more than 50% compared to the contralateral side, decrease in reactivity index to less than 1.2 units in combination with signs of the retrograde blood flow in the ophthalmic artery (functioning carotid-ophthalmic anastomosis) [5—7].

Spiral CT perfusion study was the main method to evaluate blood flow, which was used in all 60 patients preoperatively and on the 7th day after EICMA surgery (a total of 120 CT perfusion studies were performed). The studies were carried out on GE Healthcare multislice computed tomograph. At the first stage, all patients underwent plain CT scan in order to assess morphological changes in the brain and detect ischemic lesions followed by CT perfusion study using a standard protocol [8, 9] with underlying intravenous injection of 40—60 ml of contrast agent (Ultravist, 300 mg/ml), depending on patient’s age and weight. Scanning was performed for 4 or 8 consecutive sliced at the subcortical nuclei level, 3 cm above the clinoid plate. Cerebral perfusion data were processed using GE Advantage Workstation with integrated software. Perfusion maps were calculated according to standard procedure based on numerical algorithms of deconvolution analysis (singular value decomposition, SVD). Arterial inflow function (AIF) required for calculation of perfusion parameter was determined by selecting the region of interest (ROI) on dynamic CT scans, which was no more than 3.5 pixels in diameter (Fig. 1a). Venous outflow function (VOF) was determined in the projection in the posterior third of the sagittal sinus.

Processing of raw data of dynamic CT produced perfusion maps with quantitative values of regional cerebral blood flow (CBF), mean cerebral blood volume (CBV), and mean transit time (MTT) calculated per 100 g of the brain matter.

Perfusion parameters in the medial cerebral artery territory were assessed on two axial slices: the first one at the level of the basal ganglia and thalamus, the second one at the level of the lateral ventricles above the basal ganglia. The entire area of blood supply to the MCA was divided into 10 conventional zones: 6 cortical areas, M1—M6 (anterior, medial, and posterior parts of the MCA territory in each slice), the insular area (M7), and 3 areas in the projection of the basal ganglia: the caudate nucleus (M8), lenticular nucleus (M9), and internal capsule (M10). This zonation of the MCA territory corresponded to the conventional radiographic ASPECTS scale (Alberta Stroke Program Early CT Scoring). Small-sized regions of interest (ROI) were selected, having an average area of 45.6±3.8 mm² without the inclusion of large vessels (see Fig. 1b). Additionally, we assessed the averaged blood flow parameters for the whole hemisphere, excluding the ventricular system of the brain and ischemic lesions that are not subject to revascularization (see Fig. 1c).

The severity of cerebrovascular insufficiency was assessed based on the intensity of interhemispheric asymmetry of perfusion parameters. MTT, CBV, and CBF values varied considerably within different regions of the hemisphere. Along with absolute values, relative values were also calculated as the ratio of the parameter values on the side of occlusion to the values on the contralateral (intact) side in order to provide more objective assessment of the level of interhemispheric asymmetry.

All patients underwent detailed neurological and neuropsychological examination both before the operation and during the postoperative follow-up period (7 days, 3 months, 6—8 months) in order to assess neurological deficit. NIHSS scale was used for objectification of the severity of neurological deficit (maximum deficit corresponds to 55 points).

Surgical formation of the EICMA between one of the branches of the superficial temporal artery and cortical branch of the MCA (M4 segment) on the side of occlusion was conducted according to standard procedures. Anastomosis function was monitored using duplex scanning on the 7th day after operation and during the follow-up period. Additionally, the value of the blood flow through the EICMA was recorded using the flowmetry mode as implemented in ultrasonic scanner. In all cases, created anastomoses were visualized during follow-up period; the average blood flow was 37.8±17.43 ml/min (95% CI 23.2—59.2).

Statistical processing was carried out using IBM SPSS 13.0 software package with parametric (Student’s t-test) and nonparametric (Mann-Whitney, Kruskal-Wallis test) methods.

Results

All patients had characteristic preoperative changes in cerebral perfusion on the side of occlusion. MTT was the most sensitive perfusion parameter to detect cerebral ischemia, which reflected the degree of blood flow slowing down first of all at the microvasculature level. Patients demonstrated hemispheric asymmetry of MTT values, which were higher on the side of ICA or MCA occlusion. Absolute MTT values on the side of occluded varied between 4.5 and 14.7, which resulted in hemispheric average of 7.84±1.25 s. In the opposite (intact) hemisphere, mean MTT value was 5.31±0.95 s (3.32 to 6.78 s) (Table 1). These data were indicative of delayed tissue blood flow in the territory of occluded ICA by 47% compared to the contralateral hemisphere.

CBV characterizes blood stream volume (per 100 g of tissue). In most cases (51 patients, 87%), analysis of absolute values revealed increase in CBV values on the
side of occlusion. The average CBV value on the side of occlusion was 2.36±0.35 ml per 100 g of the brain matter, which is 18% higher than on the contralateral side (2.05±0.22 ml per 100 g). Increase in vascular volume on the side of occlusion was indirectly indicative of the decrease in cerebrovascular reserves at the preoperative stage and was an indication for surgical revascularization of the brain.

Decrease in CBF values was observed in almost all regions of the ipsilateral hemisphere. Hemispheric average CBF values on the ipsilateral side varied from 16.1 to 32.6 ml/min per 100 g of brain matter, averaging 29.8±2.75 ml/min per 100 g. Blood flow in the intact hemisphere varied from 22.3 to 46.7 ml/min per 100 g, averaging 34.91±3.32 ml/min per 100 g.

As opposed to absolute parameters, relative perfusion parameters rMTT, rCBV, rCBF were characterized by smaller dispersion, which enabled us to detect statistically significant interhemispheric asymmetry of blood transit time (p<0.039; Student’s t-test), vascular volume, and regional tissue blood flow (p<0.05; Student’s t-test).

All examined patients were divided into three groups, depending on the outcome of surgical revascularization of the brain in order to select perfusion criteria of the efficacy of EICMA surgery. The first group included 43 (72%) patients with objective signs of neurological deficits improvement by more than 2 points as assessed on the NIHSS scale and with complete regression of transient neurologic symptoms. In 14 (43%) patients, there was no strong evidence of the dynamics of neurological status, or there were only subjective symptoms, such as improved well-being (no more than 2 points on the NIHSS scale), these patients were included in the second group. Third group included 3 (5%) patients with worsening of neurological symptoms due to perioperative ischemic complications. All three groups were significantly different in the dynamics of neurological deficit (Kruskal-Wallis test; p<0.05).

The group of patients with clinical improvement after surgical revascularization of the brain (group 1) was of greatest interest. The analysis of perfusion parameters in group 1 patients demonstrated pronounced increase in the mean MTT value on the side of the occlusion, which averaged 7.17±1.09 s. The relative rMTT value averaged 1.57±0.16, which is indicative of the interhemispheric asymmetry of MTT of more than 40% (increased blood transit time on the side of occlusion, as compared to the contralateral side). In patients who had no effect of EICMA surgery (group 2), the rMTT value averaged 1.26±0.13, i.e., the difference did not exceed 40%, as compared to the contralateral hemisphere (Fig. 2a). This difference was statistically significant (Mann-Whitney test; p<0.05).

The highest asymmetry of CBV parameter was another statistically significant difference of group 1 patients: the average relative rCBV value was 1.28±0.07 (increase on the side of occlusion was higher than 20%). These changes are indicative of more pronounced participation of the autoregulation mechanisms in cerebral blood flow compensation and, as a consequence, a greater reduction of cerebrovascular reserves (see Fig. 2b). In group 1 patients, compensatory increase in CBV, especially in the cortical regions and in the projection of the Sylvian fissure, substantially leveled blood flow delay in the territory of the occluded artery, which resulted in the greatest decrease in hemispheric blood flow: rCBF value was 0.79±0.91 ml/min per 100 g of brain matter (reduced by 21% as compared to the contralateral hemisphere). At the same time, there is considerable dispersion of rCBF values within the hemisphere: in the white matter, especially in the projection of the anterior and posterior adjacent circulation areas, decrease in the regional blood flow on
Hemodynamic significance of the formed anastomotic and its ability to restore the blood flow in the area of impaired perfusion was another important factor that affected the efficacy of EICMA surgery.

The analysis of the result of control perfusion studies has shown that surgical outcomes depended on the degree of perfusion parameters recovery (Table 2). Thus, the most significant recovery of the tissue blood flow on the revascularization side, on the average, from 27.5±2.7 to 31.6 ml/min per 100 g of the brain matter (an increase by 14%), was observed in group 1.

Additionally, increase in blood flow by an average of 3% was detected on the contralateral side. This observation could reflect the adjustment of the cerebral
hemodynamics and decrease in interhemispheric steal from the intact hemisphere on account of territory of the occluded artery.

Increase in CBF was accompanied by decrease in MTT both on the side of occlusion (1.73±0.97 s) and the contralateral side (0.78±0.54 s).

It should be noted that reliable regression of MTT asymmetry MTT (p<0.05, paired Student t-test) was obtained only in group 1 patients. Postoperative increase in CBV, mainly on the operated side, was also observed (see Table 2).

The most significant dynamics was observed in the projection of the central gyrus of the MCA territory and adjacent circulation areas. Lower perfusion recovery in these areas as compared to the cerebral cortex can be explained by greater distance to the anastomosis region and lower vascularization. Characteristic change in cerebral perfusion parameters after EICMA surgery is shown in Fig. 3.

Recovered perfusion value that averaged 1.27±0.33 areas of the MCA territory, as assessed on the ASPECTS scale, and significantly differed in the analysed groups (p<0.039; Kruskal-Wallis test) was the most statistically significant factor, influencing the efficacy of surgical revascularization. The degree of cerebral perfusion recovery, in turn, depended on both the hemodynamic efficacy of created EICMA and the initial perfusion deficit (Fig. 4a). Regression analysis showed a high correlation (r²=0.731, p<0.05, Pearson’s test) between the dynamics of recovery of normal perfusion zones in the MCA territory (ASPECTS) and blood flow volume (see Fig. 4b). It is noteworthy that cerebral perfusion began to change, when EICMA blood flow was 20 ml/min. Blood flow through anastomosis of more than 30 ml/min usually resulted in perfusion recovery in one area of the MCA territory. Regression in more than 3 hypovolemic areas in the MCA territory was observed in the case of well-functioning EICMA with blood flow of 50—60 ml/min. This additional flow through anastomosis was usually sufficient for complete recovery of cerebral perfusion parameters on the side of occlusion.

In 7 cases, control spiral CT perfusion study showed no significant recovery of cerebral perfusion, 0—1 points on the ASPECTS scale. Typically, these patients had only local MTT reduction within the range of 5—10% along with slight increase in SBV in richly vascularized areas of the medial cerebral artery (see Table 2). However, there were no conclusive data on normalization of perfusion parameters below the thresholds in these areas.

After EICMA surgery, recovery of an average of 1.27±0.33 areas of the MCA territory was observed in the analyzed group of patients as assessed on the ASPECTS scale. The average value of the blood flow through the EICMA was 37.8±17.43 ml/min. Therefore, at least 24 ml/min is required for revascularization of one area of the MCA territory. In particular, anastomoses having blood flow of 50 ml/min provided retrograde filling of the MCA territory up to M2 segment, and thereby completely compensated for perfusion deficit in the territory of occluded MCA or ICA.

Therefore, restoration of cerebral perfusion in at least one area of the MCA territory (as assessed on the ASPECTS scale) may be considered as a perfusion criterion of hemodynamic significance of EICMA. This criterion is entirely consistent with previously formulated views about the hemodynamic significance of anastomosis based on angiographic signs of retrograde filling of the MCA territory [5].

**Discussion**

The correct evaluation of changes in cerebral blood flow in patients with unilateral symptomatic occlusion of the carotid artery plays a key role in selecting the optimal

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Fig. 2. Perfusion deficit in a patient with occlusion of the right (D) ICA (group 1).

a — MTT (asymmetry of more than 1.46); b — CBV (asymmetry of 1.36); c — CBF (slight asymmetry, 0.91). Symptoms of cerebral blood flow subcompensation are noticeable mostly in the white matter and the posterior adjacent circulation region.
Treatment strategy for chronic cerebral ischemia. Clinical implementation of modern methods to study cerebral perfusion parameters (CT, MRI) enabled more detailed study of cerebral circulation in candidates for surgical revascularization of the brain. In particular, it is currently possible to assess not only hemispherical, but also local changes in tissue blood flow in the cortex and white matter of the brain and to determine the size of hypoperfusion area and its severity. The high sensitivity and specificity of these techniques in detecting changes characteristic of acute stroke (Wintermark, 2004) was shown. However, no uniform criteria for evaluation of perfusion changes in patients with chronic cerebral ischemia and consequences of previous ischemic stroke have been elaborated until now. In this work, we analysed cerebral perfusion parameters depending on the outcome of surgical revascularization of the brain in 60 patients with unilateral carotid artery occlusion in different terms after cerebrovascular accident.

Despite the fact that cerebral blood flow (CBF) was decreased on the side of occlusion in all patients in combination with increase in mean transit time (MTT) and circulatory bed volume (CBV), large dispersion of the absolute values of perfusion parameters hindered correct diagnosis of the severity of cerebrovascular insufficiency. Evaluation of interhemispheric asymmetry calculated based on the relative perfusion parameters in the form of the ratio of their values on the side of occlusion to the values on the contralateral side was more informative. This approach leveled methodological and individual errors of perfusion measurement, and thereby significant asymmetry of MTT and CBV parameters was found (Mann-Whitney test; \( p < 0.037 \)). A similar approach was used when interpreting the data of positron emission tomography within COSS study, wherein the relative parameters of perfusion and metabolism have been found to be the most reproducible and informative in the diagnosis of cerebrovascular insufficiency [2].

Preoperative cerebral perfusion study enabled predicting the effectiveness of EICMA operation. Thus, pronounced improvement in the clinical symptoms after EICMA surgery was associated with the initially increased MTT in the affected hemisphere by more than 40% as compared to the contralateral hemisphere (\( r_{MTT} = 1.56 \pm 0.15 \)), which was significantly higher than in the group of patients with no clinical response to the surgery. Furthermore, higher CBV values were observed on the side of occlusion, which in turn indicated greater involvement of autoregulation mechanisms and decrease in cerebrovascular reserves.

When analyzing perfusion maps, it becomes apparent that the value of decrease in hemispheric CBF have no significant effect on the surgical outcomes. This can be explained by heterogeneity of perfusion changes in the

<table>
<thead>
<tr>
<th>Table 2. The dynamics of the absolute and relative interhemispheric perfusion parameters in patients after surgical revascularization of the brain</th>
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<tbody>
<tr>
<td><strong>Perfusion parameter</strong></td>
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<tr>
<td>MTT dynamics, s:</td>
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<tr>
<td>Occlusion side</td>
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<td>Contralateral side</td>
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<td>CBV dynamics, ml per 100 g</td>
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<td>Occlusion side</td>
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<td>Contralateral side</td>
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<td>CBF dynamics, ml/min per 100 g</td>
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<td>Occlusion side</td>
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<td>Contralateral side</td>
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**Dynamic of the relative parameters**

\( r_{MTT}^1 \)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>Postoperative</th>
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</thead>
<tbody>
<tr>
<td>Occlusion side</td>
<td>(1.48 \pm 0.11)</td>
<td>(1.31 \pm 0.13)</td>
<td>(1.64 \pm 0.21)</td>
<td>(&lt;0.05^1)</td>
<td></td>
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<tr>
<td>Contralateral side</td>
<td>(1.25 \pm 0.07)</td>
<td>(1.24 \pm 0.11)</td>
<td>(1.78 \pm 0.24)</td>
<td></td>
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</tr>
<tr>
<td>( r_{CBV} )</td>
<td></td>
<td></td>
<td>n/s</td>
<td></td>
<td></td>
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<tr>
<td>Occlusion side</td>
<td>(1.21 \pm 0.08)</td>
<td>(1.11 \pm 0.05)</td>
<td>(1.26 \pm 0.07)</td>
<td></td>
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</tr>
<tr>
<td>Contralateral side</td>
<td>(1.29 \pm 0.12)</td>
<td>(1.17 \pm 0.07)</td>
<td>(1.11 \pm 0.1)</td>
<td></td>
<td></td>
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<tr>
<td>( r_{CBF} )</td>
<td></td>
<td></td>
<td>n/s</td>
<td></td>
<td></td>
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<tr>
<td>Occlusion side</td>
<td>(0.79 \pm 0.06)</td>
<td>(0.89 \pm 0.09)</td>
<td>(0.77 \pm 0.06)</td>
<td></td>
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<tr>
<td>Contralateral side</td>
<td>(0.85 \pm 0.04)</td>
<td>(0.91 \pm 0.06)</td>
<td>(0.62 \pm 0.08)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perfusion recovery (ASPECTS)</td>
<td>(2.24 \pm 0.49)</td>
<td>(0.85 \pm 0.23)</td>
<td>(-1.62 \pm 0.47)</td>
<td>(&lt;0.039^2)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>(42 (72%))</td>
<td>(14 (23%))</td>
<td>(3 (5%))</td>
<td></td>
<td>60</td>
</tr>
</tbody>
</table>

**Footnote.** ¹ — pair-wise comparison of preoperative and postoperative \( r_{MTT} \) parameters (paired Student’s t-test); ² — differences in parameters in the groups according to Kruskal-Wallis test; n/s — statistically nonsignificant difference.
hemisphere on the side of occlusion, especially in patients with consequences of complete ischemic stroke. In these cases, local areas of pronounced hypoperfusion were detected mostly in the white matter and adjacent circulation areas, which were leveled by enhanced compensated blood flow in the cortical regions and territories of the anterior and posterior cerebral arteries. Given the moderate asymmetry of hemispheric blood flow, this perfusion deficit was closest to stage I cerebrovascular insufficiency according to Baron [12—14], but non-uniformity of cerebral perfusion within the affected hemisphere in patients with

Fig. 3. The dynamics of perfusion parameters (MTT, CBV, and CBF) before (a) and after (b) EICMA surgery on the left (S) — cerebral hypoperfusion regression of more than 5 points on the ASPECTS scale in the revascularization territory (the area of recovered perfusion in the territory with created EICMA).

Fig. 4. a — distribution of ASPECTS parameters recovery; b — correlation between the blood flow value through EICMA and the number of recovered areas as assesses on the ASPECTS.
show that cerebral blood flow restores as early as on the period (more than 6 months after the operation), can of cerebral perfusion parameters in the late postoperative revascularization of the brain, leading to the restoration functionally important regions of the brain. Surgical rehabilitation after recovery of cerebral blood flow in neurological deficit and improved prognosis of hypoperfusion (ischemic penumbra).

functional (neurological) deficit not so much with consequences based on the modern paradigm, associating approach to the treatment of ischemic stroke morphologically intact brain regions reflects a new on detection of areas with long-standing hypovolemia in degeneration [17—20].

Determining indications for EICMA surgery based on detection of areas with long-standing hypovolemia in morphologically intact brain regions reflects a new approach to the treatment of ischemic stroke consequences based on the modern paradigm, associating functional (neurological) deficit due to inhibition of conduction pathways and development of diaschisis [8, 14]. Such conditions are abnormal, because they can lead to selective necrosis of neurons and a progressive cerebral degeneration [17—20].

The literature [18, 20—22] reports cases of regressed neurological deficit and improved prognosis of rehabilitation after recovery of cerebral blood flow in functionally important regions of the brain. Surgical revascularization of the brain, leading to the restoration of cerebral perfusion parameters in the late postoperative period (more than 6 months after the operation), can play a significant role in this process [23]. Our results show that cerebral blood flow restores as early as on the 7th day after EICMA surgery, and there is significant relationship between the clinical efficacy of the operation and the size of the restored perfusion area. Thus, the highest clinical efficacy of EICMA was observed in cases with timely restored perfusion in more than one area of the MCA territory (on the average, 2.24±0.49 ASPECTS areas). This fact confirmed contribution of anastomosis in the process of lost function recovery in patients with ischemic stroke consequences and therefore much attention should be paid to the quality of created anastomosis and its flow capacity.

Revascularization of less than one MCA area was not accompanied by positive dynamics of clinical symptoms (on the average, 0.9 areas as assessed on the ASPECTS scale). Typically, this was associated with low hemodynamic significance of created EICMA and the initial changes in cerebral perfusion characteristic of chronic oligemia stage (MTT asymmetry less than 40%). It is noteworthy that significant perfusion deficit was detected only in 1.23±0.51 morphologically intact areas of MCA territory in this group of patients, which initially reflected low need for additional revascularization. In these cases, created anastomosis to a greater degree substituted for the existing collateral circulation paths and did not lead to changes in cerebral perfusion even despite high values of the blood flow through the EICMA.

In the analyzed group of patients, signs of cerebral blood flow decompensation included increased hemispheric blood transit time on the side of occlusion by more than 80% compared to the contralateral side in combination with unstable clinical course of cerebral ischemia. These criteria most closely reflect the state of “starvation perfusion” (grade I cerebrovascular insufficiency according to J.C. Baron). In this group of patients, EICMA surgery was highly effective in preventing the development of hemispheric ischemic stroke, which enabled us to achieve stable regression of transient neurological symptoms in 72% of cases. At the same time, we should take into account high perioperative risks (25%), and therefore it is advisable to perform preoperative differential diagnosis with developing ischemic stroke, when conservative treatment is the method of choice.

Therefore, the use of the aforementioned perfusion criteria in clinical practice enabled identifying patients, in whom surgical revascularization of the brain lead to regression of neurological deficit in 72% of cases. This value is significantly higher than in patients selected for surgical treatment based on just ultrasonic criteria of cerebrovascular insufficiency, where postoperative improvement of clinical symptoms was observed only in 53% of cases [1]. The revealed relationship between outcomes of EICMA surgery and cerebral perfusion recovery provides a fresh look at the role of the EICMA in the treatment of chronic cerebral ischemia caused by arterial occlusion in the carotid territory, especially in patients with consequences of complete ischemic stroke.

Conclusions

The use of SCT perfusion examination enables more correct selection of candidates for surgical revascularization of the brain and thereby improves its clinical effectiveness. EICMA operation is effective in patients with consequences of ischemic stroke and ineffective rehabilitation, when there is long-standing oligemia in morphologically intact adjacent circulation regions with interhemispheric MTT asymmetry of more than 40%. In patients with unstable clinical course and increased mean transit time (MTT) on the side of occlusion by more than 80%, surgical revascularization leads to improvement of neurological symptoms, but it is associated with high perioperative risk of ischemic complications. The effectiveness of EICMA surgery depends on the size of the restored perfusion region (more than one area as assessed on the ASPECTS scale), especially in functionally important areas of the brain.

Authors declare no conflict of interest.
Despite the significant progress in the fundamental and applied research in the field of cerebrovascular diseases at the turn of XX and XXI centuries, acute cerebrovascular accidents (ACA) still remain the most important medical and social problem in all developed countries all over the world. Moreover, unprecedented increase in the number of elderly people in the general population of the Earth places cerebrovascular accident among the leading causes of death. In Russia, mortality rate in the acute phase of stroke is up to 3.5% and increases by almost 15% by the end of the first year of the disease. Post-stroke disability ranks first among all possible causes of disability. Only about 20% of patients who had a stroke can return to previous job, despite the fact that 1/3 of patients belong to socially active age group.

Since ischemic CVDs account for the vast majority of all cerebrovascular diseases and ischemic stroke is 4 times more frequent than hemorrhagic one, the development of methods to protect the brain from focal ischemia, reduce cerebral infarction size, and improve the outcome of ischemic stroke become the research priorities in modern angioneurology, neurosurgery, and vascular surgery.

The relevance and significance of this problem is not in doubt. The objective of the study is formulated clearly and concisely: to determine the effectiveness criteria of surgical revascularization of the brain based on cerebral perfusion CT in patients with unilateral major cerebral artery occlusive diseases: comparison with cerebrovascular reactivity to acetazolamide and cerebral blood flow SPECT imaging for detecting ischemic perfusion in patients with unilateral major cerebral artery occlusive diseases; comparison with cerebrovascular reactivity to acetazolamide and cerebral blood flow SPECT imaging. Clin Nucl Med. 2012;37:3:235-240.

this regard, selecting perfusion criteria of the effectiveness of this operation is extremely important.

The authors selected SCT perfusion study with perfusion maps recording with quantitative values of the cerebral blood flow (CBF), the average cerebral blood volume (CBV), and mean transit time (MTT) calculated per 100 g of the brain matter as the primary method to assess the cerebral blood flow. This approach is fully justified: it is several orders of magnitude less costly and energy-intensive compared to positron tomography. In addition, such a study is available in almost all large medical hospitals equipped with computed tomography.

The authors have substantiated the fact that MTT is the most sensitive parameter for detection of cerebral ischemia, which reflects the slowing of the blood flow at the microvasculature level. Furthermore, the study proved that the relative perfusion parameters rMTT, rCBV, and rCBF have lower dispersion compared to absolute values. This fact, in turn, enabled detecting statistically significant interhemispheric asymmetry of the mean transit time, vasculature volume, and regional tissue blood flow both before and after EICMA surgery.

The authors investigated another interesting parameter that defines the area of perfusion deficit and confirms the positive role of EICMA as a method of treatment of patients with chronic cerebral ischemia.

The work clearly defines the most significant factor influencing the effectiveness of surgical revascularization, reperfusion volume. It was proved that restoration of cerebral perfusion in at least one area of the medial cerebral artery territory can be considered as a perfusion criterion of hemodynamic significance of EICMA.

Let me remark here that mathematical processing of the results is beyond praise and deserves extra applause.

The authors demonstrated methodologically competent approach to selecting indications for EICMA surgery based on detection of zones with long-standing oligemia in morphologically intact brain regions, which reflects a novel approach to treatment of the consequences of ischemic stroke.

This is perhaps the main difference between the present work and previous studies, which were incorrect and cast a shadow on the point at issue discussed in the co-operative research of EICMA problem in 1985 and 2008 and did not reveal any positive effect of this operation despite the scarce reports on pronounced positive results.

The conclusions of the present study are absolutely consistent and undoubted. The authors proved that EICMA operation is fairly effective and is advantageous over conservative therapy given the adequate selection of patients and determining indications in each case.

I have no criticism for this study. The authors obtained very interesting results, which will be extremely helpful for practicing neurosurgeons and neurologists in terms of methodological approach to this issue. I hope that this study will stop disputes about the advisability of EICMA operations, since it is vital for certain patients with chronic cerebral insufficiency.

G.I. Antonov (Moscow region, Russia)
Supraorbital Keyhole Craniotomy in Surgery of Anterior Circle of Willis Aneurysms

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The progress in surgical treatment of intracranial aneurysms is based on the introduction of modern minimally invasive techniques. Among the variety of keyhole approaches, supraorbital craniotomy is most often used in surgical treatment of anterior circle of Willis aneurysms. The authors present the preliminary results of application of supraorbital keyhole craniotomy for anterior circle of Willis aneurysms in 27 patients. Most of the patients had unruptured aneurysms (18 patients). Nine patients had SAH, and 4 of them were operated on in the acute period. The patients’ condition was assessed as a grade 1—2 (Hunt—Hess scale) and grade 1—3 (Fisher scale). There were no intraoperative aneurysm ruptures, other serious complications, and deaths. Postoperative complications were assessed at 2 weeks and 6 months. The postoperative cosmetic outcome was assessed by patients as excellent.

Keywords: supraorbital craniotomy, keyhole, eyebrow incision, minimally invasive surgery, aneurysm.

The progress in surgical treatment of intracranial aneurysms is based on the introduction of modern minimally invasive techniques. Endovascular interventions are not yet fully capable of replacing open neurosurgical operations. Currently, there are many approaches to surgical treatment of anterior circle of Willis aneurysms, ranging from standard pterional craniotomy to expansive, more “aggressive” approaches, such as frontotemporozigomatic craniotomy [1—4]. They undoubtedly have their advantages with respect to freedom of using microtools and options for polypositioning of the microscope viewing angle. However, classical approaches are often accompanied by iatrogenic trauma, caused by expansive cuts of soft tissues and muscles, wide osteotomy with opening of the dura mater and, accordingly, wide exposure of the cortex. All this can lead to the formation of a large cutaneous scar, alopecia, hypoesthesia, atrophy of the temporal muscle, which causes asymmetry of the face, dysfunction of the temporomandibular joint, pain during chewing. Some patients note discomfort when wearing glasses [5—9]. The risk of formation of epidural hematoma and/or development of liquorrhrea after the use of standard approaches is also well known [5, 7, 8, 10]. In addition, excessive exposure of corresponding area of the cortex can lead to the formation of lesions, infection, and other adverse effects. These negative factors are associated with an increase in hospitalization and long-term disability, which entails large economic costs [7].

“Keyhole” surgery or surgery through a “keyhole” is a modern concept of approach, which significantly reduces traumatic component of surgical intervention. The pioneer of “keyhole” surgery, A. Perneczky, formulated the basic idea of minimally invasive interventions as following “maximum surgical efficiency with minimal traumatization of tissues” [6, 11—13]. The main goal of “keyhole” surgery is the reduction in the number of complications associated with the surgery rather than simply reducing the size of the trepanation [10, 14].

Among the variety of keyhole approaches, supraorbital craniotomy is most often used in surgical treatment of anterior circle of Willis aneurysms. Supraorbital craniotomy was first described by A. Pernezcky et al. and J. Paladino et al. [10, 15, 16]. Nowadays, certain experience has been accumulated, proving the effectiveness of surgery through the supraorbital keyhole approach for treatment of supratentorial aneurysms in case of proper selection of candidates for the procedure [12—17, 24].

The aim of the work is to present the results of using supraorbital keyhole craniotomy in treatment of anterior circle of Willis aneurysms in the neurosurgical clinic of the Russian Medical Academy of Postgraduate Education.

Material and Methods

From March 2014 to December 2015, 27 aneurysms were clipped using supraorbital craniotomy. The localization of aneurysms was distributed as follows: 16 aneurysms of the anterior cerebral artery — anterior communicating artery (ACA-ACA) complex, 5 aneurysms of the internal carotid artery (ICA) in the region of the posterior connective artery mouth, 3 ophthalmic aneurysms and 3 aneurysms of the M1 segment of the middle cerebral artery (MCA). The average age of patients was 56.4 years, the ratio of men to women was 1:2. Most patients had unruptured aneurysms (18 patients). Nine patients had SAH, and 4 of them were operated on in the acute period. The condition of patients with SAH was assessed using Hunt—Hess scale and the extent of SAH, using Fisher scale. All patients had SAH grade I or II on Hunt—Hess scale and grade 1—3 on Fischer scale.

Preoperatively, all patients underwent 2D and 3D CT angiography. The choice of surgical approach was...
determined after a thorough evaluation of the anatomy of the intracranial structures and aneurysms. All aneurysms clipped using supraorbital craniotomy were of small or medium size, no more than 15 mm in diameter. In complex and giant aneurysms, the method of choice was wider approach, from classical pterional craniotomy to orbitozygomatic approach and its modifications. We also did not consider the use of supraorbital craniotomy in patients in a state of decompensation (Hunt—Hess IV—V), with massive subarachnoid hemorrhages and large parenchymal hematomas, accompanied by cerebral edema and intracranial hypertension. Most of these patients, in addition to aneurysm clipping, also underwent wide decompression.

**Surgery Technique**

The patient is placed on the operating table on the back, with a head elevated above the level of the heart, tipped back and turned in the opposite direction from 15 to 60°, depending on the localization of the aneurysm. In case of MCA aneurysms, the head was rotated by 15°. In case of aneurysms of the supraclinoid section of the ICA, 20—30° rotation is sufficient. With ACA-ACA aneurysms, the angle of rotation of the head in the opposite direction is at least 40—60°. The area of the zygomatic process is the highest point. This position of the head ensures the retraction of the frontal lobe from the anterior cranial fossa, facilitating subsequent subfrontal approach. After treatment of eyebrow area with antiseptic solutions, the skin is cut directly along the eyebrows, starting from the pupillary line, and continues laterally within the eyebrows, sometimes extending a few millimeters outwards (Fig. 1).

The supraorbital nerve and artery, the frontal branch of the facial nerve, and the superficial temporal artery are always preserved. It is followed by subperiosteal dissection from the level of the supraorbital opening to the frontal-zygomatic suture to isolate the frontal, temporal and circular muscles of the eye. The temporal fascia is dissected by unipolar coagulation, and the temporal muscle is separated from the attachment site at the level of the anterior temporal line. The burr hole is superimposed posteriorly from the temporal line just above the level of the base of the anterior cranial fossa. The first cut is made parallel to the upper edge of the orbit in the medial direction. The second cut is made upward and C-shaped towards the medial point of the first cut, forming a bone defect with a width of 25—30 mm and a height of 15—25 mm. Large frontal sinuses are not a contraindication to approach. When they are opened, the mucous membrane is removed and coagulated, and later closed by a periosteal flap. If the insertion into the frontal sinus is small and there is no damage to the mucosa, it is sufficient to coat the area with surgical wax.

An important stage after the osteotomy is alignment of the inner edge of the trepanation window in the region of the upper wall of the orbit by high-speed burr. The dura mater is opened by a semi-oval incision, base facing the orbit. Next, a classic microsurgical technique with adequate lighting and the necessary magnification is

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Fig. 1. a — cut of the skin along the eyebrow in supraorbital approach (patient with carotid-ophthalmic aneurysm of the ICA on the left); b — the view of the operating field after treatment and overlay with sterile material.
employed. The optocarotid triangle, chiasmatic tank, Lillekvist membrane, terminal ventricle III and other supraparasellar cisterns are gradually opened to drain the cerebrospinal fluid and to relax the brain. The dissection of the Sylvian fissure is a prerequisite. These maneuvers create additional space for manipulating microtools and performing surgical dynamic traction of the brain.

Further technique is dictated by the localization of an aneurysm (Fig. 2).

At the end of the surgery, the dura mater is hermetically sealed and sutured along the periphery to the bone to exclude the epidural accumulation of blood. In our group of patients, after minimally invasive microsurgery there were no complications in the form of postoperative epidural hematomas. The bone flap is placed in place and fixed with a mini-plate or craniofix. In some cases, it is possible to obliterate the cutting zone with fast-hardening plastics to ensure better cosmetic effect, although in most cases classical fixation of the bone flap is sufficient and ensures good cosmetic outcome. The temporal fascia and muscle are sutured to the periosteum. Subcutaneous fat and skin are sewn layer by layer. Given the small size of the skin incision, postoperative drainage is not used.

In the postoperative period, CT control is traditionally used within the first 24 hours (Fig. 3). The cosmetic outcome as evaluated 2.5 months after the surgery was satisfactory (Fig. 4).

Fig. 2. a, b — SCT angiography — carotid-ophthalmic aneurysm of ICA is visible on the left; c, d, e — intraoperative view: isolation and clipping of the aneurysm; f — intraoperative angiography with indocyanine green after clipping.
Results and Discussion

All aneurysms were completely cut off from the cerebral blood flow, which was confirmed by both intraoperative aneurysm opening and subsequent monitoring using ICG angiography (19 patients) and by performing 3D CTT angiography in the postoperative period. Videoendoscopic assistance was used in 22 patients. There were no serious complications and deaths. Intraoperative ruptures of aneurysms were also not observed. Postoperative complications were assessed 2 weeks and 6 months after the surgery. Periorbital edema was noted in all patients and was not regarded as a complication, as it completely regressed within 3—5 days after the intervention. Hyperesthesia in the frontal region was observed in 7 patients. After 6 months, it completely regressed in all the cases. There were no atrophy of the temporal muscle and significant retraction in the area of craniotomy.

Postoperative cosmetic result was assessed by patients as excellent.

After the introduction of pterional craniotomy by G. Yasargil [20] in 1975, the wider bifrontal and expanded frontotemporal approaches were completely phased out. However, classical pterional craniotomy involves significant damage to the soft tissues and fairly wide osteotomy. This may be accompanied by an increase in the frequency of postoperative complications, not related to the immediate purpose of the surgical intervention. Often, patients are not satisfied with the cosmetic effect and complain about the presence of a large scar, depression of the bone flap and skin over the burr holes, atrophy of the temporal muscle.

Currently, modern minimally invasive techniques are replacing the established classical approaches in the surgery of cerebral aneurysms and tumors of the base of the skull. However, neurosurgical assessment of keyhole surgery is not limited to mere miniaturization of approach, but involves understanding of this phenomenon from the perspective of the evolution of surgical approaches. It is well known that the skull base surgery began precisely with the wide, “aggressive” approaches, accompanied by a significant number of postoperative, sometimes fatal complications. A. Perneczky et al. [6, 10, 13, 14, 25] introduced and widely used supraorbital craniotomy through the eyebrow incision in treatment of various skull base formations, and adapted the technique to the treatment of supratentorial aneurysms and parasellar tumors.

There are many factors that influence the choice of approach for aneurysms of the anterior part of the Willis circle: presence and extent of hemorrhage, presence of cerebral angiospasm, edema and secondary ischemic changes in the brain, severity of the condition and the patient’s age, localization and size of the aneurysm, presence of cerebral atrophy and extended reserve spaces, time of surgical intervention.

In case of massive hemorrhage, presence of intracerebral and/or intraventricular hemorrhage, edema of the brain, i.e. in patients in subcompensated and decompensated state, the use of classical approaches, such as pterional craniotomy and its modifications, and in some cases, decompressive craniectomy is preferable. In some cases, with complex and giant aneurysms, the use of “keyhole” approach involves a significant risk to the patient.

Fig. 3. CT of the brain with contrasting (a, b) and craniography (c) after supraorbital craniotomy and clipping of carotid-opthalmic aneurysm of ICA on the left. A bone defect fixed by craniofixes is visualized by craniography.
However, in case of unruptured aneurysms and compensated patients after SAH, the use of minimally invasive approaches to minimize surgical trauma can be a method of choice.

A necessary assistance in “keyhole” surgery of aneurysms is provided by additional imaging techniques: fluorescent intraoperative angiography with indocyanine green and video endoscopic assistance [3, 6, 10, 16, 24]. Neuroendoscopic assistance plays an important role in keyhole approach surgery, since it improves visualization and illumination in a small and deep surgical wound, allows to assess the correct position of the clip on the aneurysm neck and prevents penetration of perforators between the branches of the clip [27].

Supraorbital approach has clear advantages over classical pterional craniotomy: small surgical wound, reduction in operation time and blood loss, low risk of damage to the olfactory tracts when accessing an aneurysm of ACA-ACA, low risk of epidural hematoma and liquorhea, minor temporal muscle damage, less pronounced pain syndrome in the postoperative period, rapid healing of the wound and small cutaneous scar. Recovery and discharge of the patient happen in a shorter time [12, 13, 15, 25, 28].

Conclusion

In case of adequate selection of candidates for the operation, supraorbital approach proved to be highly effective and safe approach in our group of patients. Despite small size of craniotomy, supraorbital approach...


Commentary

In the present work, the authors discuss the advantages of small bone-plastic trepanation and the use of endoscopic assistance in microsurgery of small aneurysms in the anterior Willis circle. This approach was mainly used in patients with unruptured aneurysms and in patients in the cold period of subarachnoid hemorrhage, without angiopasm and cerebral edema.

The idea of ultrasmall bone-plastic trepanation was first proposed by a Japanese neurosurgeon Zentaro Ito in the 70—80s of the last century. Later his ideas were developed by T. Fukushima. In the 1980s, the use of ultra-small craniotomy, rounded spatula, painted in dark or matte colors to prevent glare in the depth of the wound, etc. seemed to be a truly innovative solution. In our country in this direction was explored by professor V.P. Sakovich, under whose guidance V.S. Kolotvinov defended the thesis “Pterional “keyhole” approach to surgery of intracranial aneurysms” in 2003

As for endoscopic assistance in the surgery of cerebral aneurysms, its role is very limited and specific: control of the anterior villous artery in case of aneurysms of the internal carotid arteries and stem perforators in the aneurysms of the posterior cerebellar arteries.

There is one indisputable rule. Things which provide a clear advantage in practical work are instantly replicated by the majority and are adopted for many years, as, for example, is the system of brain retractors by professor Gazi Yasargil.

The present work certainly deserves attention. As an experience implemented in a small series of operated patients, keyhole approaches in the surgery of cerebral aneurysms require further study and comparison with “orthodox” bone-plastic trephination, which are currently based on the principle of sufficiency of the trepanation window for performing certain tasks in cases that may be absolutely different.

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The Technique of TachoComb application in Dural Reconstruction in Surgeries for Posterior Cranial Fossa Tumors

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**Introduction.** Liquorrhea is a condition characterized by cerebrospinal fluid (CSF) leak from the cranial cavity due to loss of integrity of the dura mater (DM) and bone structures of the skull base. The following types of liquorrhea are distinguished in surgery for posterior cranial fossa (PCF) lesions: wound liquorrhea when CSF leaks from a surgical wound and the basal liquorrhea (nasal or, less often, otoliquorrhea). The main cause of basal liquorrhea is injury (including surgical injury) resulting in a defect in the DM and bone structures (mastoid cavities in case of using the suboccipital retrosigmoid approach). There are a variety of DM restoration techniques, ranging from closure of the dura mater or placement of a synthetic or autologous patch to application of various synthetic adhesives in the form of adhesive compositions (Tissucol) and adhesive materials (TachoComb). This article describes the experience of using the TachoComb sponge gained at the 5th Clinical Department of the Burdenko Neurosurgical Institute.

**Materials and Methods.** The study included 176 patients with acoustic neuromas. At the final stage of surgery, all the patients underwent dural reconstruction using a TachoComb collagen sponge. CSF leak occurred in 3 (1.7%) patients, each of them having a Koos grade 4 tumor. One (0.56%) patient had wound liquorrhea and 2 (1.1%) patients had nasal liquorrhea. CSF leak was managed by placing a lumbar drain; no postoperative wound revision was required. **Conclusion.** Using the TachoCombR sponge for dural reconstruction in PCF surgery is an effective way to prevent postoperative CSF leak, provided that the algorithm of manipulations described in the article is carefully followed.

**Keywords:** posterior cranial fossa, neurinoma, liquorrhea, TachoComb.

Liquorrhea is the cerebrospinal fluid (CSF) leak from the cranial cavity as a result of loss of integrity of the dura mater (DM) and bone structures of the skull base. The following types of liquorrhea are distinguished in surgery for posterior cranial fossa (PCF) neoplasms: wound liquorrhea when CSF leaks from a surgical wound and the basal liquorrhea (nasal or, less often, otoliquorrhea). Upon basal liquorrhea, CSF first fills one of the paranasal sinuses (the sphenoidal or the frontal sinus, or the ethmoidal labyrinth) and then outflows directly into the nasal cavity. CSF may either outflow through the nasal passages or penetrate into the esophagus through the nasopharynx.

The main cause of basal liquorrhea is injury (including surgical injury) resulting in a defect in the dura mater and bone structures (cells of the mastoid process in case of using the suboccipital retrosigmoid approach). Impaired CSF dynamics presenting as CSF malabsorption, which is observed upon a number of interventions and most typically in surgery of epidermoid cysts, is an important factor for aggravating the situation.

Since liquorrhea may cause meningitis even after antibiotic therapy, prevention of the development of this complication becomes topical in surgery of PCF lesions. There are many techniques aimed at restoring the integrity of the dura mater, ranging from closure of the dura mater or placement of a synthetic or autologous patch to application of various synthetic adhesives in the form of adhesive compositions (Tissucol) and adhesive materials (TachoComb). In order to prevent CSF penetration into paranasal sinuses, the opened mastoid cavities are sealed with wax (if the cavities are small) or autografts (muscles, broad fascia, or adipose tissue) in combination with the aforementioned adhesive compositions. During many years, neurosurgeons have been using various synthetic and natural materials for dural reconstruction. The key problem of using synthetic materials is development of adhesion induced by a foreign body and, rather frequently, of aseptic meningitis, which negatively affects patient’s length of stay. On the other hand, application of biological (cadaver) allografts is associated with the risk of transmitting viral infections, while autografts are not always available during surgery.

The TachoComb collagen sponge has recently been commonly used in neurosurgery. The sponge contains fibrinogen and human thrombin and creates a water impervious membrane that acts as a dural regeneration matrix as it increases fibroblastic activity. This article describes the experience of using the TachoComb sponge gained at the 5th Clinical Department of the Burdenko Neurosurgical Institute.

**Materials and Methods**

In 2015, 835 patients were operated on at the 5th Neuro-Oncology Department of the Burdenko Neurosurgical Institute. Interventions for PCF neoplasms were performed in 425 of these patients (in 226, for acoustic neuroma; in 140, for meningiomas; and in 59, for other neoplasms of the cerebellar pontine angle, fourth ventricle, and cerebellum). Since patients with
acoustic neuromas predominated in our series, it is this group that was analyzed.

The study included 176 patients (50 males and 126 females) with acoustic neuromas who had not been previously operated on at other medical centers. The median age was 47 years (mean age, 19—75 years). The classification proposed by Koos et al. (2002) was used to analyze the tumor size. Patient distribution relative to tumor size is shown in Table.

At the final stage of the surgery, all patients underwent closure of the DM using the TachoComb collagen sponge. TachoComb material is an absorbing hemostatic agent consisting of collagen sponge coated with fibrin sealant components on one side. When contacting the bleeding wound or other bodily fluids, this layer releases the coagulation factors and thrombin converts fibrinogen to fibrin. Hence, fibroblasts are activated.
Table 1. Size distribution of acoustic neuromas

<table>
<thead>
<tr>
<th>Tumor size according to the Koos classification</th>
<th>Number of patients (n=176)</th>
<th>Number of liquorhea cases, %</th>
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Dural closure technique

At the main stage of neurosurgical intervention, after hemostasis was completed, a TachComp sponge patch is placed under the dural mater with its yellow side facing the surgeon so that sponge edges were placed under the margins of the incision of the dura mater by 5—6 mm (Fig. 1). The TachoComb sponge patch needs to be dry to be secured in the proper position between the brain tissue and the dura mater. Next, the dura mater is closed by single interrupted sutures (Fig. 2). Both resorbable and nonresorbable sutures are used.

The dura mater needs to be closed in such a way that there were diastases left 6—7 mm wide, with the yellow surface of the TachoComb sponge visible through them. Next, a moist fragment(s) of the TachoComb sponge is placed onto the partially closed dura mater, with their adhesive (yellow) side facing the dura mater. Beyond the dura mater, the TachoComb sponge is placed to overlap the defect by several millimeters (Figs. 3 and 4). Hence, the adhesive sides facing one another stick together, thus sealing the dural mater in the incision area.

Results and Discussion

The mortality rate in the study group was 1.1% (2 patients). Liquorrhea was observed in 3 (1.7%) patients; these patients had grade IV tumors according to the Koos classification. One (0.56%) patient had wound liquorhea; 2 (1.1%) patients, nasal liquorrea. Liquorrhea was stopped by placing a lumbar drain; no revision of the postoperative wound was required.

Hence, the results of surgical treatment of patients with acoustic neuromas in the study group are consistent with those achieved at foreign clinics. Hence, the reported technique of application of the TachoComb sponge allows one to prevent postoperative liquorrea after removing PCF neoplasms.

In our opinion, dural reconstruction is most efficient if the following requirements are met:

1. The TachoComb fragment placed under the dura mater needs to extend beyond the defect margins by at least 2—3 mm (preferentially, 5—6 mm).
2. The dura mater should be closed in such a way that diastases were left, which enable the contact between the two adhesive sides of the agent.

Conclusion

Application of the TachoComb sponge for dural reconstruction during surgeries for the PCF is an effective method to prevent the development of postoperative liquorrea provided that the algorithm described above is followed.

Authors declare no conflict of interest.

REFERENCES


Chiasm and Optic Nerve Glioma Manifested as Hemorrhage (Two Clinical Cases and a Literature Review)

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The article presents two rare clinical cases of low-grade (WHO grade I—II) glioma of the anterior visual pathway structures, the chiasm and optic nerves, in adults. The feature of these cases was the benign nature of a chiasm and optic nerve glioma in adults as well as its presentation in the form of hemorrhage to the tumor and parenchymal and subarachnoid space, which to some extent complicated making the correct diagnosis. Removal of an intracerebral hematoma and open tumor biopsy were performed in one case, and removal of a hematoma and partial tumor resection followed by radiotherapy were performed in the other case.

Keywords: anterior visual pathway, glioma, hemorrhage.

Abbreviations:
- AVPG — anterior visual pathway glioma
- Gy — Gray, unit of absorbed ionizing radiation dose
- LI — labeling index
- MRI — magnetic resonance imaging
- MeV — megaront electron volt
- S-CTA — spiral CT angiography
- CD — cumulative dose
- OD — right eye
- OS — left eye
- WHO — World Health Organization

Gliomas of the anterior visual pathway (optic nerves, chiasm, visual tracts) are a relatively rare but yet important group of tumors. The disease usually manifests itself as visual disorders and often in the first and second decades of life. AVPG comprises 3 to 5% of intracranial tumors in children, it is usually presented as piloid astrocytomas and occupies the second place among the causes of blindness in patients with neurosurgical pediatric pathology. AVPG is less common in adults [1, 2]. In adult patients, these tumors are believed to be usually represented by malignant astrocytomas or glioblastomas [3].

Tumors of adult patients are morphologically characterized by pronounced cellular polymorphism, multiple mitoses, tissue necrosis, regions of endothelial proliferation and a vast number of vessels in the tumor stroma, which can be accompanied by microhemorrhages to the tumor [4—6]. At the same time, significant hemorrhages to the tumor are observed quite rarely [7—9].

Unlike for adult patients, in children, the disease can be detected at late stage of visual disturbances, which are worsening rather slowly. Despite the fact that tumors in children are usually presented as piloid astrocytomas, there is an opinion that certain histological features indicative of a more aggressive type of tumor growth exist in gliomas affecting the posterior regions of the anterior visual pathway structures (posterior regions of the chiasm and visual tracts) [10—13].

We supervised 2 patients with AVPG, which was clinically manifested as hemorrhage to the brain and tumor stroma.

Case 1.

Patient T., 17 years of age. The patient was first examined at Burdenko Neurosurgery Institute at the age of 15 in 2013. The disease manifested itself as an episode of severe headache, vomiting, loss of consciousness and sopor. Speech disturbance and deterioration of the left eye visual acuity were noted. Symptoms gradually regressed, the quality of vision restored. MRI revealed a mass lesion in the left half of the chiasm and left optic nerve, which did not accumulate contrast agent, and a hemorrhagic cyst in the left frontal region. No pathology of cerebral vessels was found. No pathological changes in the right eye were noted during ophthalmologic examination at Burdenko Neurosurgery Institute. Visual acuity of the left eye: 0.5 s−2.0=0.7 (1.0 in vicinity). Visual field of the left eye was narrowed in the lower half. There was no exophthalmos. No oculomotor disorders were noted. There was a slight pallor of the optic disc on...
the temporal side, extensive physiological excavation. Disc boundaries were clear. Thus, despite the fact that MRI revealed glioma of the chiasm and the left optic nerve, the patient was recommended for dynamic observation and S-CTA 6 months later due to high visual functions, including the left eye. The examination was not conducted. Two years later, the patient suffered another episodic loss of consciousness and visual deterioration in the left eye, which gradually regressed.

The patient was hospitalized at Burdenko Neurosurgery Institute with suspected saccular aneurysm of the cerebral vessels. Brain MRI showed the same picture as before: glioma of the chiasm and the left optic nerve with hemorrhagic cyst in the left frontal lobe (Fig. 1a, b). According to bilateral carotid angiography, no pathology of the cerebral vessels was detected (see Fig. 1c, d).

Ophthalmic symptoms remained practically unchanged compared to the examination conducted in 2013, except for the defect in the upper temporal quadrant of the right eye, which was healthy earlier (Fig. 2).

Optical coherence tomography revealed the following: 1) right eye: thinning of the retinal ganglion cell complex in the nasal half, thickness of the peripapillary layer of nerve fibers is within normal range; 2) left eye: pronounced thinning of the retinal ganglion cell complex and the peripapillary layer of nerve fibers in the upper, temporal and lower quadrants (Fig. 3).

The patient underwent surgery, osteoplastic trephination on the left side, pterional approach, in 21.09.15. Chiasm tumor intimately blended with the basal surface of the left frontal lobe was found. Tumor fragment was excised for histological examination. Further manipulations were not performed due to preserved visual functions and high risk of its deterioration upon tumor removal. The cavity of subacute intracerebral hematoma was opened by microencephalotomy of the basal regions of the left frontal lobe. The contents of the hematoma cavity were aspirated in the form of lysed blood of about 30 ml of volume. Biopsy data: the material consists of a blood clot and small fragments of piloid astrocytoma (WHO Grade I) of microcystic structure with increased Ki-67 LI (up to 8%), pilomyxoid variant cannot be excluded (WHO Grade II).

Visual functions were preserved at the preoperative level after surgery. Visual acuity at the follow-up
examination 2.5 months after surgery: OD=1.0; OS=0.8—0.9 s — 1.0. Visual field was changed within the same limits.

Stereotactic radiation therapy is planned.

**Case 2.**

Patient M., 22 years of age. Anamnesis data: the patient lost consciousness and was hospitalized at the place of residence on 26.08.15. When returned to consciousness, she noted that she could hardly see with her right eye. MRI revealed a tumor in the chiasmal-cellar region with signs of hemorrhage to the tumor and subcortical structures on the left side (Fig. 4).

The patient was hospitalized at Burdenko Neurosurgery Institute for surgical treatment. Ophthalmological examination revealed 0.03—0.04 visual acuity of the right eye, eccentric, not corrected, and 1.0 visual acuity of the left eye. Examination of the field of vision showed left-sided homonymous hemianopia with a loss of the central vision of the right eye (Fig. 5). Optic nerve disc on the right side was pale, mainly in the temporal half, disc on the left side was of light pink color, homogenous. Disc boundaries were clear. Thus, there were symptoms of the lesion of the right optic nerve, chiasm and the right visual tract.

The patient underwent surgery, osteoplastic trephination in the right frontal region, subfrontal approach to the chiasmal-cellar region. The arachnoid membrane was thickened, infiltrated, of yellow color, indicative of suffered hemorrhage. The right optic nerve presented a tumor-like formation. The tumor was of yellow color with traces of hemorrhages and spread to the chiasm region destroying the hypothalamus, the pituitary foot and the visual tract. The tumor was removed as far as possible between the optic nerves and partially from the right visual tract. A cavity of the removed hematoma was formed in the center of the tumor. A significant amount of the tumor was removed from the basal parts and the interpeduncular cistern. Further removal of the tumor was not performed due to the infiltrative growth of the tumor and results of an urgent biopsy (glioma with the signs of malignancy). The left optic nerve looked preserved in its initial region.

Tumor biopsy data: the material is represented by fragments of astrocytic glioma consisting of bipolar astrocytes with microcysts, Rosenthal fibers, eosinophilic droplets, necrosis foci. Focal Ki-67 LI iss up to 10%. Conclusion: morphological picture and immuno-phenotype correspond to the diagnosis of “pilomyxoid astrocytoma (WHO Grade II)”.

The right eye became blind after surgery. Visual functions of the left eye remained at the same level.

Optical coherence tomography revealed: 1) right eye: pronounced thinning of the retinal ganglion cell complex and the peripapillary layer of nerve fibers in the temporal, upper and lower quadrants; 2) left eye: pronounced thinning of the retinal ganglion cell complex in the nasal half, peripapillary layer of nerve fibers in the nasal and temporal quadrants (Fig. 6).

In the period of 12.11.15 to 23.12.15, the patient underwent a course of stereotaxic radiotherapy using “Novalis” (a linear accelerator with a photon energy of 6 MeV equipped with a micromultileaf collimator) according to the plan for targeting the chiasmal-cellar region of 32.341 cm$^3$. A total of 30 fractions 1.8 Gy each on average with six conformal static fields without margin to 54 Gy CD (Dmax 56.94 Gy) have been performed. Patient’s condition during irradiation was satisfactory.
Neurological and ophthalmologic status remained without dynamics.

**Discussion**

AVPG is known to be a rare pathology, especially among adults, in whom, unlike in children, it is usually presented by malignant tumors. Spontaneous hemorrhages associated with optical glioma are even more rare cases. Incidence of a combination of low-grade glioma and hemorrhage does not exceed 4—12% [14]. In adults, hemorrhages can be traced more often than in children, which is associated with histological features of the tumors. Hemorrhages in AVPG complicate the diagnosis of the genuine process.

The feature of our two observations was hemorrhage, both to the tumor stroma as well as parenchymal and subarachnoid space. The disease manifested itself through the hemorrhage symptoms. We found a case of optical glioma with subarachnoid and intraventricular hemorrhage.

![Fig. 3. Patient T. Optical coherence tomography of the retina and optic nerve 3D OCT-2000, Topcon.](image)
a — 3D Disc scanning protocol. Thickness of the peripapillary layer of nerve fibers; b — 3D Macula V scanning protocol. Thickness of the retinal ganglion cell complex of the right (OD) and left (OS) eyes.

![Fig. 4. Patient M. Brain MRI.](image)
a — axial projection, T2 mode; b — sagittal projection, T1 mode with contrast enhancement, heterogeneous contrasting of the tumor is shown in the projection of the cell region; c — frontal projection, T1 mode without contrast enhancement; traces of hemorrhage are shown (indicated by arrow).
Fig. 5. Patient M. The field of vision: incomplete left-sided homonymous hemianopsia (kinetic perimetry).

Fig. 6. Patient M. Optical coherent tomography of the retina and the optic nerve (3D OCT-2000, Topcon).

a — 3D scan disc protocol. Thickness of the peripapillary nerve fiber layer; b — 3D Macula V scanning protocol. Thickness of the ganglion cell complex in the retina of the right (OD) and left (OS) eyes.
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The authors presented in detail two clinical cases of patients with gliomas of the chiasm and optic nerves, which clinically manifested as an acute form and resembled cerebral vascular pathology, arterial aneurysm rupture with intracranial hemorrhage.

Being sufficiently biologically benign, especially in childhood, gliomas of the chiasm and optic nerves are quite rare tumors that usually develop slowly, progressively and manifest themselves in visual disturbances. The authors rightly emphasize that this group of tumors is usually pathomorphologically presented with piloid astrocytomas (WHO Grade I classification) in children, while the degree of anaplasia typically increases in adults, and the tumors become anaplastic (WHO Grade II—III). In terms of malignant glial tumors, the fact of blood circulation disorder, primarily to the tumor stroma with formation of hematomas and, subsequently, cystic cavities, is generally known.

In the presented clinical cases, age of the patients at the time of acute clinical manifestations was 15 and 22 years, both patients clinically noted a sudden emergence of cephalgic syndrome with the development of cerebral symptoms, loss of consciousness to coma. Patients were hospitalized with suspicion of a possible vascular accident, intracerebral hematomas from probable arterial aneurysms or malformations. However, vascular pathology was not confirmed during clinical examination using objective instrumental methods, including serial angiography. Further detailed examination at Burdenko Neurosurgical Institute revealed space-occupying lesions of the chiasm and optic nerves. At this period of time, visual function disorders already dominated in the clinical syndrome.

Ophthalmologists used all objective methods of sophisticated diagnostics and, in particular, optical coherence tomography, which had been recently included in the diagnostic process and allowed objectification of the nuances of the state of the retina, glial cells and fibers in the examined patients.

Both patients underwent surgery: microsurgical removal of the maximum possible volume of the tumors was conducted, hematomas were removed, and posthemorrhagic cysts were emptied. Based on the results of pathomorphological examination, grade II anaplastic gliomas were established, and modern radiological stereotaxic treatment was performed.

In the presented discussion, the authors focus on the sufficient rarity of such clinical manifestations of gliomas of the chiasm and optic nerves. The regularity revealed by the authors has its reason: tumors occur in the early childhood, progress very slowly without being clinically manifested; but, when the patients reach a certain age, anaplastic reorganization of the tumor takes place, it becomes malignant, hemorrhages to the tumor appear, and, thus, neurological clinical symptoms develop rapidly.

This conclusion is convincingly illustrated in the article, it is proved by the presented clinical materials and the data of modern objective methods of research.

The article is informative, well written and illustrated, undoubtedly interesting and instructive for ophthalmologists, neurologists and neurosurgeons.

V. L. Puchkov (Moscow, Russia)
Improvement of Visual Functions after Successful Microsurgical Exclusion of a Giant Aneurysm of the Right Internal Carotid Artery Using Revascularization Techniques

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We describe a clinical case of successful treatment of a female patient with a giant paraclinoid aneurysm of the right ICA. The aneurysm had a pseudotumoral course and manifested as pronounced progressive visual impairments. The patient underwent microsurgery including trapping/clipping of the right ICA aneurysm after creation of an EICMA and a high-flow anastomosis between the ECA and the M2 segment of the MCA. The surgery enabled decompression of the optic nerves, avoiding their injury. Postoperatively, the patient underwent transcutaneous electrical stimulation of the optic nerves. The case feature was that the patient developed gradual restoration of the blind eye vision.

Keywords: giant aneurysm, revascularization, anastomosis, optic nerve electrical stimulation.

Abstract

Paraclinoid aneurysms of the ICA are formed in the segment between the distal dural ring and the mouth of the posterior connective artery [1—3]. Due to complex topographo-anatomical structure of the region, paraclinoid aneurysms remain one of most challenging neurosurgical pathologies [3, 4]. Despite the advancements in endovascular surgery, in some cases the treatment of large and giant paraclinoid aneurysms is possible only by microsurgical methods [5, 6]. One of the frequent consequences of clipping paraclinoid aneurysms is visual impairment [1, 2, 7]. Moreover, pre-operative visual impairments, especially long-term ones, usually regress only poorly after the surgery [5, 8].

In our work, we describe a clinical case of partial restoration of visual function after a microsurgical operation for a giant aneurysm of the paraclinoid section of the right ICA.

Description of the clinical case

Patient L., female, 67 years old, was examined for a decrease in vision first in the right, and then in the left eye. Visual impairments which manifested as visual field defects and loss of visual acuity first appeared in 2013 and gradually progressed. In January 2015, after significant impairment of vision in the right eye, the patient underwent MRI of the head which revealed a giant aneurysm in the right ICA with the maximum diameter of 29 mm.

At May 20, 2015, the patient was hospitalized to the Burdenko Neurosurgical Institute for surgical treatment. Neurological status did not include any cognitive, speech, motor and sensory disorders. According to ophthalmological examination, the visual acuity of the right eye was 0, and the visual acuity of the left eye was 0.2 in the nasal half (Fig. 1). Therefore, there were signs of lesion of the right and, to a lesser extent, left optic nerves, the chiasma, and the right visual tract. The stage of visual impairment: advanced.

According to the MRI of the brain, an aneurysm does not contain thrombi (Fig. 2).

CT AG revealed a disconnected Willis circle: there was no anterior connective artery and hypoplasia of the posterior connective arteries was present on both sides, which suggests high risk of ischemic complications in case of deconstructive surgery on the right ICA (Fig. 3).

After the consultation among the specialists, which involved endovascular neurosurgeons, it was decided to abandon endovascular surgery in favor of microsurgical
technique, since the latter allows performing decompression of the optic nerves with a hope to restore their function. The plan of the surgery included an attempt to clip the aneurysm through the creation of an ICA lumen by using IBA. In case of failure, an alternative option was to trap the aneurysm after creating a high-flow bypass anastomosis between the ECA of the neck and M2 segment of the MCA. The patient underwent Alain’s test, which showed good collateral blood supply to the forearm and possibility of collecting the radial arteries on both hands.

**The course of the surgery.** Standard pteryonal craniotomy was performed from a semi-ovoid cut of the skin. The common and internal carotid arteries were exposed from the linear section on the neck.

After a wide dissection of the chiasmatic cistern, it was revealed that the aneurysm was located in the segment between the ophthalmic and posterior connective arteries. The eccentric part of the aneurysm went under the right optic nerve and chiasma. The right optic nerve was sharply stretched. The wall of the ICA at the level of branching of the aneurysm contained many atherosclerotic deposits. Moreover, the ICA at the level of the aneurysm was at an angle, which would have been associated with high probability of stenosis of the ICA lumen in case of its modeling by tunnel clips. An attempt to perform intravascular blood aspiration from the common carotid artery in the neck under temporary trapping conditions (temporary clips on the eye artery, posterior connective artery on the right, A1 and M1 segments on the right) was ineffective and did not provide sufficient relaxation of the aneurysm walls.

It was decided to perform revascularization of the distal branches of the right MCA and the aneurysm trapping. The blood flow was measured with a flowmeter: the volumetric velocity in the right ICA distal to the aneurysm was 70 ml/min, in the A1 segment of the right anterior cerebral artery, 30 ml/min, and in the M1 segment of the right MCA, 40 ml/min. To prevent ischemic complications in construction of high-flow anastomosis, the first stage included EICMA of end-to-side type by a 10-0 thread, between the parietal branch of the superficial temporal artery and the cortical branch of the MCA. According to fluorescent video angiography, the anastomosis was functional.

The next stage included the selection and collection of the radial artery on the right forearm. Under the conditions of temporal clipping of the frontal branch (37 min), an anastomosis of the end-to-side type was created using a 9-0 thread between the donor artery and the frontal branch (M2 segment) of the right MCA. The blood flow in the frontal branch was restored. The graft was carried out under the skin above the zygomatic arch to the wound on the neck. The proximal part of the donor artery was clipped, and the distal part of the radial artery was connected with the frontal branch of the right MCA.

![Fig. 1. Perimetry before the surgery.](image1)

![Fig. 2. Magnetic resonance imaging of the brain before the surgery. Axial projection, T2 mode. In the chiasmatic-sellar region there is a giant aneurysm with a maximum diameter of 29 mm.](image2)
artery was stitched end-to-side to ECA using a 7-0 thread. After restoration of blood flow, both visual observation and flowmetry showed that the anastomosis was functional. The volumetric blood flow in the graft was 70 ml/min.

Further, the aneurysm was trapped by two standard Neuron-N clips: in the proximal part, a straight clip was installed distal to the ophthalmic artery mouth, and in the distal part, a clip curved along the rib was superimposed proximally to the posterior connective artery. Fluorescent video angiography showed that the aneurysm is not filled. Aneurysm lumen was opened, bleeding was not observed. Its walls were relaxed.

The volumetric blood flow after trapping in the right ICA distal to the clip was 30 ml/min, in the right anterior cerebral artery, 35 ml/min, in M1 segment of the right MCA, 70 ml/min, and in the graft, 110 ml/min. The dura mater was sewn, the bone flap was fixed. Soft tissues were sewn layer-by-layer.

In the postoperative period, there were mild cerebral symptoms in the form of headaches, which were managed by analgesic agents. The patient received conservative symptomatic treatment.

CT AG, performed on the second day after the surgery, confirmed complete exclusion of the aneurysm and good filling of both anastomoses. No ischemic and hemorrhagic foci were detected (Fig. 4).

Upon recommendation of the neurologist-opthalmologist, transcutaneous electrostimulation (TCES) of the optic nerves was performed; a total of 5 sessions were conducted during the period of hospitalization. There was positive dynamics in the form of increase in visual acuity of the left eye to 0.8. In the right eye, amaurosis was preserved in the early postoperative period.

The patient was discharged on the 10th day after the surgery. The condition on Glasgow scale was 4 points.

In the postoperative period TCES of the optic nerves was continued; a total of 5 sessions were performed. At a follow-up examination after 5 months, the visual acuity of the left eye was 0.8, and vision started to re-appear in the lower nasal quadrant of the right eye with a visual acuity of 0.08 (Fig. 5).
Discussion

Giant aneurysms account for 3—11% of the total number of cerebral aneurysms [9—12]. Without surgical treatment, half of giant aneurysms are at risk of rupture within 5 years [13]. Aneurysms of paraparacloidal localization, due to their position in close proximity to the optic nerve and the chiasma, are often the cause of visual impairments. As the aneurysm grows, it compresses and deforms the ipsilateral optic nerve, and when it reaches gigantic size it stretches the chiasma and the nerve, from the opposite side, resulting in visual field disorders and worsening of visual acuity. At the entrance to the cranial cavity, the optic nerve is fixed in the dural ring of the visual aperture, which, even in case of small ophthalmic aneurysms, leads to its compression and trophic impairment. Paraclinoid aneurysms of large and giant size disrupt the normal blood supply to the optic nerve, causing compression of the eye artery, as well as its small branches, the suprasellar and parasellar arteries [14, 15].

Complications in treatment of giant paraparacloidal aneurysms are weakly correlated with the choice of method: for direct surgery, their incidence, according to the literature [3, 16—18], is 9—22%, while for endovascular techniques it is 9—18%. Since after the treatment, visual impairments can be exacerbated for any of the techniques, the question of choosing the appropriate treatment remains open [19—21].

IBA technique has proved to be successful for direct exclusion of the aneurysms of paraparacloidal localization of large and gigantic sizes [6, 22]. The use of IBA allows relaxing the aneurysm sac, creating conditions for its exclusion and good visualization in the wound. Surgeries with IBA are associated with high radicality, 90—92%, with a relatively low number of complications (3.6—17.3%) [5, 6, 23]. In rare cases, IBA technique does not provide sufficient relaxation of the aneurysm. As a rule, this is caused by unyielding, rigid walls of the aneurysm, fusion of the sac with the surrounding tissues and narrowed lumen of the ICA on the neck in the presence of atherosclerosis.

According to the data obtained by different authors [24, 25], visual and oculomotor disorders are observed in about 13—22% of cases of clipping of giant paraparacloidal aneurysms. The mechanism of lesions is attributed to nerve traumas during dissection and traction, thermal damage during the coagulation and bone resection by a microbore. There are also suggestions that retinal ischemia may play a role in the genesis of visual impairment after surgery using IBA [26—29].

Prior to the introduction of flow stents, approximately 50% of patients with complex (giant, fusiform, dissection) aneurysms could not be operated on using existing microsurgical and endovascular methods of aneurysms clipping. The method of choice was deconstructive surgery (ligation or balloon occlusion of the ICA, direct or endovascular aneurysm trapping), which is associated with high risk of development of neurological deficits and death (30, 31). Aneurysm trapping is gentler technique, since it allows to avoid surgical trauma of the optic nerve and to hope for regression of visual impairments in the postoperative period. Preparations for deconstructive

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Fig. 4. CT of the brain on the 2nd day after the surgery.

a, b — CT AG (MIP): axial (a) and coronary (b) projections. The satisfactory functioning of the high flow anastomosis and EICMA is visible, artifacts from the clips in the region of the right ICA, the absence of aneurysm filling; c — CT AG (3D): reconstruction of intracranial vessels. Part of the bone is graphically hidden; d — CT: axial projection, moderate postoperative pneumocerephaly, there are no data indicative of ischemic and hemorrhagic disorders.
surgery should include assessment of collateral blood flow with balloon-occlusive test, CT perfusion, and electrophysiological monitoring [32, 33]. The choice of the method of revascularization and the type of anastomosis depends on the deficit of cerebral perfusion and the clinical condition of the patient [33—36]. According to L. Sekhar, for patients with a blood flow level of 20—35 cm$^3$/100 g/min it is enough to compensate the blood flow with low flow anastomosis (EICMA), while patients with blood flow below 20 cm$^3$/100 g/min or with a neurological deficit require a high-flow shunt. In our case, taking into account the anomalous structure of the vessels of the Willis circle and high risk of ischemic complications, a decision was made to employ “double” revascularization scheme: creation of an arterial high-flow bypass shunt to replace blood flow in the MCA pool and protective anastomosis (EICMA) for the period of sewing the former.

The TCES technique to treat the optic nerve has been used in the Burdenko Neurosurgical Institute since 1989. According to N.M. Eliseeva [37], the improvement of visual function is due to the polarizing effect of electric current on the nerve and electrostimulation of retinal cells. The technique in combination with drug therapy allows to achieve a certain degree of restoration of visual function.

**Conclusion**

The capabilities of modern neurosurgical techniques make it possible to achieve radical exclusion of complex paraclinoid aneurysms of the ICA with good functional outcome. Even with pronounced visual impairment caused by an aneurysm, one can expect the recovery in case of elimination of the mass effect and preservation of the nerve and vascular structures of the visual analyzer.

**Authors declare no conflict of interest.**

**REFERENCES**


The article presents a case of treating a patient with a giant aneurysm of the paraclinoid section of the right internal carotid artery (ICA).

The choice of a method of treatment for this pathology is always complicated. On the one hand, the goal is to radically exclude the aneurysm in order to eliminate the risk of intracranial hemorrhage, and on the other, to prevent visual impairment. In the Burdenko Neuro-surgical Institute, the interest in this problem has emerged from the moment of development of endovascular neurosurgery with balloon-catheter technology. However, in patients with giant paraclinoid aneurysms and insufficient collateral circulation, the use of this method was limited. The use of EICMA in combination with endovascular balloon occlusion at the level of the aneurysm of the neck (Yu.M. Filatov et al., 1987, F. Serbinenko et al., 1990) yielded better results not only in terms of radical aneurysm exclusion from the blood flow and reduction of ischemic complications, but also in ensuring the improvement of visual function due to retraction of thrombi in the excluded aneurysm with a decrease in its size and pseudotumoric effect on the optic nerve and the chiasma. It is more difficult to treat such aneurysms in the absence of connective arteries. Under these conditions, EICMA does not provide reliable protection against ischemic complications. This served as an impetus for development of high-flow anastomoses in the surgery of giant aneurysms of the ICA.

At the current stage of neurosurgery development, most interventions for unruptured aneurysms of the ophthalmic and cavernous segments of the ICA are performed endovascularly using spirals or flow-guided stents. At the same time, in case of giant paraclinoid aneurysms intravascular operations sometimes are not the method of choice because they are associated with high risk of hemorrhage after stenting against in the presence of dual antiplatelet therapy and preservation of the mass effect when the aneurysm cavity is occluded by spirals.

The technique of aneurysm trapping after revascularization of the distal branches of the middle cerebral artery is technically complicated, but, as the authors of the article point out, it has some advantages in terms of minimizing the trauma to the optic nerve during the surgery.

Improvement of visual functions of the blind eye of the patient in this case was largely due to proper choice of surgery tactics.

The article is interesting, instructive and is, in our opinion, a milestone on the way to wider application of high-flow anastomoses in surgery of giant aneurysms of the ICA, especially in case of paraclinoid localization.

V.A. Lazarev (Moscow, Russia)
Giant Partially Thrombosed Aneurysm of the Vertebral Artery: Case Report and Literature Review

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Introduction. Giant partially thrombosed aneurysms of the vertebral artery are recalcitrant to treatment by microsurgical trapping and thrombectomy. Application of endovascular interventions is limited due to substantial brainstem compression and cranial neuropathy. Combined endovascular exclusion and microsurgical excision provides an approach to treatment of this pathology.

Clinical case. A 48-year-old female patient was admitted with progressive complaints of ataxia, diplopia in the left lateral gaze, and dysphagia. Imaging studies (CT, MRI, angiography) revealed a giant partially thrombosed aneurysm of the right vertebral artery and pronounced brainstem compression.

Treatment. The initial phase of treatment involved endovascular occlusion of the vertebral artery and aneurysm trapping, which did not lead to changes in patient's neurological status. Postoperative MRI demonstrated complete aneurysm thrombosis and a weak TOF signal in the vertebral artery near the proximal portion of the aneurysmal neck. Because of persistent brainstem compression, the patient underwent right suboccipital craniectomy and hemilaminectomy of the CI arch for aneurysm excision one week after endovascular occlusion. After isolation of the aneurysmal sac, the vertebral artery was transected, and two small branches extending from the aneurysm neck to the brainstem were also coagulated and transected followed by aneurysm excision. Numerous vasa vasorum in the wall of the proximal portion of the vertebral artery and aneurysm neck were coagulated in order to stop bleeding. After surgery, the patient developed neurological symptoms (right leg ataxia and worsening of dysphagia) due to lateral medullary infarction (confirmed by MRI) that presumably resulted from coagulation of two small perforating branches coming from the aneurysm neck to the brainstem. Conservative treatment led to recovery of the patient's neurological functions. The patient was discharged with mild right leg ataxia and preoperative left abducens paresis.

Conclusion. Compression of the medulla oblongata associated with a giant thrombosed aneurysm of the vertebral artery can be eliminated by endovascular trapping followed by surgical excision of the aneurysm. Preservation of vasa vasorum feeding the brainstem is crucial to prevent ischemic complications.

Keywords: endovascular occlusion, lateral medullary infarction, thrombosed giant aneurysm, vertebral artery, microsurgical treatment.

Abbreviations
CT — computed tomography
CT-AG — computed tomography angiography
MR-AG — magnetic resonance angiography
MRI — magnetic resonance imaging
MRI-TOF — Time of Flight Magnetic Resonance Angiography
VA — vertebral artery

Aneurysms of the vertebral artery (VA) account for less than 5% of cerebral aneurysms. Most often, they manifest as intracranial hemorrhage, and, when reaching large or giant size, lead to compression of adjacent neural and vascular structures. Increase in aneurysm dimensions due to gradual thrombogenesis is accompanied by various neurological manifestations resulting from direct impact on the medulla oblongata and cranial nerves, development of occlusion hydrocephalus due to obstruction of the fourth ventricle, and ischemic lesions of the brain stem caused by circulatory disturbance in the compressed perforating vessels [1—13].

Along with microsurgical techniques of VA aneurysm exclusion from circulation, endovascular techniques are used, which enable avoiding some complications associated with “open” surgical treatments. However, intravascular intervention in the early postoperative period does not always lead to elimination of compression effect on the adjacent neural structures, which is especially true in the case of partially thrombosed large and giant aneurysms of the VA [1, 2, 5, 6, 8, 11, 14—16].

The present report describes the clinical case of a giant partially thrombosed aneurysm of the VA, which was treated by successive application of endovascular and microsurgical techniques.

Clinical case

Patient D., 48 years old, was admitted on 13.04.15 with complaints of headache, dizziness, hypotaxia, dysphagia, and diplopia in the left lateral gaze. The patient experienced headache, dizziness, and ataxia since July 2014. These symptoms slowly worsened during the following several months followed by dysphagia and diplopia in the left lateral gaze. MRI, CT, and CT-AG...
examination detected giant partially thrombosed aneurysm of the right VA accompanied by obstructive hydrocephalus. Ventriculo-peritoneal bypass surgery was conducted on 11.09.14 at the regional hospital according to the place of residence, which resulted in partial regression of disease symptoms.

Evaluation of neurological status at admission revealed horizontal nystagmus to the left and left abducens paresis, as well as ataxia with intention tremor during coordination tests. CT-AG conducted on 13.04.15 confirmed the presence of giant partially thrombosed fusiform aneurysm of the right VA, having a total size of 47x39x42 mm, whose functioning portion reached 21x12x11 mm. The wall of the aneurysm included numerous calcification foci; the thickness of the thrombosed part varied within the range of 4—19 mm. Medulla oblongata and inferior portions of the fourth ventricle were significantly deformed and dislocated to the left with dilation of the ventricular system (Fig. 1).

Catheterization of both VAs followed by contrast imaging of vertebrobasilar vessels was carried out on 17.04.15 through bilateral femoral puncture approach under endotracheal anesthesia. Right VA was elongated and deformed throughout the whole intracranial segment. The cavity of a giant partially thrombosed fusiform aneurysm located eccentrically with respect to the aneurysm-bearing vessel is observed in the proximal third of the intracranial segment of the VA. The length of the distal third of the VA, which was deformed and shifted by aneurysm dome, was about 20 mm. The mouth of the right posterior inferior cerebellar artery was not visualized, however, its distal branches were filled through anastomoses with ipsilateral anterior inferior cerebellar artery. Both VAs and the point where they merged into the basilar artery were deformed and shifted to the left (Fig. 2a, b).

Microcatheter was pulled from the right femoral artery to the ipsilateral VA and its tip was mounted distal to the aneurysm; the lumen of the vessel was occluded with coils for up to 5 mm. Positioning of the tip of the catheter and microcoils was monitored using contralateral (retrograde) angiography. Extended occlusion of VA together with the aneurysmal neck was achieved using gradual proximal tightening of the microcatheter and additional microcoils. Control angiography showed no opacification of the aneurysmal cavity and medial part of the intracranial segment of the right VA. Blood flow in the basilar artery and its branches was provided by the left VA (see Fig. 2c, d).

The patient underwent VA occlusion without neurological complications and CT confirmed the absence of intracranial hemorrhagic and ischemic brain lesions on the second day after intervention. On 21.04.15, MRI and MR-AG revealed total thrombosis of the aneurysm and the absence of antegrade magistral blood flow in the right VA with retrograde filling of its distal segment from the basilar artery. Signs of low blood flow were detected in the right VA up to the fusiform aneurysm, including its wall, as evidenced by the presence of MR-TOF signal (Fig. 3).

On 23.04.15, the patient underwent right-sided suboccipital craniectomy and hemilaminectomy of the atlas, exposing extracranial segment of the right VA, through the medial approach in patient’s sitting position. After dissection of the dura mater (DM), giant thrombosed aneurysm was visualized in the tonsilomedullary fissure (Fig. 4a). Right VA, whose wall included numerous dilated vasa vasorum, was connected to the lower portion of the fusiform aneurysm. Medulla oblongata and upper spinal cord were accurately displaced to the left by the aneurysmal dome. Loops of microcoils installed during endovascular intervention were visible through the thinned bottom wall of the aneurysm (see Fig. 4b). The wall of the aneurysm was partially excised in its medial portion in order to remove dense thrombi. Size reduction enabled aneurysm shifting in the lateral direction to visualize the distal segment of the VA, sharply deformed medulla oblongata, and inferior portion of the fourth ventricle. The vertebral artery was coagulated and transected together with endoluminal coils distal to its exit from the aneurysmal sac (see Fig. 4c).

Two thin arteries extended from the lower parts of the fusiform wall of the VA aneurysm to the inferior medulla oblongata, which were coagulated and transected. Moderate bleeding was observed during transection of the proximal segment of the artery at the site where it was connected to the aneurysm. Hemostasis was achieved by coagulation of the vascular walls up to the dural penetration of the VA. The aneurysm was removed and the fibers of the hypoglossal nerve and caudal group of cranial nerves pulled on the anteroinferior portion of the dome were isolated and anatomically preserved (see Fig. 4d). Continuous DM suture was followed by wound closure using standard technique.

Control CT scan of the brain on the day after surgery detected no hemorrhagic or ischemic lesions. Clinical presentation was characterized by increased ataxia and incoordination in the right lower limb, as well as dysphagia with choking that required installation of nasogastric tube, which was removed in 6 days due to regression of bulbar disorders.

On 30.04.15, MRI revealed small ischemic lesion in the right part of the medulla oblongata (Fig. 5). The patient was discharged from the hospital 2 weeks after aneurysm excision, having only mild ataxia in his right leg and left abducens paresis.

Discussion

Giant partially thrombosed aneurysms of the VA, involving significant portion of the vascular wall, in most cases cannot be treated by neck clipping with preservation of the lumen of the aneurysm-bearing artery and all its branches. The optimal treatment for these aneurysms is
not determined as of now due to their parastemal location, wide neck, calcification of the walls, and dense intraarterial thrombi. Preservation of perforating thin branches running from the aneurysmal neck to the brainstem, reduction of aneurysm size, and revascularization of hemodynamically significant branches of the aneurysm-bearing vessel subjected to microsurgical or endovascular exclusion is of key importance to prevent ischemic disorders [2, 4, 13, 18—23].

Microsurgical treatment of VA aneurysms is a challenging problem due to close proximity of critical cerebral structures, such as the medulla oblongata and caudal group of cranial nerves. Various posterolateral approaches, including retromastoidal, transcondylar, and presigmoid retrolabyrinthine approaches provide quite good visualization of VA aneurysms in the lateromedial direction. Limitations of existing surgical techniques include the need to operate in a narrow surgical tunnel, which may be accompanied by growth of neurological deficits caused by direct microsurgical manipulations, ischemic disorders due to coagulation and vasoconstriction of the perforating vessels of the brainstem [2, 9, 13, 22, 23].

Development of new techniques, such as stent-assisted occlusion of the aneurysmal cavity and the use of flow-diverting stents resulted in significant improvement of the results of treatment of large and giant intracranial aneurysms. Endovascular techniques enable aneurysm exclusion from the circulation and significantly reduce the risk of intracranial hemorrhage. However, they also have some disadvantages, such as incomplete occlusion and delayed recanalization of the aneurysm, as well as stent thrombosis [24—26]. Persistence or increase in the volumetric effect on adjacent neural structures accompanied by increase in neurological deficit is an important feature of endovascular interventions, caused by increase in aneurysm dimensions in the early postoperative period due to thrombosis, [1, 6, 8, 15, 16, 21].

These characteristic features necessitate the use of the strategy of blood flow minimization in the aneurysm
The main treatment methods for these aneurysms include proximal occlusion of the aneurysm-bearing vessel, aneurysm exclusion, distal occlusion, and reconstruction of the vascular lumen.

G. Steinberg et al. [28] showed that, in patients with giant aneurysms of the VA, complete thrombosis of aneurysms was observed in 87% of cases after proximal occlusion of the aneurysm-bearing vessel followed by decrease in neurological disorders. In the case of partial thrombosis of giant aneurysms, increase in neurological loss was observed in 67% of cases, which was lethal in 86%. S. Nagahiro et al. [9] have summarized the clinical data of patients with giant thrombosed aneurysms of the VA as exemplified by 20 cases, 17 of which have been studied in the literature. Surgical treatment was performed in 17 cases, while in the remaining cases surgical interventions were not carried out because of severe neurological deficit and related respiratory disorders. In 4 cases, clipping of dense and wide aneurysmal neck was carried out and good results were achieved in 2 of them. Proximal occlusion of the VA using clip or balloon was carried out in 8 patients, of whom 1 patient died, 2 patients demonstrated good effect, and 5 patients required additional surgery due to neurological deterioration. The authors concluded that proximal occlusion of the aneurysm-bearing vessel is an inadequate treatment for this group of aneurysms, as evidenced by the fact that thrombosed aneurysms continued to increase in size in 2 cases of spontaneous VA occlusion observed by the authors [9].

Proximal VA occlusion using endovascular technique or open clipping may result in gradual improvement of patient’s condition due to slow decrease in size of thrombosed giant aneurysms. Proximal occlusion is often accompanied by progressive worsening of stem-related disorders arising due to increase in aneurysm dimensions accompanied by compression and ischemic effect on the brainstem and cranial nerves. In these cases, it is necessary to exclude the aneurysm from circulation by
occlusion of the aneurysm-bearing vessel distal to the aneurysmal neck, which may also be accompanied by stabilization and improvement of patient’s condition due to gradual decrease in compression effects [1—6, 8, 9, 11, 12, 14—16, 21, 27, 29, 30].

Single-step or step-by-step combination of proximal and distal (microsurgical or endovascular) occlusion of the aneurysm-bearing vessel usually results in aneurysm exclusion, but in some cases the size of the aneurysm may progressively increase [6, 10, 14—16].

K. Iihara et al. [19] studied the effect of multimodal surgical approach on the size of large and giant partially thrombosed aneurysms in the posterior circulation in a group of 17 patients, including 6 cases of VA aneurysm located on the arterial segment without branches. Four patients underwent endovascular trapping, 1 — distal occlusion (with almost complete spontaneous proximal occlusion), and 1 — open proximal occlusion. In 3 cases, aneurysms were located near the mouth of the posterior inferior cerebellar artery (PICA); in 2 cases, revascularization of the PICA was performed followed by proximal clipping and endovascular trapping. When comparing aneurysm sizes, locations, MRI features, and used surgical techniques, the authors concluded that endovascular trapping of giant partially thrombosed aneurysms results in delayed decrease in their size. For aneurysms located at branching points, the strategy of concomitant phased maximum change in blood flow and revascularization is effective. It was also noted, that the lack of opacification of the aneurysm wall and perifocal edema is indicative of both the low potential of its growth, and low probability of reduction in its size [19].

The mechanism for increase in size of subtotally thrombosed giant aneurysms manifested by pseudotumorous clinical course is still unknown. They increase in size due to hemodynamic factors and repeated hemorrhage from vasa vasorum into the thickened vascular wall and intraluminal thrombotic mass [9, 14, 31—34]. S. Nagahiro et al. [9] analysed instrumental, surgical, and post-mortem data of 3 patients with giant thrombosed VA aneurysms. Microscopic examination of the excised aneurysms confirmed the presence of wide tortuous channels partially coated with endothelial lining, which was previously detected by other investigators. These vascular channels, extending from the vascular wall depthward the thrombotic masses, are the source of bleeding into thrombotic mass accompanied by gradual growth of aneurysms.

Under normal conditions, vasa vasorum are present only in the proximal segments of the intracranial portions of vertebral and carotid arteries, near to the site where they pierce the DM. The absence of these vessels in infants and children is indicative of the acquired character of vascularization of vascular walls. Increase in the density of vasa vasorum occurs not only due to atherosclerosis, but also due to vascular thrombosis accompanied by hypoxia of the arterial wall [6]. Thus, extensive adventitial neovascularization, consisting of dural and leptomeningeal vessels closely adjacent to the walls of the aneurysm-bearing artery sealed by thrombi and microcoils, can be the source of blood supply to the aneurysm.

Investigation of MRI characteristics of dolichoectatic and fusiform aneurysms showed that the presence of the hyperintense signal and contrast accumulation in the aneurysmal wall are important predictors of its progressive growth [6, 9]. K. Iihara et al. [19] reported a case, wherein the giant partially thrombosed aneurysm of the VA was successfully excluded from the circulation using two successive endovascular procedures. MRI examination revealed increase in severity of previously existing brainstem edema and opacification of the peripheral parts of the aneurysm. According to the authors, these findings are due to neovascularization process and mild re-hemorrhage into the aneurysm, resulting in worsening of patient’s condition. Surgical exploration found pronounced vasa vasorum, extending from the VA to the aneurysmal wall. Partial excision of the wall and removal of thrombus with microcoils led to regression of neurological disorders.

In the present case, the neck of the giant aneurysm represented significant portion of the VA wall and diagnostic tests revealed that its distal portion was filled from the basilar artery with agenesis of the posterior
inferior cerebellar artery. This anatomical structural feature of the vertebrobasilar basin enabled the use of VA occlusion with aneurysm exclusion from the blood stream as a safe method of treatment.

The need for elimination of the brainstem compression and persisting hydrocephalus and the possibility of recanalization or increase in thrombotic mass volume gave the reasons for surgical excision of the giant thrombosed aneurysm of the VA. Various combinations of endovascular or microsurgical exclusion of the aneurysm-bearing vessel with simultaneous or delayed removal of the thrombosed aneurysm were applied by several authors with varying success [2, 6, 14, 16, 21, 35, 36].

Low intensity of MR-TOF signal from the proximal segment of the VA after occlusion may indicate the initial stage of aneurysm recanalization due to coil packing or their displacement into the thrombotic masses. Preservation of the antegrade blood flow in the small intracranial branches or vasa vasorum of the VA itself and the aneurysmal wall may be another reason the unusual MRI picture. This hypothesis is supported by our finding that there is low antegrade flow in the VA, which was previously completely occluded using the endovascular technique during its transection near to its

Fig. 4. Intraoperative images of a giant partially thrombosed aneurysm.
C1 — first cervical nerve root; IX—XI — caudal group of cranial nerves; XI — accessory nerve; XI (Sp.) — spinal fibers of the accessory nerve; XII — hypoglossal nerve.
entrance to the aneurysmal wall. A similar intraoperative finding was reported by other authors, who mentioned the importance of adventitial neovascularization of the occluded vessel as a potential source of blood supply to the aneurysm from the surrounding dural and leptomeningeal vessels [13, 16, 19, 36].

Dysphagia in the immediate postoperative period after microsurgical procedures may be caused by manipulations on the caudal group of cranial nerves during isolation, clipping, and excision of the VA aneurysms [37]. Transient neurological disorders (dysphagia and spinocerebellar tract disorders) that developed in this case correspond to clinical manifestations of lateral medullary infarction (Wallenberg’s syndrome). Neurological symptoms of lateral infarctions of the medulla oblongata resulting from lesions of the VA and posterior inferior cerebellar artery widely vary due to the variability of blood supply to brainstem structures, and thus depend on the extent of the ischemic lesions of the lower brainstem both in transverse and vertical directions [38, 39]. In the present case, relatively small ischemic injury occurred in the dorsolateral medulla oblongata, which fully complied with neurological manifestations. Circulatory disorders were most probably caused by transection of thin arterial branches running to the brainstem from the aneurysmal wall. It should be emphasized that endovascular occlusion accompanied by termination of antegrade blood flow in the VA did not lead to additional neurological symptoms or change in MRI characteristics of the brainstem. This fact supports the assumption that transected thin vessels are the prolongation of VA vasa vasorum, which gradually formed and widened as a result of repeated intraparietal hemorrhages, causing aneurysm growth. Increase in the number and size of vasa vasorum is accompanied by neovascularization process in adjacent brain structures as a result of their anastomosis with leptomeningeal vessels. Transection of vasa vasorum, running from the aneurysmal wall, during aneurysm removal resulted in circulatory problems in the medulla oblongata in this case.

The reported clinical case demonstrates that endovascular occlusion of the aneurysm-bearing artery followed by microsurgical removal is an effective combination for treatment of giant partially thrombosed VA aneurysms. In the cases, where thin VA branches supplying blood to the brainstem are detected, microsurgical intervention should be limited to removal of intra-aneurysmal thrombotic masses. Thrombectomy and partial resection of aneurysmal wall retaining leptomeningeal branches running therefrom provide adequate decompression of adjacent neural structures and thus reduce the risk of ischemic lesions of the medulla oblongata.

Authors declare no conflict of interest.
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The article reports a case of successful two-stage surgical treatment of giant partially thrombosed aneurysm of the vertebral artery with phased application of endovascular and microsurgical techniques. Surgical treatment of patients with giant partially thrombosed aneurysms is still a challenging problem in modern vascular neurosurgery. This article is relevant and important for vascular neurosurgeons, since it presents clinical features, neuroimaging picture, and treatment strategy exemplified by clinical case. There are also extensive literature data, concerning the issues of genesis and surgical treatment of giant partially thrombosed cerebral aneurysms. This study reports a good example of high effectiveness of the combination of two major neurosurgical techniques in treatment of intracranial aneurysms; it is attractive due to logical choice of treatment tactics, good illustrations, and complete discussion of the problem, including analysis of literature data. The issues of aneurysm growth mechanism were covered, the importance of hemodynamic factors and the role of vasa vasorum in the blood supply to the nearby brain structures were discussed. In our view, clipping of the vertebral artery stump before transection is safer than long-range coagulation of its stem. Regarding the time of the second stage of surgical treatment, it is advisable to do it as soon as possible, if there is at least a minor blood flow in the precervical portion and there are pronounced vasa vasorum.

Microsurgical aneurysm exclusion from the circulation followed by removal of thrombotic masses in order to eliminate compression of surrounding brain structures is the optimal way to treat these aneurysms. However, this procedure is often difficult and sometimes impossible, since most of these aneurysms have dense calcified atherosclerotic walls. Often, aneurysm growth leads to inclusion of aneurysm-bearing artery or its perforating branches to the wall of aneurysmal body or neck, as it occurred in the reported case. The aforementioned factors often make aneurysms inoperable, especially in the case of vertebrobasilar location. Implementation of modern endovascular techniques led to broadening of indications to surgical treatment of large aneurysms and improved treatment outcomes. However, the use of the latter does not fully solve the problem of treatment of “complex” cerebrovascular aneurysms. Under these conditions, vascular neurosurgeons use various combinations of two treatment techniques for cerebral aneurysms, as shown in this paper. In our view, microsurgical revascularization surgery is a promising surgical technique to treat these aneurysms.

A.S. Kheyreddin (Moscow, Russia)
Combined Surgical Treatment of Cavernous Internal Carotid Artery Pseudoaneurysm


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We report a clinical case of surgical treatment of cavernous internal carotid artery (ICA) pseudoaneurysm that developed due to damage to the artery during transsphenoidal resection of pituitary adenoma. Clinically, the aneurysm presented with episodes of profuse epistaxis that required tight nasal packing. Given the incomplete circle of Willis, the patient underwent staged surgery that included formation of a high-flow extra-intracranial anastomosis followed by endovascular ICA occlusion at the pseudoaneurysm level using balloon-assisted coiling and endoscopic debridement of the nasal cavity. The combined surgical treatment of this rare complication resulted in successful pseudoaneurysm exclusion from the bloodstream, which led to complete regression of nasal hemorrhage.

Keywords: transsphenoidal approach, complications, high-flow anastomosis, pseudoaneurysm, internal carotid artery injury.

Endoscopic endonasal transsphenoidal approach is widely used to remove tumors of chiasmosellar area. In the literature [1], there are publications that focus on the efficacy and safety of endoscopic transsphenoidal approach, which is currently used to remove more than 95% of all pituitary adenomas.

Injury of the cavernous segment of the internal carotid artery (ICA) is one of the most serious and even potentially fatal complications in transsphenoidal surgery, whose incidence, according to various authors [2, 3], is 0 to 3.8%. According to P.L. Kalinin et al. [2], among the 4 cases of this complication (0.13% of the total number of patients, who underwent transsphenoidal surgery), mortality was 50%.

Here we report a clinical case, demonstrating an example of surgical complication and treatment with a favorable outcome.

Clinical case

Patient Z., 41 years old. Clinical diagnosis: hormonally inactive endo-suprasellar pituitary adenoma (Fig. 1). The disease manifested in the form of cranial pain.

Medical history. 21.04.16 endoscopic transsphenoidal tumor resection was carried out according to the place of residence. During the operation, cavernous segment of the right ICA was damaged. Bleeding was stopped by tamponade of the main sinus with gauze tampons. There were no focal neurological symptoms.

When changing the tampons on day 4 after surgery, there was an episode of massive profuse nasal hemorrhage. CT angiography detected pseudoaneurysm of the cavernous segment of the right ICA.

The patient was transferred to the Burdenko Neurosurgical Institute. At admission, neurological status was without focal cerebral symptoms. Nasal cavity was firmly plugged, gauze tampons soaked with blood, brown, with a strong putrefactive odor, since they were not changed for more than a week due to the risk of profuse bleeding. Patient was administered with antibiotic therapy due to the risk of septic complications.

Cerebral angiography confirmed the presence of the pseudoaneurysm of the cavernous segment of the right internal carotid artery (Fig. 2a), whose walls were formed by muscle fragments placed in the sphenoidal sinus and tightly tamponed with gauze. Under these conditions, endovascular exclusion of the pseudoaneurysm, while maintaining ICA patency, was not possible due to the extensive defect of the arterial wall and high risk of recurrent profuse bleeding from the rupture after removal of the tampons that formed pseudoaneurysm walls. Exclusion of the ICA from the circulation was associated with high risk of ischemic stroke in view of angiographic signs of incomplete circle of Willis (see Fig. 2b).

In this regard, we decided to form a high-flow extra-intracranial anastomosis (EICMA) on the right as the first stage followed by single-stage occlusion of the damaged internal carotid artery at the level of rupture.

Operation. Proximal portion of the sylvian fissure was dissected through the pterional approach followed by separation of the temporal branch of M2 segment of the right medial cerebral artery (MCA) from arachnoid adhesions. Its diameter was up to 2 mm. Simultaneously, approach to the right common, external, and internal carotid arteries was performed along the medial edge of the sternocleidomastoid muscle. Allen test confirmed
good collateral circulation in the left hand, and 30 cm-long fragment of the left radial artery was separated, tied up, transected at the wrist and immediately distal to the bifurcation of the ulnar artery.

Temporary clipping of the temporal branch of M2 segment of the right MCA was followed by formation of end-to-side microvascular anastomosis with autoarterial graft at this level, using continuous suture with Prolene 9.0. The autoarterial shunt was temporarily clipped immediately proximal to the anastomosis. Blood flow in the M2 segment was restored; good pulsation of M2 was visualized distal and proximal to anastomosis; anastomosis was leak-tight. M2 clamping time was 32 minutes. Autoarterial graft was pulled to the wound at the right anterolateral neck surface through the subcutaneous and axillary preauricular channel with partial resection of the zygomatic arch. With underlying temporary clipping of the proximal segment of the right external carotid artery (ECA), vascular end-to-side anastomosis was formed by continuous suture at an angle of 45° between the proximal end of the autoarterial graft and ECA. ECA clamping — 12 min. Good filling of the shunt was detected after consequential removal of clips from the ECA and autograft (Fig. 3a). Functioning of the anastomosis was confirmed by fluorescent angiography, IR800 (see Fig. 3b).

After formation of anastomosis, the patient was transferred to the X-ray operation room, still being under general anesthesia, to perform endovascular stage of the surgery. Balloon test occlusion of the right internal carotid artery was carried out (Fig. 4a). Control angiography of the right common carotid artery confirmed functioning of the high-flow shunt between the ECA and M2 segment of the right MCA with good filling of the anterior cerebral artery and right MCA systems. Stationary balloon-assisted endovascular occlusion of the right ICA was carried out at the level of pseudoaneurysm with three coils. Pseudoaneurysm was fully excluded from the bloodstream together with the right ICA. Blood supply to the right ICA system was established through the high-flow shunt between the ECA and the M2 segment of the MCA (see Fig. 4).

As the third stage, endoscopic endonasal revision of the nasal cavity was carried out in the X-ray endovascular operating room without awkening the patient. There was no arterial bleeding after tampon removal from the nasal cavity. Nasal cavity and sphenoid sinus were debrided. In the early postoperative period, the patient developed mild pyramidal symptoms in the form of left-sided hemiparesis (strength decrease to 3—4 points), left-sided hemihypesthesia, and left-sided homonymous hemianopsia. MRI of the brain showed local ischemic lesion in the right temporal region. Hemiparesis almost completely regressed during conservative therapy. Hemihypesthesia and homonymous left-sided hemianopsia persisted. The patient gradually became more active and began to get up and move independently.

There were no recurrent episodes of nasal bleeding. Control SCT angiography detected functioning extra-intracranial high-flow anastomosis (Fig. 5). The right ICA and pseudoaneurysm were not contrasted.

The patient was discharged in satisfactory condition on the 12th day after the operation.

**Discussion**

Injury of the cavernous segment of the internal carotid artery (ICA) is a rare, but potentially fatal complication in the transsphenoidal surgery. A. Tabaei [4] reported 2 deaths after endoscopic transsphenoidal operations, which accounted for 0.24% of patients in his series. All of them were associated with ICA injury. The
The incidence of this complication undoubtedly depend on the surgeon’s experience. According to I. Ciric [5], the incidence of ICA damage was 1.4% in the group of patients operated on by surgeons having little experience of transsphenoidal operations (up to 200 operations) and 0.4% in the group of patients operated on by more experienced surgeons (more than 500 operations). These complications can also be caused by poorly resolved natural anatomical landmarks (nasal septum, choana, rostrum, bottom of the sella turcica, sinus caroticus), which often occurs after repeated operations, in the case of underdeveloped primary sinus in children and in patients with severe infrasellar tumor growth, and in patients with acromegaly [3].

Currently, there is no unified tactics of surgical treatment of ICA injuries. In some cases, it is possible to coagulated small defects of the artery using bipolar coagulation [6, 7], or perform ICA trapping in the region of rupture. Thus, A. Kassam et al. [7] described an example of clipping of damaged ICA distal and proximal to the defect from the endoscopic transsphenoidal approach. The operation was associated with great technical difficulties and accompanied by development of ischemic complications.

Tamponade of the sphenoidal sinus with muscle is another possible method to stop bleeding from damaged ICA, but this tactics is not always effective. Thus, according to P. Gardner [6], in 7 cases of ICA damage during removal of pituitary adenomas (0.3% of the total number patients in the series), bleeding from the damaged vessel was successfully stopped by sinus cavity tamponade with muscle in only one patient. In our...
In similar cases, surgical treatment is aimed at fastest possible tamponade of the sphenoidal sinus and nasal cavity with hemostatic materials and gauze tampons followed by cerebral angiography and selection of defect closure technique [2].

Endovascular occlusion of the vessel at the level of vascular defect or stent graft installation is suggested as the primary method to treat iatrogenic damage of the cavernous segment of the ICA [2, 8]. These interventions are limited by severe defects of the ICA, which make the use of flow-redirecting stents ineffective, and the lack of adequate collateral circulation, which may lead to the development of ischemic stroke after occlusion of the damaged vessel [2]. Similar situation was observed in the patient, whose case we report in this paper.

Surgery for cerebral revascularization is carried out on the side of occlusion in order to prevent ischemic complications associated with exclusion of damaged ICA from the circulation. This approach has been successfully used in the surgical treatment of giant aneurysms of the ICA. Pre-operative assessment of the possibilities of collateral circulation is a key factor in the choice of shunting options. Thus, formation of low-flow

**Fig. 4.** a — functioning anastomosis (shown by red arrows) with underlying temporary test occlusion of the ICA.

Control angiography after endovascular occlusion of the pseudoaneurysm together with damaged right ICA, lateral (b) and frontal (c) view. 1 — external carotid artery; 2 — balloon-occluded internal carotid artery; 3 — medial cerebral artery.

**Fig. 5.** Control spiral CT angiography in the multiplanar (a) and 3D (b) reconstruction mode confirmed well-functioning anastomosis (shown by arrows).
anastomosis between the branches of the superficial temporal and medial cerebral arteries can not fully compensate for the lack of cerebral circulation in the system of occluded ICA, which causes severe ischemic complications [9—11]. In these cases, formation of high-flow EICMA is indicated. Thus, in the series of L. Rangel-Castilla [12], high-flow extra-intracranial anastomoses with proximal branches of the MCA were formed on the side of occlusion in 8 patients with ICA injury before carotid artery exclusion. In all cases, severe ischemic complications were avoided.

In the present clinical case, flow-substituting revascularization of the brain using a high-flow autoarterial shunt was indicated due to angiographic signs of the incomplete circle of Willis. This provided adequate compensation of the cerebral blood flow, which enabled exclusion of the pseudoaneurysm along with damaged ICA from the blood flow with minimum ischemic complications in the form of homonymous hemianopsia and hemihypesthesis.

The above case shows that ICA damage accompanied by profuse bleeding is a challenging surgical problem that should be treated using a multimodal approach. Several operating teams were involved in this surgical intervention, who carried out open, endovascular, and transnasal surgical stages. The correct interpretation of angiographic results was the key to successful treatment of this complication and prevented undue urgent occlusion of the ICA, which would inevitably lead to severe ischemic complications.

In this regard, prevention of ICA injury is highly important when planning transphenoidal surgical procedures. In particular, more thorough preoperative study of anatomical features of the chiasmosellar area based on preoperative MRI data, assessment of the size of primary sinus and its air content, and timely detection of medial displacement of the cavernous ICA are required [2]. Furthermore, intraoperative use of Doppler sonography, which enables visualization of the ICA, is appropriate [13].

**Conclusion**

Damage to the ICA is a severe complication of endoscopic surgery for pituitary adenomas, whose correction requires a detailed angiographic examination and the use of staged multimodal approach to treatment. The use of extra-intracranial high-flow anastomoses compensates for cerebral blood flow in patients with insufficient collateral circulation, when exclusion of the damaged ICA from the blood stream is required. It is advisable to use Doppler sonography, which provides visualization of the ICA during the extended lateral transsphenoidal approach, in order to prevent these complications.

**Authors declare no conflict of interest.**

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Damage to the wall of the intracranial segments of internal carotid artery followed by the development of pseudoaneurysm is a rare complication, which is associated with extremely high risk of disability and mortality. These complications are increasingly more frequently reported in recent literature due to popularization of endoscopic techniques in skull base surgery. Of course, the ideal method to treat damaged arterial wall is to restore its integrity. At the present state of the art in neurosurgery, it can be achieved using various methods described in this article. However, in some cases, deconstructive techniques with exclusion of the internal carotid artery from the circulation at the damaged area are required. In these situations, surgical tactics is similar to treatment of giant aneurysms of the internal carotid artery, when assessment of collateral blood supply to the brain distal to the damaged area plays a key role, when making a decision about the possibility of artery occlusion.

The authors have reported a unique case, when pseudoaneurysm developed as a result of iatrogenic damage to the cavernous internal carotid artery after endoscopic surgery. Blood flow in the main artery could not be restored, while its exclusion from the circulation, most likely, would have led to the development of severe stroke due to the lack of adequate collateral blood supply through the intracranial arteries. Formation of high-flow extra-intracranial anastomosis followed by occlusion of the internal carotid artery in its cavernous segment was the only plausible solution of this surgical problem, which was successfully done by three neurosurgical teams. A wide repertoire of neurosurgical techniques used at the Burdenko Neurosurgical Institute enables conducting all surgical stages simultaneously. First, high-flow anastomosis was formed in the vascular surgical room instrumented for microsurgical interventions; the second stage included occlusion of the cavernous segment of the internal carotid artery in the endovascular operating room under x-ray guidance; at the final stage, the team of endoscopic neurosurgeons removed tampons from the nasal cavity and sphenoidal sinuses.

This case demonstrates the advantage of well-equipped major neurosurgical centers, where patients with any neurosurgical pathology can be operated on and possible complications, which are inevitable in surgical practice, can be successfully solved.

V.A. Lazarev (Moscow, Russia)
In recent years, the widespread use of non-invasive brain study techniques has led to the fact that cerebral aneurysms are frequently detected before their rupture, which has raised the issue of managing these patients. According to the international literature, there are no definite recommendations on this issue. Obviously, the risk of hemorrhage from an aneurysm as well as high post-hemorrhage disability and mortality require new approaches to hemorrhage prophylaxis.

For many years, surgical treatment of unruptured aneurysms (UAs) has been considered in Western Europe, Japan, and the US as a method to prevent subarachnoid hemorrhage. In these countries, the number of operations for UAs is progressively increasing. According to Japanese authors, early treatment of UAs reduces the number of SAHs. However, there are still no generally accepted recommendations on the management of UA patients. Large neurosurgical clinics dealing with this problem rely mainly on their own experience when choosing the tactics for managing patients.

The introduction of the so-called surgical prophylaxis of SAH in Russia is a challenge that requires defining the principles of patient selection and choosing a treatment option for unruptured cerebral aneurysms.

The purpose of this review is to describe modern approaches to treatment of asymptomatic cerebral UAs, based on the concepts of aneurysm epidemiology and natural course.

Prevalence of intracranial aneurysms

In the international literature, there are numerous publications devoted to studying the incidence rate of intracranial aneurysms (IAs). According to various data, the prevalence of IAs in the population ranges from 0.2 to 9.0% (mean, 2.8%) [1—3]. According to the autopsy data, the rate of disease does not usually exceed 2%. For example, a large study by J. Fox [4] analyzed 20 patho-anatomical series (more than 160 thousand cases) and found that the rate of IAs was 0.8%. Similar conclusions were made by J. Rosenørn [5] and M. Romy and co-authors [6] (11,696 autopsies): according to our data, the prevalence of aneurysms was 0.6 and 1.2%, respectively. W. McCormick and J. Nofzinger [7], based on a series of 7,650 autopsies, concluded that the prevalence of UAs was 2%. An exception is a study by W. Stehbens [8] who reports an aneurysm rate of 5.6% per 1,364 autopsies.

According to studies based on analysis of cerebral angiograms, the rate of IAs is higher. For example, Japanese authors who analyzed angiograms of patients with various head diseases demonstrated that the prevalence of IAs was 2.5 to 3.0% [9, 10].

G. Rinkel and co-authors [11] who reviewed publications on this topic showed that the rate of IA detection was highly dependent on the study design. For example, in retrospective studies, the mean rate of IA detection was 0.4% per 43,000 autopsies, and 3.7% in the analysis of 2,934 angiograms; in prospective studies, the rate was 3.6% (5,500 autopsies) and 6% (3,751 angiograms), respectively. On the basis of these data, the authors concluded that the mean prevalence of IAs was 2%.

R. Komotar and co-authors [3] summed up all the above data and concluded that the mean prevalence of UAs was 1% in the adult population (from 1% in young patients to 4% in elderly patients).

The natural course of unruptured intracranial aneurysms

When addressing the UA issue, a very important question often arises: how significant is the risk to life and health of the patient diagnosed with an IA? To answer the question, it is first necessary to evaluate the risk of cerebral aneurysm rupture. A generalization of the results of numerous studies demonstrates that the rate of an aneurysm rupture varies from 0.5 to 2.5% per year [2]. According to a prospective large multicenter study (USA, Canada, EU) of unruptured IAs (ISUIA) (1,692 patients), the 5-year risk of rupture of anterior circle
of Willis aneurysms is 0% for aneurysms of less than 7 mm, 2.6% for aneurysms of 7 to 12 mm, 14.5% for aneurysms of 13 to 24 mm, and 40% for aneurysms of more than 25 mm in size. For aneurysms of the posterior circle of Willis circle, including the posterior communicating artery (PCoM), the risk is 2.5% for aneurysms of less than 7 mm, 14.5% for aneurysms of 7 to 12 mm, 18.4% for aneurysms of 13 to 24 mm, and 50% for aneurysms of more than 25 mm. According to a retrospective ISUIA study, the total rate of SAH from aneurysms of less than 10 mm is 0.05% per year and 0.5% per year in the case of previous SAH from another aneurysm; the rate is 1% per year for aneurysms of more than 10 mm in size for both groups [12, 13]. However, many authors have noted that this study has a large number of design defects, in particular in patient randomization [3]. Other authors believe that the rupture risk of an unruptured aneurysm is significantly higher. H. Winn and co-authors [14] report 1—2% per year. According to Finnish researchers [15] (142 patients with 181 aneurysms; a follow-up period of 19.7 years), the risk of UA rupture is 1% per year and 1.3% per year in the case of SAH from another aneurysm in a medical history. The total rate of hemorrhages is 10.5% for 10 years, 23% for 20 years, and 30.3% for 30 years. According to other 19 studies [16] (4,705 patients with 6,556 aneurysms), the risk of hemorrhage ranges from 0.6 to 1.3% per year [16]. Japanese researchers [17] draw attention to the fact that there are numerous cases of rupture of aneurysms of less than 5 mm in size, which contradicts with the ISUIA data. The authors, based on their study (374 patients), conclude that the risk of rupture of aneurysms of less than 5 mm in size is 0.34% per year for a single aneurysm and 0.95% for multiple aneurysms (mean, 0.54%).

Thus, the literature data indicate a relatively low annual rate of UA rupture, but given a growing life span, this risk constantly increases to a substantial level. In addition, the rate of rupture is shown to depend on a number of factors that will be discussed below.

Risk factors for formation, growth, and rupture of aneurysms

According to a meta-analysis that includes 19 studies [16], the following factors are associated with a high risk of aneurysm rupture: the age over 60 years, aneurysm size >5 mm, female gender, location in the posterior circle of Willis, and presence of symptoms. According to another meta-analysis [18] including 68 studies (a total of 94,912 patients from 21 countries, including 1,450 IA patients), the risk factors for aneurysm development include female gender, old age, family history of IAs, and autosomal dominant polycystic kidney disease. In addition to the gender and age that are factors identified by almost all studies [16, 19, 20], many authors also indicate the following risk factors for development, growth, and rupture of aneurysms: the size [12, 13, 16, 21], configuration [1, 22], and location [13] of aneurysms as well as smoking [19, 21], a history of arterial hypertension [1, 19], autosomal dominant polycystic kidney disease [23, 24], Ehlers-Danlos syndrome type IV [25], acromegaly [26], sickle-cell anemia [27], coarctation of the aorta [28, 29], a bicuspid aortic valve [30], and alcohol consumption [19]. Most authors believe that an unfavorable natural course is more typical of posterior circle of Willis aneurysms [12, 13, 16] as well as of patients having first-degree relatives with detected aneurysms [1, 12, 13, 18, 24, 31—33] or a previous history of aneurysmal SAH [12, 13].

Aneurysm size

Many authors believe that the aneurysm size is one of the most important factors for predicting aneurysm rupture [2, 21]. Some studies have demonstrated that ruptured aneurysms are larger than unruptured ones [12, 13]. For example, W. McCormick and J. Nofzinger [7], based on a series of 7,650 autopsies, found that UAs were smaller than ruptured aneurysms (mean size of 3.9 mm vs. 9.9 mm, respectively).

According to the ISUIA and Stroke Council of the American Heart Association, an increased risk of rupture is characteristic of aneurysms of more than 10 mm in diameter [12, 13, 34]. According to other data, most SAHs occur from aneurysms of less than 10 mm in diameter (80% according to H. Winn [14], 85.6% according to T. Forget et al. [34]) and aneurysms of less than 5 mm in diameter (65% according to H. Lai et al. [35]). In a study by S. Joo and co-authors [2] (627 ruptured aneurysms), 71.8% of aneurysms were less than 7 mm in diameter, and 87.9% of aneurysms were less than 10 mm in diameter. Among these, anterior cerebral artery — anterior communicating artery (ACA-AComA) aneurysms most often, compared to aneurysms of other locations, were less than 10 and 7 mm in size, respectively [2]. Small aneurysms may have a higher risk of rupture, which depends on their location and size relative to the parent vessel [37].

Studies have shown that the aneurysm size is not constant, it can increase over time [3, 21, 38]. For example, S. Juvela and co-authors [37] found that aneurysm growth in 31 of 87 (36%) UA patients who were conservatively treated for 18.9 years was > 3 mm, on average.

Therefore, when assessing the risk of aneurysm rupture, it is necessary to remember that small aneurysms are also dangerous, and it is necessary to have options for their exclusion [2].

The aneurysm size to parent vessel diameter ratio (size ratio (SR))

Many authors [39] have drawn attention to the fact that the risk of aneurysm rupture depends on the parent artery diameter: the smaller the parent artery diameter, the smaller the size of a ruptured aneurysm.

M. Rahman and co-authors [39] evaluated the risk of aneurysm rupture depending on the ratio between aneu-
Aneurysm size and mean parent vessel diameter. The study results demonstrated that the mean aneurysm size was significantly smaller in the UA group. The mean diameter of parent vessels was not significantly different in groups of ruptured and unruptured aneurysms. In the group of unruptured aneurysms, SR was significantly smaller. On the basis of their research, the authors concluded that an increased rupture risk was typical of aneurysms with SR > 3. The authors believe that SR is an informative parameter for assessing the risk of aneurysm rupture.

Aneurysm location

According to the ISUIA data, if anterior and posterior circle of Willis aneurysms have equal sizes, the rupture risk for the latter aneurysms is much higher. For example, the 5-year risk of rupture of anterior circle of Willis aneurysms is 0% for aneurysms of less than 7 mm, 2.6% for aneurysms of 7 to 12 mm, 14.5% for aneurysms of 13 to 24 mm, and 40% for aneurysms of more than 25 mm. For aneurysms of the posterior circle of Willis, including the PComA, the risk is 2.5% for aneurysms of less than 7 mm, 14.5% for aneurysms of 7 to 12 mm, 18.4% for aneurysms of 13 to 24 mm, and 50% for aneurysms of more than 25 mm [12, 13]. M. Wermer and co-authors [16] conducted a meta-analysis of 19 studies and demonstrated that posterior circle of Willis aneurysms had an increased risk of rupture.

B. Weir and co-authors [40] examined 945 patients and reported that 40.3% of ruptured aneurysms were located on the ACA or AComA, while only 13% of UAs had this location. S. Joo and co-authors reported similar data [2]: out of 627 ruptured aneurysms, ACA-AComA and middle cerebral artery aneurysms amounted to 36.4% and 27.4% of cases, respectively. T. Forget and co-authors [34] noted that 94.4% of ruptured AComA aneurysms were small, with 44% of the aneurysms being less than 5 mm in size. Therefore, anterior circle of Willis aneurysms can rupture before they reach large sizes [39].

Some studies have demonstrated that aneurysms of the anterior circle of Willis, AComA, and PComA have an increased risk of rupture, while aneurysms of the cavernous internal carotid artery have a very low risk of rupture [3, 13]. A. Molyneux and co-authors [41] and T. Nguyen and co-authors [42] also note that small paraclinoid aneurysms have a more favorable natural course than aneurysms of more distal portions of the cerebral arteries.

Family history

The prevalence of aneurysms in subjects whose first-degree relatives had aneurysms or aneurysmal SAHs in medical history amounts to 8—10%, which is 4—5-fold higher than that in the population [27]. According to some authors, the incidence rate of IAs is 4% for subjects having one first-degree relative with aneurysms or aneurysmal SAHs in medical history and 8% for those with 2 such relatives [11]. A. Bor and co-authors [30] assessed the risk of SAH in 130,373 relatives of 5,282 SAH patients and found that the risk of SAH was 2.15-fold higher in subjects with one relative with SAH and 51-fold higher in subjects with two relatives with SAH. In a series presented by I. Loumiotis and co-authors (212 patients) [43], 23% of the patients had relatives with an aneurysm. In these subjects, the risk of SAH was 3—7-fold higher than that in the population [33]. According to J. Broderick and co-authors [31], the rupture risk for familial aneurysms is 1.2% per year. According to some authors [33, 45], ruptures of familial aneurysms account for 10% of all SAHs. In subjects with a family history, multiple aneurysms develop more often than in the population, and hemorrhages occur at a younger age [45, 46]. According to J. Bromberg [32], familial aneurysms have a more unfavorable outcome in the case of hemorrhage (52% versus 37% for the general population). According to R. Brown [46], subjects older than 30 years who have a family history of aneurysms, smoke, and suffer from hypertension are detected with IAs in 19% of cases.

Diagnosis of unruptured aneurysms

The widespread use of non-invasive brain study techniques has led to incidental detection of cerebral UAs. In Western Europe, Japan, and the USA, where surgical treatment of UAs is considered as a method to prevent SAH, there has emerged the need to develop recommendations for identification of UA patients using risk factors for aneurysm development. Until now, there have been no generally accepted criteria for selection of patients to whom screening examination might be recommended, but this issue has been discussed in the literature, and some authors suggest examining the following groups of patients:

1) relatives (first degree of kinship) of patients with ruptured aneurysms;
2) young smokers (especially females) with hypertension and non-specific neurological symptoms (headache, eye pain, cervical pain, transient ischemic attacks, etc.);
3) patients with hereditary connective tissue diseases (autosomal dominant polycystic kidney disease, Marfan syndrome, Ehlers-Danlos syndrome type IV, coarctation of the aorta) [18, 48].

Examination of patients with a family history of aneurysms

In the world practice, there is no consensus on examination of subjects with a family history of aneurysms. N. Chalouhi and co-authors [26] suggest the following tactics. If the family has a patient with an aneurysm/aneurysmal SAH, then a single examination of first-degree relatives should be performed only if at least 3 of the following signs are present: female gender; mature age; arterial hypertension; active smoking; the patient is a brother or sister of the given subject; the patient had multiple aneurysms at a young age. If a relative is under 18 years of
age or over 70 years of age or has a short life expectancy, the need for examination should be considered individually. If the family has 2 patients with aneurysms, examination of relatives should be performed every 5 years, regardless of the presence of other risk factors, except cases where the subject is under 18 years of age or over 70 years of age or has a short life expectancy. In these cases, examination is not recommended.

Some authors recommend relatives to be examined several years before the age at which aneurysms are discovered in the family because there is evidence that aneurysms develop in brothers and sisters at about the same age [49], while in children, aneurysms develop earlier than in parents [27]. A. Bor and co-authors [49] assessed the cost-effectiveness ratio for examination of subjects having two or more relatives with SAH. According to their calculations, examination of subjects aged 20 to 80 years every 7 years is optimal. However, there are data indicating that aneurysms can develop and lead to SAH within a 5-year interval between examinations [51]; therefore, the issue of optimal inter-examination intervals remains open.

Most authors agree that examination of family members of aneurysm patients is necessary [20, 27, 52]; however, there is no consensus about examination of subjects having one sick relative. According to a large American study, prevention of one SAH requires examination of 149 relatives, and prevention of one fatal SAH requires examination of 298 relatives. The authors believe that examination of relatives of patients with sporadic SAH is unreasonable [53]. On the basis of this study, the American Heart Association does not recommend examining subjects having only one sick relative [20, 34]. But in our opinion, this recommendation is controversial because before examination of relatives of the SAH patient, it is impossible to understand if the aneurysm developed sporadically or because of a family predisposition.

**Tactics of treatment**

The tactics of treating UA patients still remains contradictory [2, 20, 52].

On the basis of a study of unruptured IAs (ISUIA), the Stroke Council of the American Heart Association issued recommendations that give preference to expectant management of patients with aneurysms of less than 10 mm in diameter. The recommendations indicate that aneurysms of less than 10 mm should be subjected to a special examination if the patient has first-degree relatives with aneurysms or aneurysmal SAHs in a medical history, if the aneurysm is multi-lobular, and if there are changes in the aneurysm size and configuration over time [12, 13, 20, 34]. I. Loumiotis and co-authors [53] and R. Solomon [54] believe that the observational tactics is reasonable for the management of unruptured aneurysms of less than 10 mm in diameter. According to I. Loumiotis and co-authors, the observational tactics is preferable because UAs are mainly detected at old age when the risk of aneurysm rupture is very low, an estimated life expectancy is small, and there are various co-morbidities. P. Mitchell and co-authors [55] believe that the risk of surgery exceeds its benefit if the patient’s life expectancy is less than 20 years. Therefore, the authors recommend observation in elderly patients, in the presence of concomitant diseases, and absence of risk factors for aneurysm rupture. In addition, the peculiarities of aneurysm location and the patient’s attitude to surgery should be taken into account [54]. According to I. Loumiotis and co-authors [53], R. Solomon [54], and R. Brown [51], endovascular or surgical treatment is indicated at a young age in the presence of a family history, posterior circle of Willis aneurysms, and risk factors for aneurysm rupture (arterial hypertension, active smoking), with allowing for patient’s preferences. Most authors prefer endovascular treatment. Surgical treatment is indicated only if endovascular treatment is not possible or is associated with a high risk of complications [54]. But according to R. Solomon [54], microsurgical treatment is preferable in young patients because long-term aneurysm obliteration provided by this technique is more reliable.

R. Komotar and co-authors [3] suggested the following tactics for managing UA patients.

1. All symptomatic UAs, with rare exceptions, should be treated. Severe concomitant diseases, advanced age, and complex anatomical characteristics of the aneurysm may be contraindications for surgery if risks of death and disability after treatment reach a total of 25%.

2. Small asymptomatic aneurysms of less than 5 mm in diameter should remain under observation practically in all cases. Exceptions are young patients with severe mental disorders caused by UAs.

3. Patients under 60 years of age with aneurysms of more than 5 mm should be treated if there are no serious contraindications. In patients older than 60 years, treatment tactics is less clear. In these cases, the aneurysm location plays an important role. Also, it is necessary to remember that aneurysms of the anterior communicating artery, posterior communicating artery, and main artery bifurcation are at a higher risk of rupture than aneurysms with other locations. In these cases, treatment is reasonable if there are no serious concomitant diseases.

4. Asymptomatic aneurysms of more than 10 mm should be treated in all patients under the age of 70 years. The indications for older patients are less convincing.

5. Microsurgical clipping is the method of choice in young patients with small aneurysms of the anterior circle of Willis. In cases of large and giant aneurysms and aneurysms with a high neck to body size ratio, outcomes of microsurgical treatment are usually better than those of endovascular treatment (however, with the introduction of flow-diverting stents, this statement has become controversial. – Authors’ note). In cases of complex aneurysms, combined procedures (e.g., performing an arterial
bypass, followed by proximal endovascular occlusion of the parent vessel) are important.

An endovascular intervention is a reasonable alternative when surgery is associated with a high risk, e.g. in elderly patients with severe concomitant diseases as well as in cases that are anatomically adverse for direct surgery (vertebrobasilar territory aneurysms).

The progress in endovascular techniques has expanded the range of indications for the use of endovascular surgery, even in cases of aneurysms with a wide neck and an unfavorable neck to body ratio.

N. Chalouhi and co-authors [1] suggest the tactics for managing patient, which is based on evaluation of the aneurysm size and the presence of risk factors. The risk factors are divided into two groups. Group A factors include active smoking, arterial hypertension, posterior circle of Willis aneurysms, previous SAH from another aneurysm, a family history of aneurysms, and an aneurysm neck to body ratio>3. Group B factors include a young age, the presence of symptoms, changes in the aneurysm size or structure over time, multi-lobular aneurysms, and multiple aneurysms. For aneurysms of less than 5 mm, treatment is indicated in the presence of at least 2 group A factors or any group B factor. For aneurysms of 5—7 mm, treatment is indicated in the presence of at least one risk factor from any group. For aneurysms of more than 7 mm, surgical treatment is indicated for any case.

When choosing the tactics of treatment, psychosocial factors should be considered. According to M. Wermser [56], 44% of patients who were diagnosed with UAs stopped working, and 66% of patients changed their plans for the future and their attitude to themselves and others. In these patients, the quality of life decreases. J. Broderick and co-authors [31] note that patients with a family history of aneurysms are more likely to choose surgical treatment because they have seen the consequences of hemorrhage in their relatives and also because of the understanding of a more unfavorable natural course of the disease.

Conclusion

The international literature provides numerous recommendations on the management of patients with unruptured asymptomatic aneurysms. However, there are currently no generally accepted standards, therefore each particular case requires an individual approach.

When choosing tactics for UA treatment, neurosurgeons primarily rely on the anatomic and topographic features of an aneurysm, such as size, the presence of several lobes and diverticula, and location. It is generally accepted that the larger the aneurysm size, the higher the risk of its rupture. The multi-lobular aneurysm structure, presence of diverticula, midline location, as well as location in the vertebrobasilar territory are also associated with an increased risk of hemorrhage and are the indications for surgical treatment. Additional factors supporting surgery include a young age, positive history (family history of aneurysms, smoking, hypertension), aneurysm multiplicity, the absence of severe somatic diseases, and a positive patient’s attitude toward surgery.

The decision on surgery should be made in each particular case after informing the patient about disease, its natural course, and potential complications and consequences of the procedure.

The experience of surgeons, availability of various techniques for exclusion of aneurysms, and hospital facilities are of great importance.

Authors declare no conflict of interest.

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Commentary

The implementation of the Federal Program for the Provision of Medical Care to Patients with Vascular Diseases in Russia led to establishment of regional vascular centers (RVCs) in almost all regional or republican hospitals. Improving non-invasive methods of brain diagnostics has increased the number of patients with cerebral aneurysms before their rupture, which has arisen numerous questions about the tactics for managing these patients. The authors present a review of the world experience in this field.

In Western Europe, Japan, and Finland, treatment of unruptured aneurysms has been considered for long time as a method for prevention of subarachnoid hemorrhage. In these countries, the number of operations for unruptured aneurysms is constantly increasing. However, there are no generally accepted recommendations on the tactics for managing patients with unruptured aneurysms.

The introduction of the so-called surgical SAH prophylaxis in Russia is an extremely topical task and requires defining the principles for selection of patients and choosing a treatment option for unruptured aneurysms (microsurgery, endovascular neurosurgery).

The article is undoubtedly helpful and important. Treatment of these patients will further require a discussion and preparation of an advisory protocol of the Association of Neurosurgeons of Russia.

V.A. Lazarev (Moscow, Russia)
Decompressive Craniotomy in Patients with Intracranial Aneurysmal Hemorrhage

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Decompressive craniotomy (DCT) has been used for treatment of patients with acute aneurysmal subarachnoid hemorrhage (SAH) for more than 20 years. But so far, the attitude to this surgery is controversial, and the indications and contraindications for it are not clearly defined. The article reviews the domestic and foreign literature devoted to the issues of validity and efficacy of DCT in treatment of cerebral edema and intracranial hypertension in patients with aneurysmal SAH.

Keywords: decompressive craniotomy, subarachnoid hemorrhage, aneurysm.

Resective craniotomy first began to be used as a stand-alone surgery aimed at combating uncontrolled cerebral edema in late 1890s [1, 2]. The intervention was referred to as ‘decompressive hemicranioectomy’ or ‘decompression craniectomy’ (DCT) [3]. Initially, this surgery was used mainly in patients with craniocerebral trauma [4], then in other diseases accompanied by pronounced cerebral edema, especially in extensive ischemic stroke in the basins of the internal carotid or middle cerebral arteries [5], and subsequently in intracranial hemorrhage of aneurysmal genesis [6].

DCT has been used for treatment of patients with acute aneurysmal subarachnoid hemorrhage (SAH) for more than 20 years. But so far, the attitude to this surgery is controversial, and the indications and contraindications for it are not clearly defined.

The aim of this review is to analyze the validity and effectiveness of DCT in treatment of cerebral edema and intracranial hypertension in patients with aneurysmal SAH based on the data presented in domestic and foreign literature.

Analysis of publications on the use of DCT in patients with intracranial hemorrhage of aneurysmal genesis

In intracranial hemorrhages, cerebral edema due to ruptures of aneurysms can be caused by various pathological processes, such as formation of large ICH, impaired cerebral circulation, angiospasm and cerebral ischemia, postoperative complications, and it is ultimately one of the main causes of death or severe disability. The development of methods for prevention and treatment of cerebral edema, intracranial hypertension (IH) and brain dislocation has always been one of the main tasks in treatment of patients with aneurysmal hemorrhage [7—10]. Nevertheless, so far, a combination of surgical and pharmaceutical measures aimed at eliminating these complications (external ventricular drainage, lumbar drainage, hyperventilation, drug sedation, use of osmoliuretics and hypothermia) is often ineffective, which promotes further search for alternative solutions, and in particular the use of DCT.

The search for publications on treatment of patients with aneurysmal SAH revealed only 14 studies involving DCT and the analysis of their outcomes has been conducted. The first article, published in 1994, is written by C. Fisher et al. [6] and is a description of one case of bilateral decompressive trepanation in a coma patient. Subsequent studies include from 3 to several dozen patients (Table 1).

A Russian study, conducted in Burdenko Neurosurgical Institute in 2006 [15], analyzed the largest number of clinical cases, 98. The analysis of these articles demonstrates that the interest in the issue is stable, but the method is not widely used, although the number of patients in the series has been increasing in recent years (see Table 1).

The overwhelming majority of the analyzed works are retrospective assessments of relatively small groups.
and subgroups of patients. The data analyzed in some publications are taken from databases of earlier prospective studies on aneurysmal intracranial hemorrhage [14, 22]. The control group (patients who did not undergo DCT) was included in two studies only. In the article by A. D’Ambrosio et al. [14] the control group was formed based on the same criteria as the group of patients for DCT (age<75 years, H—H status IV—V, large hematoma in the sylvian fissure or the temporal lobe of the brain on CT, clinical signs of brain compression), but DCT surgery was not performed for various reasons. Y. Uozumi et al. [22] also created the control group from the existing database by including patients who were similar to the study group in terms of age, sex, WFNS status, Fisher haemorrhage type, and vasospasm. At the same time, the authors themselves indicate that the study and control groups were significantly different in other parameters such as ICH resistance to drug therapy (significantly less common in the control group) and clinical signs of tentorial herniation (42.9 and 5.4%, respectively).

Characteristics of patients with DCT

In most articles, there is no mention of the proportion of patients in the acute period of aneurysmal SAH for whom DCT was performed among all such patients treated in the clinic. In those works where this indicator is provided it ranges from 6.8 to 19.7% [16, 20, 22, 23].

In most studies, DCT was used in patients in severe condition, whose status was assessed as stage IV—V on H—H scale or WFNS. Among the patients who underwent DCT, the proportion of patients admitted to a hospital in serious condition amounted to 69—81.6% [16, 17, 19, 20]. Some groups included patients whose baseline condition was assessed as I—III on H—H scale or WFNS [17, 19, 20, 22]. Apparently, these patients underwent DCT due to progressive deterioration of the condition in the future.

In 5 studies, the inclusion criterion was the presence of a large hematoma in the sylvian fissure or in the temporal lobe of the brain as a factor leading to a lateral dislocation of the brain and contributing to the formation of ischemic foci in the basin of the middle cerebral artery [11, 12, 14, 18, 21]. In other studies, such patients were classified into individual subgroups [6, 13, 15-17, 20, 22, 23]. These groups and subgroups consisted, either predominantly or exclusively, of patients with aneurysms of the middle cerebral arteries. In a number of studies in addition to patients with ICH, DCT was also performed in patients with cerebral edema caused by other mechanisms, in particular ischemic, and comparative evaluation of outcomes was conducted for these subgroups [15, 16, 20, 22]. Some works included only patients without ICH with clinical signs of cerebral edema caused by angiospasm or other causes [17]. All these studies included patients with aneurysms of different localizations.

Only direct microsurgical method was used to clip aneurysms from the blood stream in some studies [12, 16, 18], while other studies included patients with both microsurgical and endovascular interventions [14, 17, 22].

In the vast majority of studies, aneurysm surgery was performed within the first 72 hours after hemorrhage. Some groups also included patients who did not undergo aneurysm surgery [14]. In addition to aneurysm clipping, external ventricular drainage was installed in many patients either immediately upon the admission or after the main surgery. Postoperative management and drug treatment in the vast majority of studies were carried out in accordance with international recommendations protocols [24—26]. In many studies, preoperative and/or postoperative ICP monitoring was performed using parenchymal or ventricular sensors, which is also a part of the standard for treatment of patients in severe condition [26].

Timing of DCT. Primary and secondary DCT

DCT was performed both directly during the surgery to clip the aneurysm (primary DCT) and as the second stage after aneurysm clipping in case of progressive deterioration of the condition and/or cerebral edema refractory to drug therapy (secondary DCT). DCT in patients who had an aneurysm clipped by endovascular method and who then underwent decompressive craniotomy almost immediately after this intervention, should also, perhaps, be classified as primary DCT. In these cases, indications for DCT included signs of edema and/or dislocation of the brain caused by ICH or clinical signs of edema and dislocation in patients without ICH, which were detected prior to endovascular intervention [20]. Some studies also mentioned an option in which the bone flap was not set in place after direct surgery on the aneurysm and standard craniotomy, and additional bone resection was performed if the condition worsened [20]. This option is also referred to as a secondary DCT.

Indications for DCT surgery

As already mentioned above, the main indication for DCT was severe condition of the patients (H—H IV—V, WFNS IV—V), presence of large ICH in the temporal lobe and signs of lateral dislocation of the brain on CT. In such cases, DCT was most often primary.

Another reason for carrying out a single-stage DCT was clear visual signs of cerebral edema observed during direct surgery. In such cases the decision was made immediately after clipping of the aneurysm.

In patients without large ICH, the decision to perform DCT was based on clinical signs of intracranial hypertension, which most authors understood primarily as appearance of anisocoria and the progression of signs of middle brain damage (mydriasis). DCT was also performed in case of stable ICP recorded with sensors.
Table 1. Outcomes of DCT in patients with aneurysmal intracranial hemorrhage, according to different authors

<table>
<thead>
<tr>
<th>Publication</th>
<th>Year of publication</th>
<th>Characteristics of patients</th>
<th>Number of patients/Control group</th>
<th>Evaluation of the outcome after SAH</th>
<th>Favorable outcome*, abs. (%)</th>
<th>Severe disability**, abs. (%)</th>
<th>Mortality, abs. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.A. Sazonov et al. [15]</td>
<td>2006</td>
<td>H—H II—V</td>
<td>98</td>
<td>1 month</td>
<td>28 (28)</td>
<td>—</td>
<td>20 (20)</td>
</tr>
<tr>
<td>U. Buschmann, et al. [16]</td>
<td>2006</td>
<td>4 groups of patients</td>
<td>38</td>
<td>1 year</td>
<td>20 (53)</td>
<td>10 (26)</td>
<td>8 (21)</td>
</tr>
<tr>
<td>N. Otani, et al. [18]</td>
<td>2008</td>
<td>H—H IV—V</td>
<td>ICH of the temporal lobe</td>
<td>57</td>
<td>1 month</td>
<td>21 (37)</td>
<td>24 (42)</td>
</tr>
<tr>
<td>E. Güresir, et al. [19]</td>
<td>2009</td>
<td>5 groups of patients</td>
<td>79</td>
<td>6 month</td>
<td>21 (27)</td>
<td>36 (45)</td>
<td>22 (28)</td>
</tr>
<tr>
<td>C. Dorfer, et al. [20]</td>
<td>2010</td>
<td>4 groups of patients</td>
<td>66</td>
<td>1 year</td>
<td>18 (27)</td>
<td>23 (35)</td>
<td>25 (38)</td>
</tr>
<tr>
<td>Y. Uozumi, et al. [22]</td>
<td>2014</td>
<td>WFNS I—V</td>
<td>Several groups of patients</td>
<td>54/54</td>
<td>1 year</td>
<td>15 (28%)/24 (44%)</td>
<td>23 (42)/14 (26)</td>
</tr>
<tr>
<td>U. Hwang, et al. [23]</td>
<td>2014</td>
<td>H—H IV—V</td>
<td>70</td>
<td>1 month</td>
<td>9 (13)</td>
<td>32 (46)</td>
<td>29 (41)</td>
</tr>
</tbody>
</table>

Footnote. * — favorable neurological outcomes: modified Rankin scale 0—3 or GOS 4—5. ** — severe disability: modified Rankin scale 4—5 or GOS 2—3.

(pressure above 20 mmHg) which is refractory to other types of treatment [12, 16—19, 22]. Such patients were divided into two groups: those without ischemia and those having an ischemic focus [16, 19]. In these cases, the surgery was most often deferred (secondary DCT).

Some authors performed primary DTP in clinically severe patients without ICH, based on the data of preoperative ICP measurement using implanted parenchymal or ventricular pressure sensors. The hypertension was diagnosed in case of stable (not less than 1 hour) pressure exceeding 20 mmHg [16, 19].

In addition to clinical manifestations, CT data and ICP values, some studies relied on other indicators in selecting patients for DCT, such as assessment of the state of the cerebrovascular system and brain oxygenation (assessment of angiospasm severity, cerebral vascular reactivity, tissue oxygen tension (ptiO2)) [13, 19]. According to T. Reithmeier et al. [27], ptiO2 drop to a level below 10 mmHg is an indication for DCT.

Features of DCT surgery

The optimal anteroposterior diameter of the DCT for ICH clipping in case of aneurysmal SAH varies from 11 to 15 cm [16, 19, 20]. It has been pointed out that such size of the DCT can ensure 55—60% reduction in ICP in the early postoperative period compared to the baseline one.

At the same time, some authors note that large initial trepanation window may lead to difficulties in accessing an aneurysm and prefer to perform primary DCT of no more than 9 cm [16, 20] in size. In the future, if there is stable ICH, the maximum diameter of the DCT is increased by 30—40% for the repeated intervention.

The outcomes of operations and their dependence on various factors

Outcomes of surgeries in the analyzed papers were assessed using the standard or modified Glasgow Outcome Scale (GOS, mGOS), as well as the modified Rankine scale. Generally, the outcomes were classified as favorable (GOS 4—5, mGOS 5—8, Rankin...
The ICP, but also by improving the oxygenation of the brain in DCT conditions. Other researchers do not see the dependence of the results of treatment on the timing of the DCT for SAH [14, 16, 19, 20].

There is no consensus in respect of the outcomes of primary and secondary DCT either. Table 2 presents the clinical outcomes of primary and secondary DCT in patients with aneurysmal SAH based on three relatively large series. As can be seen from the data in the Table, in all groups the mortality was higher in case of primary DCT, and the frequency of favorable functional outcomes in primary and secondary DCT is approximately equal. The comparison of the data from different authors did not reveal any trends in the differences in the parameters and do not allow any general conclusions.

A number of works discusses the role of the ICH etiopathogenetic factors in the outcome of the surgery. According to C. Dorfer et al. [20], the outcomes of DCT in direct operations on aneurysm are better in patients with clinically significant hematomas than in patients with ischemic edema, and, especially, in those with formed infraction.

Some authors attempted to determine the relationships between the outcome of the surgery and quantitative characteristics of the dislocation of the brain. According to N. Otani et al. [18], the magnitude of the shift of the midline did not affect the outcome. H. Wang et al. [21] noted a mean shift of 8.5 mm in patients with favorable results after DCT and 11.5 mm in patients with poor outcomes (GOS 3—1).

All authors point to the importance of ICP evaluations when deciding on a surgery. This is consistent with the results of a study by R. Streege et al. [28], which showed that the abnormal increase in ICP values in case of ICP monitoring always precedes the clinical deterioration of patients.

Direct and endovascular surgery

U. Hwang et al. [23] published results of treatment of 70 patients in serious condition (H—H IV—V), 40 of whom underwent DCT simultaneously with clipping of aneurysms and 30 others immediately after endovascular occlusion of aneurysms with spirals. There was no significant difference in the mortality between the groups: 45% of patients died after direct interventions and 36.7% after endovascular ones. However, better outcomes at discharge (GOS 5 and 4) were more often observed after endovascular operations compared with microsurgical operations: 22.5 and 5.8%, respectively. Conversely, in the study by C. Dorfer et al. [20] the levels of mortality in patients with aneurysm clipping and spiral occlusion in primary DCT were comparable (36.4 and 30.7%, respectively), and the level of favorable outcomes was lower after endovascular interventions (36.3 and 15.4%, respectively) [20].
Conclusion

The use of DCT in treatment of patients with severe aneurysmal hemorrhage is based on the positive experience of using this surgery in case of ICH in patients with craniocerebral trauma and in patients with ischemic stroke, which is most similar in pathogenesis to such complications of aneurysmal hemorrhage as angiospasm and its consequences [29—36]. The positive effect of DCT in cerebral ischemia is due to significant decrease in ICP, increase in oxygenation of the brain tissue and improvement in cerebrovascular reactivity [13].

However, the results of DCT in patients with aneurysmal hemorrhage were less promising than in patients with ischemic stroke, despite the similar severity of the condition in these two groups. Most researchers who work on with this problem explain this fact primarily by wide range of pathological processes leading to cerebral edema and ICH in patients with aneurysmal SAH.

Analysis of DCT studies in patients with ruptured aneurysms also demonstrates wide range of opinions regarding indications for and timing of the surgery. The treatment outcomes obtained by the authors also have significant differences. All these features, combined with small number of patient in the groups, do not allow reliable comparisons between various studies.

At the same time, the results of the literature analysis do not contradict the opinion that the method can be used in severe patients with clinical signs of persistent ICH or its progression, if conservative therapy is ineffective.

The use of DCT is most justified in patients with direct interventions for aneurysms, with large hematomas in the sylvian fissure or temporal lobe of the brain, as well as in case of initial clinical signs of tentorial herniation. In patients with ischemic edema of the brain, it is preferable to conduct the surgery before the formation of the infraction. The operation is indicated to patients in severe conditions after endovascular occlusion of the aneurysm in case of clinical and radiological signs of brain dislocation. An additional factor in favor of a decompressive surgery is a persistent, refractory increase in ICP (more than 20 mmHg), based on monitoring using implanted sensors. Secondary DCT is also justified in patients with persistent refractory ICH in case of worsening condition of the patient.

It has been convincingly shown that the surgery is more effective if it is performed before the occurrence of irreversible dislocation impairments.

The small number and low reliability of the available data on DCT in the literature precludes the inclusion of this surgery in the list of actions recommended by international protocols for treatment of patients with aneurysmal intracranial hemorrhage [24—26].

Clarification of indications for DCT can only be performed on the basis of prospective cohort studies with unified principles and timing of assessment of various preoperative and postoperative indicators and outcomes.

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Rather high incidence of hemorrhages due to the rupture of intracranial aneurysms and the respective very high level of unfavorable outcomes requires constant optimization and development of new approaches in therapeutic tactics for these patients. The review presented by the authors is devoted to very narrow section of surgical treatment of patients with intracranial hemorrhages caused by ruptures of aneurysms: the need for decompressive craniotomy. Despite the obvious importance of solving the problem of intracranial hypertension, edema and dislocation of the brain, decompressive craniotomy in this group of patients has not become so widespread as in patients with craniocerebral trauma. Moreover, the number of works published on this topic over the past two decades is very small.

Critical analysis of all available literature on this aspect of surgical treatment allowed the authors to determine the indications, timing and features of the surgery, as well as evaluate the results of treatment and define risk factors for adverse outcomes. Obviously, the work done by the authors can serve as the basis for a prospective study aimed at clarifying the effectiveness of decompressive craniectomy in patients with intracranial hemorrhages caused by rupture of aneurysms. This review will be extremely useful for neurosurgeons, resuscitators, and neurologists who treat patients with intracranial aneurysms.

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