## ORIGINAL ARTICLES


Microsurgical treatment of aneurysms of vertebral and posterior-lower cerebellar arteries: surgical approaches, exclusion options, treatment results

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
</tr>
</tbody>
</table>


Intracisternal administration of verapamil for the prevention and treatment of vasospasm in patients after microsurgical treatment of cerebral aneurysms in the acute period of hemorrhage

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
</tr>
</tbody>
</table>


Individual preoperative 3D modeling of vascular brain pathology

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
</tr>
</tbody>
</table>


The prognostic value of MRI-classification of traumatic brain lesions level and localization depending on neuroimaging timing

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
</tr>
</tbody>
</table>

Saifutdinov M.S., Ryabykh S.O., Savin D.M., Tretjakova A.N.

Quantitative characterization of risk of iatrogenic damage to pyramidal tracts based on data of intraoperative neuromonitoring during surgical correction of spinal deformities

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
</tr>
</tbody>
</table>

## CASE REPORTS

Krylov V.V., Lukyanchikov V.A., Dalibaldyan V.A., Staroverov M.S., Barbakadze Z.A., Grigoriev I.V., Ryzhkova E.S., Guseynova G.K.

Use of the «bonnet» bypass in treating a patient with symptomatic occlusion of the ipsilateral carotid arteries. Clinical observation

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
</tr>
</tbody>
</table>

Kosyrkova A.V., Gavrilov A.G., Eliava Sh.Sh., Kravchuk A.D.

Giant thrombosed aneurysm of the pericallosal artery: clinical observation, literature review

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>74</td>
</tr>
</tbody>
</table>

Kheyreddin A.S., Kaftanov A.N., Sazonov I.A.

Combination of intraoptic anterior cerebral artery with an aneurysm of the ACA-AcomA complex. Case study and literature review

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>82</td>
</tr>
</tbody>
</table>

Kudryavtsev D.V., Karpov N.V., Mamas'yan E.A., Shishkina L.V., Karnaukhov V.V.

Surgical treatment of a patient with a traumatic arterial aneurysm of the M4 segment of the left middle cerebral artery. Case report and literature review

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
</tr>
</tbody>
</table>

Serova N.K., Shkarubo A.N., Tropinskaya O.F., Eliseeva N.M., Shishkina L.V.

Neurosarcoidosis of the anterior visual pathway (a case report and literature review)

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>97</td>
</tr>
</tbody>
</table>

## REVIEWS

Bergen T.A., Mesropyan N.A., Smagina A.V.

Magnetic-resonance imaging under degenerative changes in lumbar spine: state of the art

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>104</td>
</tr>
</tbody>
</table>

Rebrikova V.A., Sergeev N.I., Padalko V.V., Khotyrov P.M., Solodkii V.A.

The use of MR perfusion in assessing the efficacy of treatment for malignant brain tumors

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>113</td>
</tr>
</tbody>
</table>


Comprehensive treatment of patients with parasagittal meningiomas

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>121</td>
</tr>
</tbody>
</table>

## ANNIVERSARIES

Evgeny I. Chazov (on his 90th anniversary)

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>126</td>
</tr>
</tbody>
</table>

Evgeny I. Gusev (on his 80th anniversary)

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>127</td>
</tr>
</tbody>
</table>
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

- Current trends in neuroanesthesiology
- Neuropsychological changes in island lobe tumors
- Primary pineal melanocytoma
Microsurgical treatment of aneurysms of vertebral and posterior-lower cerebellar arteries: surgical approaches, exclusion options, treatment results

SH. SH. ELIAVA, YU. V. PILIPENKO, O. D. SHEREHTMAN, A. S. KHEYREDDIN, D. N. OKISHEV, AN. N. KONOVALOV*, A. M. SPIRU, S. A. KISARIEV, V. A. GOROZHANIN, M. D. VARYUKHINA

Burdenko Neurosurgical Center, Moscow, Russia

Aneurysms of vertebral (VA) and posterior inferior cerebellar arteries (PICA) are relatively rare pathologies and account for 3.4% of the total number of intracranial aneurysms.

Material and methods. The experience of microsurgical treatment of 67 patients with VA and PICA aneurysms in N.N. Burdenko National Medical Research Center for Neurosurgery of the RF Ministry of Health from 2012 to 2017 is presented. Results. Most patients underwent reconstructive microsurgical interventions: clipping of the aneurysm neck in 42 (62.7%) patients and complex clipping with the formation of arterial opening — in 10 (14.9%). Exclusion of the aneurysm together with the carrier artery (trapping, proximal clipping) was performed on 10 (14.9%) patients. In 5 (7.5%) patients, deconstruction of the carrier artery of the aneurysm was performed after creating local anastomoses. The radical exclusion of aneurysms in the studied group was 95.5%. Postoperative dysfunction of the caudal group of cranial nerves was detected in 11 (16.4%) patients. There were no lethal outcomes, or cases with vegetative status outcomes.

Conclusion. Microsurgical intervention is an effective way to treat VA and PICA aneurysms, subject to the principles of patient selection based on existing treatment algorithms as well as adherence to an interdisciplinary approach.

Keywords: PICA aneurysm, aneurysm of the vertebral arteries, aneurysms of the posterior-lower cerebellar arteries posterior inferior cerebellar arteries, clipping, microsurgery, anastomoses.

List of abbreviations

PICA — posterior inferior cerebellar artery
CT — computerized tomography
CALF — clipping with arterial lumen formation
VA — vertebral artery
SAH — subarachnoid hemorrhage
MSC — median suboccipital craniotomy
CN — cranial nerve
GOS — Glasgow outcome scale

Aneurysms Vertebral arteries (VA) and posterior inferior cerebellar arteries (PICA) make up 2—4.5% of all brain [1—3]. Most of them manifest as subarachnoid or ventricular hemorrhages and are associated with high risk of disability or death without timely surgical treatment [1,4,5].

Choice of treatment of VA and PICA aneurysms (microsurgical or endovascular procedure) remains debatable to this day [3, 6—10].

In this article we present the results of microsurgical treatment of VA and PICA aneurysms in Federal State Autonomous Institution N.N. Burdenko National Medical Research Center of Neurosurgery of the Ministry of Health of the Russian Federation (NMRCN) and provide types of surgical access and options for closing aneurysms depending on location and anatomical features.

Materials and methods

We performed a retrospective analysis of clinical, surgical and angiographic data of patients with VA and PICA aneurysms, who were treated in NMRCN from 2012 to 2017.

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During this period in NMRCN, we operated on 3396 patients with intracranial aneurysms of various localization. Among them 116 (3.4%) had aneurysms of VA and PICA. Fifteen patients were not included in this group, as they had combination of PA and PICA aneurysms with arteriovenous malformations of posterior cranial fossa, as these patients have different treatment plans and results.

Procedure choice was based on NMRCN-accepted algorithms of treating cerebral aneurysms [11,12]. Primary criteria of these algorithms are:
1) preference of endovascular procedures in patients with aneurysms of intracranial (V4) segment of VA, including aneurysms in the area of PICA ostium;
2) preference of microsurgical procedures in all aneurysms of PICA and in aneurysms of VA, when PICA originates from the neck or body of the aneurysm.

Contraindications for endovascular procedures:
1) acute period of subarachnoid hemorrhage (SAH), when stenting or antiplatelet therapy are indicated;
2) antiplatelet therapy resistance or intolerance;
3) limited endovascular approach to the aneurysm (tortuosity or atherosclerosis of VA)

When there are contraindications for endovascular procedure or in case of its failure, microsurgical procedure is recommended. Contraindications for microsurgical treatment were decompensation of severe somatic diseases and systemic hypocoagulation.

In total, microsurgical procedures were performed in 67 cases and endovascular — in 49 cases.

In this article we analyze the results of microsurgical interventions.

Clinical data on patients of study group

Age of patients varied from 7 to 68 years (average age was 47.5 years). Children (7—11 years old) made up 4.5% (3 cases) There were 25 men (37.3%) and 42 women (62.7%). 63 patients (94%) had SAH previously, but only six patients were operated during the first 14 days, and three patients were operated on from 15th to 21st day. Four patients (6%) did not have hemorrhages: In three of them asymptomatic aneurysms were found occasionally, and in one patient with a giant aneurysm clinical presentation was associated with the increasing mass-effect.

There were seven patients (10.4%) with multiple aneurysms. In four out of seven cases, when there was a combination with aneurysms of anterior parts of circle of Willis, PICA aneurysms were the source of hemorrhage.

Anatomical and topographical features of the aneurysms

Intracranial part of VA is divided into 3 segments:
— VA proximally to the PICA ostium (VAprrox);
— PA in the area of PICA ostium;
— PA distally to PICA ostium (VAdist).

According to J.Lister et al. classification [13], PICA is divided into five segments:
p1 — anterior medullar;
p2 — lateral medullar,
p3 — tonsillo-medullar,
p4 — telovelotonsillar;
p5 — cortical.

C. Drake [1] divided all aneurysms of PICA into proximal (about 1 cm from the PICA ostium) and distal. According to this classification, we assigned VA aneurysms in the area of PICA ostium and aneurysms of anterior medullar segment of PICA to proximal PICA aneurysms (PICAprox), and all aneurysms in segments p2—p5 — to distal PICA aneurysms (PICAdist).

In this way, we distinguished four main types of VA and PICA aneurysms localization:
1) VAprrox;
2) VAdist;
3) PICAprox;
4) PICAdist.

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<thead>
<tr>
<th>Table 1. Anatomic and topographic characteristic of aneurysms</th>
</tr>
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<tbody>
<tr>
<td><strong>Localization of aneurysm</strong></td>
</tr>
<tr>
<td>VAprox</td>
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</table>

BURDENKO’S JOURNAL OF NEUROSURGERY 4, 2019
In Table 1 we present aneurysms distribution by segments in dependence on their shape and size, as well as presence of intra-aneurysmal thrombus.

The most frequent localization of aneurysm was PIC-Aprox segment. There were 20 (29.9%) peripheral aneurysms (PICAdist). VA aneurysms (VAprox and VAdist) were the rarest — only eight (11.9%) cases. Saccular aneurysms mainly localized in PICAprox: they occurred in 35 (89.7%) of 39 cases of aneurysms in this segment. Fusiform aneurysms were more often located in the VA area (VAprox and VAdist) — 6 (75%) of 8 cases, and also in the PICAdist region — 14 (70%) of 20 cases. In 16

Fig. 1. Surgical access in cases of VA and PICA aneurysms.
Linear incision (a) and craniotomy with resection of posterior arch of atlas (b) for suboccipital access. Semi-oval incision (c) and craniotomy (d) for retrosigmoid access. L-like incision (e) and craniotomy (f) for extended lateral access.
There were 12 fusiform and 4 saccular aneurysms among them. In most cases, aneurysms were small-sized (38.8%) and medium-sized (46.3%). It is noteworthy that all large and giant aneurysms (n=10) were fusiform and most often located in the area of PICAdist (n=8).

Surgical approaches

Three types of approaches (fig.1) were used for aneurysms closure, as well as four positions on the operative table (fig.2).

Surgical treatment features

Most often (77.6%) medial suboccipital craniotomy (MSC) with lateralization towards the hemisphere of the cerebellum in dependence on the aneurysm side was used as a surgical approach (table 2).

Usually linear incision was enough for this type of craniotomy (n=47). In 5 cases MSC was performed using L-like skin incision for lateralization of the craniotomy and provision of access to medially displaced (towards anterior surface of the medulla) complex VA—PICA. Positions on operative table according to surgical approach is demonstrated on fig.2.

In 31.3% of cases, posterior arch of the first cervical vertebra was resected during MSC (table 2).

In 45 cases MSC was performed in sitting position. In 7 cases, where an option of closing the aneurysm with anastomosis formation was considered, MSC was performed in prone position.

Far-lateral craniotomy with resection of atlas posterior arch and partial resection of occipital bone condyle was performed only in one case of VAdist aneurysm, which was located close to VA merging point. We performed access using L-like skin incision in lateral decubitus position.

Retrosigmoid craniotomy from linear or arcuate incision was performed in 20.9% (table 2). More often (n=10) we performed this type of access in supine patients with head turned 90 degrees and a small additional tilt of operating table towards contralateral side (table 2). In 13 cases this access was used for closing PICAprrox aneurysms and one case — aneurysms of VAdist.

Choice of option of aneurysm closure (table 2) depended on its localization, shape, size and presence of intra-aneurysm thrombi.

In most of saccular aneurysms patients, regardless of localization (in 42 (97.7%) out of 43 cases), aneurysm neck was clipped. More often, this type of aneurysm closure was used in PICAprrox aneurysms.

In cases of fusiform aneurysms, complex clipping with arterial lumen formation (CALF) was used more often.
Aim of this procedure was the closure of eccentric part of fusiform aneurysms with preservation of blood flow in carrier artery. CALF was performed in all three cases of VAprox aneurysms, in PICAdist aneurysms (fig.3) and less often in PICAprox aneurysms.

Only in one out of four cases of partially thrombosed saccular aneurysms, preliminary thrombectomy from aneurysm lumen was required for neck clipping.

In fusiform partially thrombosed aneurysms (n=12), a preliminary thrombectomy before CALF was required in 2 cases of PICAdist aneurysms. In seven cases of large and giant partially thrombosed PICAdist aneurysms thrombectomy was performed after aneurysm closure to decompress adjacent parts of brain and cranial nerves.

Deconstructive procedures (proximal clipping or trapping) was performed in 10 cases of fusiform aneurysms, when CALF was not possible and was considered impractical because of significant length of the aneurysm or even dilation of its walls.

Decision of aneurysm closure with a segment of PICA was made after confirmation of good retrograde blood flow through distal parts of PICA with intraoperative fluorescent videoangiography. In case of absence of retrograde flow, revascularization procedures with anastomosis formation were performed (fig.4, II).
Other criteria of combining deconstruction of PICA with an anastomosis, in our opinion, are large diameter of closed PICA, hypoplasia of contralateral PICA or VA and low-grade contrasting of ipsilateral PICA or superior cerebellar artery during angiography.

In accordance with these criteria, revascularization procedures were performed in five cases. We formed in situ anastomoses of side-to-side type (n=1), end-to-side type (n=1) and end-to-end type (n=3).

After the PICA closure, deconstruction of the artery was also possible in cases of fusiform aneurysms of VAdist. Deconstruction of this segment using proximal clipping was carried out using clipping in two patients and trapping — in one patient.

Conditions of closing VAdist with an aneurysm were preservation of PICA (clip was placed distally to this artery’s ostium) and a presence of the second VA, which was comparable in diameter with the primary artery.

Our attention was attracted by the fact that in cases of fusiform aneurysms in the segment of VA from the ostium of PICA to the area of VA merger no large perforating arteries supplying the medulla arose.

Refusal of CALF was due to close contact of this segment of VA with caudal group of cranial nerves (CN), medulla and narrowness of operative corridor (fig.5).

Results of surgical treatment

Results of procedures, intraoperative and postoperative complications are summarized in table 3.

Intraoperative complications

Intraoperative rupture of the aneurysm occurred in 5 (7,4%) cases.

From this group, two patients with PICA-prox aneurysms and one patient with PICAdist aneurysm did not have neurological complications in postoperative period. One patient presented with moderate CN IX and X disorders after clipping PICAprox aneurysm.

In one patient aneurysm rupture was complicated with significant intraoperative bleeding, which required aneurysm closure with the ostium of PICA on the right side, leading to ischemia in correspondent basin in postoperative period.

Because of significant bulbar disorders, patient received a tracheostomy. She was discharged in 90 days after the procedure (GOS 3).

Fig. 3. Clipping with artery lumen formation in the case if excentric fusiform partially thrombosed aneurysm of tonsillomedullar segment (p3) of the left PICA in a 35 years old female patient.

Vertebral angiography, lateral projection (a): functioning part of the aneurysm of left PICA is contrasted. Surgical view before clipping (b): 1 — proximal parts of intracranial segment of the left VA, 2 — CN XI, 3 — segment of PICA proximal to the aneurysm, 4 — aneurysm, 5 — segment of PICA distal to the aneurysm. Excision of excentric thrombosed part of the aneurysm. (c) Arterial lumen formation with transverse placement of four clips. (d) Confirmation of absence of PICA occlusion after clipping in fluorescent videosangiography. (e) Control CT-angiography on day seven: Arrow points to left PICA without occlusion (f).
A specific aspect of bleeding control in VA aneurysms is the necessity of proximal and, in sometimes, distal control of VA (in cases of significant retrograde blood flow from basilar artery and contralateral VA). Performing of distal temporary clipping, especially in the segment between PICA and VA merging point, often requires medical traction of the medulla, which is associated with a risk of caudal CN damage.

*Intraoperative thrombosis of PICA was registered in two patients (2.9%) (table 3).*

In one patient with PICAprrox aneurysm after multiple clips repositions, right-sided PICA thrombosis occurred at its ostium. An attempt was made to reimplant PICA into proximal segments of VA, but the formed anastomosis was impassable. After the procedure, right-sided CN XII paresis was noted. There were no ischemia foci in the cerebellum according to postoperative brain CT scan. Patient was discharged on the seventh day after the procedure in satisfactory condition (GOS 4).

In another patient with fusiform partially thrombosed aneurysm of tonsillomedullar (p3) segment of left PICA, a thrombosing of PICA occurred after a CALF attempt. Attempts to restore blood flow in distal segments of PICA intraoperatively were unsuccessful. After the procedure, a large ischemia focus formed in the left hemisphere and cerebellar vermix with a significant edema in the posterior cranial fossa (PCF).

Two days after the primary procedure, a decompressive craniectomy of PCF was performed. Patient was in comatose state for a long period on mechanical ventilation. He was discharged at day 47 after the procedure (GOS 3).

By the time of discharge patient was conscious, there were no limb movement disorders, but mild bulbar disorders and severe cerebellar symptoms persisted.

Air embolism during craniotomy was noted in two (4%) out of 50 patients, who were operated in sitting position. After hemostasis with large emissary veins occlusion in both cases the procedure was continued, In post operative period one patient had bilateral pneumonia, which in combination with mild CN IX and X disorders required a tracheostomy.

**Postoperative complications**

47 patients (70.1%) were discharged without postoperative worsening. Average hospital stay without neurological complications was 9.4 days.

**Fig. 4. Examples of procedures with preliminary occlusion test using fluorescent videoangiography.**

1. Patient V., 40 years old. Ia — CT-angiography (3D-reconstruction): Fusiform aneurysm of left PICAprrox can be seen; Ib — surgical view: 1 — aneurysm; 2 — left PICA; 3 — right PICA; 4 — temporary clip on the ostium of left PICA. Ic — fluorescent videoangiography: Satisfying retrograde contrasting of left PICA, which points to developed collateral blood flow. Id — CT-angiography (MIP) after aneurysm trapping — retrograde contrasting of left PICA (marked by an arrow)

II. Patient P, 49 years old. IIa — CT-angiography (3D - reconstruction): fusiform aneurysm of right PICAprrox is seen. Iib — surgical view: 5 — aneurysm; 6 — left PICA; 7 — right PICA; 8 — clip on the ostium of right PICA. IIc — fluorescent videoangiography: No retrograde contrasting of right PICA, indicating absence of collateral blood flow. IIId — CT-angiography (MIP) after proximal clipping of the aneurysm with subsequent reimplantation of right PICA into left PICA (anastomosis is indicated by an arrow).
The most often neurological complications were symptoms of CN IX and X disorders (dysphonia, dysphagia etc.), which were identified in 11 (16.4%) patients. In three cases these symptoms were pronounced, which required a tracheostomy for the rehabilitation period. In nine cases CN IX and X disorders were noted in patients with PICAprox aneurysms. Thus, among 39 patients with PICAprox aneurysms, bulbar disorders as the result of innervation pathology of caudal group of CN were registered in 23.1%. In three patients with CN IX and X symptoms, CN XII function was also impaired, which presented as tongue deviation and dysarthria.

In three cases of PICAprox aneurysms, there was an isolated CN XII paresis at the side of intervention.

Postoperative ischemic complications were registered in six patients. In three patients, aneurysms clipping was complicated with thrombosing of PICA and forming of an ischemic focus in brain hemisphere. In one patient with PICA closed at the level of the ostium and in one with PICA closed at the level of tonsillomedullar (p3) segment there were significant cerebellar and stem disorders, which required tracheostomy and prolonged rehabilitation. In one patient an ischemic focus about 1.5 cm formed as the result of PICA closure at the level of telovelomedullar (p4) segment, which did not lead to explicit neurological disorders.

In three patients, MRI found small ischemic foci in medulla, which presented with mild hemiparesis in one patient and hemihypesthesia in two others.

There were no postoperative hematomas or other hemorrhagic postoperative complications.

Complicated postoperative wound healing was registered in three patients. In one case, because of subcutaneous accumulation of cerebrospinal fluid at the procedure site, we installed external lumbar drain for five days, after which regression of this complication occurred. Two patients had wound liquorrea after the procedure. They had revision operations with dura mater defects sealing. In one of these patients, meningitis was diagnosed afterwards. Etiotropic antibacterial treatment was administered with favorable outcome.

Postoperative complications associated with SAH were rare because of relatively low number of patients operated on in acute period. In one patient, who had surgery at day 4 after SAH, focal hemispheric symptoms occurred at day three after the procedure. Angiography showed a significant spasm in the basins of both middle cerebral arteries (MCA), which led to ischemic foci formation in cerebral hemispheres (fig.6).

Posthemorrhagic hydrocephalia was registered in 13 (20.6%) out of 63 patients with previous SAH. In six patients, ventriculo-peritoneal shunt was implanted.
Control angiography was performed in postoperative period in 39 (58.2%) patients (direct selective angiography — 18, CT-angiography — 21). Complete closure was confirmed in 37 (92.3%) cases, neck contrasted was registered in two (5.1%) cases, neck and fundus — in one (2.6%).

Patients with partial contrasting of aneurysm neck were left for observation. One patient with aneurysm fundus contrasting subsequently received endovascular aneurysm occlusions with spirals.

In 28 patients, radicalism of aneurysm closure was confirmed with intraoperative florescent angiography with subsequent aneurysm body opening. Because of that, control angiography was not performed.

Thus, total PICA and VA aneurysms closure in microsurgical procedures was achieved in 64 (95.5%) cases.

**Discussion**

There are several points of view regarding surgical approaches to VA and PICA aneurysms.

Some authors [2, 14, 15] insist that maximally basal approaches with partial resection of occipital condyles provide the best aneurysm exposure and lower the risk of postoperative dysfunction of caudal group of CN. At the same time, transcondylar approaches increase total procedure time, risk of unsatisfactory postoperative wound healing, cranio-cervical instability and neck pain [2,16]. We agree with authors [16, 17] who think, that in the majority of cases conylar resection is not necessary. Best surgical view in some cases is achieved with intradural resection of jugular tubercle [5, 15, 18].

It is fairly stated, that the main obstacle in PICA and VA aneurysms are not bone projections, but neurovascular structures, which cover the aneurysm neck. [5]

Necessity of routine resection of posterior arch of the first vertebra for PICA and VA aneurysms access, is, as some authors suggest [2, 6, 4, 17] in our opinion, exaggerated. Real need for this manipulation arises in microsurgical access to VApex aneurysms and low PICAprox aneurysms. In cases of VAdist and PICAprox aneurysms, C1 posterior arch resection is usually not required.

Our experience of the last few years shows, that retrosigmoid craniotomy is an adequate access to small aneurysms of PICAprox and VA dist. Other authors are of the same opinion [4, 5, 16]. Advantage of retrosigmoid craniotomy for access to mentioned aneurysms is gravitation traction of cerebellum and brain stem medially and superiorly from skull base and VA elevated above the skull base. Because of narrow operative corridor, we do not use this approach in cases of large of fusiform aneurysms, especially in cases when the procedure may include anastomosis formation. M. Tjahjadi et al. [5] recommend retrosigmoid craniotomy (simple lateral suboccipital approach) in cases of PICA prox aneurysms when complex of PICA-VA is located 10 mm above foramen magnum. In the opposite situation, these authors recommend to extend the craniotomy medially and downwards to the lateral part of foramen magnum.

Even in case of significant bleeding from VA and PICA aneurysm, usually there are no complication in microsurgical approaches. H. Al-khayat et al. [15] draw attention to the fact, that in these procedures significantly weak traction of brain structures is applied and involved structures (brain stem and CN) do not become edematous after SAH like brain hemispheres.

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**Fig. 5.** Trapping of fusiform aneurysm of right VAdist in a patient M., 43 years old. Vertebral angiography before the surgery.

a — fusiform aneurysm of right VAdist is seen. CT-angiography after the surgery; b, c — 2 clips can be seen in the projection of closed segment of right VA and normal flow in right PICA (indicated by an arrow).
In one of six patients, operated on before day 14 after SAH, ischemic foci formed in brain hemispheres because of vasospasm. Risk of supratentorial cerebral ischemia of vasospastic genesis in SAH from VA and PICA aneurysms is, according to literature [15, 19, 20], 1,9—7%. Thrombi extraction from basal cisterns of anterior and middle cranial fossae during microsurgical procedures on PICA and VA aneurysms is not possible. Accordingly, patients with increasing linear blood flow in middle cerebral artery in cases of progressive clinical worsening may require cerebral angiography and vasospasm treatment with vasodilators [18].

Postoperative mortality in surgical series of patients with VA and PICA aneurysms is 1,8 — 3,7% [15—17]. It was noted, that unfavorable results of treatment directly depend on severity of patients conditions on admission [3,6]. In studied group, most of the patients were compensated at the time of the procedure; there were no lethal cases or outcomes into vegetative state.

Ischemic disorders in cerebellum and brain stem in patients with PICA and VA aneurysms are mostly associated with surgical issues. In one of the studies, postoperative ischemic cerebellar complications were diagnosed in 19% patients. [5] Usually, these complications are associated with PICA occlusion. Question of choosing the segment of PICA, where relatively safe occlusion may be performed, is still open. Many researchers point out, that in case of PICA occlusion distally to lateral medullar segment (p2), ischemia occurs rarely, as stem perforating arteries arise more proximally and blood supply of distal parts is provided with collateral branches from the anterior or low cerebellar artery, superior cerebellar artery and contralateral PICA [13, 21—23].

Our experience showed that pronounced ischemic disorders in the cerebellum might occur in occlusion of PICA and at the level of tonsillomedullar segment (p3). On the other side, ischemia may not occur after closure of the ostium of PICA. Thus, N.Chalouhi at al. [19] noted a postoperative cerebellar infarction in four patients (36,4%) among eleven patients with fully closed PICA.

Unfortunately, there are no exact risk criteria of PICA occlusion to date. We focus on a test with temporary clipping of PICA and its retrograde contrasting in fluorescent videoangiography. However, evaluating of the results of this test is simple only in extreme variants: Either in...
case of fast intensive retrograde contrasting of PICA with other intact arteries, or in case of its absence. In case of prolonged in time low- or medium-grade retrograde contrasting of PICA, it is not possible to evaluate the risk of ischemia at the moment. In our opinion, in questionable cases it is better to insure with the revascularization of the artery that is being closed.

According to P. Seoane et al. [17], in 5.4% of cases anastomoses in VA and PICA aneurysms patients are necessary. We performed such procedures in 7.5 cases. In most of the patients, we try to evade the area of VA or PICA aneurysm using in situ anastomoses. Other neurosurgeons follow similar algorithms [24—26]. In case of inability to form in situ anastomosis, revascularization using occipital artery as donor artery is the alternative.

Primary problem of microsurgical procedures in VA and PICA aneurysms are postoperative disorders of caudal group of CN on the side of the intervention. According to the literature, [3, 5, 16], incidence of these complications is 7.4—29%. According to our data, CN disorders incidence in patients with VA and PICA aneurysms was 16.4%, with PICAprox — 23.1%.

There is encouraging evidence that the incidence of CN disorders recovery in six month is above 76% [15]. To reduce the risk of CN disorders, it is recommended to carry out a sharp vasoneural dissection to prevent the tension of CN IX, X and XII, to reduce the time of preventing arterial clipping (to 6 minutes) and, if possible, to avoid temporary trapping of VA [5, 15, 16].

Our study showed that with microsurgical treatment we could achieve a high incidence of full closure of VA and PICA aneurysms. According to the literature [2,5,7,8,17], high grade of radicalism of microsurgical method is noted — 90—97%, and in some articles it achieves 100%.

In clinical series, including both microsurgical and endovascular methods, comparable clinical results of the treatment of VA and PICA aneurysms are noted.

**Conclusion**

Microsurgical treatment is an effective method of treating VA and PICA aneurysms. Complex basal accesses with condyles and CI vertebræ is not required for closure of the most of VA and PICA aneurysms. Complications decrease and increase of radicalism of microsurgical procedures in cases of VA and PICA aneurysms may be possible through careful preoperative planning using modern methods of neurovisualization, practice of reconstructive clipping technique, forming anastomoses and compliance with principles of patients selection considering developed algorithms and joint consultations with endovascular surgeons.

The authors declare that there is no conflict of interest.

**REFERENCES**


Due to subjective and objective reasons, surgical activity in patients with vertebrobasilar basin in our country was low for a long time, and operative treatment was mostly performed using intravascular method. A few publications, summarizing the results of conservative and operative treatment of patients with aneurysms of specified localization in acute period of the hemorrhage, demonstrated so depressive prospects, that the very thought of open surgery of aneurysms of posterior cranial fossa seemed like a pipe dream. Along with this, the presence in available foreign literature of reports, containing radically different approach to this problem, caused a natural information dissonance among specialists.

Thanks to the implementation of national healthcare projects in the Russian Federation, regional medical institutions were equipped with modern equipment for radiation diagnostics of brain vessels pathology, which radically improved the detection of people with ruptured and intact vertebrobasilar basin (VBB) aneurysms and, in turn, made practical doctors systematically solve tactical issues of treating such patients. However, only after our neurosurgeons had the opportunity to see the successful “live surgery” of VBB aneurysms with their own eyes as a part of educational programs, surgical activity on the ground moved from a dead point. Due to demographic and epidemiological features, the personal experience of microsurgical treatment of patients with VBB aneurysms in most regional medical institutions remains low now. In this regard, the report analyzing the possibilities of open surgery for patients with aneurysms of the vertebral (VA) and posterior lower cerebellar artery (PICA) from the leading neurosurgical center in Russia is interesting and relevant.

The authors presented a clear algorithm for the selection of patients for microsurgical and intravascular interventions, in which the priority in the treatment of VA aneurysms is given to the intravascular method, and PICA aneurysms to the microsurgical one, which corresponds to the current trend in cerebral aneurysm surgery. When analyzing the clinical data, it was proposed to separate aneurysms of VA and PICA according to the anatomical criterion into proximal and distal, which makes it possible to stratify the operational risks associated with the possibility of compromised blood flow in functionally significant arteries of the VBB. At the same time, the proposed division does not take into account the variability of the arising PICA ostium, as well as the options for the location of the VA trunk within the posterior cranial fossa, which limits the possibility of using this classification to select the optimal surgical access to the aneurysm and predict the postoperative dysfunction of the caudal group of CN.

Authors used three classic accesses to PCF structures for PA and PICA aneurysms closure. Taking into account the presented algorithm for the selection of patients for microsurgical treatment and, accordingly, the tactical tasks that were solved during the operations, the use of these accesses seems to us absolutely justified. We fully share the authors’ point of view that in the microsurgical closure of aneurysms of PICA and VA, there is no need for routine resection of the posterior half-arch of the atlas and, moreover, resection of the condyles of the occipital bone.

Section of the report, dedicated to the analysis of the results of deconstructive procedures on VA and PICA aneurysms and operations with microsurgical revascularization is extremely interesting. The authors presented a detailed and honest analysis of the intra- and postoperative complications that developed during open surgery, which once again emphasizes the technical complexity of such interventions and the need for careful preoperative planning and selection of patients for surgery, as well as its impeccable execution in all details.

In general, the work leaves the most pleasant impression and, no doubt, will be useful to all specialists who provide medical care to patients with aneurysmal brain disease.
Intracisternal administration of verapamil for the prevention and treatment of vasospasm in patients after microsurgical treatment of cerebral aneurysms in the acute period of hemorrhage


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The first results of intracisternal administration of verapamil for the prevention and treatment of cerebral vasospasm (CVS) in patients in the acute period of subarachnoid hemorrhage (SAH) after microsurgical clipping of cerebral aneurysms are presented.

Objective — safety assessment of the method of prolonged intracisternal infusion (PII) of verapamil.

Material and methods. Over the period from May 2017 to December 2018, 42 patients were included in the study, who underwent clipping of aneurysm of the anterior segments of the Willis circle. Most patients (78.6%) were operated during the first 6 days after SAH. For each patient, a thin silicone catheter was installed, through which verapamil was infused. A prerequisite was the installation of external ventricular drainage and opening of the lamina terminalis. The daily dosage of verapamil varied from 25 to 50 mg of the drug diluted in 200—400 ml of isotonic sodium chloride solution. The indication for the use of the PII method was the presence of one of the following factors: a score on the Hunt—Hess scale from III to V, 3 or 4 points on the Fisher scale, confirmed angiographically by the CVS before the operation.

Results. The PII procedure was performed from 2 to 5 days. The average dose of verapamil was 143.5±41.2 mg additionally, in the presence of an angiographically confirmed CVS accompanied by clinical manifestations, 14 (33.4%) patients received intra-arterial injection of verapamil in several stages, with individual selection of the drug dose. The formation of new cerebral ischemic foci of vasospastic genesis was observed in only 1 (2.4%) patient. No infectious intracranial complications were noted. The average follow-up period was 297.6±156.1 days. Long-term treatment outcomes, assessed by a modified Rankin scale from 0 to 2 points, were observed in 83.3% of patients. There were no outcomes such as vegetative status and no deaths. The frequency of liquorodynamic disorders, as well as epileptic syndrome did not exceed that among patients with SAH according to the literature.

Conclusion. The study has confirmed the safety of prolonged PII. The efficacy of the method, compared with other methods for CVS treatment requires further investigation. The first results look quite promising: the observation shows a low percentage of new foci of cerebral ischemia and the absence of deaths associated with it. In patients with severe CVS, the efficacy of the PII method is increased when combined with intra-arterial administration of verapamil.

Keywords: cerebral aneurysms, SAH, clipping, cerebral vasospasm, cerebral ischemia, verapamil.

List of abbreviations

ICP — intracranial pressure
IIV — Intracisternal infusion of verapamil
CT — computerized tomography
LVB — linear velocity of blood flow
MRS — modified Rankin scale
EVD — external ventricular drainage
SAH — subarachnoid hemorrhage
MCA — middle cerebral artery
TCDU — transcranial Doppler ultrasound
CVS — cerebral vasospasm

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Introduction

Subarachnoid hemorrhage (SAD) and subsequent cerebral vasospasm (CVS) and brain ischemia are still one of the primary reasons of high disability and mortality in cerebral aneurysm rupture patients. Existing methods of prevention and treatment of CVS, such as oral and intravenous administration of vasodilators, balloon and pharmacological angioplasty, may be effective in single cases, but they are not universal for all patients. [1—3]

During microsurgical treatment of aneurysms in acute period of SAH, wide arachnoid dissection and removal of blood clots from basal cisterns are recommended for prevention of CVS. [4, 5].

Method of intrathecal administration of fibrinolytics for blood clots removal from basal cisterns is widespread [6—9]. However, this method can be effective only in early administration (initiation of therapy no later than 48 hours after the moment of SAH) [8].

More than that, hemorrhagic complications are possible, especially in patients, who had microsurgical procedures previously. [10].

A number of studies have shown encouraging results in the treatment of CVS with intrathecal administration of vasodilators. The most common drugs for these purposes were calcium channel blockers: nicardipine and nimodipine [11, 12]. In animal experiments and clinical series it was shown, that the method is relatively safe and effective in lowering incidence of CVS and complications, associated with it [7, 13—16].

In N.N. Burdenko National Medical Research Center of Neurosurgery, selective intraarterial administration of verapamil into spasmodic vessel is used since 2012 [17].

This allows in some cases to prevent cerebral ischemia and to avoid the development of severe neurological disorders. Limitations of this method are its discreetness (usually, one procedure a day) and limited period of an-

Fig. 1. System for intracisternal infusion.

a — introduction of thin silicon catheter into the contralateral Sylvian cistern during the procedure; b — brain CT: end of the catheter in Sylvian (contralateral) cistern on the left; c — brain CT: end of external ventricular drainage in the anterior horn of left lateral ventricle (arrow); d — view of the patient’s head: external ventricular drain is indicated by a white arrow, cisternal catheter is indicated by a yellow arrow; e — headboard view: reservoir of the external ventricular drainage is indicated by a white arrow, infusion (inflow) system is indicated by a yellow arrow.
tispasmodic effect. Besides, daily endovascular proce-
dures, the number of which may reach from six to eight,
are expensive.

Using world experience on intracisternal administra-
tion of fibrinolytic and vasodilating drugs and positive ex-
perience of treating CVS using intraarterial administra-
tion of verapamil, in the N.N. Burdenko NMRC of neu-
rosurgery a method of intracisternal administration of
verapamil (IIV) for prevention and treatment of CVS in
patients after microsurgical procedures on brain aneu-
rysms in acute period of SAH was developed and is now
being implemented in clinical practice.

Aim of this study is to determine the safety of IIV
method used for prevention and treatment of CVS of an-
euryasmal origin.

**Materials and methods**

**Method description**

During microsurgical procedure after convincing clo-
closure of ruptured aneurysm and extraction of blood clots
from available basal cisterns, a thin silicone catheter (ex-
ternal diameter and length of which were 1,5 mm and
80 cm respectively) was introduced into one of the cisterns
(chiasmatic or Sylvian).

Cistern choice depended on localization of the aneu-
rysms, as well as localization and severity of visually regist-
tered vasospasm. After the introduction of the catheter,
surgical wound was sutured in layers and the catheter was
brought out through the contraperature and fixed to the
skin. In aseptic setting, an intracisternal infusion system
was connected to the catheter (fig. 1).

We used verapamil as the vasodilator in our series.
It was administered in the following dilution 25—50 mg
of verapamil (as a solution 2mg per ml) per 200—400 ml
of isotonic solution of sodium chloride. Infusion rate was
controlled by infusomat and was from 9 to 18 ml per hour.

For the prevention of hydrocephalia, brain edema
and increase of intracranial pressure (ICP) during ad-
ministration of additional volume into intracranial space,
the following measures were taken: Opening of terminal
lamina during the procedure, which provided an addi-
tional connection of basal systems with brain ventricles,
and introduction of external ventricular drain (EVD) in-
to the anterior horn of the lateral ventricle. EVD was al-
ways introduced through standard Kocher point into the
contralateral lateral ventricle before craniotomy and an-
euryasmal closure. More often, we used silicon catheters
with 2 mm external diameter and lateral openings in the
distal part as EVD. Wider ventricular catheters (3 mm in
diameter) were used in intraventricular hemorrhages,
which lowered the chance of drain obstruction with
blood clots.

IIV was continuous if EVD was always opened and
functioned correctly.

All patients, who received IIV, were in neuroICU,
where their vital functions were monitored round the
clock. Dynamic assessment of patients’ condition includ-
ed neurological examination, transcranial Doppler ultra-
sound (TCDU) and, if there were indications, computed
ized tomography (CT) or cerebral angiography. Depend-
ing of the results of the assessment, decisions were made
on continuation or discontinuation of IIV and on concen-
tration changing of administered drug.

We purposefully did not perform IIV after five days
from the surgery, so as not to increase the risk of intracra-
nial infectious complication. Antibacterial therapy was
used only preventively, at the day of the surgery (cefazo-
lin 2,0g IV in 40 minutes before the incision and 6 hours
after the first administration). In the absence of clinical
and laboratory signs of infection, additional antibacterial
therapy was not administered during IIV.

IIV earlier than 5 days after the surgery was discon-
tinued in case of absence of clinical deterioration and in-
crease of CVS according to instrumental methods, found
during at least 2 days.

**Characterization of patients**

From May 2018 to December 2018 in N.N. Burden-
ko NMRS of neurosurgery, prolonged (from 2 to 5 days)
IIV procedure was performed in 42 patients who received
clipping of ruptured cerebral aneurysms. Each case of use
of the method was considered at a meeting of the medical
commission of Neurosurgery center and was approved by
local ethic committee. In all cases, consent for surgery was
obtained from patients and their relatives and risks of nat-
ural course of the disease, surgery and used treatment
methods were explained.

Indication for IIV was the presence of at least one of
the following factors:
— condition according to Hunt—Hess scale from III
to V on admission;
— 3 or 4 points on Fisher scale assessment
— angiographically confirmed CVS before the sur-
gery, regardless of severity.

Preoperative contraindications for IIV:
— allergic reactions to calcium channel blockers;
— confirmed pregnancy;
— age less than 18 years.

Study group inclusion criteria
— less than 14 days after aneurysmal SAH;
— convincing microsurgical closure of ruptured an-
euryasm;
— incision of lamina terminalis;
— introduction of EVD;
— cisternal catheter insertion;
— IIV duration more than 24 hours after surgery.

Seven patients were excluded from the study group, because they had IIV system removed during the early postoperative period (within the first day). The reasons for that were: Dislocation of cisternal catheter, patients’ activity (n=3), absence of CSF flow through EVD, persistent intracranial hypertension with ICP above 20 mm Hg. (n=2).

Study group included 16 (38,1%) male and 26 (61,9%) female patients, average age was 51,6±9,19 years (median age — 52 years). Majority of patients (n=33) in our series were operated on within 6 days from the hemorrhage.

In all 42 cases aneurysms, that were the cause of the hemorrhage, were localized in the anterior parts of Circle of Willis:
— in the area of anterior cerebral — anterior communicating artery — 22 cases,
— internal carotid artery — 13 cases,
— middle cerebral artery (MCA) — 7 cases.

Indications for cerebral angiography were:
— Systolic linear velocity of blood flow (L VB) in M1-segment of MCA, according to TCDU, above 240 cm per second or daily increase of L VB above 50 cm per second;
— onset of focal neurological deficit;
— decrease of wakefulness; technical difficulties of reliable assessment of blood flow velocity using TCDU.

CVS, depending on the severity of artery narrowing according to angiography, is divided into mild (narrowing below 30% of vessel diameter), mild (30—60%) and severe (above 60%) [18]. It was previously established, that narrowing of MCA in CVS of more than 70% is prognostically unfavorable for the development of cerebral ischemia [17]. We defined such grade of arterial narrowing as critical. MCA narrowing grade was calculated relatively to average diameter of the artery, which is 4 mm [19]. In TCDU results analysis, maximal values of peak (systolic) velocities in M1-segment of MCA were considered in calculation. Lindegaard index and mean blood flow velocity could not be estimated reliably in every case, so they were not analyzed in this study.

Criteria of effectiveness of IIV method were:
— absence of new foci of cerebral ischemia associated with CVS;
— absence of extension of existing foci of cerebral ischemia associated with CVS;
— clinical condition of patients after 2—4 weeks after the operation, assessed using modified Rankin scale (MRS);
— clinical condition of patients in long-term postoperative period (more than 3 months), assessed using MRS.

— Catamnestic was inspected in all patients from 68 to 597 days (2,6 and 19,6 months respectively). Average catamnestic time was 297,6 days (9,8 months ±156,1 days), median —287 days (9,4 months).

Results

In all 42 patients, microsurgical clipping of ruptured aneurysm and direct blood clot aspiration from ipsilateral chiasmatic and Sylvian cisterns were performed. Additionally, for blood clots removal from interpeduncular cistern, Liliequist membrane was opened. Clots removal from contralateral chiasmatic and, partially, Sylvian cisterns was performed in nine cases.

In two cases, during the primary procedure, clipping of non-ruptured aneurysms of contralateral carotid basin was performed. In seven out of nine patients with multiple aneurysms, IIV did not result in growth or rupture of non-ruptured aneurysms of other basins (according to control angiography).

Primary microsurgical procedure was complicated with intraoperative aneurysm rupture in 6 (14,3% cases), Decompression trepanation was performed in 7 patients (16,7%)

ICP was controlled invasively in postoperative period in 11 patients. In patients with functioning EVD, external decompression trepanation, and, in some cases, other methods of ICP decrease (elevated head-side, osmotherapy, deep sedation), we managed to keep ICP lower than 20 mm Hg during the treatment period.

Intracisternal verapamil dosage varied during treatment from 50 to 255 mg (average value 143,5±41,2 mg), solution volume was from 220 to 1200ml (average value 725±202,4 ml).

In 5 cases, verapamil was administered intracisternally for 1—2 days after the surgery. In these cases, discontinuation of IIV was forced and was associated with dysfunction of EVD (in three cases).

In 37 cases, verapamil was administered intracisternally for 3—5 days after the surgery. In 33 patients (89, 2%) from this group, IIV was discontinued because of absence of CVS increase, according to TCDU, and its clinical manifestation. In two cases, IIV was ceased on day 3 after the procedure because of wound CSF leak: catheter was extracted, place of its insertion was sutured. In other two cases, in spite of persistent CVS, according to TCDU, cisternal catheter was removed in 5 days after the procedure in order to minimize the risks of infection complications.

Cerebral angiography was performed in postoperative period in 23 (54,8%) patients.

Additionally, in cases of angiographically confirmed CVS with clinical manifestations, 14 (33.4%) received intraarterial administration of verapamil in several stages with individual dosages.
Number of procedures varied from 2 to 6, total (in all basins) intraarterial dosages of verapamil per course was from 70 to 255mg, average value — 161,4±82,7mg. Average length of hospital stay was 19,2±9,5 days (median value = 16 days).

On discharge, functional status of the majority of patients (24 patients, 57,2%) and corresponded to 1—2

![Treatment outcomes (general patient group)](image)

**Fig. 2.** Treatment outcomes in early and long-term postoperative periods in patients who received IIV.

![Treatment outcomes (isolated IIV)](image)

**Fig. 3.** Treatment outcomes in early and long-term postoperative periods in patients, who received only IIV.
points on MRS, which implied no signs of disability or its mild symptoms. Sixteen patients (38,1) were discharged with signs of disability (3—4 points on MRS). In two patients (4,8%) condition on discharge was consistent with vegetative state (5 points on MRS). There were no lethal cases.

83,3% (n=35) had long-term follow-up (more than 3 month) with positive outcomes (0—2 points on MRS). Two patients, discharged in a vegetative state, recovered to 4 points on MRS (fig.2).

Group of patients who only received IIV

Group of patients who only received IIV without additional intraarterial administration of verapamil consisted of 28 people. Severity of condition and hemorrhage according to Hunt—Hess and Fisher scales are listed in tables 1 and 2.

Patients of this group were operated on, on average, 4,4 days after SAH (from 1 to 12 days). Mean duration of IIV was 3,5 days (from 2 to 5 days). Average total dose of verapamil per course was 141,8±39 mg. In 3 (10,7%) from 28 patients discontinuation of IIV was forced.

Maximal values of systolic LVB in M1 segment of MCA during the course of treatment in this group varied from 150 to 300 cm per second, average value was 207,3±40,6 cm per second, and median value — 192,5 cm per second. Cerebral angiography was performed in nine patients.

In one case, there was a mild spasm of M1 segment of MCA, and in another one case — a significant spasm (more than 60%).

In other seven patients, there was a moderate CVS — from 30 to 60%. There was no critical narrowing of MCA (above 70%) in this group.

Early and long-term outcomes in patients with isolated IIV are demonstrated in fig.3.

Clinical example of isolated IIV is presented in fig.4. Patient went into surgery on day 2 after SAH. Her condition was evaluated as Hunt—Hess stage IV. During the procedure, bilateral aneurysms of MCA were clipped from left pterional access. Verapamil was administered intracisternally for 4 days. Total verapamil dosage was 180 mg. Catheter and EVD were removed on day 5. On discharge on day 15, patient’s condition correspondent to 2 points on MRS, and a year later — 0 points on MRS.

![Fig. 4. Patient K, 65 years old.](image)

a — preoperative brain CT: massive SAH (Fisher 3); b — CT-angiography: ruptured aneurysm of left MCA (blue arrow) and non-ruptured aneurysm of right MCA (green arrow); c — cerebral angiography four days after the procedure: absence of severe CVS; d — brain CT seven days after the procedure: absence of ischemic foci.
**Group of patients with combined verapamil administration**

In 14 patients IIV was complemented by intraarterial infusion of verapamil. Usually, this course was chosen in cases, when microsurgical aneurysm clipping was performed on patient with pre-existing CVS, and we followed an aggressive tactics of prevention of delayed cerebral ischemia. We noted, that verapamil, when administered intracisternally, had its vasodilating effect mostly on the vessels of the cerebral crus, and at the same time had less effect on distal parts of cerebral arteries. In this way, we complemented IIV in a number of patients with severe (distally to M1-segment) with intraarterial administration of verapamil.

On average, patients in this group went into surgery in 4.7 days (from 1 to 8 days) after SAH. Average duration of IIV was 3.6 days (from 2 to 5 days). Average dosage of IIV was 148.6±45.4 mg. In six (42.9%) from 14 patients discontinuation of IIV was forced. Hunt—Hess and Fisher scales values for this group of patients are stated in Table 1 and 2. Maximal values of systolic LVB varied from 160 to 360 cm per second, average value of systolic velocity of blood flow in M1 segment was 259.6±66.5 cm per second, and median value — 300 cm per second.

Maximal severity of CVS in this group, according to angiography, did not correspond with mild spasm. In eight (57.1%) patients spasm was evaluated as moderate and in 6 (42.9%) — as severe. In 2 cases (14.3%), there was a critical CVS (above 70%). Treatment outcomes in this group are demonstrated on fig.5.

In clinical example, presented on fig.6, patient was admitted on day 5 after SAH. Condition according to Hunt—Hess scale was stage III (taking into account pre-operative CVS on angiograms). The same day she was operated on, left MCA aneurysm neck was clipped, intracerebral hematoma of left frontal lobe was removed, basal cisterns were cleared from blood clots, cisternal catheter was inserted, EVD was introduced into the frontal horn of right lateral ventricle. Just after the procedure, IIV was started with verapamil dosage of 50 mg per day. In spite of the treatment, on postoperative day 2, patient presentted with transient movement disorders in right extremities and speech disorder. During cerebral angiography, critical CVS in left carotid basin was diagnosed, and additional course of intraarterial verapamil was started. Totally, patient received 255 mg of verapamil intracisternally and 320mg (6 procedures) — intraarterially. This was the largest individual dose of the drug in our group. No complications, associated with 575mg of verapamil, were noted. We managed to prevent the formation of ischemic cerebral foci in this patient. She was discharged on day 13 after the procedure. There were no speech or movement disorders in neurological status, moderate cognitive disorders persisted (2 points on MRS). Symptoms regressed totally (0 points on MRS) in 8 months.
Table 1. Hunt—Hess preoperative condition of patients with isolated and combined postoperative administration of verapamil

<table>
<thead>
<tr>
<th>Hunt—Hess stage</th>
<th>Isolated IV, n (%)</th>
<th>Combined treatment (IV + IAV), n (%)</th>
<th>Total, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>II</td>
<td>4 (9,5)</td>
<td>—</td>
<td>4 (9,5)</td>
</tr>
<tr>
<td>III</td>
<td>10 (23,8)</td>
<td>8 (19,1)</td>
<td>18 (42,9)</td>
</tr>
<tr>
<td>IV</td>
<td>13 (31,0)</td>
<td>5 (12,0)</td>
<td>18 (42,9)</td>
</tr>
<tr>
<td>V</td>
<td>1 (2,4)</td>
<td>1 (2,4)</td>
<td>2 (4,8)</td>
</tr>
<tr>
<td>Total</td>
<td>28 (66,7)</td>
<td>14 (33,3)</td>
<td>42 (100)</td>
</tr>
</tbody>
</table>

Table 2. Fisher hemorrhage severity in groups with isolated and combined postoperative verapamil administration

<table>
<thead>
<tr>
<th>Fisher hemorrhage severity</th>
<th>Isolated IV, n (%)</th>
<th>Combined treatment (IV + IAV), n (%)</th>
<th>Total, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>2 (4,8)</td>
<td>—</td>
<td>2 (4,8)</td>
</tr>
<tr>
<td>3</td>
<td>15 (35,7)</td>
<td>8 (19,1)</td>
<td>23 (54,8)</td>
</tr>
<tr>
<td>4</td>
<td>11 (26,2)</td>
<td>6 (14,3)</td>
<td>17 (40,5)</td>
</tr>
<tr>
<td>Total</td>
<td>28 (66,7)</td>
<td>14 (33,3)</td>
<td>42 (100)</td>
</tr>
</tbody>
</table>

Fig. 6. Patient K, 28 years old.
a — brain CT two days after the hemorrhage: massive SAH and left frontal lobe hematoma (Fisher4); b — left carotid arteriography on the fourth day after the hemorrhage: an aneurysm of the MCA on the left and a pronounced CVS of the internal, front and middle cerebral arteries on the left are determined; c — angiography on the second day after surgery (7th day after hemorrhage): critical (above 70%) CVS of left carotid artery basin is seen; d — brain CT on the seventh day after surgery: absence of ischemic foci.
Among our patients with IIV, treatment outcomes and need for additional intraarterial administration of verapamil varied substantially depending on timing of microsurgical clipping of the aneurysm.

**Group of patients, operated on from one to three days after SAH**

Among all patients, operated on from one to three days after SAH (17 patients), none had ischemic foci, associated with CVS.

Angiographic diagnosis of CVS was performed in 6 patients: moderate CVS in MCA, varying from 30 to 60% was diagnosed in all patients.

Three (17.7%) patients received additional course of intraarterial treatment with verapamil.

Treatment outcomes in this group are presented in [fig.7](#). There were no patients with treatment outcome evaluated as 5 points of MRS.

**Group of patients, operated on from four to eight days after SAH**

Additional verapamil was administered intraarterially in 11 (55%) out of 20 patients, included in that group. In two patients, formation of ischemic foci associated with CVS was noted. In one case, focus started to form prior to operation. In another case, formation of new foci was noted in spite of combined infusion of verapamil.

In this group, moderate vasospasm in patients who received cerebral angiography was diagnosed more often — in 53.3% of cases. In one patient (6.7%) mild vasospasm was diagnosed, and in 40% - severe CVS. Critical CVS (above 70%) was diagnosed in 2 (13.3%) cases.

Treatment outcomes in patients of this group are presented in [fig.8](#).

**Group of patients, operated on from nine to twelve days after SAH**

Five patients were operated on from nine to twelve days after SAH. Among them, in one case an ischemic focus, associated with CVS, was diagnosed using CT. None of the patients in this group had new ischemic foci during the treatment, and combining of IIV with intraarterial administration of verapamil was not required.

Angiography was performed in 2 patients, maximal spasm of M1 segment of MCA was 41.2 and 51.8% respectively.

According to catamnesis, outcomes in this group corresponded to 0—2 points on MRS and were evaluated as positive.

**Complications**

Forming of new ischemic foci was noted only in 1 (2.4%) patient ([fig.9](#)). She was admitted in state of Hunt—Hess grade IV (in deep stupor, without speech or movement disorders). Maximal value of preoperative systolic LVB before TCUS was 270 cm per second. Patient went into surgery on the day of admission, on day 8 after SAH. Deterioration was noted in early postoperative period, which presented as progression of impaired consciousness. Critical CVS, according to cerebral angiography, was
diagnosed on the first postoperative day, after which combined verapamil treatment was initiated. Total drug dosage was 325mg. Treatment was unable to prevent the formation of multiple foci of cerebral ischemia in both hemispheres. Patient was discharged with MRS of 5 points. In catamnestic follow-up 18 month later, her condition was found to be improved and evaluated as 4 points on MRS. We associate early deterioration of the patient, in spite of combined treatment with verapamil, with the fact that the patient was already in a state of acute cerebral ischemia at the time of the operation. Standard brain CT performed prior to the intervention did not find ischemic foci.

In total, three (7.1%) patients had delayed ischemia associated with CVS, and in two of them it was verified with head CT on admission.

There were no infection complications in the study group.

In 2 patients (4.8%), a single seizure episode was registered during the treatment. In one case, an episode of generalized epileptic seizures was registered on the second day of IIV, which resulted in discontinuation of this procedure. In another case, a short loss of consciousness and seizures developed during intraarterial administration of verapamil in combined administration of the drug. There were no repeated episodes of seizures in these patients. No epilepsy developed in long-term period in other patients.

Formation of severe posthemorrhagic hydrocephalia was noted in 5 (11.9%) out of 42 patients. In all cases, CSF-shunting procedures were performed, which improved neurological status of these patients.

Causes of disability (4—5 points on MRS) from two to four weeks after the procedure are listed in Table 3.

### Discussion

There has been interest in intrathecal administration of vasodilators in CVS for many years [20]. In world literature [12, 21—23], clinical series of patients who received intrathecal administration of nicardipine, nimodipine, magnesium sulfate, sodium nitroprusside etc. are described.

Intrathecal administration of calcium channel blockers for prevention and treatment of CVS has a number

<table>
<thead>
<tr>
<th>Cause</th>
<th>Patients (4—5 points in MRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerebral ischemia, associated with CVS</td>
<td>1</td>
</tr>
<tr>
<td>Cerebral ischemia, associated with surgical complications</td>
<td>3</td>
</tr>
<tr>
<td>Primary brain damage after hemorrhage</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6</strong></td>
</tr>
</tbody>
</table>

Fig. 8. Treatment outcomes in early and long-term postoperative periods in patients operated on from four to eight days after SAH.
Fig. 9. Patient Z, 44 years old. Aneurysm of left internal carotid artery.

a, b — brain CT before surgery, on the 8th day after SAH; Absence of ischemic foci; c, d — cerebral angiography on 9th day after SAH (first day after aneurysm clipping procedure): Critical CVS in MCA basins on both sides; e, f — brain T2 MRI on 16th day after surgery (8th day after surgery): Multiple ischemic foci in both hemispheres.
of advantages over its intravascular administration: drug concentration in the area of interest is higher because of lower grade of dilution in CSF in comparison with circulating blood volume; the drug is not inactivated in the liver, thus it does not lose effectiveness; absence of severe systemic influence makes it possible to use calcium channel blockers in patients with unstable hemodynamics.

In experiment it was demonstrated, that decrease of blood volumetric blood flow in spasmotic vessels and pathological alteration of endothelial and subendothelial layers of the vascular wall due to hemorrhage, such as hyperplasia and fibrosis, may impair transport of vasodilators to smooth muscle cells in intravenous or intraarterial infusion. If there is no obstruction of subarachnoid space with blood clots, loose adventitia is more permeable for the drug in comparison with its intraluminal effect [20].

In addition to the influence on cardiac conduction and smooth muscles of the vessels, calcium channel blockers, and, in particular, verapamil, have a neuroprotective properties: It is associated with direct effect on calcium channels of neurons, blocking of excess calcium ions flow into cells, and, therefore, preventing activation of neuronal apoptosis and cerebral ischemia. Besides, verapamil inhibits excess activation of microglia and decreases the activity of inflammation in CNS, which positively affects functional outcomes [15, 25—27].

The feature of out method is that intracisternal infusion of the drug was continuous during the course of treatment. This, in our opinion, is an advantage in comparison with fractional infusion. In order to determine average daily dosage of verapamil for intracisternal infusion as 25—50 mg, we used experience of endovascular administration of this drug into spasmotic vessels [17]. Volume of isotonic solution of NaCl, which was used as a solvent, was determined empirically. We do not exclude the fact, that besides vasodilating effect, in patients of the studied group an effect of cistern clearance from products of blood decomposition because of inflow and outflow system functioning may have been present, which, probably, could have had a positive effect.

Received data shows that suggested system of infusion and evacuation of additional fluid into intracranial space functions throughout the course of treatment (3 — 5 days) in the majority of cases.

At the same time, functioning of this system depends on a number of components: Correct placement of cisternal catheter and EVD, adequate functioning of EVD in the state of ventricular hemorrhage etc. Because of violation of these statements, we could not perform IIV in 7 patients, for whom this procedure was indicated. Nine patients received an incomplete course of IIV, because of catheters dysfunction and high risk of catheter infections. This led to additional intraarterial administration of verapamil in 6 patients.

Prolonged catheter placement in the cisterns and brain ventricles may become the cause of intracranial infection, so all manipulations associated with IIV system introduction and maintenance should be performed under sterile conditions. In case of liquorrea, it is necessary to treat the wound as soon as possible with additional sutures placement, and, together with resuscitators and an epidemiologist, to decide on the continuation or termination of IIV, as well as on the need for additional antibiotic therapy.

IIV method is contraindicated for patients with persistent intracranial pressure (ICP) above 20 mm Hg. If intracranial hypertension is associated with primary brain damage in state of SAH and/or intracerebral hematoma, it is highly probable, that in case of early operation (evacuation of intracerebral hematoma, external decompressive trepanation and EVD insertion), the problem of increased ICP will be managed and it will not prevent IIV. On the other hand, if persistent intracranial hypertension is associated with cerebral edema in a state of the formed cerebral ischemia, an IIV may not be practical. The question of the possibility of reducing the area of forming ischemia against the background of IIV in combination with intrarterial administration of verapamil requires further study.

Among other hypothetical complications that can worsen the condition of the patient, epileptic syndrome and hydrocephalus should be highlighted.

Based on the literature data [28—30], the incidence of epileptic syndrome after aneurysmal SAH is 4—12%. Chronic posthemorrhagic hydrocephalus, which necessitates CSF-shunting surgery in patients with ruptured aneurysms, occurs in 17—21% of cases [31—33]. In the study group, 2 (4.8%) patients had single generalized epileptic seizures. Ventriculoarterial shunting was performed in 11.9%. Thus, with the method we describe, the incidence of epilepsy and cerebrospinal fluid disturbances did not exceed the average values in patients with SAH of aneurysmal genesis.

In this study, we can also observe the trends of effect of IIV method on the formation of ischemic foci. According to the literature [34, 35], the incidence of angiographically registered CVS in case of aneurysmal SAH is 49—67%, of which 1/3 of the cases occur in severe CVS. Ischemic foci of vasospasmogenic genesis form in 29—33% of patients with cerebral aneurysm rupture [34—36], Main predictors of CVS and associated ischemia are severe grades of hemorrhages and severity of patients condition, evaluated with generally accepted classifications Hunt—Hess, WFNS, Fisher et al. [37, 38].

In our group, patients condition on admission in 85.5% of patients corresponded to Hunt—Hess stage III—IV and in 95.3% — to Fisher grade 3—4. Moreover, despite the fact that the majority of patients included in the study group had high risks of an unfavorable outcome, foci of cerebral ischemia associated with CVS were recorded only in 7.1% of cases. Formation of new ischemic foci
during treatment was registered only in one (2.4%) patient.

IIV method was more effective as a preventive measure in CVS formation and cerebral ischemia in patients, operated on in the early stages (1—3 days) after SAH.

In a number of patients with severe and peripheral CVS, operated on in 4 to 8 days after SAH, IIV was supplemented with staged intraarterial infusion of verapamil. The latter method has proven itself in our clinic in recent years [17]. An increase of the total (intracisternal and intraarterial) dose of verapamil administered in such patients did not lead to an increase in the number of cerebral and other complications.

In the world literature, we did not find clinical series, where verapamil was used as a drug for intracisternal infusion. Off-label administration of the drug always imposes additional responsibility on medical staff and the clinic, where the study is conducted. That is why each case of IIV was examined and approved at a meeting of the Center’s medical commission, and the local ethics committee approved the preliminary treatment protocol.

At this stage of the research of safety and effectiveness of IIV, we cannot recommend this method in other hospitals, especially in clinics with little experience of aneurysmal SAH treatment and having unfavorable epidemiological situation regarding hospital infections.

Conducting further research with the recruitment of a large group of patients and the formation of a comparison group will allow us to draw more reliable conclusions regarding the prevention and treatment of CVS based on the developed protocol.

**Conclusion**

Method of prolonged IIV as safe, it does not increase the risk of intracranial infection complications, incidence of hydrocephalus and epilepsy.

Clinical effectiveness of the method in comparison with other methods of treatment CVS require further research. The first results demonstrated in this series of observations look quite encouraging: a low percentage of the formation of new foci of cerebral ischemia and the absence of fatal outcomes associated with it were noted.

In patients with severe CVS, effectiveness of IIV increases in combination with intraarterial verapamil administration.

The authors declare that there is no conflict of interest.


Commentary

The work carried out by the authors is extremely relevant in modern neurosurgical practice. A significant amount of research has been devoted to the problem of cerebral vascular spasm (VS) in patients with ruptured aneurysms. Vascular spasm should be considered as a multifactorial process that occurs because of blood entering the subarachnoid space. In this regard, in our opinion, the treatment of vascular spasm should be complex and consist of a combination of various techniques that affect different elements of pathogenesis.

Among the most common methods of dealing with this formidable complication are the systemic use of calcium channel antagonists, sanitation of basal cisterns (removal of blood clots, drainage of cisterns, and intracisternal administration of fibrinolytics), the use of balloon and chemoangioplasty, and the use of antiplatelet agents. It would be useful for the authors to consider not only foreign studies on the prevention of VS and cerebral ischemia, but also Russian studies on this topic.

The authors presented an interesting experience of intrathecal drug administration in clinical practice for the prevention and treatment of VS in patients with cerebral aneurysm rupture. The methodology is based on the local effect of calcium channel blockers on the wall of intracranial arteries in the subarachnoid space. The most interesting and successful, as it seems to us, is the idea of combining various methods of controlling VS: intrathecal infusion of verapamil and the administration of chemoangioplasty. However, both methods affect one pathogenesis link — an increase in the intracellular calcium concentration in the smooth muscle cells of intracranial arteries. In our opinion, the basis of treatment of VS should be the principle of a combination of different techniques that affect different parts of pathogenesis. The authors presented valuable and relevant experience. The combination of intracisternal administration of vasodilators with other methods of prevention and treatment of spasm (sanitation of basal cisterns, antiplatelet therapy, the use of nitric oxide donors, magnesium, etc.) will potentiate the therapeutic effect of the techniques. Such an approach to the treatment of spasm can become the basis for conducting large multicenter studies in this direction.

A.V. Prirodov (Moscow)
Individual preoperative 3D modeling of vascular brain pathology

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The possibility of segmenting three-dimensional objects by DICOM-series is well known and available both on specialized workstations and on personal computers. The technique, however, is relatively rarely used in clinical practice, and we believe that the benefits of preoperative preparation using segmented 3D models are underestimated.

The article is devoted to our experience in using segmentation of anatomical structures based on CT and MRI for preoperative preparation for surgical operations performed in neurosurgical departments on patients with vascular pathology. The paper discusses the types and possibilities of segmentation, provides some examples describing the clinical use of the technique.

Keywords: segmentation, anatomical modeling, surgical simulation, rapid prototyping, 3D printing.

List of abbreviations

AVM — arteriovenous malformation
AG — angiography
SCA — superior cerebellar artery
ICA — internal carotid artery
CT — computerized tomography
CT-AG — computerized tomography in angiographic mode
MRI — Magnetic resonance tomography
MRI-AG — Magnetic resonance tomography in angiographic mode
ACA — anterior communicating artery
MCA — middle cerebral artery
EICMA — extraintracranial microanastomosis
3D — related to positioning in three-dimensional space
DICOM — Digital Imaging and Communications in Medicine (industry standard for transmission and visualization)
DLP — Digital Light Processing (color LED projection, technology option)
FDM — Fused deposition modeling
FIESTA — Fast Imaging Employing Steady state Acquisition (MRI sequence)
MIP — Maximum intensity projection (voxel data visualization method)
PET-G — Polyethylene terephthalate glycol-modified
PLA — Polylactic acid
PMMA — Polymethyl methacrylate
SLA — Stereolithography
SPGR — spoiled gradient-recalled acquisition in the steady state (MRI sequence)
T2 CUBE — MRI sequence name
TOF — time-of-flight (MRI sequence)
TRICKS/TWIST — Time-Resolved Imaging of Contrast Kinetics/Time-resolved angiography With Stochastic Trajectories (MRI sequences)
VPS — vinyl polysiloxane

Currently, there are many neuro-entgenological studies that can be performed on a patient with vascular disease in order to plan the surgery in detail. Taking advantage of the various possibilities of CT, MRI and direct AG, vascular anatomy and access anatomy can be fully analyzed, taking into account the ratio of blood vessels, brain and bone structures. Modern methods of visualization also have in their arsenal methods of determining the thickness and density of the vascular wall [1], the calculation of the volume characteristics of blood flow with the ability to predict its changes in the shutdown of certain vessels [2]. For a surgeon, in contrast to a radiologist, the relationship between different formations, which are often difficult to evaluate on two-dimensional tomographs, is very important for the planning of surgery. These relationships are easier to evaluate on a 3D model. At present, no special equipment is required to create 3D models, and it is possible to restore images using a personal computer.

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The aim of the study is to demonstrate our experience in the application of anatomical structure segmentation in clinical practice.

General overview of segmentation and its application

For the last few years we have been using segmentation (selection) of objects of interest by DICOM-series when preparing for operations. The method we use offers semi-automatic voxel and polygonal approximation of various anatomical formations. The final scene is a set of selected structures that allows you to plan the solution to a specific surgical task. The final result of segmentation depends significantly on both the quality of the source data and the carefulness of the object selection. A big advantage of this approach is the ability to create models only from the objects necessary to solve the problem, saving the scene from the insignificant "radiological noise" in terms of surgery. The possibility of combining formations segmented from different series or even studies is also extremely valuable. Thus, for example, it is possible to create a scene where soft tissues, bone and vascular structures will be segmented by CT, brain - by MRI sequence without contrast, and volume formation - by MRI sequence with contrast. In doing so, it is of course very important to take into account as accurately as possible the overlapping of research coordinates.

Software and methodology description

Currently, both paid and free programs are available for installation on a personal computer, which have sufficient functionality for segmentation: Materialise mimics (Belgium), Osirix DICOM viewer (Switzerland), Inobitec DICOM viewer (Russia), Invesalius (Brazil), Amira (Germany), 3Dslicer, Itk-SNAP, VuePACS3D, SpinFire Reader (USA) and some others [3-8]. Due to the availability of fast and affordable technical support, we chose Inobitec software. The first stage was always a semi-automatic voxel approximation of the object, then in most cases a polygonal grid was generated around the voxel 3D-model. Depending on the nature of the original data, the selection of the voxel object could be done using a 3D reconstruction using a suitable color table, or a preset interval of intensity/density in the split plane mode. Depending on the situation and on the segmentation method, the object was either left with the colors of the selected color table or assigned a unique color for the scene. When objects from several studies were combined in one scene, the series were preliminarily merged with the maximum possible control of the accuracy of anatomical elements comparison. The final scene was viewed either in the 3D viewer of Inobitec DICOM viewer itself, or polygonal objects were exported to Stanford Polygon File Format (.ply) for subsequent formation of the scene in external programs. We used two free software products: Autodesk Meshmixer and Blender. This option was needed to use certain features of these programs when viewing: variable transparency of objects, step-by-step navigation through the scene, etc.

Examples of clinical use

Using simple voxel 3D models

In many programs used in practice for viewing images there is a possibility to create a voxel 3D-model of any structure by the given characteristics of densiness and intensity [3]. Thus, objects of high density/intensity are usu-
ally evaluated: bones and vessels, although the use of an appropriate color table allows, for example, to perform reconstruction of intra-ranial vessels on the basis of a low intensity signal in 3D T2 mode. Creation of a voxel 3D model based on the presented KT-AG or MRI-AG series takes several seconds. To date, we can say that voxel 3D-models are used when viewing images of a patient with vascular disease routinely at the stage of diagnosis, and at the stage of planning surgery (Fig. 1).

**Estimating the volume of complex forms of education**

Assessing the volume of pathological education in neurosurgery is crucial, and sometimes critical, to the choice of treatment tactics. For example, it is often necessary to measure the volume of the hematoma in order to determine the indications for the operation and to track the effect of the measures taken, for example, when draining the operation, to assess the changes in the tumor volume in order to resolve the issue of the operation, etc. Segmentation of the formation naturally solves this problem, as the closed polygonal figure has a certain area and volume (Fig. 2). Segmentation of a hyperdensic hematoma takes several seconds, the accuracy of the result of such a calculation is many times higher than the estimate made manually. The superposition of two volumetric figures on top of each other can provide surgically significant information about changes in the structure of education. Dynamic assessment should maximize the comparison of research and segmentation parameters.

**Segmentation of the craniocerebral nerves**

The surgeon often has to rely on access to the base and cerebrospinal vessels during manipulation to minimally injure the craniocerebral nerves, separate the vessels from them and separate the aneurysm, sometimes in the conditions of a crude adhesion process. For example, the position of a paraclinoid aneurysm in relation to optic nerves, chiasma and bone structures should be detailed to plan its microsurgical shutdown, or in some cases to recognize the impossibility of its safe conduct. The most actual research for the construction of 3D-model of the skull base vessels with adjacent bone structures is now considered to be CT-AG. Performing two spiral series before and during bolus injection of contrast makes it easy to achieve separate visualization of vessels and bone elements. Many MRI specialists believe that nerve imaging is most convenient in FIESTA mode. Our experience has shown that in the conditions of altered anatomy due to the displacement of nerves by the aneurysm bag FIESTA does not allow to segment the optic nerve qualitatively, to differentiate it from the base of the frontal lobe, and sometimes from the aneurysm itself, because due to the turbulent blood flow in the aneurysm the intensity of the signal from the nerve and the aneurysm may be indistinguishable. A comparative analysis of the 3D TOF, T2 CUBE, FIESTA and 3D SPGR modes showed the advantage of the latter for segmentation of the shifted optic nerve and chiasma (Fig. 3, 4). In T1 SPGR mode, the nerve looks more intense than the basal frontal lobe. The nerve also differs significantly from the aneurysm and vessels. Introduction of contrast interferes with nerve segmentation by means of residual contrasting of membranes and small vessels.

Useful additional information for planning the operation can be obtained by segmentation of the neurovascular conflict area. Segmentation of this area according to FIESTA is often difficult because the intensity of the vessel and nerve is often comparable. Our experience shows that the creation of 3D-model is convenient to carry out, having a series of 3D TOF, on which the stem of BMA is clearly visible in the distal direction, and 3D SPGR, which

---

**Fig. 2.** Hemorrhage with intracerebral hematoma formation with rupture into the ventricular system.

| a | b | c | d |

---

a, b — result of semi-automatic segmentation of intracerebral component by high density. Automatic volume calculation of the segmented figure — ~67 ml; c,d — the proposed trajectory for the planned endoscopic emptying of the hematoma along its length.
**Fig. 3.** Left SCA aneurysm of paraclinoid localization.

Comparison of MRI in different modes for segmentation of the chiasma and optical nerve (red arrows — optical nerves, green arrows — chiasma, blue arrow — optic tract).

- a — MRI in 3D TOF mode: only nerves in the intraorbital section are distinguishable;
- b — MRI in T2 CUBE mode: It is impossible to differentiate nerve and chiasma from cerebrum;
- c — MRI in FIESTA mode: It is hard to distinguish nerves from cerebrum and aneurysm;
- d, e, f — MRI in 3D T1 FSPGR mode: nerves are differentiated from the aneurysm and from cerebrum tissue, segmentation is possible.

**Fig. 4.** Large medial paraclinoid aneurysm of left SCA.

CT-AG overlayed with chiasma and optic nerves, segmented using MRI 3D SPGR (red arrows —, blue arrows — optic nerve, green arrows — ostium of a. ophthalmica).

- a — left-sided 3D reconstruction;
- b — intraoperative view;
- c — right-sided reconstruction: Chiasma is thin and partially not segmented.
allows you to easily segment the trigeminal and facial nerves, as well as the surface of the brain stem. For distal BMA visualization, 3D TOF with contrast amplification can be performed in some cases, while 3D SPGR, on the contrary, is undesirable, as it will make nerve segmentation much more difficult. The use of the same modality (MRI) for segmentation and vascular and nervous structures is necessary for the most accurate comparison of series, which is extremely important in this pathology. With CT-AG, bone structures can also be added to the scene and access can be fully simulated (Fig. 5).

**Segmentation of the cortex and convection veins for accurate calculation of encephalotomy in the search and removal of small volume formations**

When searching for and removing a number of intracerebral formations, clear anatomical guidelines are much more effective than any other neuronavigation apparatus, as the latter may be inaccurate due to intraoperative displacements. For search and transcortical removal of small vascular formations, in particular peripheral aneurysms and cavity, we have recently often been guided by voxel 3D-reconstruction of the cerebral cortex. With the use of the standard color table voxel reconstruction of the bark is easily achievable by 3D T1 or 3D T2 FLAIR sequences (Fig. 6). Orientation is also significantly assisted by the application of a polygonal model of surface veins on the cortex, which can be easily restored by T1 with contrast amplification, or by 3D TOF-venography (Fig. 7).

**Segmentation of partially thrombosed aneurysm**

The tactics of microsurgical shutdown of partially thrombosed aneurysms differs significantly from the tactics of fully functioning aneurysms. When analyzing images of partially thrombosed aneurysms, it is absolutely necessary to have a clear understanding of the size and interposition of the thrombised and functioning parts. Shutting down such an aneurysm is often impossible without prethrombectomy, which can be performed on functioning vessels in a complete and safe manner if the necessary infor-
information is available. Reduction of the total time of the carrier arteries shutdown reduces the risk of postoperative ischemic complications and speeds up the operation. It should be noted that in large and giant aneurysms pseudotumorrhage type of the disease flow is often observed, therefore, the removal of thrombulated volume is an independent task of the operation. The optimal method for segmentation of the functioning part of the aneurysm is KT-AG. Segmentation of the total volume of the aneurysm is possible with a certain error by the contrastless CT (Fig. 8), but it can be done most accurately by one of the 3D MRI-sequences, and T2-mode is preferred.

Segmentation for ABM excision planning

AVM vascular architecture is often quite complex and individual. When planning the microsurgical removal of ABM, it is necessary to have a clear understanding of fast and safe access to the main afferent vessels, to be able to differentiate them from normal arteries, to be able to determine in advance with a minimum sufficient volume of cortical resection. Currently, direct AG is considered a useful but insufficient study for planning the microsurgical excision of ABM. The main advantage of direct AH is the presence of time contrast sweep and, as a consequence, the ability to differentiate between arteries and veins. However, at present, time resolution images can already be taken on both MSCT and MRI (TRICKS/TWIST modes). Details of such images are not inferior to those of direct AG. At the same time, the localization of the ABM of direct AG often has to be determined on the basis of its location relative to bone structures and large vessels. The tomography shows the localization of AVM relative to brain structures and hematoma in detail. The primary studies for patients with suspected vascular disease are CT-AG and MRI-AG in 3D TOF mode. Our experience shows

Fig. 6. Access to small cavernoma of left frontal lobe through a fissure, found using 3D-reconstruction of the cortex.
A — segmentation of the cavernoma using 3D T1; b — voxel 3D model of cortical surface above the cavernoma (green arrow indicates probable access trajectory); c — on the intraoperative photo sought-for gyrus pattern is seen clearly, encephalotomy point is marked (arrow); d — intraoperative photo: Precise access to the cavernoma through the fissure.

Fig. 7. Reconstruction of the cortex with convexital veins above the cavernoma of right temporal lobe.
a — T2 MRI: Cavernoma is indicated by an arrow through the nearest fissure; b — voxel 3D model of cortical surface: Segmented veins (red color), green marker — supposed point of encephalotomy through the marked fissure; c — intraoperative photo: Structures are easily identified.
**Fig. 8.** Segmentation of a large partially thrombosed ACA on CT-AG.

a — voxel 3D-model with standard color chart does not allow us to evaluate true intraoperative situation, thrombosed part of the aneurysm is not visualized; b — whole volume of the aneurysm is segmented by hyperdense signal; c, d — scene consisting of polygonal 3D model (c — front view, D — right view): Thrombosed part of the aneurysm is marked by translucent turquoise color, a functioning part is seen through it; e, f, g, h — intraoperative photo: yellow arrow — optic nerve, blue arrow — thrombosed body of the aneurysm, green arrows — A2 segments of the ACA, orange arrows — A1 segments of the PMA; d — a large aneurysm sac of significant size is visualized; e — A2 segments were able to be visualized after abduction of the aneurysm body, as was expected when studying the 3D model; g — thrombectomy from the dissected aneurysm body with an ultrasonic aspirator; h — the body of the aneurysm is completely empty, the neck of the aneurysm is clipped.

**Fig. 9.** Segmentation of AVM of right temporal bone on CT-AG (soft tissues, skull, efferents) and MRI (afferents, nidus of the AVM, brain matter).

a — MIP CT-AG; b, c — segmented access. Abducted skin, bone access, abduction of frontal lobe; d — intraoperative view. Green arrows show both clipped large afferent vessels, orange arrow — M1-segment of MCA.
that a detailed study of these images often allows us to differentiate between afferent, efferent and normal vessels. Their separate segmentation provides a much more informative model than the direct AG model. Simultaneous cortical segmentation by MRI allows us to clarify sufficient encephalotomy, and bone structure segmentation by CT to plan minimal sufficient craniotomy (Fig. 9).

**Segmentation for planning revascularizing operations**

The creation of extra-intracranial micro- and wide-spanning anastomoses requires careful observance of the length of the transported branches and grafts, taking into account the anatomy of brain and bone structures. Thrombosis of an overstretched or bent branch in a loop is a common complication. The analysis of 3D-models helps to prepare the donor artery correctly, to assume its necessary length, to choose the recipient vessel and the place of anastomosis, to take into account the formation of bends in accordance with the peculiarities of anatomical structures in the course of the vessel (Fig. 10).

**Segmentation for reconstructive modeling**

In reconstructive bone surgery, bone defect segmentation is used for the subsequent modeling of the implant [9, 10]. For patients with vascular pathology bone reconstruction is relevant after decompression resection trepanations of the skull after severe hemorrhages. The software we use not only makes it easy to segment the existing defect, but also to simulate the defect in a situation where the patient is only planning a primary or additional resection of bone structures. In this way, an individual implant is created according to the defect at the end of the operation. For this purpose it is necessary to create a 3D-model with the planned resection and modeling of the stencil to perform the required sawing, as well as the implant or mold for intraoperative formation of the implant. The peculiarity of such a flap from PMMA will be the difficulty of its full installation "on the ground" in the place of resection on the stencil, as it is difficult to predict the microroughness of the relief and minor changes in the angle of the sawing. Stability and tightness of the edge in such a situation is logical to carry out overlays on the bone edge, maintaining the necessary thickness to ensure the strength of the flap. This approach can be used in the following situations: inappropriate for the main stage (aneurysm clipping, dissection of AVM) resection trepanation after removal of the hematoma (Fig. 11), the need for bone resection in hyperostatic meningiomas, the need for large resection trepanation in elderly patients, cranioplasty surgery of the skull defect after partial lysis of the autocranial defect after previous plasty. Note that at the moment we have completely abandoned cranioplasty with sterilized autocompatibility [11].

**Segmentation for 3D printing**

3D printing can be an important element in preoperative preparation and training [12]. Anything that can be segmented into a solid polygonal model can be printed. Thus, it is possible to create simple and composite printing layouts, print using materials of different colors and properties, or print forms to duplicate secondary materials [6–8, 13–15]. By the beginning of 2019, a large number of available FDM and SLA/DLP 3D printers, including domestically produced ones, had become available. Note that for printing complex anatomical models it is necessary to use at least two extruders and soluble supports, but the price of such printers in assembly is high. Simple models can be realistically reproduced on a single-extruder FDM printer, which is cheaper (Fig. 12).

Returning to the topic of reconstructive modeling, it should be noted that the additive production directly at the clinic has long been used in dentistry: a lot of biocompatible polymers have been developed for printing dental prostheses, surgical templates, bridges and crowns, orthoses and eliners. There are no significant technical or legal barriers to the establishment of similar "neurotechnical" laboratories. Neurosurgical additive production already exists in a number of countries [16, 17].
Fig. 11. Segmentation of “stencil” cranioplasty after aneurysm clipping.
Patient had here surgery at her place of residence, 70 ml cerebral hematoma is removed, decompressive craniectomy is performed (a). After condition stabilization, aneurysm of bifurcation of MCA was diagnosed. For aneurysm clipping with further cranioplasty, modelled with press-forms, required part of bone was removed (b), and implant and press-form for its formation were modelled (c); d — intraoperative photo after abduction of soft tissue: e — stencil is placed on the bone edge for performing a planned resection around the patch; f — individual bone implant made of PMMA is pressed and installed, contour shows a part of the implant, modelled using 3D model with planned resection.
In several neurosurgical departments in Russia, 3D printers have also been purchased for various purposes, and, apparently, in the near future we should expect the creation of laboratories of additive production at large neurosurgical departments and centers.

Conclusion

Our experience in segmentation of various formations by DICOM-series has shown that this is an affordable technology with great opportunities. There are many programs that support segmentation. The models can be used for a variety of purposes. Creation of individual 3D models for preparation for surgery is already actively used in a number of areas of neurosurgery. Printing of segmented objects is possible even in a small branch without large financial investments.

The authors declare that there is no conflict of interest.

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The article is devoted to one of the most relevant topics in neuroimaging - the possibility of creating 3D models that most accurately reflect the anatomical features of the selected area and are sufficiently demonstrative for the neurosurgeon to plan the tactics of the operation. The software existing today is available for use in routine practice and should be mastered by radiologists and neurosurgeons.

In subsequent works, for a clearer understanding of the advantages of modeling, it may be worth to separately consider the construction of 3D models based on segmentation and the issues of creating implants, including for 3D printing.

It would be interesting to get acquainted with the experience of the authors on the use of 3D models in patients with tumors of the base of the skull or aneurysms of the basilar artery.

The authors emphasize the clinical importance of 3D modeling, but it should also be pointed out that the topic is no less relevant for the formation of teaching aids, the mathematical processing of the constructed models, and the development of neurosurgeon skills in simulation centers.

Grigorieva E.V. (Moscow)
The prognostic value of MRI-classification of traumatic brain lesions level and localization depending on neuroimaging timing


Burdenko Neurosurgery Center, Moscow, Russia

Objective — the aim of this study was to estimate the prognostic value of magnetic resonance imaging (MRI) classification of traumatic brain lesion localization and levels in patients with a brain injury of various severity in a few days to three weeks after the injury.

Material and methods. The cohort of 278 patients with traumatic brain injury (TBI) of various severity aged 8—74 y.o. (average — 31.4±13.8, median — 29 (21.3; 37.0) was included in the analysis. The severity of TBI at admission varied from 3 to 15 Glasgow coma scores (GCS) (average — 8±4, median — 7 (5; 12). The main indications and conditions for MRI were: inconsistency between computed tomography (CT) data and neurological status, the necessity to clarify the location and type of brain damage, the absence of metal implants, the stabilization of the patient’s vital functions, etc. MRI was performed during the first three weeks after the injury using T1, T2, T2-FLAIR, DWI, T2*GRE, SWAN sequences. The damage to the brain was classified according to 8 grades depending on the lesion levels (cortical-subcortical level, corpus callosum, basal ganglia and/or thalamus, and/or internal, and/or external capsules, uni- or bilateral brain stem injury at a different level). Outcomes were assessed by the Glasgow outcome scale (GOS) 6 months after injury.

Results. The significant correlations were found for the entire cohort between MRI grading and TBI severity (by GCS) and outcome (by GOS) of the injury (R=-0.66; p<0.0001; R=-0.69; p<0.0001, respectively). A high accuracy (77%), sensitivity (77%) and specificity (76%) of the proposed MRI classification in predicting injury outcomes (AUC=0.85) were confirmed using the logistic regression and ROC analysis. The assessment of MRI-classification prognostic value in subgroups of patients examined during the first, second, and third weeks after injury showed significant correlations between the GCS and the GOS as well as between MRI-grading and GCS, and GOS in all three subgroups. In the subgroup of patients examined during the first 14 days after the injury, the correlation coefficients were higher compared with those obtained in a subgroup examined 15—21 days after the injury. The highest correlations between MRI grading, TBI severity, and the outcome were found in the subgroup of patients who underwent MRI in the first three days after the injury (n=58).

Conclusion. The proposed MRI classification of traumatic brain lesion levels and localization based on the use of different MR sequences reliably correlated with the clinical estimate of TBI severity by GCS and the outcomes by GOS in patients examined during the first three weeks after injury. The strongest correlation was observed for patients examined during the first three days after the injury.

Keywords: traumatic brain injury, magnetic resonance imaging, classification.

High sensitivity of magnetic resonance imaging (MRI) in all types of focal and diffuse damage of structures of hemispheres and brain stem in comparison with computerized tomography, determined an increased interest in specifying indications for this method, choice of MR-sequences and evaluation of prognostic value of diagnosed damage in traumatic brain injury (TBI) of various grades of severity. In previous articles authors used various sequences of MRI, and timing of scanning varied from a few days [1—4] to a few weeks [5—7], which complicates comparison of the results and determination of optimal timing of use of this method. Besides, authors analyzed mostly subgroups of patients with TBI of one or another grade of severity. For the detailed identification of all types of non-hemorrhagic and microhemorrhagic injuries in the first 3 weeks after the injury, the following sequences were used in an MRI study: T1, T2, T2-FLAIR, DWI, T2*GRE, SWAN, which detect nonhemorrhagic and mi-
crohemorrhagic lesions and do not require additional post-processing. It determined a possibility to offer an extended MRI-classification of localization and levels of brain damage, which showed high prognostic value in heterogenic group of patients with TBI of various severity grade [8—11]. In a recent review [5], 27 publications on the results of studies, carried out in 28 days after the trauma, were included in meta-analysis on evaluation of prognostic relevance of MRI in the acute period of moderate to severe TBI. According to the authors of the review, most of the studies included in meta-analysis, had a high level of methodological bias, which is primarily due to wide range of trauma patients examination time. In this regard, there is a relevant question of to what extent the timing of MRI studies can affect the prognostic value of the data obtained, since some patients in the acute period of injury have contraindications or significant limitations for their implementation.

Aim — to study the prognostic value of the proposed MRI classification of traumatic brain damage during examination of patients with varying degrees of severity from a few days to 3 weeks after the injury.

Clinical observations and research methods

In the studied group, patients who received brain MRI during the first three weeks after TBI of various severity from 2001 to 2017 are included. Main indications for an MRI-scan, which were formulated during a joint discussion of specialists involved in the examination and treatment of patients, were the inconsistency of CT data and the neurological picture, as well as its dynamics, the need to clarify the location and type of brain damage. Mandatory conditions for performing MRI were the absence of metal implants, the informed consent of relatives or the patient (in a clear mind), regression of psychomotor agitation, and restoration of the patient’s behavior adequacy. Additional conditions for MRI in patients with severe TBI were stabilization of hemodynamics, normalization of intracranial pressure, possibility of full monitoring and life support during transportation and scanning.

This study's inclusion criteria was a possibility to assess condition severity using Glasgow coma scale (GCS) on admission and outcome using Glasgow outcome scale (GOS) six months after trauma in direct contact with the patient or his or her close relatives. 278 patients met the criteria and were included in the analysis. These patients were 15.7% of all patients admitted during the stated period with “acute TBI” diagnosis.

In the analyzed group there were 83 women and 195 men at the age from 8 to 74 years (average age — 31.4±13.8 years, median value — 29 (21.3; 37.0 years). Condition severity varied from 3 to 15 points on GCS, average value was 8±4 points on GCS (median value — 7 (5; 12 points). Median value of GOS was 4 points (3; 4 points).

Main characteristics of the study group are presented in Table 1.

As it is seen in Table 1, traffic injury dominated (67%) in the analyzed group, a significant part consisted of patients with severe TBI (62%), a smaller part — with moderate TBI (23%) and only 15% had mild TBI In 54% of patients of the studied group positive outcomes were registered (satisfactory recovery and moderate disability) and in 45% — unfavorable outcomes (death, vegetative state or severe disability).

### Table 1. Basic characteristics of the studied cohort of patients with TBI (n=278)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>male</td>
<td>195</td>
<td>70</td>
</tr>
<tr>
<td>female</td>
<td>83</td>
<td>30</td>
</tr>
<tr>
<td>Age, years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average ± SD</td>
<td>31±14</td>
<td>8—74</td>
</tr>
<tr>
<td>Range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trauma mechanism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic accidents</td>
<td>143</td>
<td>67</td>
</tr>
<tr>
<td>assault</td>
<td>87</td>
<td>16</td>
</tr>
<tr>
<td>fall</td>
<td>37</td>
<td>13</td>
</tr>
<tr>
<td>other</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Condition severity on admission (GCS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild (13—15 points)</td>
<td>42</td>
<td>15</td>
</tr>
<tr>
<td>Moderate (9—12 points)</td>
<td>64</td>
<td>23</td>
</tr>
<tr>
<td>Severe (3—8 points)</td>
<td>172</td>
<td>62</td>
</tr>
<tr>
<td>Outcomes in 6 months (GOS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Favorable (satisfactory recovery, mild disability)</td>
<td>151</td>
<td>54</td>
</tr>
<tr>
<td>Unfavorable (severe disability, vegetative state, death)</td>
<td>127</td>
<td>46</td>
</tr>
</tbody>
</table>

Note. SD — standard deviation.
MRI-scan results analysis was conducted according to previously suggested MRI-classification of localization and levels of brain damage (Table 2). According to this classification, the following gradations were distinguished:

1) no damage;
2) cortical and subcortical damage of the hemispheres or cerebellum;
3) corpus callosum damage ±2;
4) subcortical structures damage (basal ganglia, thalami, internal and external capsule) ±2—3;
5) Unilateral damage of the brain stem on any level ±2—4;
6) Bilateral damage of the midbrain ±2—4;
7) bilateral damage of the pons ±2—6;
8) bilateral damage of the medulla ±2—7 [8,10].

In order to assess the prognostic value of the MRI classification of TBI, correlations between gradations (from 1 to 8), GCS severity and GCS outcomes were analyzed both in the group of 278 patients and in the subgroups of patients examined during the first 7 days (n = 110), 8—14 days (n = 88) and 15—21 days (n = 80) after the injury.

MRI-scans were performed on 1.5 T tomographs (Signa Excite, GE) and 3.0T (General Electric Signa). The MRI protocol included the structural sequences T1 FSE (TR/TE/NEX = 400—640 ms/15—20 ms/2), T2 FSE (TR/TE/NEX = 3000—5000 ms/≥80 ms/2), T2-FLAIR (TR/TE/T1/NEX = 8,000—11,000 ms/120—130 ms/1900—2400ms/1) with a slice thickness of 5 mm, diffusion-weighted images (DWI) (SE-EPI, b = 1000 s/mm²) with a slice thickness of 5 mm (in axial projection), FOV = 240 × 240 mm. The gradient echo sequence for different years included T2 * GRE, 3D GRE —

![ROC-curve](image1.png)

**Fig. 1.** ROC-curve for assessing the prognostic value of MRI-grading scale of the levels and localization of brain damage in traumatic brain injury.

![Risk factors](image2.png)

**Fig. 2.** Risk factors of unfavourable outcome determined with the logistic regression model (OR — odds ratio, n=278), * — subcortical structures: basal ganglia, internal and external caps.

| Condition                  | Coefficient | Std error | z     | Pr(>|z|)         |
|----------------------------|-------------|-----------|-------|-----------------|
| Corpus callosum            | 1.4992      | 0.4423    | 3.3892| 0.0007*         |
| Brain stem                 | 1.1224      | 0.3699    | 3.0337| 0.0024*         |
| Thalamiures                | 1.0624      | 0.4580    | 2.3195| 0.0203*         |
| Cortical formations*       | 0.8375      | 0.4064    | 2.0605| 0.0393*         |
SWAN (for SWAN, 3.0T MRI — TR/TE/NEX/flip angle = 91.5 ms/42.5 ms/1/20°, slice thickness 2.8 mm, FOV = 220 × 220 mm). SWAN sequence was carried out in 149 patients.

In cases of massive intracerebral damage foci or intracranial collections of blood of large volume, MRI scans in sagittal and frontal projection.

Statistical data analysis was performed using the language and environment for statistical programming R (Version 3.5.0, www.r-project.org). Differences in continuous quantitative values were evaluated using the non-parametric Mann – Whitney test, categorical ones — using the χ 2 criterion. Correlation analysis was performed using Spearman non-parametric correlation coefficient. In order to evaluate the role of various structures in the probability of unfavorable outcome, a method of binary logistic regression was applied. The same method was used to evaluate the prognostic value of suggested MRI-grading with subsequent calculation of the specificity, sensitivity and accuracy of the model and the area under ROC-curve (AUC — Area Under Curve). Model was built on a training sample of 70%, testing was performed on sample of 30% from the original one. Statistical test results were considered significant at the level of statistical significance p < 0.05.

**Results**

For the entire group of patients (n = 278), significant correlations were found (R = −0.66; p <0.0001; R = −0.69; p <0.0001, respectively) between MRI gradation of the level of brain damage, severity of condition victims according to GCS and outcomes according to GOS. Using the methods of logistic regression and ROC analysis, high accuracy (77%), sensitivity (77%) and specificity (76%) of the proposed MRI classification in predicting the outcomes of TBI (AUC = 0.85) were confirmed (Fig. 1). The most significant prognostic MRI signs of adverse outcomes (death, vegetative state, or deep disability) were injuries to the corpus callosum, brain stem, thalamus, and subcortical structures, including the basal ganglia, inner and outer capsules (Fig. 2). High chances of adverse outcomes were also noted in the presence of intracerebral hemorrhages, less significant — with compression of the basal cisterns and subarachnoid hemorrhages.

In 131 (47.1%) of the 278 examined patients, damage to the brain stem was registered (Table 2), while the most significant (statistically significant) factors of adverse outcomes in this group were damage to the thalamus and signs of compression of the basal cisterns. Fig. 3 shows the odds ratio of adverse outcomes in patients who have these symptoms.

Then we compared the groups of patients, in which MRI-scan was performed in 1, 2 and 3 weeks after the TBI. There were no statistical differences in age and gender between these groups. In the first group we picked out patients, who received MRI-scan in 3 days and on days 4—7th day after the TBI. Differences in condition severity in these subgroups (median values according to GCS — 12 (7;14) and 8 (6;12) points respectively) were statistically significant (p=0,020). Differences in brain stem damage incidence and outcomes according to GOS were not significant (Table 3).

The severity of the condition of patients who received MRI-scan in 7 days and on the 8—14th day after the TBI (median values according to GCS — (7; 14) and 7 (5; 11) points respectively, see Table 3) were significantly different (p = 0,0003). Differences in brain stem damage incidence and outcomes according to GOS was higher in the subgroup of patients, who received MRI-scan on 8—14th day after the injury (p=0,003).

In the subgroups of patients who received MRI-scan on the 8—14th day and on the 15—21st day after the TBI, no statistically significant differences were observed in severity according to GCS, incidence of brain stem damage and outcomes according to GOS.

Separate analysis of prognostic significance of MRI-classification in 3 subgroups, who were scanned in 1, 2 and 3 weeks after the TBI, showed reliable correlations between GCS and GOS scores on one side and MRI-gra-
Fig. 3. Factors affecting the risk of unfavourable outcome and the corresponding odds ratios in the subgroup of patients with single or bilateral brain stem injuries (OR — odds ratio, n=131), * — subcortical structures: basal ganglia, internal and external capsules.
Thus, the MRI data (in T1, T2, T2—FLAIR, DWI, T2 * GRE, SWAN modes) obtained at the earliest dates after the trauma were of the highest prognostic value.

### Discussion

Our previously suggested MRI classification of brain injury [8—12] was based on an assessment of the localization and level of damage to the hemispherical and stem structures of the brain in 162 patients with brain injury of varying severity in the first 3 weeks after the injury. According to this classification, patients were divided into 8 grades depending on the involvement of the cortico-subcortical structures, corpus callosum, subcortical structures (basal ganglia, thalamus, internal and external capsules), uni- or bilateral damage to the brain stem at the level of the midbrain, pons and medulla (table. 2). For the detailed identification of all types of non-hemorrhagic and microhemorrhagic lesions in the first 3 weeks after the trauma, the following sequences were used in an MRI study: T1, T2, T2—FLAIR, DWI, T2*GRE, 3D GRE (SWAN).

It should be emphasized that T2 * GRE, and especially the 3D gradient echo (SWI or SWAN), are highly sensitive to blood products and deoxyhemoglobin and are successfully used in the diagnosis of microhemorrhages from the first day to several months and years after an injury [13—20].

The developed MRI classification showed a high correlation with the severity of the patient’s state according to GCS and the outcomes of the injury according to the GOS, and therefore it was included in the clinical recommendations for the diagnosis and treatment of severe TBI [21]. Further accumulation of clinical observations according to our protocol of MRI studies allowed us to accumulate data from 278 patients and confirm the high prognostic significance of the proposed classification on a larger volume of observations. At the same time, the correlation coefficients between MRI grading, GCS score and GOS score in a larger series (R = −0.66; p < 0.0001; R = −0.69; p < 0.0001, n = 278, see table 4) were close to similar indicators calculated in a smaller series (R = −0.62; p <0.01; R = −0.72; p <0.01, n = 162) [8, 10, 12]. Besides, specificity, sensitivity and accuracy of suggested MRI-classification in prognosis of trauma outcomes were also confirmed using methods of logic regression and ROC-analysis (fig. 2).

Considering that a part of TBI patients had contraindications or limitations to MRI-scan early after the trauma, we performed a comparative analysis of prognostic value of MRI-classification in examination of patients during the first 3 days, 1st, 2nd and 3rd weeks after trauma. Average age, ration between male and female patients was not significantly different in the subgroups; condition of patients, who were examined during the first week, was less severe, and outcomes were more favorable, than in patients who were examined during the further 2 weeks (see table 3). In all subgroups of patients, who were scanned in different terms after the trauma, MRI-classification showed reliable correlation with the severity of condition and outcomes according to GCS, GOS. At the same time, specific features of these indices were noted. Thus, in our series 58 patients received MRI-scan during the first 3 days after the trauma. For this subgroup, correlation of MRI-gradation with evaluation according to GCS was R=−0.84 (p<0.0001), and to GOS — R=−0.78 (p<0.0001). Similar correlation coefficients for 52 patients examined from the 4 to 7th day were R=−0.53 (p<0.0001) and R=−0.60 (p<0.0001). Thus, the early MRI data after the trauma had the maximum prognostic value. It is well known, that condition severity evaluated according to GCS is one of the most reliable prognostically valued clinical signs, as there is a strong and reliable correlation between this scale and patients outcomes. In the first series of observations we confirmed this relation, correlation coefficient was R=0.64 (p<0.000001) [10]. As it is seen in table 4 coefficients of correlation between GCS and GOS scores, as well as between MRI-gradation and GCS and GOS scores in all terms of examination were high and reliable, but the highest values of these coefficients were in patients, who were examined during the first 3 days after the trauma, and the lowest — in patients who received MRI-scan on the 15—21st day.

It should be emphasized, that strong correlation between MRI-classification and condition severity according to GCS, as well as the outcomes, when it is difficult or impossible to evaluate condition using GCS (e.g. because of the pronounced edema or hematoma of perior-

**Table 4.** Statistically significant (p<0.0001) correlations between the evaluations according to MRI-gradation, GCS and GOS in the studied cohort (n = 278) and in the subgroups of patients whose brain MRI was performed at various periods after TBI

<table>
<thead>
<tr>
<th>Value</th>
<th>Whole cohort</th>
<th>1—3rd day after TBI</th>
<th>4—7th day after TBI</th>
<th>1—7th day after TBI</th>
<th>8—14th day after TBI</th>
<th>15—21st day after TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n=278)</td>
<td>(n=58)</td>
<td>(n=52)</td>
<td>(n=110)</td>
<td>(n=88)</td>
<td>(n=80)</td>
</tr>
<tr>
<td>Correlation coefficient between GCS and GOS scores</td>
<td>0.67</td>
<td>0.80</td>
<td>0.68</td>
<td>0.73</td>
<td>0.60</td>
<td>0.52</td>
</tr>
<tr>
<td>Correlation coefficient between MRI-gradations and GCS score</td>
<td>−0.66</td>
<td>−0.84</td>
<td>−0.53</td>
<td>−0.71</td>
<td>−0.64</td>
<td>−0.52</td>
</tr>
<tr>
<td>Correlation coefficient between MRI-gradations and GOS score</td>
<td>−0.69</td>
<td>−0.78</td>
<td>−0.60</td>
<td>−0.75</td>
<td>−0.72</td>
<td>−0.56</td>
</tr>
</tbody>
</table>
It is well known that primary brain damage (especially diffuse axonal) causes a cascade of secondary damage at the microstructural level, the identification of which in some cases is possible only using sequences such as diffusion tensor, diffusion kurtosis MRI with analysis of the spectrum of quantitative diffusion characteristics of brain tissue. These, as well as neuroimaging methods such as MRI spectroscopy, perfusion, functional MRI and other (more time-consuming) sequences require special conditions and indications. The question of the appropriateness of using different MRI sequences to assess the severity of brain injury, the dynamics of the traumatic process and predicting outcomes is being addressed today taking into account specific tasks and the clinical conditions for their implementation.

**Conclusion**

The study demonstrated, that suggested MRI-classification of localization and level of traumatic brain damage, based on the use of various MR-sequences, reliably correlates with clinical evaluation of condition severity using GCS and outcomes using GOS in cases of MRI-examination during the first 3 weeks, and the highest correlation indices were obtained in examination of patients in the first 3 days after trauma.

Main indications for MRI-examination in TBI are: inconsistency of CT data with neurological status and its dynamics, the need to clarify the location and type of brain damage, as well as to predict outcomes. In the absence of contraindications, the timing of MRI studies is determined by the clinical condition of the patient and may vary from several days to 3 weeks. A high correlation between MRI-grading and the severity of the patient’s condition, as well as the outcomes, is especially important in situations where it is difficult or impossible to assess the condition using GCS (severe edema or periorbital hematoma, intubation or tracheostomy with mechanical ventilation, the need for sedation and analgesia, or a combination thereof).

**Authors’ contribution:**

Research concept and design — A.A., N.E., G.V., I.N.

Data collection and processing — N.E., E.V., A.D., A.V., A.A., A.A., I.A.

Statistical processing — G.V.

Writing — A.A., N.E.

Editing — N.E., A.A., GV, I.N.

The authors declare that there is no conflict of interest.
The article presents the results of a study of the prognostic value of MRI classification of the localization and level of traumatic brain damage to determine the severity of brain damage and predict outcomes in patients in the acute period of TBI.

Relevance of the problem is undeniable. Clinical assessment of the severity of damage, as well as the prognosis of head injury is often difficult due to the presence of many factors that affect the patient’s condition in the acute period of injury.

Neuroimaging using MRI of structural and hemodynamic disorders of the brain is an important diagnostic method for assessing the severity of damage and outcome. CT data do not always correspond to the neurological state of the patient. This is due to difficulties in diagnosing damage to brain stem structures, and inadequate CT diagnostics of diffuse brain damage.

MRI-classification of localization and level of brain damage, suggested by the authors, proves its consistency and rather high level of correlation with TBI severity assessment in acute period using GCS and outcomes according to GOS in 6 months after trauma. The value of this study is especially important for determining the severity of primary brain damage and assessing prognosis in conditions that are difficult for clinical evaluation. Such complex and frequently encountered factors include severity assessment during deep sedation, in cases of severe combined injuries and associated secondary disorders, including disorders of systemic hemodynamics, hypoxia, septic conditions, which greatly complicate the assessment of primary brain damage.

At a high methodological level, the authors analyzed the state of 278 patients with TBI who underwent an MRI scan during the first 3 weeks after the injury. It is stated that in the previously published works of a number of authors, the timing of studies of patients with TBI ranged from several days to several weeks, which undoubtedly affects the results of the analysis. Wide range of patients’ examination timings after trauma may be a methodological bias. However, for more persuasiveness, it would be appropriate to see an analysis of the reasons for this dependence, confirming this conclusion. Perhaps, an increase in the frequency of secondary damaging factors for brain damage, septic complications, hypoxia and systemic hemodynamics should be demonstrated in groups of patients examined in 8—14 and 15—21 days.

The application of the classification proposed by the authors in clinical practice will improve the clinical understanding of severity, level of brain damage and prognosis of the outcome by practitioners, and therefore improve the quality of treatment for patients with TBI.

O.S. Isakhov (Moscow)
Quantitative characterization of risk of iatrogenic damage to pyramidal tracts based on data of intraoperative neuromonitoring during surgical correction of spinal deformities

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Federal State Budgetary Institution Russian Ilizarov Scientific Center «Restorative Traumatology and Orthopaedics», Kurgan, Russia

Objective — development of a quantitative indicator for the risk level of intraoperative iatrogenic motor disorders in the process of surgical correction of spinal deformity based on current neurophysiological monitoring data.

Material and methods. 288 patients 12.6±0.35 y.o. underwent surgical correction of spinal deformities under the control of intraoperative neuromonitoring. The nature of changes in motor evoked potentials was assessed according to the earlier proposed ranking scale. The incidence of different variants of changes in the rank values of the state of the pyramidal system during the operation and the resulting postoperative motor disturbances was calculated.

Results. By comparing probabilities of various changes in the conduction properties of pyramidal tracts during surgery with the incidence of the observed motor deficiencies we quantitatively assessed the possible correlation between these phenomena. We propose a method for calculating the risk index for postoperative motor disorders depending on the maximum rank of the pyramidal system’s response to surgical aggression.

Conclusion. The developed system of ranking evaluation of changes in motor evoked potentials during surgical correction of spinal deformity makes it possible to quantify the risk of postoperative motor disorders and, accordingly, to monitor the level of anxiety for a neurosurgeon during individual stages of surgical intervention.

Keywords: spinal deformity, spinal surgery, intraoperative neuro-monitoring, somatic motor system, neurological complications.

In spite of the development of advanced medical technologies, problems of surgical correction of vertebral deformities are far from final solution [1—3]. In particular, one of these problems is the risk of the development of iatrogenic motor disorders in postoperative period [4]. In order to prevent them, an intraoperative neuromonitoring (IONM) [5—7] with motor evoked potentials (MEP) [8—10] is used widely nowadays.

During IONM, a neurophysiologist concentrates his or her attention only on critically important changes of parameters. Actions of surgeons may be accompanied by a slight reaction of the MEP, which most often remains without consequences, but sometimes can be a harbinger of danger.

It complicates the accurate assessment of the risk of surgeon’s actions at a particular moment of the operation. Some authors [11] suggested an increase of IONM modalities in order to decrease the number of false-positive and false-negative reactions during the intraoperative control. However, it complicates the procedure and increases the time of preoperative preparation of the patient.

We suggested a scale for ranging MEP variations [12] observed during IONM, and for scoring of general reaction of conductive system of spinal cord to surgical aggression.

Observation of statistical regularities of rank rating of MEP variations in large groups of patients in a wide age range with various conditions during surgical correction of spinal deformity gives the opportunity to compare it with the distribution pattern of postoperative motor disorders and to create an index of the level of risk associated with surgeon’s actions at the moment.

Aim of this study is to develop a quantitative index of risk of intraoperative occurrence of iatrogenic motor disorders during the surgical correction of spinal deformity based on the data of current neurophysiologic control.

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Materials and methods

This study was conducted in accordance with the requirements of the Helsinki Declaration of the World Medical Association (as amended in 2013). All patients who took part in it, gave written consent. The study is approved by the ethics committee of Russian Ilizarov Scientific Center for Restorative Traumatology and Orthopedics (RISC RTO).

We analyzed a sample of 288 patients (107 male and 181 female) aged from 1 year 4 months to 27 years with spinal deformities of various etiologies: idiopathic scoliosis was diagnosed in 76 patients, spinal deformities of congenital origin and systemic skeletal lesions in 173 patients, neuromuscular and neurogenic scoliosis — in 15 patients, spinal deformities associated with other causes were registered in 24 patients. The magnitude of the deformation varied from 20 to 105° in the scoliotic component and from 15 to 134° in kyphotic.

All patients received an instrumental correction of the deformity with subsequent transpeduncular fixation of the segments of thoracic/thoracolumbar spine using various submersible systems [13]. In each patient, methods of mobilization of the posterior column of the spine of I—III level according to F. Schwab classification were used, in 189 (59%) of patients three column osteotomy of types III—IV were performed [14,15]. Total intravenous anesthesia was provided by a combination of narcotic analgesic fentanyl (10–3 μg/kg/h) and hypnotic propofol (10–4 mg/kg/h), their administration was carried out through an infusomat. Mechanical ventilation was performed through an intubation tube.

Intraoperative neurophysiological control of current status of pyramid pathways of patients was carried out using ISIS IOM («Inomed Medizintechnik GmbH», Germany) according to the plan described by us earlier [12]. Indicator muscles for MEP were chosen in dependence of the level of surgical intervention into the spine and the results of preoperative electromyographic assessment [16]. 320 IONM protocols were analyzed.

Registration of baseline MEP started after 40—60 minutes after a single administration of the myorelaxant rocuronium (before the tracheal intubation). Subsequent tests were conducted after the implantation of supporting elements of the frame and at various stages of corrective maneuvers at the command of a neurosurgeon. The monitoring duration ranged from 45 min to 9 h 52 min (3.5 ± 0.09 h).

When comparing the results of the current testing with the basic MEPs, a decrease in the amplitude by more than 50% of the initial level and an increase in the latent period exceeding 10% were considered as diagnostically significant changes in the response characteristics [17]. Observed MEP reactions were ranked according to the scale we developed [12]. Complex of changes of rank rating of MEP during the surgery was the basis for assigning the corresponding score to the identified type of reaction of the motor system. We calculated the incidence (ν) for the identified types of reactions as the ratio of the number of observations of t type (n_t) to total number of observations (N) and standard error (S_ν): [Equation 1]

\[ \nu_t = \frac{n_t \cdot 100\%}{N} \]

\[ S_\nu = \sqrt{\frac{\nu(1-\nu)}{N}}. \]

Mathematical analysis of the obtain data was conducted using Microsoft Excel 2010 with integrated data analysis package Attestat [18].

Table 1. Rank assessment of the response of parameters of motor evoked potentials (MEP) to the current surgical impact

<table>
<thead>
<tr>
<th>№</th>
<th>Rank (R)</th>
<th>Electrophysiological phenomenon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Unchanged shape and amplitude-time parameters of the MEP close to the original at the time of testing</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>The increase in the amplitude of the MEP relative to the initial level, often accompanied by the appearance of additional phases</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>Moderate decrease in the amplitude of the MEP, not accompanied by a significant change in its shape</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>Instability of amplitude-time characteristics and shape (fluctuations in the number and severity of phases) of the response</td>
</tr>
<tr>
<td>5</td>
<td>4a</td>
<td>A significant decrease in the amplitude of the MEP (by more than 50% from the initial level), accompanied by fluctuations in its latency and depletion (reduction) of the shape with the subsequent restoration of the characteristics of the MEP close to the original</td>
</tr>
<tr>
<td>6</td>
<td>4b</td>
<td>A significant decrease in the amplitude of the MEP (more than 50% of the initial level), accompanied by fluctuations in its latency and depletion of the shape, followed by the preservation of inhibited responses and / or further suppression of the MEP, until the complete disappearance</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>Complete absence of the response (no longer than 15 minutes), followed by restoration to a level close to the original</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>Complete absence of the response, followed by partial restoration</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>Complete absence of the MEP without signs of recovery by the time the surgery is completed</td>
</tr>
</tbody>
</table>

Note. j is the serial number corresponding to the rank position on the scale.
Results

Rank scale that reflects grade of changes of MEP in the current testing relative to the baseline is demonstrated in Table 1. Ranks starting from 4b and higher were considered “critical” (fig. 1), as they pointed to the significant decrease of conductive function of the pyramid system according to the danger criteria, described in literature [17].

In the group of muscle-indicators used for monitoring, reactive changes may be identical or different in the grade of MEP decrease and the transformation of their shape, indicating localization of dangerous iatrogenic effect (Fig.1). General condition of the pyramid system was assigned a rank, maximal for the selected group of muscle-indicators. In the subsequent testing, rank rating either persisted, or changed in accordance with the registered reactive changes of the MEP. Eventually, during the monitoring process a series of successive rank ratings of the pyramid system condition was formed.

Summarizing the dynamics of the rank rating of MEP during the whole procedure, we identified 5 stable (reproducible in different patients) types of rank combinations (Table 2), which, in our opinion, match the patients’ main reaction types to the operative correction of spinal deformities.

Reaction type is determined by the maximal rank value in successive testing during the operation:
- type I — calm operation without any stressful episodes;
- types II and III — mild decrease and instability of MEP;
- type IV — significant oppression of MEP at the end of the procedure (decrease of the amplitude by more than 50% from the baseline level and increase of the latent period exceeding 10%);
- type V reaction — complete oppression of MEP by the end of the operation (number of such observations during the IONM use was below 10%).

Clinical example

Patient K, 6 years and 6 months old, with congenital progressing scoliosis with multiple malformations of the cervical, thoracic, lumbar and sacral spine, received the Schwab level III vertebrotomy at the top of the deformity of the lumbar spine, correction of the spine deformity and posterior instrumental fixation with the dynamic system with transpeduncular fixation points.

Before the start of the operation, in the leads from the muscles of the lower limbs, reproducible polyphase MEPs (fig. 1, green lines) During the vertebrotomy, a probe, allowing to perform the direct electric stimulation of the nerve structures, was introduced to control the condition of the spinal roots, and appearance of spontaneous electromyographic activity of muscle-indicators was controlled.

During the vertebrotomy, instability of the shape and characteristics of motor responses developed, which expressed in (fig.1) their mild increase (left m. tibialis anterior lead), mild decrease (m. vastus medius on the left and right, m. tibialis anterior on the right), significant decrease (m. sphincter ani on the left) up to total oppression (m. Sphincter ani on the right). Absence of negative MEPs in the control leads (m.m. thenar on the left and right), localized significantly higher than the area of surgical interest, showed, that the observed reaction of the pyramid system of the patient is not associated with the action of the anesthesia components and the changes of hemodynamic characteristics of the patient. Considering previous operative interventions, in order to reduce the surgical stress patient received methylprednisolone, and before the corrective maneuver, epidural ropivacaine (0.375%) was administered.

At the end of the surgical intervention most of the MEP leads recovered to the level close to the baseline. Significant decrease of the amplitude of motor response persisted in two leads. But after the patient’s awakening, he had no motor disorders, so the negative condition of MEP, probably, was due to ropivacaine.

Table 2. Types of patients motor system reactions on operative correction of spine deformity.

<table>
<thead>
<tr>
<th>Type</th>
<th>Rank combination</th>
<th>Incidence</th>
<th>motor disorders</th>
<th>critical transitions</th>
<th>RL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>types of reactions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0, 1, 2</td>
<td>169</td>
<td>53,1±2,78</td>
<td>0 0 1</td>
<td>0,011</td>
</tr>
<tr>
<td>II</td>
<td>0—3, 4a</td>
<td>29</td>
<td>8,8±1,59</td>
<td>0 0 1</td>
<td>0,021</td>
</tr>
<tr>
<td>III</td>
<td>0—3, 4a, 5</td>
<td>50</td>
<td>15,7±2,02</td>
<td>0 0 1</td>
<td>0,200</td>
</tr>
<tr>
<td>IV</td>
<td>0—3, 46, 5, 6</td>
<td>46</td>
<td>14,5±1,99</td>
<td>0 0 1</td>
<td>0,350</td>
</tr>
<tr>
<td>V</td>
<td>0—3, 46, 5—7</td>
<td>20</td>
<td>6,3±1,37</td>
<td>4 0,2 1</td>
<td>0 0</td>
</tr>
</tbody>
</table>

Note. $f_m$ is the proportion of motor complications for the t-th type of reaction; $X_1$ and $X_2$ — weighting coefficients from equation (3); $p_t$ are the probabilities of a critical increase in the rank value during subsequent testing; RL is an indicator of risk. The percentage was calculated without taking into account six observations with initially absent motor potentials.
After the intraoperative obtaining of MEP, current value of the total rank would reflect the risk level (RL) of postoperative motor disorders, which consists of two components: incidence (f_M) of these disorders in the given type of reaction and probability (p_k) of the increase of the observed changes rank during subsequent testing to the critical values, i.e. probability of critical transition (Fig.2).

$$RL = X_1 f_M + X_2 p_k$$  \hspace{1cm} (3)

Where $X_1$ and $X_2$ — weight coefficients that reflect the importance of the both components in the total risk level. For convenient calculation, $X_1$ is considered equal to one; $X_2$ depends of type of reaction and is determined empirically.

In order to distinguish the incidences of type of pyramid system reactions and risk score, the first ones are represented in table two in percent, and components of the second from the formula (3) — in fractions of one.

For types I — III the first component of the formula, i.e. the incidence of motor and sensory iatrogenic disorders in the analyzed sample equals to zero. In type IV only sensory disorders were registered (three observations: skin sensitivity and disorders and neuropathic pain), so for motor disorder in this group $f_M = 0$.

All 20 cases of type V ($N_V = 20$) were associated with total absence of MEP at the end of the surgical intervention, after correction was finished and at the end of the corrective maneuver. In four observations the absence of the respond was monolateral and in the others — bilateral. In four observations amplitude of the response de-
creased to zero during epidural administration of ropivacaine. At the same time, as well as in 12 other cases of type V registration, after the completion of the intervention, no motor or sensory disorders were registered (16 observations out of 20). In four patients ($n_V = 4$) after the awakening, local transitory motor disorders were registered. We managed to treat them in postoperative period. Because of that, in case of type V reaction in the analyzed sample $f_M = n_V / N_V = 0.2$.

The second component of quantitative index of risk, i.e. Probability of rank increase to the critical level in subsequent testing, is defined as limit of incidence of critical periods in state of the increase of the analyzed sample volume ($N$), when $N$ tends to infinity, i.e. in large enough sample incidence is roughly equal to the probability.

Index of the risk level of clinical signs of conductive function of pyramid system disorders in postoperative period for types I—III tends to zero, as the first component of the formula, as it was stated previously, equals to zero, and the second is scornfully small because of close to zero values of the weight coefficient $X_2$ and probability $p_k$ — a small number of cases of abrupt decrease of responses or their complete absence right from baseline (Table 2). We consider such a course of surgical intervention as favorable. In type VI reaction index of risk level is also determined only by the second component of the formula, and is equal to 0.15 (Table 2). We consider such risk as moderate. In type V reaction, risk index is equal to the incidence of postoperative motor disorders, as rank 7 is the maximal value in the scale and it cannot be increased, i.e. the second component of the formula (3) equals to zero. In this case, risk equals to 0.2, i.e., in our opinion, becomes high.

Discussion

Initially, the ranking scale for the degree of changes in MEP during the operation we developed allowed us to compare the nature of intraoperative neurophysiological control in groups of patients with different clinical fea-
When using it directly in the process of neuro-monitoring, it should be remembered that ranks 1 and 2 should not cause concern, ranks 3 and 4a require the attention of an anesthesiologist (the change in the depth of anesthesia and hemodynamic characteristics of the patient is specified). Ranks 4b and below require a joint decision by the neurosurgeon and anesthesiologist regarding measures taken to eliminate the problem (drugs administration, changing the depth of anesthesia, re-passage of screws, resetting corrective efforts, etc., up to the wake-up test). In the future, after the accumulation of a large amount of statistical data, it became possible to give a statistical characterization of the observed changes and evaluate the probabilistic relationship between them and the incidence of postoperative motor deficiency. The difficulty persists in determining the weight coefficients \( X_1 \) and \( X_2 \) relating the heterogeneous parameters used in formula (3). If the frequency of occurrence of motor disorders observed in the postoperative period after registering the j-rank during the intervention directly indicates the risk of their occurrence, then the prob-

*Fig. 3. An example of increasing the rank of the depth of changes in the conductor properties of the pyramidal pathways of the spinal cord, revealed during intraoperative testing.*

I — condition of basic MEP: A — high-amplitude polyphase responses with a stable configuration (frequency of occurrence, %); B — low-amplitude unstable 2—3-phase potentials; C — absence of MEP. II — testing number i: D — preservation of the basic level responses; E — subcritical decrease of MEP; F — critical decrease of MEP (critical transition). III subsequent (i+1) testing: G — lowering the rank of Ri+1 outside the critical area; H — conservation of Ri+1=Ri within the critical region; K — further increase in hazard rank Ri+1 > Ri. PAF — probability of transition from state A to state F; PFK — probability of transition from state F to state K; PM — probability of identifying postoperative motor disorders.
ability of an increase in $R_i$ during subsequent testing to a critical level (critical transition) is just an indirect indicator that does not give a quantitative measure of the possibility of postoperative motor deficiency. A critical transition (increasing the rank of changes of ME$P$ to a critical level and beyond) is an intraoperative event that has a double meaning. It may indicate a direct danger to the nervous tissue associated with the actions of the surgeon or ischemia. However, it may be the result of anesthesia. However, even in this case, it potentially masks the possible consequences of surgical aggression.

This relationship can be traced by comparing the probabilities of the transition of the pyramidal system from one state to another under the influence of factors of surgical intervention (Fig.3). The chance of occurrence of motor disorders after registering the rank $R_j$ during the current testing will be equal to the multiplication of the probabilities of these events [23]. On Fig.3 it is $P_{AF}=P_{FK}=P_{M}$. However, $P_{AF}=P_{k}$ from formula (3), and the product $P_{FK}P_{M}$ will be the weight coefficient $X_2$, linking the current drop in the conductor function with the possibility of postoperative motor disorders.

This value should depend on the age of the patients, the etiology of the disease and the severity of the pathology, therefore, requires further clarification.

**Conclusion**

Thus, the system of ranking assessment of changes in motor evoked potentials developed by us in the process of surgical correction of spinal deformities that we developed makes it possible to quantify the risk of postoperative motor disorders and accordingly monitor the level of anxiety for a neurosurgeon during individual stages of surgery.

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The authors declare that there is no conflict of interest.

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Commentary

The article highlights the possibility of using a system of ranking assessment of changes in motor evoked potentials (MEP) in the process of surgical correction of spinal deformities in order to quantify the risk of postoperative motor function disorders.

The authors developed an objective indicator for assessing motor disorders in the process of neurophysiological intraoperative examination.

The scientific novelty of the work lies in the development of a mathematical and statistical algorithm for assessing changes in MEP parameters during intraoperative neurophysiological monitoring of possible motor function disorders as a result of surgical treatment. The practical value of the work is to confirm the importance and the need for intraoperative neuromonitoring to exclude or minimize any complications during surgery and in the postoperative period.

E. M. Troshina (Moscow)
Use of the «bonnet» bypass in treating a patient with symptomatic occlusion of the ipsilateral carotid arteries. Clinical observation

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In this article we present the clinical case of 63 y.o. man with chronic occlusion of the right common, internal, and external carotid arteries, and critical stenosis of the left internal carotid artery, with complaints of muscle weakness and decreased sensitivity of the left limbs. The patient underwent a staged brain revascularization, the left carotid endarterectomy was performed at the first stage and followed by bonnet bypass, which consists in anastomosing the contralateral superficial temporal artery with the ipsilateral intracranial artery by autograft interposition. In the postoperative period, the patient’s neurological symptoms regressed. This case demonstrates the possibility of using bonnet bypass as an alternative revascularization method in patients with cerebral blood circulation insufficiency.

Keywords: bonnet bypass, radial artery, common carotid artery occlusion.

Surgical revascularization of the brain has a half-century history dating back to 1967, when M. Yasargil et al. [1] applied the first microvascular anastomosis. Since then, the indications and approaches to performing this type of intervention have been revised, the range of nosologies requiring the use of revascularization has been expanded,

Fig. 1. CT angiography scans.
a — occlusion of right common, internal and external carotid arteries (arrow); b — critical left internal carotid artery stenosis.
the methods of anastomoses are modified, the search for new donor arteries, recipients and grafts does not stop. The generally accepted and most affordable options for bypass surgery are the use of the ipsilateral arteries of the head and neck and the direct anastomosis between them or the use of various vascular grafts. However, in some cases, the possibility of the using ipsilateral arteries as donors may be not available. One of the solutions in this situation is the use of bonnet-type shunting (from the French “bonnet”), which was first performed by R. Spetzler et al. [2] in 1980. The method of extra-intracranial shunting is used for occlusive lesions of the common carotid artery (CCA), internal carotid artery (ICA), external carotid artery (ECA) and its branches. The principle of method is to create an anastomosis between the contralateral superficial temporal artery with the ipsilateral intracranial artery through an autograft. We did not find a description of such interventions in domestic literature; therefore, we present our own experience in performing the so-called “bonnet” bypass.

**Clinical Observation**

The patient I., born in 1956, was admitted to the N.V. Sklifosovsky Research Institute of Emergency Medicine with the complaints of muscle weakness and decreased sensitivity of the left limbs. From the history of the disease it was known that in 2014 he was treated in the neurological department for ischemic stroke in the system of the right middle cerebral artery (MCA). After detecting symptomatic stenosis of the right ICA, the patient underwent carotid endarterectomy (CEE). During the control ultrasound, the right CCA, ICA, and ESA were passable, the patient was discharged with improvement. In December 2018, the patient had an episode of transient ischemic attack, and then a minor stroke in the system of the right hemisphere.

![Fig. 2. CT-perfusion scan.](image)

a — CBF; b — CBV; c — MTT, hypoperfusion regions are indicated in the right hemisphere.
Fig. 3. Planning and surgical approach marking before operation.

a — searching for donor and recipient arteries; b — 3D reconstruction of the donor and recipient arteries, interpositional graft, trepanation site (1 — left superficial temporal artery (STA) and it’s branches, 2 — supposed graft, 3 — right middle cerebral artery branches, 4 — supposed trepanation site); c — patient registration in the navigation system, marking of the skin landmarks.
MCA, which was caused by thrombosis of the CCA, ICA and the ECA on the right (Fig.1).

The neurological examination revealed a decrease in muscle strength to 4 points, a decrease in pain and temperature sensitivity in the left limbs. Walks with a cane. NIHSS — 4 points, Modified Rankin Scale (MRS) — 2 points, Rivermead Mobility Index — 12 points.

When examining the patient with ultrasound and CT angiography of the brachycephalic arteries, there was a lack of blood flow in the right CCA, ICA, ESA, thrombotic masses in the lumen of the arteries, critical stenosis of the left ICA (Fig.1).

According to the results of CT perfusion, hypoperfusion of the right hemisphere of the brain was noted (Fig.2).

In the light of clinical findings and the instrumental data obtained, the patient decided to conduct a staged revascularization of the brain. The left CEE was performed at the first stage. 2 weeks after the first intervention, due to the inability to use the ipsilateral right superficial temporal artery (STA) as a donor for the applying of the classic extra-intracranial microvascular anastomosis, the patient was scheduled to perform a “bonnet” bypass as the second stage.

Preoperative planning was accompanied by the use of a frameless navigation system to determine the left STA, M3 and M4 segments of the right MCA, as well as to determine the estimated localization of the burr hole and modeling the graft in the bone canal. After determining the key landmarks of surgical access, the estimated desired graft length is measured with a centimeter ruler. The length from the planned point of the graft and the parietal branch anastomosis to the presumed recipient artery (taking into account the depth of the artery + 1.5—2.0 cm) was 22—23 cm. The data obtained were compared with the results

![Planning and surgical approach marking before operation.](image)

**Fig. 3.** Planning and surgical approach marking before operation.

d — patient registration in the navigation system, marking of the skin landmarks; e — measuring of the required graft length; f — measuring of the radial artery length.
The length of the right radial artery, which was 26.5 cm. Given the sufficient length of the radial artery, it was finally decided to use it as the graft (Fig.3).

The operation was performed by two surgical teams (the main stage and the radial artery dissection). The patient, in a supine position, with his head fixed in a Mayfield three-screw bracket, performed a biauricular incision. In the cortical layer of the cranial vault, the bone canal was formed to place the graft using mechanical burr (Fig.4). After that, the operating table was turned in the direction of the occluded artery (to the right), and the parietal RTA branch was isolated on the left side. Then,
after turning the table to the left, a temporoparietal craniotomy was performed on the right with a size of 4.0 × 6.0 cm², transilvian access was used to isolate the artery segment M3 of the right MCA.

The second surgical team simultaneously performed the right radial artery dissection, carried out its preparation and hydrostatic dilation. Next, anastomosis of the distal end of the selected graft with the artery of the segment M3 of the MCA was applied according to the end-to-side type, the time of clamping the recipient was 38 minutes. The graft was placed in the prepared bone canal of the cranial vault, then the table was again turned towards the interested carotid artery (to the right). Anastomosis of the proximal end of the graft with the parietal STA branch was applied according to the end-to-end type, the clamping time of the arteries was 17 minutes. In order to level the difference in diameters between the graft and the parietal STA branch, the anastomosis was applied using “the double fish-mouth” method (Fig.5).

The blood flow was launched, a distinct pulsation of the graft was noted, the radial artery was fixed in the formed bone canal with an adhesive hemostatic sponge. Graft patency was confirmed by the Akland test, as well as flowmetry data (volumetric blood flow through the graft was 43 ml/min) (Fig.6). Layer wound closure was performed.

The postoperative period was uneventful, the patient woke up without an increase in focal neurological deficit, activated on the 2nd day, the wound healed by primary intention.

According to the control CT-angiography, graft filling was observed along its entire length; the volumetric

![Fig. 7. Benchmark studies on bonnet bypass.](a) a, b — CT-angiography (1 — left STA, 2 — RA graft, 3 — trepanation graft); c, d — bypass ultrasound, the RA in the frontal area with flow volume 64 ml/min.)
blood flow through the shunt in the postoperative period was 64 ml/min (7th day after surgery) (Fig.7).

According to the results of control CT-perfusion, an increase in perfusion indices in the right hemisphere of the brain was noted (Fig.8).

The patient was discharged on the 10th day after surgery. The significant regression of the neurological deficit was noted: walking along the corridor without support and a cane, NIHSS — 1 point, Modified Rankin Scale — 1, Rivermead Mobility Index — 14 points. Recommendations are given regarding lifestyle and protecting the graft from compression and injuries (Fig.9).

Discussion

Currently, in the literature there are no more than 20 observations of the use of bypass type "bonnet". In these observations, the main indications for this bypass type were:

1) ischemic cerebrovascular accidents associated with chronic occlusion of the CCA, ECA and ICA [3—7];
2) revascularization operations when turning off complex aneurysms from the bloodstream [8, 9];
3) removal of tumors, requiring shutdown of the main arteries of the brain [10, 11];
4) the impossibility of forming a subcutaneous tunnel for high-flow extra-intracranial anastomosis caused by radiation therapy or an infectious process on the ipsilateral side [2].

In addition to the classic “bonnet” bypass, the literature describes varieties of this method. In one of the varieties (Naturally (Spontaneously) formed "bonnet" STA), ipsilateral STA with determined retrograde blood flow is used. The retrograde blood flow allows the use of STA as a donor [7, 10, 12]. Another variety of methods involves the connection of STA with one of the pericallosal arteries through an autograph and is called “Hemi-bonnet” [8, 9].

The following interventions are also known as alternative methods for brain revascularization with respect to “bonnet” bypass:

1. Stage shunting: transverse artery of neck — ECA, then — shunting of the M4 MCA segment by the STA branch [13].
2. Subclavian-carotid prosthetics and shunting [14, 15].
3. Subclavian-carotid shunting as the first stage before the classical EICMA [16].
4. High-flow shunting of the M2 segment of MCA from the V3 segment of the vertebral artery using the graft from the radial artery [17].
5. Shunting of the M2 segment of MCA from the subclavian artery using the graft from the great saphenous vein [17].

The choice of a particular surgery method depends on the anatomical integrity of the CCA bifurcation and its branches, the possibility of using the vertebral artery as a donor, the severity of the patient’s condition, his rehabilitation potential, surgical preferences and experience in performing microsurgical interventions by the surgical team. In the described clinical case, the use of the “bonnet” method and transplantation of the radial artery made it possible to obtain a well-functioning middle flow bypass with high clinical efficacy.

Conclusion

The “bonnet” bypass method is rare and painstaking type of bypass brain vessels shunting. However, in some cases, it is as an alternative and effective way to treat patients with cerebral ischemia of various etiologies.

The authors declare that there is no conflict of interest.

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Fig. 8. CT-perfusion.

a — CBF; b — CBV; c — MTT, 3 days after surgery, perfusion improvements are indicated.

Fig. 9. Patient I., 63 y.o. before the discharge with regress of the neurological deficit.
The article is devoted to a rare clinical observation — surgical revascularization of the middle cerebral artery system in a patient with extracranial occlusions of the entire carotid system by cross-shunting from the contralateral superficial temporal artery. The radial artery was used as the shunt. The use of the described type of shunting in patients with ischemic cerebrovascular accidents is a new approach to the surgical treatment of occlusions of arteries of the carotid system and expands the arsenal of modern vascular neurosurgery used in the treatment of this pathology. An alternative approach in the treatment of common occlusions of the common carotid arteries is the staged extra-anatomical reconstruction of the external carotid system by subclavian-carotid shunting followed by classical EIKMA. This approach has been shown to be effective in treating patients with combined occlusions of the common and internal carotid arteries, but it has limitations — the high incidence of postoperative thrombosis of the reconstruction area with widespread lesions of the external carotid artery system and the need to divide the intervention into two stages. This slows down the clinical effect of surgical treatment in patients with subacute or acute clinical symptoms.

In the described observation, the use of “bonnet” type cross-shunting made it possible to immediately achieve a good clinical effect by compensating for the pronounced perfusion deficiency.

Nevertheless, the described variant of revascularization of the brain is a technically complex, invasive method, requiring clarification of indications and contraindications for its use. In addition, the asymmetry of the diameters of the anastomosed arteries and the possibility of compression of the shunt by the scalp tissues indicate the likely risks of postoperative thrombosis of the anastomosis. In this regard, for the correct assessment of the proposed brain revascularization method, it is advisable to provide follow-up data on the patency of the created shunt in the long-term postoperative period.

The article is excellently illustrated, contains a detailed description of the technical aspects of the performed surgical intervention, and, undoubtedly, will be interesting to vascular neurosurgery specialists.

D. Yu. Usachev (Moscow)
Giant thrombosed aneurysm of the pericallosal artery: clinical observation, literature review

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Distal aneurysms of the anterior cerebral artery (ACA), as well as distal aneurysms of the cerebral vessels in general, are a rare pathology. Distal ACA aneurysms account for up to 6% of all intracranial aneurysms. Among pericallosal artery aneurysms, giant ones, the size of which exceeds 25 mm, are especially rare. In the world literature, descriptions of patients with such pathology are sporadic. The atypical clinical signs of giant aneurysms and the morphological features of distal ACA aneurysms still make its treating difficult for neurosurgeons.

Clinical Observation

Patient S, 58 y. o. was admitted to N. N. Burdenko NMRC of Neurosurgery in July 2016, with the complaints of muscle weakness of the right limbs, memory loss, general fatigue, stubborn hiccups. According to the patient and his relatives, these symptoms gradually progressed over the past 6 months. Of the chronic diseases, only grade I arterial hypertension can be noted.

A neurological examination revealed a right-sided pyramidal symptomatology in the form of a decrease in muscle strength in the limbs to 4 points, brisk tendon reflexes, and Babinsky's pathological symptom. What's stand out are the expressed emotionally personality and mnemonic disorders: a decrease in initiative, apathy, almost complete disorientation in one's own personality, place and time. The eyegrounds and visual functions are without pathology. On the presented MRI-tomograms with intravenous contrast agent, a large formation of the left hemisphere of the brain with clear contours, spreading into the cavity of the left lateral ventricle, with pronounced perifocal edema, heterogeneously accumulating contrast medium, and obstructive hydrocephalus were determined.

Objective — the aim of the article is to present the clinical observation of a successfully treated giant aneurysm of the pericallosal artery in a 58-year-old man, and also analyze the publications on distal cerebral aneurysms.

Material and methods. The data of a patient hospitalized with a suspected tumor of the left brain hemisphere spreading to the left lateral ventricle is presented. Repeated MRI suggests a giant subtotal thrombotic aneurysm of the left perical artery, which was confirmed by SCT angiography. The patient underwent aneurysm trepaning-clipping with dissection of the aneurysm sac.

In the analysis of the literature it was shown that the frequency of perical artery aneurysms varies from 5.3—6.0%, and giant aneurysms of this localization are extremely rare and occur in 1—4.5% of all perical artery aneurysms. Unlike distal anterior cerebral artery aneurysms of small and medium size, giant aneurysms are characterized by pseudotumorrhagic symptoms, which causes diagnostic difficulties.

Conclusion. It is necessary to remember about the diagnostic difficulties caused by the pseudotumorrhosis of the giant aneurysms of the pericallosal artery and the frequent negative angiography data due to total thrombosis of the aneurysmal sac. The gold standard is microsurgical clipping with excision of the aneurysmal sac. The prognosis for this group of patients is favorable.

Keywords: distal aneurysms of the anterior cerebral artery, giant aneurysms of pericallosal artery, giant thrombosed aneurysms.

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Initially, a differential diagnosis was made between various tumors of the brain and its membranes: meningioma, ependymoma, glioma. Because of the atypical tumor MRI-type, it was decided to repeat brain MRI with intravenous contrast agent in the radiology department, N.N. Burdenko NMRC of Neurosurgery, according to which a giant supratentorial aneurysm was suspected (Fig.2). The diagnosis was confirmed by CT-angiography of the brain, which revealed a giant, with a maximum transverse size of about 70 mm, subtotally thrombosed aneurysm of the left pericallosal artery, almost completely fulfilling the cavity of the left lateral ventricle (Fig.3).

There was only a small functioning area of the aneurysm with a wide base greater than twice the diameter of the carrier vessel. After the diagnosis verification, the operation was performed: trapping of the aneurysm of the left pericallosal artery with the removal of thrombotic masses and excision of the aneurysmal sac walls. During surgery after intraoperative puncture of the right lateral ventricle, typical interhemispheric access to the distal segment of the anterior cerebral arteries was performed. In the depths of the fissure, the lateral wall of the aneurysmal sac spreading from under the falx was found. Before long, the efferent vessel was found. The proximal segment of the peri-
callous artery was difficult to isolate, since it was located anteriorly and inferiorly from the aneurysm. After careful dissection of the carrier vessel, it was found that the aneurysm actually does not have a neck, i.e. the proximal and distal vessels exit the wall of the aneurysmal sac at a distance from each other (Fig. 4a). In this regard, trapping of aneurysms was performed (Fig. 4b, 4c). The wall of the aneurysmal sac was opened, thrombotic extraction was performed. The aneurysmal sac was completely excised: partly through the already created access with dissection of the falx, partly by encephalotomy of the left frontal lobe in the premotor area. When excising an aneurysmal sac, the left lateral ventricle was wide open. According to the histology: the wall of the aneurysmal sac was with deposits of hemosiderin granules, calcinates: there was a large number of thrombotic masses in the lumen of the aneurysmal sac. In the postoperative period, there was a temporary increase in the neurological deficit in the form of right-sided hemiplegia and aphasia, which completely regressed on the treatment at time of hospital discharge. The patient was discharged on the 19th day after surgery.

**Discussion**

Distal aneurysms of the vessels of the Willis circle are extremely rare and make up about 6.5% of all intracranial aneurysms [1]. Among them, distal aneurysms of the anterior cerebral artery (ACA) confidently prevail, the incidence of which, according to the most significant studies, varies in the range of 5.3—6% [2—4]. The most aneurysms have small (less than 7 mm) and medium (7 to 14 mm) sizes - 62 and 31%, respectively [1-8]. Large (14 to 25 mm) and giant (over 25 mm) aneurysms account for 4% and 1—4.5%, respectively. In the English-language Pubmed database, the key component of which is the largest bibliographic database of articles on medical sciences MEDLINE, we found 36 articles in the search words “giant distal anterior artery aneurysm/giant aneurysm A2—A3/giant aneurysm of the pericallosal” on the description of observations patients with giant pericallosal artery aneurysms. All publications are clinical observations; only one of them presents a review of the case histories of 2 patients [9]. Giant pericallosal artery aneurysms have both common features characteristic of distal aneurysms of PCA of any size and unique features (see **table**).

According to the literature data [3, 10—13], distal aneurysms of the anterior cerebral artery, as a rule, have a saccular shape (99%), however, in the group of giant aneurysms more often than among small and medium-sized aneurysms, there are fusiform aneurysms - a description of 4 such observations was found in 36 articles. Also, any size distal PCA aneurysms are often combined with rare variants of its structure, for example: with the formation of a single vascular trunk at the level of the A2 segment - azigosomes (0.2—10%), with the presence of three A2 segments - triplication (3—13%), the presence of a single A1 segment — the bighemisphere type of structure (0.2—12%) [3]. Azigos was observed in 9 out of 37 patients presented in publications [14—22]. At the same time, a combination with aneurysms of a different localization is not typical for giant aneurysms of the pericallosal artery: only 2 patients had aneurysms of a different location, while in the group of patients with small and medium pericallosal aneurysms this phenomenon was observed in 44.4—58% of cases [23, 24]. Lehecka et al. presented detailed description of the morphological characteristics of small and medium pericallosal artery aneurysms [3], which was confirmed by data of other authors. As a rule, distal PCA aneurysms are localized in the A3 segment per Fischer classification (79%
Aneurysms are much less common in the A2 (13.2%) and A4-5 (8%) segments. Unlike small and medium-sized aneurysms, A2 segment is a favorite localization of giant aneurysms. This fact can be explained by rather stable hemodynamic conditions in the A2 segment, which reduces the probability of the aneurysms formation in general and the formed aneurysms rupture, allowing them to reach large sizes. The largest pericallosal artery aneurysm was described by O’Neill et al. [25] - its largest size was 80 mm, while in most cases the diameter of the aneurysm did not exceed 40 mm. The clinical signs in patients with this rare pathology was also significantly different. In 50% of cases, the disease was manifested by pseudotumor symptoms, while smaller aneurysms manifest a rupture (54 to 90%, by various authors [5–8]). Only 11 observations of giant aneurysms described a rupture with the formation of subarachnoid, intraventricular hemorrhage and intracerebral hematoma [14, 32, 33]. In 1 case, the disease was manifested by symptoms of transient ischemic attack [15], in the other, it was an accidental finding [26]. Atypical clinical signs make it difficult to make a correct diagnosis. In 16% of cases, because of the pseudotumor symptoms, the tumor process was initially suspected [18, 25, 27-30]. The high prevalence of the pseudotumor course of the disease is due to both the significant size of the aneurysms and aneurysmal sac thrombosis, which is described in 68% of patients. The presence of total or subtotal thrombosis makes it difficult to confirm the diagnosis even with the use of CT-angiography and direct angiography. In one of the cases, the distal aneurysm of the ACA was verified only after the taking biopsy [25].

As a rule, all patients with pericallosal artery aneurysms require surgery either because of the risk of rupture (typical for small and medium sized aneurysms), or because of the neurological symptoms onset and the continued risk of rupture (giant aneurysms). In 87% of cases of giant aneurysms, open surgery used, during which it is possible not only to turn off the functioning area of the aneurysm from the bloodstream, but also to perform decompression of nerve formations. According to the analysis of literature data [28, 32], interhemispheric access can be called traditional access; in 2 publications, interhemispheric access was supplemented with encephalotomy. In 4 patients, when approaching the aneurysmal sac, ligation and excision of the superior sagittal sinus and the falx in the anterior third were performed [10, 11, 19, 32]. None of these cases showed an increase in neurological deficit. According to the literature data [14, 16, 18, 27, 29, 33], it is not always possible to clip a giant aneurysm. Often in this cases, surgeons resort to trapping, ensuring the safety of bloodflow by applying a vascular anastomosis [10, 11, 34, 35]. In some cases, the pericallosal artery is turned off without anastomosis [32]. The selection of candidates requiring anastomosis is individual and based on angiography data. Shimizu [26] proposed an intraoperative test according to the meta-analysis [3]).

![Intraoperative photos.](image)

Aneurysmal sack with the selected distal segment of the pericallosal artery (a), aneurysmal sack with the selected distal and proximal segments of the carrier vessel (b), aneurysm trapping (c): 1 — falx cerebry; 2 — aneurysmal sack; 3 — distal fragment of the left pericallosal artery; 4 — proximal fragment (bringing vessel) of the left pericallosal artery; 5 — medial surface of the right hemispheres; 6 — vascular clips.
with temporary occlusion of the carrier artery and simultaneous registration of motor potentials to solve this issue. Considering that neurological symptoms are often caused by the presence of a mass effect, many authors propose to complete the main stage of the surgical intervention with decompression, which consists in either removing thrombotic masses or removing thrombotic masses along with excision of the aneurysmal sac walls.

The latter variant is often fraught with significant difficulties, since such aneurysms are characterized by pronounced calcification of the walls and the presence of an adhesion process with brain tissue. Despite all the diagnostic and intraoperative difficulties, the prognosis for this group of patients is favorable: in most cases, symptoms regress or neurological status maintains at the preoperative level, although some patients have described a temporary increase in neurological deficit that regresses in the postoperative period.

**Conclusions**

Giant distal aneurysms of ACA are an extremely rare pathology. They are observed mainly in middle-aged patients, which is, in general, typical for pericallosal artery aneurysms. As a rule, giant pericallosal artery aneurysms are located in the A2 segment, and more often than smaller aneurysms, they are combined with the ACA developmental variation called azigos. For this group of patients, the pseudotumor course of the disease is especially typical, which in combination with negative angiography data creates diagnostic difficulties. Surgery of these formations to this day remains a problem. Given the need to remove excess volume, as a rule, resort to open intervention. Often it is necessary to trap aneurysm. The selection of patients who need to apply a vascular anastomosis is still an open question. Despite of these factors, the prognosis in patients with giant pericallosal aneurysms is favorable.

The challenges for future trials are to identify a group of patients with brain mass needed additional diagnostic testing to exclude giant peripheral cerebral aneurysms, and to further develop a differentiated approach to the surgical treatment of giant aneurysms. An interesting question is the study of pathomorphological and genetic features in patients with giant cerebral aneurysms.

The authors declare that there is no conflict of interest.

### Comparative characteristics of all and giant aneurysms of the pericallosal artery on the basis of the analysis of world literature

<table>
<thead>
<tr>
<th>Clinical Characterization</th>
<th>Giant pericallosal aneurysms (data from 36 publications found in world literature)</th>
<th>Pericallosal aneurysms (by Lehecka analysis data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex-age structure</td>
<td>Mean age, years 49</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Males 38% (14)</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>Females 43% (16)</td>
<td>61%</td>
</tr>
<tr>
<td></td>
<td>Gender not specified 19% (7)</td>
<td>NA</td>
</tr>
<tr>
<td>Localization, ACA segment</td>
<td>A2 43% (16)</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>A2-3 10% (4)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>A3 5% (2)</td>
<td>79%</td>
</tr>
<tr>
<td></td>
<td>A4-5 3% (1)</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Localization not specified 38% (14)</td>
<td>NA</td>
</tr>
<tr>
<td>Morphological characteristics</td>
<td>Mean size 40 mm</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Saccular 89% (33)</td>
<td>99%</td>
</tr>
<tr>
<td></td>
<td>Fusiform 11% (4)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Combination with another localization aneurysms 2 (5%)</td>
<td>44,4—58,0%</td>
</tr>
<tr>
<td>Clinical signs</td>
<td>Rupture 30% (12)</td>
<td>54—90%</td>
</tr>
<tr>
<td></td>
<td>Pseudotumor course of the disease 51% (19)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Incidental finding 2,7% (1)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Clinical signs not specified 16,2% (6)</td>
<td>NA</td>
</tr>
<tr>
<td>Surgery types</td>
<td>Clipping 35% (13)</td>
<td>85—100%</td>
</tr>
<tr>
<td></td>
<td>Trapping 8% (3)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Trapping combined with vascular anastomosis 22% (8)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Endovascular repair 13,5% (5)</td>
<td>7%</td>
</tr>
<tr>
<td>Outcomes</td>
<td>Favorable outcome 68% (25)</td>
<td>77,0—84,5%</td>
</tr>
<tr>
<td></td>
<td>Poor outcome 2,7% (1)</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Outcome not specified 29% (11)</td>
<td>NA</td>
</tr>
</tbody>
</table>
REFERENCES


27. Park DH, Chung YG, Shin IY, Lee JB, Suh JK, Lee HK. Thrombosed giant aneurysm of the pericallosal artery with inconclusive findings of multi-


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Combination of infraoptic anterior cerebral artery with an aneurysm of the ACA—AcomA complex. Case study and literature review

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The infraoptic anterior cerebral artery (ACA) is an abnormal vessel that usually is a bifurcation of the intradural part of the internal carotid artery (ICA) or near the site of discharge of the ophthalmic artery, which passes under the ipsilateral optic nerve and penetrates between the optic nerves into the prechiasm cistern, reaching the ACA-AcomA complex.

The infra-optic ACA is an extremely rare anomaly, but it may be of great clinical significance in surgery of the arteries of the anterior sections of the Willis circle.

The article describes the case of a combination of infra-optical ACA with an aneurysm of the ACA-AcomA complex. This observation is of interest both from the viewpoint of the rarity of the considered pathology and the associated increased risk of the formation of intracranial aneurysms.

Keywords: aneurysm, infra-optic anterior cerebral artery, anomalies of the anterior cerebral artery.

List of abbreviations

ICA — internal carotid artery
ACA — anterior cerebral artery
AcomA — anterior communicating artery
MCA — medial cerebral artery

Anomalies of the anterior cerebral artery (ACA) — the anterior connective artery (AcomA) complex, are found, as a rule, during neuroimaging studies, and their clinical significance is small. However, the location of ACA under the optic nerve (the so-called infraoptic ACA) is an extremely rare finding that can be of great clinical importance.

The article describes the case of a combination of infraoptic ACA and aneurysm of the ACA—AcomA complex. This observation is of interest from the point of view of the rarity of the pathology under consideration and the associated increased risk of the intracranial aneurysms formation.

Clinical Observation

Patient M., 44 y. o. was admitted to the Burdenko Neurosurgical Center with a diagnosis of segment A2 of the right ACA aneurysm. There were recurrent subarachnoid-parenchymal hemorrhages with the formation of intracerebral hematoma in the right frontal lobe in past medical history. According to the cerebral angiography, the patient revealed an abnormal discharge of the right ACA from the ICA near the mouth of the ophthalmic artery and aneurysm of the ACA—AcomA complex on the right (Fig.1). Microsurgical operation was performed. During the surgery, it was found that the A1 segment of the right ACA departs from the ICA at the place of its exit from the cavernous sinus, passes under the right optic nerve and follows between the optic nerves anterior to the chiasm towards the interhemispheric fissure (Fig.2). A1 segment of the left ACA was absent. Both return arteries, as well as large frontal-polar branches, leave A1 segment of the right ACA. The aneurysm with traces of hemorrhage and with multiple diverticula was found in the area of the ACA—AcomA complex. Aneurysm was successfully clipped (Fig.3). The patient was discharged on the 8th day after the surgery without aggravating neurological symptoms.

Discussion

The A1 segment of ACA usually departs from the medial wall of the ICA bifurcation and is directed forward...
over the chiasm (70% of cases) or the ipsilateral optic nerve (30%) to the site of confluence with AcomA [1]. The structural variants of the ACA–AcomA complex are extremely diverse and widespread, with a certain degree of asymmetry between the two A1 segments found in approximately 80% of cases [2].

Infraoptic ACA was first described by L. Robinson [3] in 1959 during an autopsy. The first angiographic description was made by I. Isherwood and J. Dutton [4] in 1969. The infraoptic course of the A1 segment is extremely rare — 66 cases have been described in the English literature (see table) [1–32], no such publications have been found in Russian literature. Infraoptic ACA is an abnormal vessel, which usually departs from the intradural ICA from or near the ocular artery, passes under the ipsilateral optic nerve and enters the prechiasmal cistern between the optic nerves, reaching the ACA–AcomA complex [10, 12, 33].

During angiography, the infraoptic ACA has a typical appearance: the apparent low bifurcation of the ICA and the horizontal medial course of the proximal ACA, which passes under the ipsilateral optic nerve before turning to the site of confluence with a normally located AcomA [5, 14].

Infraoptic ACA has a typical appearance when examined by magnetic resonance angiography (MRA). A rather large vessel can be seen on the lateral projection, originating from the ICA at the place of its exit from the cavernous sinus, at the level of ocular artery discharge. Some authors describe the variant when the infraoptic ACA departs from the ICA with a common trunk with the ophthalmic artery [12].

Anteroposterior and oblique projections are less suitable for recognition of infraoptic ACA, however, upon careful examination, they demonstrate the abnormally low and medial course of the proximal ACA, which is necessary for passage under the ipsilateral optic nerve before entering the prechiasmal cistern. However, the exact ratio of the proximal ACA to the optic nerve is difficult to assess using angiography or magnetic resonance angiography (MRA).

In fact, in most cases in the literature, the infraoptic ACA is described as an unexpected intraoperative finding that was not found in preoperative testings [2, 9]. MRI can be especially useful in demonstrating the spatial relationship of the ACA with optic nerves and the chiasm, and

Fig. 1. Patient M. Angiogram, 3D-reconstruction. There is the junction (shown by a thick white arrow) of the right ACA from the right ICA near the mouth of the ophthalmic artery, as well as the ACA–AcomA complex aneurysm.

Fig. 2. Patient M. Intraoperative photography. a — the right ACA is located between the optic nerves; b — the right ACA departs near the mouth of the ophthalmic artery.
### Published cases of infraoptic ACA according to Wong classification

<table>
<thead>
<tr>
<th>№</th>
<th>Author</th>
<th>Year</th>
<th>Sex</th>
<th>Age</th>
<th>Type</th>
<th>Side</th>
<th>Ipsilateral Supraoptic A1</th>
<th>Contralateral Supraoptic A1</th>
<th>Aneurysms or other pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Robinson</td>
<td>1959</td>
<td>M</td>
<td>66</td>
<td>III</td>
<td>R</td>
<td>No evidence</td>
<td>No evidence</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Turnbull</td>
<td>1962</td>
<td>M</td>
<td>81</td>
<td>I</td>
<td>R</td>
<td>Hypoplastic</td>
<td>Hypoplastic</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Decker</td>
<td>1966</td>
<td>M</td>
<td>34</td>
<td>?</td>
<td>R</td>
<td>?</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>McCormick</td>
<td>1969</td>
<td>M</td>
<td>67</td>
<td>I</td>
<td>R</td>
<td>Hypoplastic</td>
<td>Hypoplastic</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Isherwood</td>
<td>1969</td>
<td>F</td>
<td>59</td>
<td>II</td>
<td>L</td>
<td>No evidence</td>
<td>Normal</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>F</td>
<td>37</td>
<td>II</td>
<td>bilateral</td>
<td>No evidence</td>
<td>No evidence</td>
<td>An of the IMCA, An of the rMCA</td>
</tr>
<tr>
<td>7</td>
<td>Handa</td>
<td>1971</td>
<td>F</td>
<td>28</td>
<td>III</td>
<td>R</td>
<td>No evidence</td>
<td>No evidence</td>
<td>Extrudal An of the rICA</td>
</tr>
<tr>
<td>8</td>
<td>Teal</td>
<td>1973</td>
<td>M</td>
<td>41</td>
<td>III</td>
<td>R</td>
<td>No evidence</td>
<td>No evidence</td>
<td>An of the AcomA</td>
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<tr>
<td>9</td>
<td>Nutik</td>
<td>1976</td>
<td>F</td>
<td>22</td>
<td>I</td>
<td>L</td>
<td>Hypoplastic</td>
<td>Normal</td>
<td>An of the AcomA</td>
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<td>Bosma</td>
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<td>F</td>
<td>60</td>
<td>III</td>
<td>R</td>
<td>No evidence</td>
<td>No evidence</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>Kessler</td>
<td>1979</td>
<td>M</td>
<td>23</td>
<td>II</td>
<td>R</td>
<td>No evidence</td>
<td>Hypoplastic</td>
<td>multiple craniofacial abnormalities</td>
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<tr>
<td>13</td>
<td>Besson</td>
<td>1980</td>
<td>F</td>
<td>53</td>
<td>?</td>
<td>Both</td>
<td>No evidence</td>
<td>An of the AcomA</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Lehmann</td>
<td>1980</td>
<td>M</td>
<td>23</td>
<td>II</td>
<td>bilateral</td>
<td>No evidence</td>
<td>No evidence</td>
<td>An of the CA trunk</td>
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<tr>
<td>15</td>
<td>Milenkovic</td>
<td>1981</td>
<td>fetus</td>
<td>21 нед</td>
<td>I</td>
<td>R</td>
<td>Normal</td>
<td>Hypoplastic</td>
<td>An of the AcomA</td>
</tr>
<tr>
<td>16</td>
<td>Bernini</td>
<td>1982</td>
<td>F</td>
<td>50</td>
<td>I</td>
<td>R</td>
<td>Hypoplastic</td>
<td>Hypoplastic</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>Senter</td>
<td>1982</td>
<td>M</td>
<td>48</td>
<td>III</td>
<td>R</td>
<td>No evidence</td>
<td>No evidence</td>
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<td>18</td>
<td>Fujimoto</td>
<td>1983</td>
<td>F</td>
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<td>No evidence</td>
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<tr>
<td>19</td>
<td>Sheehy</td>
<td>1983</td>
<td>F</td>
<td>60</td>
<td>II</td>
<td>R</td>
<td>No evidence</td>
<td>Hypoplastic</td>
<td>An of the AcomA</td>
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<td>21</td>
<td></td>
<td></td>
<td>F</td>
<td>37</td>
<td>?</td>
<td>R</td>
<td>?</td>
<td>?</td>
<td>An of the AcomA</td>
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<td>Ushiova</td>
<td>1984</td>
<td>M</td>
<td>24</td>
<td>I</td>
<td>R</td>
<td>Is present</td>
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<td>-</td>
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<td>Rosenorn</td>
<td>1985</td>
<td>F</td>
<td>55</td>
<td>III</td>
<td>R</td>
<td>No evidence</td>
<td>No evidence</td>
<td>Craniohypophyrmoma</td>
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<tr>
<td>25</td>
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therefore it should be considered as an additional research method in situations where the anatomical relationship is unclear. MRA, as well as routine T2-weighted MRI images can be used to reliably visualize the location of the ACA and its relationship with the visual apparatus [33].

There are many variants for the location of infraoptic ACA in relation to the optic nerves and the chiasm. Most often, the infraoptic ACA is directed forward in the gap between the optic nerves or can pass through the ipsilateral optic nerve [2, 8, 34]. As a rule, infraoptic ACA are one-sided, more often to the right (65% of cases). They are found on the left in 10% of cases. However, cases of bilateral infraoptic ACA are described (25% of cases) [1, 4, 7, 8, 14, 18, 22, 26, 31, 32]. Despite of the fact that this abnormal ACA is functionally equivalent to the A1 segment of the ACA, in a few previously described cases, during angiography, surgery, or autopsy, in addition to the infraoptic ACA, the usually located (although often very hypoplastic) A1 segment of the ACA was identified [1, 11, 22, 25, 27, 30]. S. Wong et al. [1] proposed a classification of various anatomical configurations of infraoptic ACA based on the presence or absence of the ipsilateral supraoptic ACA and the contralateral A1 segment (see table) [1]. In type I, the infraoptic ACA is present simultaneously with the normally located supra-optic A1 segment. In type II, the ipsilateral supraoptic A1 segment is absent. In type III, similar to type II, there is no the contralateral supraoptic A1 segment. In type IV, in addition to a normally located ACA, there is an additional ACA extending from the ophthalmic segment of the ICA, and the initial segment of which passes under the optic nerve. Both type I and type II can be bilateral. According to this classification, the case we have presented is of type III.

As a result of the fact that infraoptic ACA often exists together with a normally located ACA, some authors [9, 11] claim that this abnormal vessel is an anastomosis between the ICA and the ACA. The embryological basis of this anomaly is unknown. There are several theories of the origin of this abnormal vessel: early ICA bifurcation [10], an increase in prechiasmal anastomosis [11, 12, 35], an anastomosis between the primitive dorsal and ventral ophthalmic arteries [8, 9, 11] that preserved after the prenatal period, or an anastomosis between the branches of the primitive olfactory and primitive maxillary arteries [8, 11, 12, 35].

As with many other anomalies in the structure of the Willis circle, the presence of infraoptic ACA is associated with an increased risk of the formation of cerebral aneurysms, which, in our opinion and in the opinion of many authors, is due to the hemodynamic features caused by this pathology [3, 9—14, 18]. With bilateral infraoptic ACA, aneurysms are found in almost all cases [1, 18, 26]. Most often, aneurysms of the ACA–AcomA complex occur [9, 15], as was in our case, too. However, aneurysms can form on any other cerebral arteries of the Willis circle.

The literature [8–11, 15, 34] also describes the cases of the combination of infraoptic ACA with other cerebral vascular anomalies, such as ICA agenesis, abnormal passage of the ipsilateral ocular artery from the branches of the ECA, the presence of three A2 segments (3.7% of cases), fenestration or duplication of AcomA (4.4—9.7% of cases), fusion of pericallosar arteries (13.1% of cases). A combination of this anomaly with diseases and conditions such as aortic coarctation, moyamoya disease [4, 8, 13], symptoms of the optic nerve and the chiasm compression [12] is also described.

Fig. 3. Patient M. Intraoperative photography.
The aneurysm of the ACA-AcomA complex after dissection (a) and after clipping (b).
Timely recognition of this anomaly is important when planning microsurgical operations on aneurysms of the ACA—AcomA complex. This is necessary in order to correctly carry out proximal control of the aneurysm and to avoid the optic nerve and the chiasm damage during dissection [12].

Conclusions

Infraoptic ACA is a rare vascular abnormality that is associated with an increased risk of cerebral arterial aneurysms and other intracranial vascular abnormalities. Timely diagnosis of this anomaly is important when planning microsurgical operations for cerebral aneurysms.

The authors declare that there is no conflict of interest.

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**Commentary**

The article is devoted to the description of a rare vascular abnormality - an infraoptic anterior cerebral artery in combination with aneurysm of the ACA-AcomA complex and its successful surgical treatment. This article is of great interest from the point of view of the rarity of the pathology under consideration. The literature describes previously 66 such observations. Knowledge of this pathology by neurosurgeons will help to avoid intraoperative complications associated with the surrounding nervous and vascular structures damage. The author provides a detailed description of the clinical observation, covers the etiology and diagnosis of these abnormalities. The authors presented a long list of references.

*V.A. Lazarev (Moscow)*
Surgical treatment of a patient with a traumatic arterial aneurysm of the M4 segment of the left middle cerebral artery. Case report and literature review

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¹Krasnogorsk City Hospital №1, Krasnogorsk, Russia; ²Burdenko Neurosurgical Center, Moscow, Russia

Objective — the purpose of the study is to present the results of successful treatment of a patient with traumatic arterial aneurysm of the middle cerebral artery (MCA).

Material and methods. A clinical case of traumatic arterial aneurysm of the M4 segment of MCA was studied. A patient with a ruptured traumatic aneurysm was transferred to Krasnogorsk City Hospital №1 for further examination and emergency surgery.

Results. On the sixth day after surgery, the patient was discharged in a satisfactory condition with almost complete regression of neurological symptoms.

Conclusion. Treatment of traumatic arterial aneurysms requires an individual approach taking into account the past medical history, the clinical presentation, aneurysm location and anatomy, as well as the mechanism of injury. It is extremely difficult to suspect an arterial aneurysm after a patient had a traumatic brain injury as the incidence of this condition is very low. An angiographic study of cerebral vessels is needed for reliable diagnosis, not just solely performing standard computed tomography of the brain. Patients with this pathology require surgical intervention.

Keywords: traumatic aneurysm, peripheral branches, surgical treatment, intracerebral hematoma, penetrating trauma.
transverse dislocation of the brain up to 10 mm to the right (Fig. 2). Additionally, CT angiography (CT-AG) of intracranial vessels was performed, in which arterial aneurysm of the M4 segment of the left middle cerebral artery (MCA) was revealed (Fig. 3). For further treatment, the patient was transferred to the neurosurgical department of the Krasnogorsk City Hospital No. 1. The decompressive trepanation of the skull in the left fronto-parietal-temporal area was performed as an emergency surgery. When cutting a bone flap, its fusion with the dura mater (DM) was noted in the fracture area. After removal of the bone from the DM defect, active arterial bleeding was observed in the projection of the fracture, regarded as an intraoperative rupture of arterial aneurysm. DM was opened. The source of bleeding was visualized, which was an aneurysmal mass 1.5 × 0.7 cm in size (torn dome of the aneurysm). Bleeding was stopped by temporarily clipping the carrier artery. Further, with the help of microsurgical equipment, aneurysm and the carrier artery were isolated. Given the impossibility of clipping the aneurysm due to the absence of the neck, as well as due to the small caliber of the vessel, trapping of the M4 segment was performed with excision of the aneurysm (Fig. 4). Then the intracerebral hematoma was removed, hemostasis and DM plastic surgery were performed. Subsequently, conservative therapy was carried out. On the control CT scan of the brain, positive dynamics were observed in the form of the absence of intracerebral hematoma and regression of lateral displacement of the brain (Fig. 5). With CT-AG, data for aneurysm were not obtained (Fig. 6). The patient was discharged on the 6th day after the surgery. There are clear consciousness, complete regression of right-sided hemiparesis, moderate dysarthria in neurological status.

Discussion

Traumatic arterial aneurysms of the peripheral branches of cerebral vessels after penetrating wounds of the skull are an extremely rare pathology that is difficult to diagnose and has a high risk of death [61].

In 1949 W. Krauland [62] described a false aneurysm of the anterior cerebral artery. This case is considered the first mention of a traumatic aneurysm of the peripheral cerebral arteries. D. Ferry and L. Kempe [63] described only 2 cases of traumatic aneurysms among 2187 patients with penetrating brain injuries, and B. Benoit and G. Wortzman [64] reported 2 peripheral traumatic aneurysms among 850 patients with intracranial aneurysms. Peripheral traumatic aneurysms are mainly found in the MCA system (58%) [65]. The most common causes of traumatic aneurysms are closed craniocerebral trauma (62%) and penetrating head trauma (27%) [66]. Direct arterial wall damage is the result of bone fragments or other wounding agents penetrating into the wound.

Traumatic cerebral aneurysms have an unpredictable course. So, C. Burton et al. [67] revealed late ruptures of traumatic aneurysms in 27 (45%) of 60 cases. According to the literature [68], mortality from rupture of traumatic arterial aneurysms reaches 54%. The mechanism of the formation of traumatic aneurysms is associated with partial vessel wall damage and its subsequent dilatation [69].
The microscopic structure of traumatic aneurysms is fundamentally different from the structure of true aneurysms, in which the changed arterial wall is protruded due to various hemodynamic factors. In traumatic aneurysms, which are essentially false aneurysms, there is no neck, which in true aneurysms contains, as a rule, all elements of the layers of the arterial wall, including the internal elastic membrane, smooth muscle cells [72]. An aneurysmal sac of a traumatic aneurysm is, as a rule, a capsule of chronic hematoma. The body wall of such aneurysm does not contain an elastic membrane, such cellular elements of the vascular wall as smooth muscle cells or myofibro-

Fig. 3. CT-AG of the intracranial vessels.
Traumatic arterial aneurysm of the M4 segment of the left middle cerebral artery (MCA).

Fig. 4. Intraoperative photos.
On the left is the trapping of the carrier artery; the opened dome of the arterial aneurysm is visible. On the right is the stage of removal of the intracerebral hematoma after removal of the dome of arterial aneurysm.
blasts, there is no formed fibrous tissue. The so-called “aneurysmal sac” is represented by layered masses of hemolized erythrocytes, fibrin fibers, hemosiderin deposits, macrophages, granulations of various maturity degrees [73].

In our observation, at the base of the aneurysmal sac, a fragment of a small artery of muscle-elastic type was found (Fig. 7a), in which there is a defect of the middle membrane in the form of fragmentation of smooth muscle fibers and a violation of its integrity (Fig. 7b). By caliper, this artery could correspond to both the artery of the pia mater, and another small adjacent artery in the damage area. Throughout the rest, the structure of the “aneurysmal sac” is represented by hemolized erythrocytes, fibrin, and granulation tissue along the periphery; no elements of the internal elastic membrane and smooth muscles were found (Fig. 7c). In the immunohistological analysis, the walls of the formation are represented by dense clusters of macrophages (Fig. 7d). SMA smooth muscle cell marker expression was absent. Thus, the described morphological picture corresponds to the wall of a false aneurysm and, taking into account the anamnesis, allows speaking out in favor of the traumatic genesis of aneurysm formation.

Fig. 5. Postoperative CT-scan images of the brain.
Total removal of ICH. Prolapse of the brain matter into a burr hole.

Fig. 6. Postoperative control CT-AG of the intracerebral vessels.
Aneurysms are not detected.
Conclusions

Traumatic aneurysms of the cerebral vessels peripheral branches are an extremely rare pathology with a high mortality and disability [74]. This aneurysms are quite difficult to diagnose, which makes this problem relevant and debatable. For successful early detection of this pathology, careful clinical observation, conducting control CT of the brain, on-demand with contrasting of the vascular bed, are necessary.

Authors participation:
Study concept and design — D.K., N.K.
Material collection and processing — N.K.
Writing — N.K., L.Sh.
Pathomorphological study — L.Sh.
Editorial revision — V.K., E.M.

The authors declare that there is no conflict of interest.

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Case reports

Traumatic aneurysm is a rather rare pathology and accounts for about 1% of all intracranial aneurysms. The article presents a clinical description of the case of surgical treatment of traumatic arterial aneurysm of the M4 segment of the middle cerebral artery. In this situation, the authors correctly and timely performed surgical treatment of the ruptured traumatic aneurysm, which allowed the patient to be discharged in satisfactory condition on the 6th day after the surgery. A detailed pathomorphological conclusion, as well as illustrations, adore the article and allow with a high degree of probability to assume the traumatic nature of the aneurysm in this patient. The publication is undoubtedly relevant and of interest to a wide range of specialists — vascular profile neurosurgeons, neurotrauma specialists, and neurologists.

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Commentary

Traumatic aneurysm is a rather rare pathology and accounts for about 1% of all intracranial aneurysms. The article presents a clinical description of the case of surgical treatment of traumatic arterial aneurysm of the M4 segment of the middle cerebral artery. In this situation, the authors correctly and timely performed surgical treatment of the ruptured traumatic aneurysm, which allowed the patient to be discharged in satisfactory condition on the 6th day after the surgery. A detailed pathomorphological conclusion, as well as illustrations, adore the article and allow with a high degree of probability to assume the traumatic nature of the aneurysm in this patient. The publication is undoubtedly relevant and of interest to a wide range of specialists — vascular profile neurosurgeons, neurotrauma specialists, and neurologists.

M.A. Stepanyan (Moscow)
Sarcoidosis is a multisystem granulomatous disease of unknown nature. The disease affects people of a young age — 3-4th decade of life. Clinical signs are most often observed on the part of the lungs, skin, eyes, orbit; in addition, peripheral lymph nodes, liver, spleen, mucous membranes, submandibular glands, and central nervous system (CNS) are also often affected [1–7].

Hutchinson first described sarcoidosis in 1898. Clinically, the disease manifested itself in skin rashes. It soon became clear that skin signs could be combined with other tissues and organs damage, including lungs, salivary glands, subcutaneous tissue, bones, eyes. In 1916, Schaumann showed that the process has a systemic, multi-organ character, and the disease was called Besnier-Boeck-Schaumann disease, or sarcoidosis (cited in [5]).

Sarcoidosis can occur without any clinical and radiological signs, and only at autopsy granulomas of various stages of development can be detected. Sarcoid granulomas are noncaseating granulomas in which epithelioid cells dominate. In the center, plots of fibrinoid necrosis are possible. There are also giant cells, nonspecific crystalline deposits and the so-called Schaumann bodies.

According to Hamilton [5], the frequency of central nervous system damage is 5–10%. However, a multicenter retrospective study conducted by a group of investigators showed a high incidence of neurosarcoidosis — up to 37%. According to V. Terushkin et al. [8], recent progress has been made in the epidemiology and pathophysiology of neurosarcoidosis understanding, as well as in its diagnosis and treatment.

The most common lesion of the CNS is granulomatous leptomeningitis, less commonly — parenchymal lesion [9, 10]. Many authors have noted a tendency to damage the structures of the base of the brain with the formation of granulomas near the cranial nerves (CN), in the area of the hypothalamus, pituitary, cavernous sinuses, chiasm, intracranial sections of the optic nerves [5, 11–13]. The formation of granulomas is often combined with perivascular leptomeningeal inflammation and leads to granulomatous angiitis, which can subsequently cause vascular occlusion and microinfarction [5].

Based on the analysis of the disease in 67 patients (from 1984 to 2006), employees of the Iowa University Hospital (USA) reported a frequency of sarcoidosis manifestation with neuroophthalmological symptoms, reaching 30% [14].

The optic nerves damage can take place independently of the other CNS regions and be the first manifestation of the disease [15, 16]. If the granuloma causes a mass effect, then an erroneous diagnosis of the tumor is possible [17, 18]. This applies not only to the intracranial, but also to the orbital section of the optic nerves [19, 20].

The study objective was to analyze 2 clinical observations of the optic nerves and chiasm sarcoidosis.

Diagnosis of the disease had certain difficulties, the nature of the process was specified only after a biopsy of the formation.
Case No. 1

Patient E., 37 y. o., female. Turned to the N.N. Burdenko NMRC of Neurosurgery in December 2015. Considers herself ill since July 2015, when she discovered a spot in front of her left eye. She was treated with a diagnosis of optic neuritis. Visual disturbances in patient receiving glucocorticoids were remitting (improvement during treatment and a rapid decrease in vision when drugs were canceled). The patient was sent to NMRC of Neurosurgery for the differential diagnosis of neuritis and a tumor of the left optic nerve. On examination, the right eye was clinically healthy. Visual acuity of the left eye was 0.3; field of view, according to manual kinetic perimetry: moderate concentric narrowing of the boundaries. Eye movements was painless, in full. There was afferent pupil-
lary deficiency. The optic nerve disc was sharply swollen, promotes into the vitreous, the vascular network are expanded, there are on the disk. A diffuse thickening of the orbital, intracranial and intracranial parts of the left optic nerve was revealed on the MRI and CT images. The optic nerve accumulated contrast medium. Preliminary diagnosis: the glial series tumor of the left optic nerve. To exclude sarcoidosis, the patient was referred to a pulmonologist, as well as to study blood serum for the presence of antibodies to herpes simplex virus, cytomegalovirus, and Epstein-Barr virus. According to the pulmonologist conclusion (January 2016), pulmonary sarcoidosis was detected; the activity of the angiotensin-converting enzyme in blood serum reached 90.0. On the treatment with the glucocorticoids, visual acuity increased to 0.6, the edema of the optic nerve disc was significantly reduced. However, after 4 months, despite of sarcoidosis remission in the lungs, there was a significant decrease in the left eye visual acuity to 0.01; optic nerve disc was pale with slight swelling. The right eye was clinically healthy. Compared to the previous, MRI revealed a slight increase in the diameter of the left optic nerve in the orbital part and a significant increase in the mass lesion in the chiasmal-sellar area (Fig. 1). Negative dynamics on MRI and at the same time positive dynamics in the lungs in response to glucocorticoid therapy led to a differential diagnosis between sarcoidosis and the tumor. An revision and open biopsy of the mass lesion were performed: osteoplastic trepanation in the right frontal area and subfrontal access to the chiasmal area. Thickening of the arachnoid membrane in the chiasmal area and its pronounced fusion with the chiasm and the optic nerves were found. The right optic nerve was not changed. The left optic nerve is significantly thickened, grayish in color. After dissection of the nerve membranes, a dense, gray-colored, low-vascular tissue was found. The mass lesion occupied mainly the medial part of the optic nerve and spread to the middle of the chiasm. Small yellow mass lesion were found along its border (petrifcates?).

The histology: the material was represented by fragments of glial tissue with a large number of either clearly defined or fused together epithelioid cell granulomas without a necrotic component, with the presence of giant multinucleated Langhans cells (Fig. 2a). Peripheral granulomas was surrounded by thick lymphoid infiltrates. An immunohistochemical study revealed intense membrane-cyttoplasmic positive expression of the total leukocyte marker CD 45 both in the central part of the granulomas and in their peripheral areas and the expression of the macrophage marker CD 68 and the marker of CD 4 T-lymphocytes mainly in the central areas of granulomas (Fig. 2b). Conclusion: the morphological pattern and the immunophenotype correspond to neurosarcoidosis.

After surgery, amaurosis of the left eye developed. Visual functions of the right eye remained normal. The glucocorticoid therapy was continued after discharge/ When viewed after 7 months after surgery: the right eye is clinically healthy. Visual acuity of the left eye: hand movement near the face. The optic nerve disc was pale, there was practically no own vascular network on the disk, the boun-

Fig. 3. Case No.1
9 months after the surgery MRI T1 mode, sagittal and coronary views. No pathological changes were detected.
The retinal vessels were narrow, sometimes neglected (a consequence of previous angiitis?). The visual acuity of the left eye was restored to the preoperative level after 9 months after the surgery. The visual field is stored in the upper nasal quadrant (approximate study). On the control MRI, no pathological changes were detected in the chiasmosellar area (Fig. 3). When viewed 14 months after surgery, there is no dynamics in the ophthalmic symptoms.

**Case No.2**

Patient Ch., 62 y. o., female. The disease manifested at the age of 41, when the patient began to worry about...
thirst. Diabetes insipidus was diagnosed and minirin was prescribed. With regard to diabetes insipidus and impaired fat metabolism, the patient was observed by an endocrinologist. After 21 years (August 2017), she noted a deterioration in vision, more in the left eye. This was the reason for conducting an MRI of the brain, on which a mass lesion was found in the chiasmal-sellar area (Fig. 4), in connection with which the patient was referred to the Burdenko Neurosurgical Center. An ophthalmological examination revealed a symmetric chiasmal syndrome, a late stage of visual disturbances. Visual acuity of the right eye was 0.2, the left eye — 0.1. Absolute bitemporal hemianopia with loss of the central vision (Fig. 5). There were no oculomotor disorders. On the fundus there was the pattern of the primary atrophy of the optic nerves. The subfrontal access to the chiasmal region was performed during the surgery. Increased chiasm and both optic nerves were found, more — the left. From the area of the posterior chiasm, where it was gray, tissue was taken for histology. This was the end of the surgery.

The histology: in small fragments of glial tissue single microscopic foci of typical epithelioid cell granulomas with few multinuclear giant Langhans cells and clear expression of CD 68 (Fig. 6) and CD 4 were revealed. Conclusion: the morphological pattern corresponds to neurosarcoidosis.

After surgery, amaurosis of the left eye developed, visual acuity of the right eye remained the same. After 2 months, the visual acuity of the right eye increased to 0.5; loss of the temporal half of the visual field.

The patient was referred for a consultation with a pulmonologist.

Discussion

In sarcoidosis, CNS involvement, according to various authors [5, 7], occurs in 5—37% of cases. A tendency to damage the hypothalamus, pituitary, cavernous sinus, chiasm, intracranial sections of the optic nerves was noted [5, 11-13]. The optic nerve in frequency of involvement in CN lesions takes the second place after the facial one and can manifest itself at any period of the disease, including during its manifestation [2, 3, 19, 21, 22]. Intraorbital lesion of the optic nerve in sarcoidosis may be the only clinical sign of the disease [20]. L. Frohman et al. [23] note that damage to the optic nerve at first can be regarded as optical neuropathy of unknown origin.

The peculiarity of our Case No.1 was that when making the initially correct diagnosis of optic sarcoidosis and treating with glucocorticoids, an increase in granulomatous lesions of the optic nerve in its orbital part and the rapid appearance of the large granulomas in the chiasm-sellar area were noted.

The observation of a 14-year-old girl with the aggressive sarcoidosis of the intracranial segment of the optic nerve and the chiasm is present in literature [24]. As in our case, only a biopsy of the neoplasm made it possible to clarify the nature of the lesion. Tolerance of the sarcoid granulomatous process to glucocorticoid therapy was noted by M. Gelwan et al. [25]. In the our first case, this was the reason for the revision of the chiasm-sellar area and the biopsy of the mass lesion. The chosen tactics made it possible to clarify the true nature of the disease and prescribe a prolonged treatment, on which a regression of the granulomatous process was noted both in the orbital segment of the optic nerve and in the cranial cavity.

Fig. 6. Case No.2

a — biopsy specimen histology. Giant multicore Pirogov-Langhans cell in granuloma (indicated by arrow), stained with hematoxylin and eosin, × 400; b — biopsy specimen immunohistological analysis. The macrophage marker CD 68 expression (brown staining), ×200.
Among patients with neurosarcoidosis, the hypothalamic-pituitary area damage reaches 50–58% of cases [26–28]. Case No. 2 is of interest from the point of view of the development of visual disturbances due to the granulomatous process in the intracranial sections of the optic nerves and the chiasm 21 years after the onset of the disease in the form of diabetes insipidus. As in the first case, the diagnosis was clarified only after a neoplasm biopsy.

The morphological pattern of granulomatous inflammation routinely requires a differential diagnosis with other granulomatous lesions, such as tuberculosis, Wegener’s granulomatosis, rheumatoid arthritis, or primary CNS angiitis [29, 30]. In our cases, no caseous nature necrotic changes or any microorganisms in the biopsy specimens were found, which made it possible to exclude tuberculous or mycotic lesions. There were no signs of hemorrhage, walls damage, vasocentric or perivascular distribution of both the granulomas themselves and lymphoid infiltrates, which did not give reason to speak out in favor of Wegener angiitis or granulomatosis. Thus, the morphological pattern and the immunphenotype of the lesion in both cases corresponded to neurosarcoidosis.

Conclusions

Neurosarcoidosis can manifest various clinical signs. Diagnosis of the disease is not always easy. Granulomatous damage to the structures of the anterior visual pathway both clinically and with the neuroimaging method can provoke a diagnosis of the tumor. For differential diagnosis, a histology of the biopsy specimens pathological tissue is necessary, which is confirmed by both of our cases.

The authors declare that there is no conflict of interest.

REFERENCES

Commentary

The article is relevant, contains interesting information about a rather rare disease. It is of interest to clinicians. The only thing that may be worth discussing is the title of the article. "Anterior visual pathway" is not a generally accepted classic name, although it can be used. In my mind, it would be more correct to name the article — “Neurosarcoidosis of the chiasmosellar area” or “Neurosarcoidosis of the chiasm and the optic nerves”. Although, if the authors insist on the primary title, then this is permissible.

V.V. Cherebillo (St. Petersburg)
Magnetic-resonance imaging under degenerative changes in lumbar spine: state of the art

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Magnetic resonance imaging (MRI) of lumbar spine is a very frequent examination in any computer tomography unit. However, there are still no scan standards or standards for scan interpretation in the world’s medical community. In this article based on our experience we describe common problems encountered by a radiologist during MRI examination of lumbar spine and its subsequent description. The literature survey and analysis are presented with a summary of current recommendations. We examined routine sequences, which could be included in MRI protocol, discussed common terminology, and showed the incidence of different pathologies. The special emphasis is made on assessing lumbar canal stenosis. In this article we focus on qualitative and quantitative criteria of lumbar spinal stenosis.

Keywords: magnetic resonance imaging, lumbar spine, spinal stenosis, degenerative disc disease.

Pulse sequence parameters for lumbar spine MRI.

<table>
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<th>Parameter</th>
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All of the above determines the relevance of the article and the need to resort to an analysis of world literature to find a methodological approach to conducting and interpreting the lumbar spine MR images. We rely on personal experience in this work only to indicate problems often encountered in the radiologist practice.

**Scanning protocol**

The first institution used a locator for the entire spine, T1-, T2-, STIR-weighted images in the sagittal plane, T2-weighted images in the coronary plane (Fig. 1). The procedure was performed on a Philips Intera 1.5T apparatus. The specifications of the pulse sequences are presented in the table.

The entire spine locator was used only to count the number of vertebrae. As a rule, T2-weighted images were used in the coronal plane, however, if non-degenerative spondyloarthropathy (for example, ankylosing spondylarthritis) was suspected, instead of the T2 sequence, STIR could be used to search for foci of bone marrow edema in the lateral masses of the sacrum and in the bodies of the ilium. T2-weighted images in the axial plane were performed as a single unit (about 30 slices) with the inclusion of at least 3 intervertebral discs in the scan area, followed by reconstruction along the plane of each disc (Fig. 2). If necessary, within one data collection, short blocks of 2-5 slices were added to unchanged segments.

The second and the third institutions used a locator for the entire spine, T1-, T2-, STIR-weighted images in

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**Fig. 1.** Lumbar spine MRI, planning technique.

a — sagittal plane localizer planning; b — sagittal plane planning.
Fig. 1. Lumbar spine MRI, planning technique.
c — axial plane planning; d — coronal plane planning.
the sagittal plane. In these institutions, T2-weighted images with a low-resolution in the sagittal plane were used as a locator to count the vertebrae and to screen for possible pathology of other parts of the spine. Programs in the coronary plane were performed in less than 10% of cases as additional sequences at the request of the radiologist. The program in the axial plane was performed by short T2-weighted blocks (2-5 sections in each block) along the plane of the intervertebral disc.

When analyzing the literature data in authoritative sources, we were not able to find guidelines or recommendations on the protocol for the lumbar spine scanning. Most authors used T1-, T2-, STIR-weighted images in the sagittal plane and T2-weighted images in the axial plane.

According to the literature [1, 2], the use of only T2-weighted images in the sagittal plane, even for screening pathology, has no diagnostic value, and, on the contrary, leads to errors. This is due to the fact that in one sequence it is not possible to exclude bone marrow infiltration. In addition, using only one sagittal plane and one weight, it is impossible to fully evaluate the disk material, spinal canal and intervertebral foramen [3]. Thus, using the sagittal plane over the entire spine in one weight for screening pathology cannot be recommended, since this will inevitably lead to systematic errors with prolonged scanning time.

The issue of using the coronary plane when performing the lumbar spine routine scanning protocol with degenerative changes is no less relevant. We were also unable to find manuals or recommendations in the literature addressed this question. However, it is necessary to take into account the fact that the transitional vertebra (lumbarization and sacralization) is quite common, according to various sources [4, 5], in 15–35% of the population. As part of a tomography, it is important not only to establish the fact of lumbarization or sacralization, but also to detail the changes in accordance with the existing classifications [6]. This is important information for the clinician, which may be the only cause of the existing clinical picture or may aggravate other changes, and also serve as an unfavorable prognostic factor for the early development of degenerative changes. In addition, if there is sacralization or lumbarization, the clinician must have this information before an invasive intervention to adequately assess the level of damage.

*Fig. 2. Reconstruction of proper disc plane from axial block.*
Besides of sacralization, on the coronary plane, it is possible to trace the course of the spinal roots in the spinal canal, lateral pockets and intervertebral foramina continuously throughout. The radiologist decide to use T1-, T2— or STIR-weighted sequences for the coronary plane depending on the clinical purpose. If it is necessary to exclude non-degenerative spondyloarthropathy in the lumbar spine tomography, it is advisable to use the STIR sequence with the inclusion of the sacroiliac joints in the scan area, since this will exclude sacroileitis and evaluate the transverse processes of the fifth lumbar vertebra. If it is necessary to trace the spinal roots along their entire length, to assess the presence and cause of their deformation, then it is advisable to use a T2-weighted sequence. In most cases, a T2-weighted sequence is performed in the coronary plane, the duration of which is less than 1 minute.

When choosing a scanning protocol, the radiologist always has a dilemma about how to set axial blocks: should it be 1—2 large blocks (20—40 slices each) or 5 blocks of 2—5 slices each. At the moment, due to the lack of guidelines and recommendations, the radiologist should proceed from the patient’s pathology and set axial blocks based on clinical purposes. It should be noted that in most cases the use of a large 2D block is justified, since this makes it possible to trace the spinal roots throughout the segment [7].

Based on the literature data analysis and personal experience, the following conclusions were drawn:
1) it is advisable to use a locator on the entire spine to count the vertebral bodies;
2) to evaluate the bone marrow and the spinal canal structures the use of T1-, T2-weighted sequences and STIR in the sagittal plane is necessary;
3) to assess degenerative changes in the lumbar spine, it is advisable to perform an axial 2D block in T2-weight covering more than one segment;
4) it is advisable to introduce the coronary plane in the routine lumbar spine scanning protocol.

**Approaches to describing the lumbar spine MRI**

As it turned out, approaches to the pathology description varied in all three institutions.

**Disk material pathology**

The first institution used the recommendations of the North American Spine Society, the American College of Radiology and the American Society of Neuroradiology (2014) [8]. In accordance with this, to describe the pathology of the intervertebral disc in the first institution, the following terms were used: bulging (symmetrical and asymmetric) when the disc material extends beyond the edges of the vertebral bodies for more than 25% of the circumference of the disc [8] and herniated disc (two forms: extrusion and protrusion) with local standing of the disk material is 25% or less of the disk circumference [8].

The second and the third institutions used their own, based on experience, and various other Russian [9] and foreign sources without standardization within the institution. In view of this, terms such as “diffuse disk protrusion”, “biforaminal disk protrusion” were used. The term "bulging" was used only to denote the displacement of the disk material more than 50% of the circumference of the disk. It should be noted that such terms as “diffuse disc protrusion” or “biforaminal disk protrusion” are absent in modern authoritative English sources.

Currently, most authors rely on the recommendations of the North American Spine Society, the American College of Radiology and the American Society of Neuroradiology (2014) [8]. Based on this guide, it is recommended to use the following information to evaluate disk material:
- bulging — displacement of disc material more than 25% of the disc circumference, it can be symmetric (around the entire disc circumference) and asymmetric (disc semicircle) [8];
- disc herniation — focal displacement of disc material (less than 25% of the disc circumference) beyond the limits of the intervertebral disc space, has two forms: protrusion (the distance between the edges of the disc herniation is less than the distance between the edges of the base) and extrusion (the distance between the edges of the disc material is greater than the distance at the base); in addition, only extrusion can have migration and sequestration.
- localization of changes is determined by zones (median, subarticular, foraminal, extraforaminal) and levels (relative to the base of the vertebral arch: pedicular, suprapedicural, infrapedicular) [8].

When interpreting changes, it is always necessary to take into account the frequency of particular hernia localization occurrence. So, according to the literature, the median group of hernias localizations (in the median and subarticular sectors) is most often found. About 80% of all hernias are localized in the subarticular sector [10], since the posterior longitudinal ligament is a dense structure and is often not damaged. The lateral localization group of hernias (foraminal and extraforaminal) occurs only in 20% of all cases of hernia detection [10].

So, firstly, at the moment, the most relevant and widely used guideline for interpreting changes in disk material is the recommendations of the North American Spine Society, the American College of Radiology and the American Society of Neuroradiology (2014) [8]. Secondly, the frequency of occurrence is dominated by disc herniation with localization in the subarticular sector [10].
Spinal stenosis evaluation

In the presence of degenerative changes, it is very important not only to exclude the intervertebral disc hernia, but also to evaluate the spinal canal and intervertebral foramen.

In the first institution, stenosis was assessed by qualitative characteristics, without taking into account quantitative data (sizes).

In the second institution, emphasis was placed on quantification. The area of the spinal canal was measured and then the ratio with an unchanged level was calculated in accordance with the recommendations of the institution placed in Yekaterinburg [9].

The third institution also performed a quantitative assessment, using different approaches to stenosis assess. One approach was to measure the anteroposterior size of the spinal canal or the anteroposterior size of the dural sac. Stenosis was classified as unexpressed (if it covered up to 30% of the canal circumference), moderately expressed (from about 30 to 50%) and significant (more than 50%). Another approach included measuring and calculating the area of the spinal canal (as in the second institution) [9].

When analyzing the findings, it was revealed that during the measurement, the degree of stenosis may vary depending on the measurement method; moreover, the data obtained from the measurements did not correlate with the clinical picture.

The ground of spinal stenosis evaluating, as well as lateroforaminal stenosis evaluating by tomograms, in our opinion, is the most difficult. So, the NNNorth American Spine Society in their guide presents non-invasive tests to assess spinal stenosis, but the radiological criteria are not included in them [11].

There is a small number of articles in which the authors use or another measurements as a diagnostic criterion. However, in these articles there are many misunderstandings.

So, in some articles, it is proposed to measure the anteroposterior spinal canal size, taking the norm as 15 mm [12] or 12 mm [13], without indicating the measurement level. Other authors propose to take 10-15 mm as a norm, taking measurements at various levels [14].

Another authors [15] propose measuring the anteroposterior dural sac size, some investigators indicate numerical values, and some indicate the relationship between altered and intact levels.

There are articles in which it is said that it is necessary to measure the distance between the inner contour of the yellow ligament in the place where it is adjacent to the facet joints at the level of the intervertebral disc [15].

One of the many suggestions is to calculate the spinal canal area. However, even here the values for stenosis diagnostose vary from 100 [16] to 130 mm2 [17].

Given such variable information and the lack of a unified approach, the use of quantitative assessment methods as diagnostic criteria in routine practice is doubtful.

In our opinion, the article devoted searching for relevant stenosis criteria based on a large study is of great interest [18]. As a result of this study, the impossibility of widespread use of quantitative criteria is shown and the qualitative criteria for the spinal stenosis diagnosis at the lumbar level are partially recognized through tomographic examination.

In conclusion, it must be said that the first question that the radiologist should answer is whether or not spinal stenosis is present. In the stenosis presence, it is necessary to indicate its cause: disc material, thickened ligaments, osteophytes, etc. [19]. Since there are currently no acceptable numerical criteria for stenosis, it is necessary to take into account the following symptoms: the presence of a disc material hernia, the epidural cellular tissue integrity and volume, a sufficient amount of cerebrospinal fluid around the cauda equina, and the free location of the spinal roots in the dural sac and intervertebral foramen [18].

No measurements, such as: determining the degree of stenosis as a percentage, measuring the anteroposterior dural sac or spinal canal size — currently have no good reason and are not presented as diagnostic in any of the current authoritative world guides.

Lateral stenosis and foraminal stenosis

The situation with lateral pockets and intervertebral foramina is similar to the situation with spinal canal measurements.

In the first institution, no measurements were carried out, the assessment was carried out according to external signs. Two other diagnostic centers measured the intervertebral foramen by constructing a straight line from various arbitrary points.

In the literature [18], there are articles that propose measuring the lateral pocket height, taking 3 mm as the norm. However, when conducting a large study, there was no correlation with clinical signs [18]. Since quantitative criteria are not applicable in this case, the need for a qualitative assessment becomes obvious.

Thus, for the lateral stenosis diagnosis with tomographic methods, it is important to evaluate the deformation of the spinal root passing in the lateral pocket [20]. Since the subarticular sector is the predominant hernias localization, for the most part lateral stenosis will be caused by the intervertebral disc hernia.

There are different opinions regarding the intervertebral foramen measuring method. So, a number of authors [18] propose measuring the anteroposterior intervertebral foramen size, taking 3 mm as the norm. Other authors [21] propose measuring the height of the intervertebral foramen, taking 15 mm as norm. However, it is important to
understand that the geometry of the intervertebral foramen changes, for example, with hypertrophy or subluxation of the intervertebral joints, osteophytes of the vertebral bodies, displacement of disc material, thickening of the yellow ligament. Therefore, it is not possible to use quantitative values as a diagnostic criterion in routine practice.

When evaluating the intervertebral foramen, as in the case of the lateral pocket, it is necessary to evaluate the spinal root and the cellular tissue around it. Recent articles suggest using qualitative criteria instead of quantitative ones [18]. In the initial stages, deformation of perineural cellular tissue without its atrophy and without radicular deformity will be present, with an increase in changes, partial preservation of cellular tissue around the spinal root will be observed, then obliteration of epidural cellular tissue will develop [22]. With obliteration of perineural cellular tissue, there is a high probability of deformation of the spinal root. Therefore, with a marked decrease in perineural cellular tissue in the foramina, it is necessary to evaluate the morphological changes in the spinal root in the form of its course violation or thickening.

As with disc hernias, it is important to consider the frequency of radicular deformity due to degenerative changes in the intervertebral foramen. Thus, the fifth lumbar spine root is most often deformed, the fourth root is on the second place, and the L3 spinal root is on the third place [22].

Due to the fact that hernias in the foraminal sector are very rare, the most common causes of foraminal stenosis and radicular deformity are the spine configuration changing, transitional vertebra, spondylolisthesis, hypertrophy of the intervertebral joints and thickening of the yellow ligament [23].

So, we conclude that hernias, including their shape such as protrusion, are quite rare in the localization under consideration and usually the cause of foraminal stenosis is not disk material, but other degenerative changes.

**Conclusions and recommendations**

Recommendations for solving frequently encountered problems can be divided into two large blocks: recommendations for conducting the actual MRI and recommendations for interpreting MRI results.

Recommendations for conducting MRI:
- include the entire spine examination in the scanning protocol to adequately count the vertebral bodies;
- use the coronary plane and axial block of T2-weighted images and 2D sequences.

Recommendations for interpreting MRI results:
- it is not recommended to use quantitative criteria for assessing stenosis due to conflicting and scattered data in the world literature at the moment;
- criteria for assessing stenosis should be extremely high-quality: when evaluating the spinal canal, it is necessary to exclude an intervertebral disc hernia, then assess the adequacy of cerebrospinal fluid around the cauda equina, obliteration or hypertrophy of the epidural cellular tissue, the free location and condition of the spinal roots;
- in the presence of stenosis signs, it is extremely important to clearly indicate the cause of the spinal canal, lateral pocket or intervertebral foramen narrowing.

**Authors participation:**

Study concept and design — T.B., N.M.
Material collection and processing — T.B., N.M.
Statistical processing — T.B., N.M.
Writing — T.B.
Editorial revision, illustrations — A.S.

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An important component of this protocol was the proposal for an evidence-based clinical guideline for the diagnosis and treatment of degenerative lumbar spinal stenosis. North American Spine Society; 2011:102.

In conclusion, it can be noted that this article is useful for radiologists, neurosurgeons and neurologists, everyone who deals with the diagnosis and treatment of degenerative lumbar spinal stenosis. BMC Musculoskelet Disord. 2014;15(1).

The proposed diagnostic algorithm allows us to solve most diagnostic problems regarding the assessment of degenerative and inflammatory changes in the intervertebral discs, vertebral bodies, ligamentous vertebral apparatus, to determine changes in the lumen of the spinal canal, in the epidural space and paravertebral.

An interesting part of the article was the discussion of various approaches to assessing the qualitative and quantitative changes in the lumbarosacral spine, as well as the discussion of the reliability and applicability of different methods for measuring the lumen of the spinal canal and intervertebral foramina.

In conclusion, it can be noted that this article is useful for radiologists, neurosurgeons and neurologists, everyone who deals with this problem both from the point of view of optimizing the lumbo-

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Commentary
sacral spine MRI conducting, and from the point of view of a standard protocol for describing changes and nominal expediency the use of quantitative measurements, which is often a stumbling block in discussions between diagnosticians and clinicians in assessing radiological findings and their clinical significance.

I.N. Pronin (Moscow)
The use of MR perfusion in assessing the efficacy of treatment for malignant brain tumors

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This literature review analyzes the capabilities of magnetic resonance imaging (MRI)-based cerebral perfusion for differentiation between post-radiation changes (e.g., radionecrosis) and continued growth. The technique is compared with other highly informative radiodiagnostic techniques used in neuroradiology. The use of MR perfusion is important in a comprehensive examination protocol. Trends in the technique development are analyzed.

Keywords: magnetic resonance imaging, MR perfusion, brain tumors, radiation injury, continued growth.

1. Relevance

In Russia, CNS tumors occupy the 3rd place in the structure of cancer mortality in men and the 4th place in women aged 15 to 35 years. According to the frequency the brain tumors are in 3rd place among all oncological pathologies [1]. The number of newly detected brain tumors is 10-15 cases per year per 100,000 people, while in 60% of cases neuroepithelial tumors, gliomas, are diagnosed [2].

It should be emphasized that CNS malignant tumors have the worst prognosis. So, according to a number of authors [3], the 5-year survival rate after diagnosis verification is no more than 10%.

The success of the anticancer treatment largely depends on the stage of the disease, which is determined by the tumor dissemination at the time of diagnosis. Currently, the generally accepted tactics of treating patients with primary malignant brain tumors is to carry out combined and / or complex treatment in the form of an obligate-possible special treatment at the first stage — surgical removal of the tumor (radical, non-radical, biopsy) and subsequent independent tumor bed or its residue radiation therapy during simultaneous chemotherapy or without it [4].

In addition, further assessment and monitoring of patients who have undergone the primary line of therapy is a separate problem. Patients with brain tumors are recommended to undergo regular dynamic MRI to detect early signs of disease progression, allowing them to determine further treatment tactics as soon as possible. However, routine MRI often fails to reliably distinguish the early stages of tumor progression from treatment-related changes, including necrosis and pseudoprogression. The relevance of the continued malignant glial tumors growth (CTG) reliable determination problem is due to the need to determine tactics and start treatment at an early stage [5–8].

An analysis of the literature data shows that still there is no single point of view and a generally accepted examination algorithm for solving this problem due to the wide range of diagnostic methods, each of which has its advantages and disadvantages. Pathophysiologically, the essence of the problem is the blood-brain barrier (BBB) damage by ionizing radiation, as a result of which the destroyed vessels endothelium causes the phenomenon of increased tissue contrast, which in some cases is almost indistinguishable from the CTG signs in MRI [9].

In addition, it is known that the use of new cytotoxic drugs and angiogenesis blockers, although it allows to in-
crease the patients with cerebral tumors longevity, but such treatment methods are indiscriminate. As a result of this, in addition to the therapeutic effect directly on the tumor itself, there are adverse toxic reactions to the adjacent areas of the brain, which can mimic the progression of the tumor [10].

2. Characteristics and types of MR perfusion

Directly at the physiological level, the term “perfusion” means the level of blood delivery to a tissue element measured by capillary blood flow. The perfusion value depends on the volume of blood and the speed of blood flow. There are non-contrast and contrast-dependent MR technologies for perfusion research, each of which has its own advantages and disadvantages.

The benefits of non-contrast perfusion include non-invasiveness and safety. Arterial Spin Labeling (ASL) was proposed by Williams et al. [11] in 1992. In the article devoted to the study of rat brain perfusion, the possibility of using the water contained in arterial blood as an endogenous contrast medium was shown. A brief method characteristic is the inversion of the hydrogen atoms spins under the influence of radio frequency pulses of an MRI tomograph. After 1.5-2.0 s, labeled protons of arterial blood enter the brain, where protons of the extracellular fluid are replaced, resulting in a slight decrease in the magnetization of water, which makes it possible to evaluate the brain blood flow. Despite of the technically difficult organization of obtaining reliable ASL perfusion results, the technological improvement of equipment and software provided further the possibility of using ASL in routine clinical practice. In general, this method is similar to the principle of isotope studies using labeled atoms and molecules, however, ASL does not require the use of radioactive agents, which provides an advantage for repeated studies, neurological or vascular tests [12].

This non-contrast MR perfusion advantages open broad prospects for its clinical use for the diagnosis of tumors, cerebrovascular accidents, vascular malformations, epilepsy, degenerative diseases, as well as basic research on the development and aging processes [13].

A significant cerebral perfusion during MRI study aspect is the use of exogenous extracellular magnetic resonance contrast media, using either the ability of the gadolinium-containing contrast medium to influence the T2* -echo-signal (visualization of MR perfusion weighted by magnetic susceptibility with dynamic contrast enhancement during the first passage), in another case, the change in the T1 -echo-signal from time to time after the administration of the gadolinium-containing contrast drug is evaluated [14].

Visualization of MR-perfusion, weighted by magnetic susceptibility with dynamic contrast enhancement (MS-DCE-MRI), known in foreign literature as Dynamics susceptibility contrast (perfusion, weighted by magnetic susceptibility with dynamic contrast enhancement), is a technology in which the passage of a contrast bolus substances through the brain are tracked using a series of T2- or T2*-weighted images. The effect of the susceptibility of a paramagnetic contrast medium leads to a decrease of the signal on the curve of the signal intensity on time dependence. Information about the received signal can be converted into the paramagnetic substance concentration on time curve for each pixel. The data obtained are the basis for constructing parametric maps of cerebral blood flow volume and cerebral blood flow velocity.

MSDCE-MRI (T2*-MR-perfusion) during the examination of the brain allows visualization and quantification for a short procedure period, being the most common and reliable method for the brain tumors diagnosis. The difficulties in determining the absolute values of the volume of cerebral blood flow, sensitivity to artifacts (such as blood elements, calcification, metal, air, bones), possible problems in visualizing the base of the skull, as well as operator dependence can be attributed to the disadvantages of this technology.

Dynamic contrast enhancement MR perfusion, also known as “permeability” MRI (in foreign literature: Dynamics contrast enhancement), consists in obtaining a series of T1-weighted images before, during and after the administration of extracellular low molecular weight gadolinium-containing agents. The subsequent construction of the signal intensity on time dependence curve reflects such perfusion parameters as vascular permeability and the volume of extravascular space. Dynamic contrast enhancement in MR imaging of perfusion is used to determine the kinetic parameters of the accumulation, plateau and contrast agent wash-out from the tissues, which gives information about the tissue properties of the at the microvascular level. For the first time, equations describing changes in concentration during the passage of a bolus of a pharmacological agent in a dynamic MRI, the so-called concentration-time curve, were used in 1990 [15]. The shape of this curve for arteries and veins reflects arterial and venous functions, which describe hemodynamic tissue parameters. The main ones are: cerebral blood volume (CBV), measured by the area under the curve, the time to reach the peak concentration (Time to Peak — TTP) corresponding to the center of gravity or the peak values on the graph, and the transit time of the contrast agent (Mean Transit Time — MTT), defined by the width of the curve. The cerebral blood flow (CBF) is calculated by the formula:

\[ \text{CBF} = \frac{\text{CBV}}{\text{MTT}}. \]

The result of this examination is the construction of perfusion maps for each indicator (CBV, CBF, MTT, PTT), for the convenience of perception performed in different shades of the color gamut. This allows to visually determine the zone of interest and using further calcula-
tions to obtain quantitative values of the listed parameters, on the basis of which a graphical curve is built [16, 17]. Compared with MSDCE-MRI, MR-perfusion with dynamic contrast enhancement allows a more detailed study of quantitative indicators of BBB and microvascular system permeability and gives a more complete assessment of brain tumor angiogenesis. Among the disadvantages of the DKU MRI technology should be noted: the difficulty in obtaining images, the need to build a pharmacokinetic model, the lack of a widespread and comparative easy to use software for post-processing results.

3. MR perfusion in clinical perfusion

Tumor progression and response to treatment are associated with a complex interaction of proliferative changes in vasculogenesis and viable tumor cells infiltration, as well as with multiple therapeutic effects, including endothelial cell death, vascular thrombosis, and hemorrhage. These processes occur when the BBB is disturbed and the edema intensifies, many authors [18–20] agree that these phenomena are difficult to distinguish performing standard MRI. However, these processes differ markedly in metabolic activity and blood supply requirements. Neovascularization is an early stage of tumor growth, mixes with the natural vasculature, facilitating the normal brain hyperperfusion [21, 22]. This state of vascular proliferation sharply contrasts with the opposite state — ischemic, which is found in areas exposed to ionizing radiation. To characterize this changes, the term "radiation damage" is used; it has several temporal correspondences. Thus, the occurrence of acute radiation reactions occurs directly during radiation exposure on the body or immediately after its completion [23, 24]. Early delayed radiation effect occur during the first 4 months, late delayed radiation effect — later than this period. According to various authors [25], depending on the fractionation mode, individual patient sensitivity, and some other factors, the incidence of radiation injuries is 3–24%.

Radiation injury is characterized by the presence of:
— radiation leukoencephalopathy;
— focal lesions, including either a contrast-positive lesion in the white matter, or a more severe form — radiation necrosis;
— secondary radiation-induced tumors [26].

The complexity of the differential diagnosis is due to the fact that on routine MRI scans, the most common focal radiation injuries have extremely similar CTG characteristics. The similar nature of the contrast enhancement and the effect of volumetric exposure also cause the perifocal edematisation [27, 28]. More than, the difficulty is in the fact that CTG can be observed at any time and coincide with one or another stage of radiation injuries. All this requires the use of additional methods of radiodiagnostics to differentiate these two states [29, 30].

The study of the MR perfusion possibilities to distinguish between radiation damage and CTG is found in many domestic and foreign studies. In particular, J.I. Savintseva et al. [31] retrospectively analyzed data from 33 patients with brain tumors after combined treatment, who performed a routine MRI, supplemented by a perfusion method with bolus contrast. In the foci of contrast enhancement, the values of CBV and CBF were determined. A part of the examined patients underwent histological diagnosis verification, while the rest underwent clinical and radiological observation for at least 6 months. As a result, perfusion-weighted imaging with contrast enhancement made it possible to distinguish between areas of increased (corresponded to CTG) and decreased (corresponded to radiation injuries) cerebral blood flow, which was the determining differential criterion.

The ability to identify morphological vascularization of tissue and to distinguish it from avascular necrosis allowed T.G. Gribanova et al. [32] to conclude that the MR-perfusion method is highly effective in the differential diagnosis of glial tumors relapse and radiation necrosis. The most informative indicators are CBV and CBF, the values of which in the presence of vascularized tissue increase from 132 to 230 and from 121 to 158%, respectively, and in the presence of necrosis, decrease from 92 to 81 and from 92 to 67%, respectively.

The high accuracy of tumor tissue and areas of radiation injury differentiation of using MR perfusion was noted by P. Patel et al. [33]. However, the authors noted that due to the significant variability of the optimal recorded threshold values, additional studies are required to standardize them and develop a specific quantitative strategy for perfusion-weighted imaging that is agreed between medical institutions.

An early MRI tomograms analysis in patients during and after chemoradiotherapy revealed many difficulties in the correct interpretation of the results — due to the presence of necrotic transformation zones, residual tumor tissue, parenchymal gliosis and “inactive” neoplasms [34]. Although increased perfusion, as a rule, is associated with the process of neangiogenesis in the tumor [35, 36], recent studies have shown that it can also indicate the appearance of hypervascularized areas — the regeneration of blood vessels in the microvasculature, which reduces the severity of hypoxic phenomena and improves drug delivery to tumors [37].

J. Park’s et al. study [38] shown, that the perfusion status of the walls of the postoperative cavities on MRI after chemoradiotherapy can be a significant predictor of the progression time in patients with malignant brain tumors. Investigators have suggested that MR perfusion data can be a prognostic biomarker for subsequent chemotherapy and identify patients who are more likely to its using respond. An area with increased perfusion may indicate an increased delivery of the chemotherapy drug, while a decrease in perfusion complicates the delivery of
Another well-known problem in evaluating the results of malignant gliomas treatment, which requires additional examination, is pseudo-progression, which is observed in 20-30% of patients receiving chemoradiotherapy. The appearance and increase in the areas of pathological contrast enhancement in the marginal zone of the postoperative defect after the combined treatment within 3 months of observation are observed visually [42, 43]. The interval in the first 12 weeks after the completion of radiation therapy was recommended by the leading neuro-oncological working group RANO, which also studied this problem [44]. The phenomenon of pseudoprogression is caused by radiation-induced endothelial injury, vascular dilatation and fibrinoid necrosis, and changes in the BBB of an inflammatory nature. Although its pathophysiology remains not completely clear, it is believed that the chemical effect induces a short-term local inflammatory reaction, edema, and increased vascular permeability, which is manifested in an increase in signal in post-contrast images [45]. The exact differentiation between pseudoprogression and continued growth is critical to making informed decisions about treatment. When using perfusion imaging, the true progression showed a higher CBV maximum than pseudoprogression, which was confirmed by radiological and clinical data in a number of studies (sensitivity and specificity were 81.5 and 77.8%, respectively) [46].

A promising direction in the study of MR perfusion method is its use as predictors of survival after completion of chemoradiotherapy [47, 48]. A number of studies [49] showed that an increase in maximum cerebral blood flow using an indicator such as normalized blood flow between the initial and subsequent images was a better prognostic factor for a shorter non-progressive period (p=0.01) than an increase tumor diameter (p=0.049). R. Mangla et al. [50] found that, with a one-month post-radiation therapy, an increase in nBV was a prediction of poor annual overall survival (sensitivity 90% and specificity 69%), while the size of the tumor did not give this information. Nevertheless, the results of these studies were debatable, as another study showed that perfusion imaging gave way to predicting survival, while tumor sizes determined using T1— and T2-weighted imaging had prognostic value [51]. A. Sorensen et al. [52] showed that 25% of patients with recurrent glioblastomas who received sederanib showed increased perfusion, and these patients had higher progression-free and overall survival than patients with stable or reduced perfusion. This has been confirmed in patients with newly diagnosed glioblastomas, whose treatment consisted of radiation therapy, temozolomide, and sederanib. Patients with increased perfusion had a longer median overall survival than patients with reduced perfusion (overall survival of 504 days versus 321 days; p <0.05) [53]. Increased perfusion was also associated with improved tumor oxygenation, which could potentially improve the sensitization of tumor cells to chemical radiation and increase the delivery of temozolomide to the tumor.

In a study in which patients with recurrent malignant gliomas were included, an independent analysis of MR perfusion images was used to characterize the degree of abnormal vasculature before and after the treatment with bevacizumab. It is known that this drug is used as targeted therapy for recurrent glioblastomas, but there are reports of its successful use in the treatment of radiation necrosis. A decrease in abnormal vasculature is associated with longer overall survival, whereas changes in tumor volume and nBV did not affect the prognosis of overall survival [54]. Together, these results show that perfusion imaging can be a tool for selecting appropriate patients for antiangiogenic therapy.

Conclusions

In conclusion, we note that most authors involved in this subject unanimously agree on the great potential of the method. Contrast-dependent MR perfusion technologies help narrow the range of differential diagnostics of the CNS pathologies number and allow detecting perfusion changes even at the stage of no changes visible using standard MRI sequences, which generally improves diagnostic accuracy. The further study of the MR perfusion using of in assessing the direct results of chemoradiotherapy for CNS malignant neoplasms, as well as the role and place of perfusion studies in the protocol of dynamic observation and early detection of different differentiation degrees gliomas recurrence, remains relevant.

The authors declare that there is no conflict of interest.
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Commentary

The article is devoted to one of the relevant problems of modern neurooncology and neuroradiology, namely, the study of hemodynamic changes based on MR perfusion that accompany continued tumor growth and radiation necrosis and, on this basis, differential diagnosis of these two conditions, which is extremely important from the point of view of development adequate and pathogenetically correct tactics of early treatment.

The authors of the work rightly note the disadvantages of the standard and most common method of postoperative control of the malignant brain tumors growth - MRI or CT using intravenous contrast enhancement. In this regard, the use of additional methods for assessing continued growth or radiation changes is an relevant and important problem. Moreover, despite of the widespread use of MR scanners, in many centers of our country there is no experience in the application of perfusion technologies in the practice of radiological units.

The article covers in sufficient detail the main aspects of the clinical use of MR perfusion; the main publications of both foreign and Russian authors are presented.

This article helps to increase the awareness of radiologists in this neuroimaging area.

The publication is important and interesting not only for neurosurgeons and neurologists, but also for radiologists. It will increase the clinicians awareness about the possibilities of MRI perfusion technologies in the diagnosis of brain tumors, the assessment of their hemodynamics, differential diagnosis of continued tumor growth, pseudoprogression and postradiation changes.

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Comprehensive treatment of patients with parasagittal meningiomas

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In the English-language literature, parasagittal (PSM) is called meningiomas associated with the superior sagittal sinus (SSS), most domestic authors include tumors associated with only the falx cerebri. The issue was considered in detail in a publication by the fourth author [1], in this study we consider only SSS meningiomas as more difficult for radical removal.

Meningiomas are the most common primary CNS tumors (37.2%), their incidence is 8.33 per 100,000 population per year [2].

The proportion of PSM among all meningiomas is not specified, since the exact localization of the meningiomas tumor in the existing registers is not taken into account, and publications reflect the data of specific clinics, and even within the framework of one clinic the ratio can change over time [3]. Based on our experience at the end of the last century, it can be assumed that PSM account for approximately 28% of intracranial meningiomas [4] and their incidence is 2.33 per 100,000 population per year, i.e. exceeds the incidence of tumors of the cranial and spinal nerves (1.89 per 100,000 population per year) [2].

In addition to a rather high incidence rate, the relevance of the PSM problem is due to the complexity of topographic anatomical relationships in the parasagittal area and, first of all, the presence of critically significant venous structures there. According to our data, an increase in the radicalism of the operation due to reconstructive interventions on the SSS is accompanied by a twofold increase in morbidity [3], and according to the literature [5, 6], fatal outcomes. A reasonable restriction of radicalism provides better functional results, but increases the risk of tumor recurrence, ranging from 25 [3, 7] to 62% [8-10].

In recent decades, stereotactic radiosurgery and radiation therapy methods have been developed and put into practice that provide comparable results. However, since different clinicians are involved in neurosurgery and radiation treatment, many publications lack a full comparison of the advantages and disadvantages of surgical and radiation methods. There is no recognized algorithm for...
choosing the optimal method for the comprehensive treatment of patients with PSM.

**Materials and methods**

When analyzing the entire data array, three groups of publications were identified. In the 1st group of publications, written mainly by neurosurgeons, the feasibility of the most radical removal of PSM is discussed. In the 2nd, more numerous group of studies carried out mainly by radiologists, the advantages and disadvantages of radiation methods are described. In this group, one publication [11] presents a meta-analysis of 28 studies; 3rd, the smallest group presents clinical recommendations made by experts with the participation of both neurosurgeons and radiologists. Studies of the 1st and 2nd level of evidence in the available literature were not found, including among the sources used in compiling the clinical recommendations.

**Discussion**

**Radicalism and the Simpson scale.** Historically, hyperostotic PSMs were the first object of manipulation in neurooncology [12], and, perhaps, due to experience gained up to the 80s of the XX century, radical removal was considered the only effective way to treat meningiomas in general and parasagittal in particular [1]. At that technology and knowledge level, this concept found substantiation in the well-known work of D. Simpson [13], and the maximum possible resection of meningioma has long been considered a priority.

The first significant remarks regarding the Simpson scale were made by K. Skullerud and A. Loken [14] in 1974 and related to subjectivity in determining the degree of radicalism (at the autopsy after the “radical” removal, according to the surgeon, macroscopic residues were found in 21% of cases tumors). Today we know that 1 mm3 of tumor tissue contains 100 million cells, and if block resection is not possible, the removal of a brain tumor can never be considered radical. In other words, almost all operations in neurooncology are cytoreductive.

Raza et al. [10] showed that the degree of radicalism on the Simpson scale and the volume of manipulations on SSS do not correlate with the probability of relapse, which amounted to 11% in their study, mortality - 0.9%, and morbidity - 3.6% with an observation period of 4.4 years. Similar results are reported by Sughrue et al. [15, 16] (373 patients with PSM WHO I, 5-year relapse-free survival after resection on the Simpson scale 1-3: 95, 85 and 88%, respectively, the differences are not statistically significant). Similar conclusions about the absence of statistically significant differences in the duration of the relapse-free period after operations of the 1st, 2nd and 3rd degrees of radicalism on the Simpson scale were made by Condra et al. [17] and Oya et al. [18]. On the other hand, in a series of 391 observations, Hasseleid et al. [20] revealed significant differences in outcomes depending on the degree of radicalism of the operation on the Simpson scale.

Moon-Soo Han et al. [19] analyzed the treatment results of 107 patients with PSM and revealed a significant dependence of the relapse probability on the SSS meningioma invasion degree. Moreover, the radical nature of the operation on the Simpson scale, histological type, tumor size and peritumor edema did not have a statistically significant effect on the relapse probability. The authors reported 21% of the complications and claim that they were reliably due to the desire for the most radical removal of the tumor.

Among the complications of the PSM surgery, edema and cerebral infarction, paresis of the extremities, cramps, visual and cognitive impairments resulting from both direct injuries of the cortex and white matter, and cerebrovascular disturbances, primarily venous, are more often reported [21].

A number of authors note a direct dependence of complications on the nature of manipulations on the SSS and cortical veins. So, M. Sindou et al. [5] report 3% mortality and 8% persistent disability in patients after radical removal of PSM with CCC resection. DiMeco et al. [6] associate the cerebral edema and the increase in neurological symptoms with damage to collateral veins and narrowing of the CCC lumen during its marginal resection, but justify the desire for maximum radicalism by reducing the relapse probability (which, according to their data, with a 10-year observation period for operations 1, 2 and 3 types on the Simpson scale is 13.5, 24 and 49%, respectively), as well as mainly the temporary nature of morbidity, which amounted to 28.7% in their series with 1.85% mortality. The authors consider these results to be good, and see the problem solution in the active use and improvement of neurorhabilitation methods. F. Tomasello et al. [29] in 2013 in the Journal of Neurosurgery published their experience in treating 67 patients in support of the thesis about the technical feasibility and the need to strive for the maximum (type 1 on the Simpson scale) PSM removal radicalism. Despite of the fact that the authors tried to maintain venous outflow in all cases, including due to reconstructive interventions on SSS, 3 (4.5%) patients died, temporary morbidity was noted in 12.5% of survivors, and permanent - in 10.9%.

Along with the apologetics of the “aggressive” approach, the literature also presents another point of view where priority is given to the functional result of the operation, even if by reducing the radicalism of PSM removal. In fact, this approach seems to be a modern development of Cushing’s position set forth in the famous “Meningiomas …” [12], but his supporters, judging by the bibliographic data, are still in the minority. In addition to refusing reconstructive interventions on the SSS and the need to preserve all venous structures, even infiltrated by...
a tumor, the authors emphasize the importance of cerebral cortex tumor invasion fact, especially in functionally significant areas. So, M. Sughrue et al. [15] showed that while maintaining all venous structures in the material of 135 operations, cerebral edema developed in only 1 (0.7%) case, but in 4 (3%) patients an increase in neurological symptoms was noted as a result of microtrauma of the motor cortex during PSM removal. Similar results of this tactics are given by P. Black et al. [7], reporting 1.7% of temporary morbidity due to surface invasion by a tumor of the cerebral cortex. Note that in the last cited works there was no mortality, but the pial membrane and cortex were not intended to be left with an infiltrated tumor. The restriction of manipulations in this area, followed by radiation treatment, would probably exclude these neurological complications.

It is noteworthy that J. Brotci [22], one of the developers and propagandists of SSS plastics, in 2013 called not to use this method unless absolutely necessary, i.e. perform reconstructive interventions in case of traumatic or iatrogenic damage to the SSS, but not in the planned PSM surgery.

Thus, it is obvious that the PSM recurrences are also observed in surgery of the highest radicalism degree, but this interventions are accompanied with higher rates of morbidity and mortality. Nevertheless, in modern literature, the point of view on the need for the most radical PSM removal formed in the last century Bonnal, Sindou, Hakuba, etc. [23–28] is significantly represented.

**Radiation methods.** The development of radiation treatment methods for meningiomas was hindered by the prevailing opinion of their “radioresistance” that prevailed until the 1980s. Radiation therapy was prescribed in isolated cases, with repeatedly recurring meningiomas, and the lack of material impeded analysis (for more details see [30]). The situation began to change with the advent in 1980 of the work of J. Yamashita et al. [31], which reported a decrease in the size of some meningiomas after radiation exposure. In parallel with studies of the meningiomas radiation therapy effectiveness, reports about the possibility of using stereotactic radiosurgery developed by L. Lexell [32] in these tumors, began to appear. Since then, radiation methods have gone from an auxiliary to an independent method of treating patients with meningiomas. It should be noted that there are currently no proven effective chemotherapy regimens for these tumors.

The effectiveness of radiosurgical treatment of small (median - 4.8 cm³) intracranial meningiomas was convincingly shown in a multicenter study by Santacroce et al. [33] published in 2012. In the material of 4565 patients (5300 tumors, verified or presumably Grade I) with a follow-up period of more than 24 months and a median of 63 months, control of tumor growth was achieved in 92.5%, and only 2.2% progression of meningioma required repeated treatment. 5- and 10-year survival without disease progression were 95.2 and 88.6%, respectively. The treatment efficiency was higher in previously unexposed patients, in women, and with single meningiomas compared with multiple. Constant morbidity was 6.6%. The authors noted significantly (p < 0.001) the worst results of radiosurgical treatment of convexital and parasagittal meningiomas compared with tumors of the skull base. These results were comparable with previously published in the classic work of Kondziolka et al. [34].

In large tumors, radiation methods provide equally high rates of intracranial meningioma growth control, but with a higher incidence of complications. So, Bledsoe et al. [35] reported that in the group of patients with large (up to 48.6 ml) meningiomas, 3- and 7-year-old control of tumor growth was 99 and 92%, respectively, but the complications of radiation treatment in the form of seizures, hemiparesis, damage to the trigeminal nerve, diplopia, heart attack, cerebral edema, and ataxia were noted in 23% of cases. The complication rate was higher compared to basal (44 and 18%, respectively) in tumors of convexital and parasagittal localization. Some publications report a greater, up to 37%, complication rate of large meningiomas radiation treatment, the most significant of which is cerebral edema [36].

A meta-analysis of 28 publications describing the results of radiation treatment for a total of 3686 patients with benign intracranial meningiomas of different sizes (median tumor volume from 12 to 107 ml) showed that stereotactic radiosurgery provides a significantly higher frequency of tumor regression compared to fractional stereotactic radiotherapy (46.2 and 28.9%, respectively; p=0.0145). The complication rate was 9.2% with stereotactic radiosurgery and 10.4% with fractionated radiation therapy, without statistical confirmation of the difference [11].

As already mentioned, in many publications a greater number of parasagittal meningiomas radiation treatment complications are noted, primarily due to the increase or appearance of peritumor brain edema [37–40]. The brain peritumor edema pathogenesis is primarily associated with the expression of VEGF tumor cells - vascular endothelial growth factor (the decongestant effect of dexamethasone is based on the suppression of the expression of this factor), but in the available literature there is no explanation why PSM and basal tumor radiation pathomorphosis leads to different consequences. The only significant difference between the parasagittal area and others is its venous anatomy, and impaired venous outflow can contribute to the severity of peritumor brain edema [41]. However, the issue requires further study.

The problem of choosing the optimal PSM treatment in the current literature is poorly presented. We managed to find the only publication in 2017 dedicated to the comparison of surgical, radiation and combined treatment methods for patients with PSM, based on 117 observations from 1993 to 2013 [42]. The fact of publication of the work in J. Neurosurg., the first in the issue, testifies to the interest of the neurosurgical community in the problem.
However, the study scope and the groups heterogeneity (in particular, the size of the tumors in the groups varied from 3 to 239 ml), as well as the lack of inclusion criteria in the groups, do not allow us to unambiguously judge the validity of the conclusions. Moreover, if the clinic operates about 5 patients with PSM per year, comparing the results of surgery and less invasive or non-invasive methods does not seem to be quite correct.

Thus, the analysis of the literature showed that an increase in the PSM removal radicalism is accompanied with an increase in the number of complications, but does not necessarily lead to a decrease in the risk of tumor recurrence. Stereotactic radiosurgery and, to a lesser extent, stereotactic radiotherapy provide better results of controlling the meningioma growth compared to microsurgery, but as the volume of the target material increases, the number of complications increases, especially with parasagittal localization of the process. The way out of this collision seems to be complex treatment - the maximum possible removal of the tumor without damaging functionally significant structures, including venous outflow pathways, followed by radiation treatment for the remains of the tumor. An algorithm for choosing the tactics of treating patients with PSM (surgical, radiation or combined), choosing the best radiation method, the number of fractions and doses is not presented in the literature.

The authors declare that there is no conflict of interest.

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Anniversary

The editorial board of the journal Burdenko’s Journal of Neurosurgery congratulates Evgeny Ivanovich Chazov, Doctor with a capital letter, an outstanding scientist, organizer of public health of the USSR and Russia, whose long-term activity allowed creating one of the first and best cardiology services in the world on the 90th anniversary.

Honorary Director of the National Medical Research Center for Cardiology created by him, Russian Ministry of Health, academician of the Academy of Sciences of the USSR and the Russian Academy of Sciences, Hero of Socialist Labor, three times laureate of the USSR State Prize and laureate of the Lenin Prize, E.I. Chazov was awarded the orders For Merit to the Fatherland I, II and III degree, four orders of Lenin, the Great Gold Medal of the Russian Academy of Sciences. M.V. Lomonosov Gold Medal, I.P. Pavlov, medals to them, S.P. Botkin and A.L. Myasnikov, Albert Schweitzer Gold Medal, European Cardiology Society Gold Medal, orders and medals of Belgium, France, Serbia and Montenegro, Cuba, Mongolia, Czechoslovakia, Poland, South Korea, the CIS countries and many other countries, professor emeritus, doctor, valid and honorary member of numerous foreign academies of sciences and universities, various scientific societies - this is an incomplete list of honored awards of Evgeny Ivanovich.

We sincerely wish Evgeny Ivanovich health and long life!

Evgeny I. Chazov
(on his 90th anniversary)
In May, the medical community celebrated the anniversary of one of the leading neurologists in Russia - Evgeny Ivanovich Gusev. He dedicated his profession all his life, from the moment when 2 years after graduating from the 2nd Moscow Medical Institute named after N.I. Pirogov, in 1964, entered graduate school at the Department of Nervous Diseases of the Pediatric Faculty of the 2nd MOLGMI, led by L.O. Badalyan. At this department, his further activities proceeded. Here he consistently defended his candidate and doctoral dissertations (1973), the main direction of which was the study of hereditary metabolic diseases that occur with damage to the nervous system. In 1975, E.I. Gusev headed the Department of Nervous Diseases with a course of neurosurgery at the Faculty of Medicine of the 2nd MOLGMI (currently the Russian National Research Medical University named after N.I. Pirogov), which he has successfully managed to date. In 1978, one of the country’s first faculty of advanced medical education was organized at the department.

The circle of scientific interests of E.I. Gusev is very wide. For many years, he and his staff have been dealing with issues such as brain vascular diseases, demyelinating diseases, paroxysmal conditions, epilepsy, and a number of others.

On the basis of studying the regularities of changes in central and cerebral hemodynamics, microcirculation and brain metabolism, he developed provisions concerning the mechanisms of development, diagnosis and treatment of ischemic and hemorrhagic strokes. Under the leadership of E.I. Gusev, one of the first complex studies of multiple sclerosis in the world was conducted, which made it possible to formulate new views on the pathogenesis of the disease, to determine the ratio of external and hereditary factors in its development, to develop new approaches to pathogenetic therapy. With its active participation, the country has set up specialized care centres for patients with multiple sclerosis, a register and a genetic database for patients with multiple sclerosis. Much has been and is being done to study epilepsy, both in experimental models and in clinical settings. Intimate mechanisms of pathology development are being studied, possibilities of new biochemical, electrophysiological, neuroimaging and other diagnostic methods are being specified, new approaches in treatment with the use of medications of different pharmacological groups are being developed.

Not only the range of interests, but also the creative activity of Evgeny Ivanovich is striking. He has published more than 500 scientific articles in leading domestic and foreign medical publications. He is the author and co-author of well-known textbooks and manuals, books on various sections of neurology. More than 60 doctoral dissertations and 200 candidate dissertations have been completed and defended under the guidance and at scientific consulting of E.I. Gusev. Many of his students head de-
partments of neurology and neurosurgery, laboratories for the study of the nervous system in the norm and pathology in educational and research medical institutions of the Russian Federation.

Yevgeny Ivanovich's extensive medical knowledge was clearly demonstrated when he headed the Clinical Medicine Department of the Russian Academy of Medical Sciences (RAMS) as an academic secretary (1992-2007). With his direct participation, the scientific councils of the Russian Academy of Medical Sciences and the Ministry of Health and Social Development of the Russian Federation were organized, and scientific programs in the main areas of clinical medicine were created and actively developed. For many years Evgeny Ivanovich has been the editor-in-chief of the Journal of Neurology and Psychiatry named after V.I. Lomonosov. S.S. Korsakov.

E.I. Gusev is the Chief Neurologist of the Ministry of Health of the Russian Federation. For 30 years he has been managing the All-Russian Society of Neurologists as Chairman of the Management Board. With his personal participation, he established and expanded contacts with neurological societies in the CIS countries, Europe, North America, Japan, China and Australia, and actively cooperates with leading specialists. E.I. Gusev is the President of the National Association for Stroke Control (NABI), established in 1999 together with V.I. Skvortsova. The Association's activities allowed to obtain information on trends in vascular diseases, the structure of risk factors, introduce new diagnostic algorithms, therapeutic and prophylactic approaches, reduce mortality and improve functional outcomes in patients with cerebral vascular disease on a national scale and in each region.

E.I. Gusev was elected a Corresponding Member of the German Society of Neurologists, Honorary Member of the Royal Medical Society of Great Britain, Co-Head of the American Biographical Association (USA), member of several committees of the European Academy of Neurology and the World Federation of Neurologists. He was awarded the honorary title of "Neurologist of the XX century" by the International Biographical Centre in Cambridge.

E.I. Gusev's scientific activity has been marked by many state awards, he is the holder of the orders "Badge of Honor", "For Merit to the Fatherland" of IV and III degrees, the honored worker of science of the Russian Federation, he has been awarded the "Badge of Honor" of the Presidential Medical Center of the Russian Federation, the Order of International Ambassadors (USA), the medical "Unity" of the United Nations.

Yevgeny Ivanovich is the undisputed leader of the national neurology, who enjoys great respect and love. He has always considered neurosurgery to be an integral part of neurology, helping to create new diagnostic methods and expanding our understanding of the brain.

The Editorial Board of the journal Burdenko's Journal of Neurosurgery and the entire neurosurgical community of the country congratulate E.I. Gusev on the anniversary date and sincerely wish him further success in the development of domestic neurology.