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SURGICAL TREATMENT OF CEREBROVASCULAR DISEASES IN A HYBRID OPERATING ROOM

A.V. Sergeev[1], V.Yu. Cherebillo[1], A.V. Savello[2], F.A. Chemurzieva[1]

[1]Academician I.P. Pavlov First St. Petersburg State Medical University; 6–8 Lva Tolstogo St., Saint Petersburg 197022, Russia;
[2]Kirov Military Medical Academy, Ministry of Defense of Russia; 6 Akademika Lebedeva St., Saint Petersburg 194044, Russia

Contacts: Andrey Vladimirovich Sergeev *md-sergeev@mail.ru*

Background. Surgical treatment of complex neurovascular pathology remains an important problem requiring use of a combination of various techniques. Utilization of a hybrid operating room allows to simultaneously or sequentially combine microsurgical and endovascular surgical methods which can improve treatment outcomes.
Aim. To improve surgical treatment of patients with cerebrovascular pathology by utilizing the capabilities of a hybrid operating room.
Materials and methods. Surgical interventions were performed in a hybrid operating room with a combination of endovascular and microsurgical methods for treating the following cerebrovascular pathologies: complex dural fistulas, complex aneurysms, arteriovenous malformations. The type of surgical intervention – hybrid, combined, staged – was chosen in accordance with the nature of the pathology.
Results. In 5 years, 41 patients underwent surgery in the hybrid operating room. Among them, 33 patients had arteriovenous malformations, 6 had complex aneurysms, 2 had complex dural fistulas. Combination interventions were performed in 27 patients, staged – in 12, hybrid – in 2. According to the Modified Rankin Scale (mRS) the following outcomes were observed: no complications in cases of complex aneurysms (6 patients) – mRS 0 (points), as well as in cases of dural fistulas (2 patients) – mRS 0 (points); in arteriovenous malformation, 30 patients did not have any complications – mRS 0, 3 patients had complications (of different types) – mRS 1.
Conclusions. The combination of microsurgical and endovascular methods of treatment in a hybrid operating room allows to combine the positive features of the two methods in accordance with surgical needs which improves the outcomes of neurosurgical interventions in complex neurovascular pathology.

Keywords: hybrid operating room, vascular neurosurgery, combined surgery, complex dural fistula, complex aneurysm, arteriovenous malformation

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INTRODUCTION

Currently, microsurgery (MS) and endovascular surgery (ES) are considered effective treatment methods in vascular neurosurgery [1, 2]. In the most complex cases, simultaneous or sequential use of these methods is required because complex approach allows to optimize solution of the problems which are impossible or difficult to solve using one of the methods. According to the Russian clinical guidelines “Diagnosis and treatment of arteriovenous malformations of the central nervous system” (27.11.2014) and clinical guidelines on treatment of complex cerebral aneurysms (14.10.2015), an integrated/hybrid operating room with possibility of performing simultaneous or sequential open and endovascular interventions is preferable. In the traditional approach, cases requiring combination of these methods imply surgical interventions under different anesthesias in different operating rooms which significantly complicates and prolongs treatment process. To combine these methods, it is expedient to use a hybrid operating room containing equipment allowing for simultaneous or sequential performance of endovascular and MS operations without patient transfer into another operating room and prolongation of anesthesia [3–7]. Therefore, in the most complex variants of cerebrovascular disorders, integrating efforts of micro- and endovascular surgeons in one operating room minimizes the limitations of each method and improves outcomes as was confirmed by research [8–13].

It is expedient to utilize the capabilities of a hybrid operating room in development of such intraoperative complications as cerebral aneurysm rupture (CA) and arteriovenous malformations (AVM) when it is necessary to quickly change surgical method and time delays can significantly worsen treatment outcomes. The authors describe the effectiveness and favorable outcomes as a result of quick

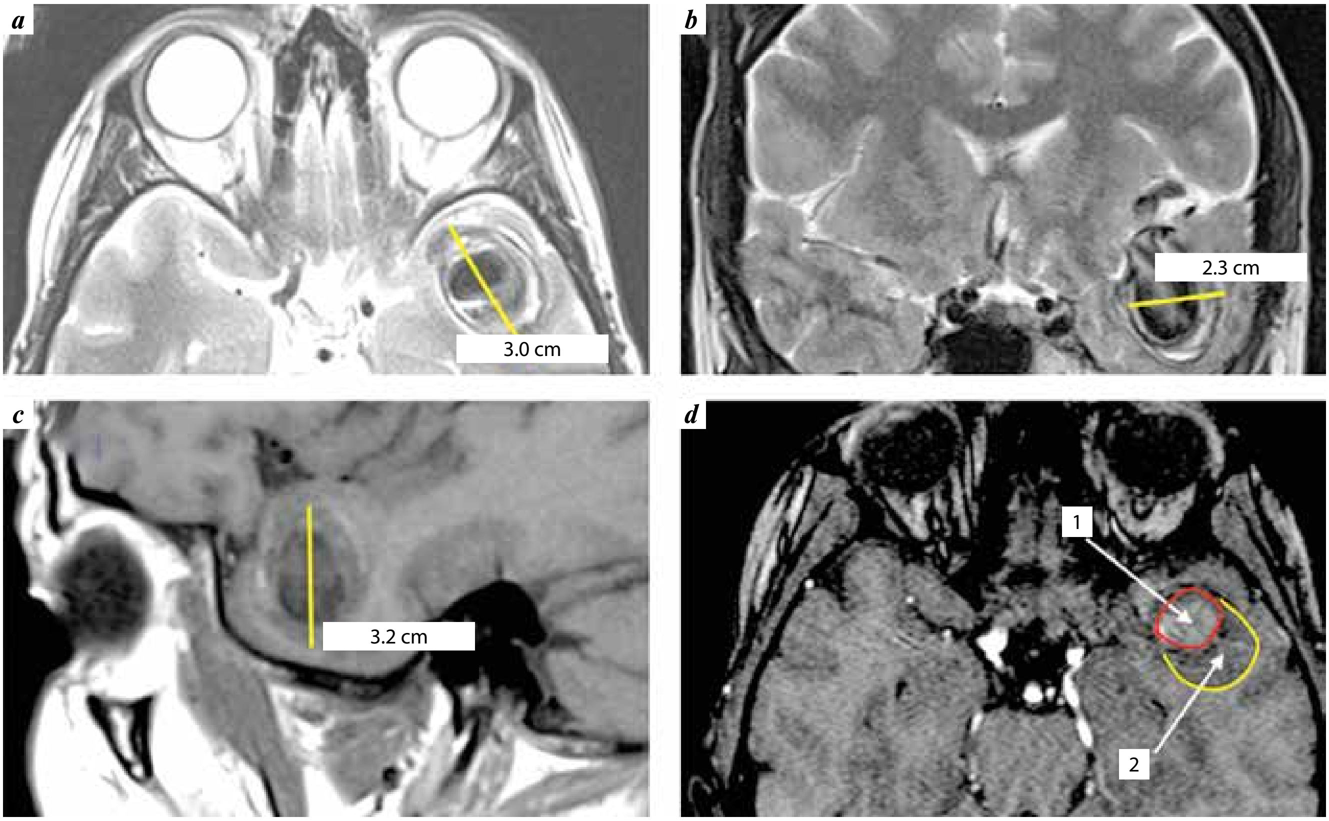

Fig. 1. *MRI of the brain: a – axial projection, T2; b – frontal projection, T2-weighted; c – sagittal projection, T1-weighted; d – MR angiography, TOF; 1 – contrasted part of the cerebral aneurysm (CA); 2 – thrombosed part of the CA*

change of the type of surgical intervention in a hybrid operating room during intraoperative CA ruptures and AVM [7, 11, 14, 15].

The article describes our own results of surgical treatment of cerebrovascular disorders with description of clinical cases, as well as a classification of interventions in a hybrid operating room depending on the method of surgical techniques combination.

The study objective is to improve surgical treatment of patients with cerebrovascular pathology by utilizing the capabilities of a hybrid operating room.

MATERIALS AND METHODS

A hybrid operating room where in sterile conditions various types of open interventions can be performed is equipped with a multiaxial robotized angiography system and an X-ray transparent operating table for ES. An intellectual system of robotized C-arm positioning allows to obtain 2D CA images in almost any projection and to perform 3D angiography and flat-detector computed tomography (CT). Hybrid operating room equipment allows to move the C-arm in different parking positions freeing additional space for patient access.

In treatment of complex dural fistulas (DF), neurosurgical access directly to the fistula cavity was performed: craniotomy with subsequent DF puncture allowing for placement of an endovascular catheter and fistula isolation.

At the 1st stage of treatment of complex CAs, a bypass was formed. At the 2nd stage (after evaluation of shunt potential using balloon occlusion test (BOT) with manometry and angiographic evaluation of condition of the collateral vessels, electrophysiological monitoring), destructive occlusion of CA and/or, if necessary, carrying artery was performed.

In surgical treatment of AVM, at the 1st stage partial endovascular embolization was performed. At the 2nd stage, MS removal of AVM with subsequent control cerebral angiography for evaluation of the surgery results was performed.

The type of surgical intervention was decided depending on the type of pathology.

- **Type I – hybrid surgery:** joint and simultaneous use of MS and ES under singular anesthesia; in this group, intervention type is planned prior to surgery;
- **Type II – combination surgery:** surgeries are performed under one anesthesiologic aid with sequential use of MS and ES; different anesthesias can be used but singular general anesthesia decreases the risk of complications;
- **Type III – staged:** separation of ES and MS stages, can performed under different general anesthesias; in this intervention group, simultaneous use of the 2 methods under one anesthesia does not carry any benefits.

Preliminary allocation of surgeries into surgical types II and III was performed prior to surgical intervention based on neuroimaging data and definitive allocation was performed based on the results of the 1st treatment stage.

RESULTS

In 5 years of hybrid operating room utilization, 41 surgical interventions were performed: 33 for cerebral AVM, 6 for CA, 2 for complex DF (Table. 1).

For the 2 cases of complex DF, hybrid intervention (type I) was used. In 33 AVM cases, 25 patients underwent combination (II) surgery, 8 patients underwent staged (III) surgery. In 6 cases of complex CA, 4 patients underwent combination (II) surgery, 2 patients underwent staged (III) surgery.

Table 1. *Distribution of operations per surgery combinations*

Pathology	Number of operations		
	Type I (hybrid)	Type II (combination)	Type III (staged)
AVM	–	25	8
Complex CAs	–	2	4
DF	2	–	–
Total	*2*	*27*	*12*

Note. *AVM stands for arteriovenous malformation; CAs – cerebral aneurysm; DF – dural fistula.*

Table. 2 presents the outcomes of surgical interventions. In the postoperative period, no complications were observed in cases of complex CAs and DFs. The results of surgeries for treatment of AVM varied according to the Modified Rankin Scale (mRS):

Table 2. *Outcomes of surgical interventions per the Modified Rankin Scale*

Pathology	mRS 0	mRS 1
AVM	30	3
Complex CAs	6	–
DF	2	–
Total	*38*	*3*

Note. *See Note for Table 1.*

- no complications (mRS 0) in 30 patients with cerebral AVMs;
- insignificant complications not affecting quality of life (mRS 1) in 3 patients with AVMs;
- transitory hemiparesis which regressed at discharge time – in 1 patient after removal of AVM of the central gyri;
- intraoperative AVM rupture at the stage of endovascular embolization – in 1 patient; intracerebral hematoma and malformation were removed simultaneously; in the postoperative period, the patient developed hemiparesis (4 points), during rehabilitation therapy, positive dynamics in partial regression of hemiparesis was observed to 3 points;
- partial loss of fields of vision in the form of quadrantanopia – in 1 patient.

CLINICAL EXAMPLE NO. 1

Female patient, 42 years old, *complained of increasing headaches. Magnetic resonance imaging of the brain (MRI) showed a giant partially thrombosed CA of the left middle cerebral artery (MCA) (Fig. 1). Angiography performed using spiral computed tomography (SCT) and preoperative selective cerebral angiography of the cerebral vasculature showed the following main features of CA structure (Fig. 2, 3):*

- *transposition of the frontal branch of the superficial temporal artery (STA) from the M1-segment of the left MCA to the CA pouch located on the lateral MCA wall;*
- *dolichoectatically expanded parietal branch (M2-segment) diverged from the CA cavity and further significantly narrowed.*

Because CA was giant and thrombosed, complications during MS and ES were possible, and a decision of using the hybrid operating room was made. Considering CA structural characteristics (pathological expansion of the parietal trunk with subsequent pronounced stenosis, presumably satisfactory collaterals between the MCA and anterior cerebral artery (ACA) basins, blood supply of the functionally important area of the left temporal lobe through STA), a variant of trapping of the M1-segment with preservation of the anterior temporal branch and full exclusion of the CA pouch with the parietal branch from the blood flow was considered. Intraoperative evaluation of collateral blood supply using BOT was planned. In case of insufficient collateral supply, anastomosis at the MCA parietal branch basin was intended.

In the conditions of hybrid operating room under general anesthesia, at the 1st stage cerebral angiography, BOT confirmed satisfactory collateral blood flow between the ACA and MCA basins and intraoperative neurophysiological monitoring showed no decrease in motor potentials (Fig. 3 b, c). The obtained data allowed to avoid bypass. Pterionatal osteoplastic trepanation with subsequent MS trapping of the MCA M1-segment with STA sparing allowed to exclude CA and pathologically altered parietal trunk from the blood flow. At the final stage of the surgery, control cerebral angiography was performed. Imaging showed that CA was not contrasted, blood flow in the frontal, parietal, temporal and occipital lobes was sufficient due to anastomosis, and blood flow of the left temporal lobe was satisfactory due to STA (Fig. 3 d). Postoperative period did not have any complications, neurological status was at the preoperative level (mRS 0). The case was classified as type II combination surgical intervention.

CLINICAL EXAMPLE NO. 2

In 2012, the patient underwent partial endovascular AVM embolization; subsequently, the patient developed generalized seizures. Drug therapy did not entirely manage seizures. Examination showed AVM of the right frontal lobe (larger than

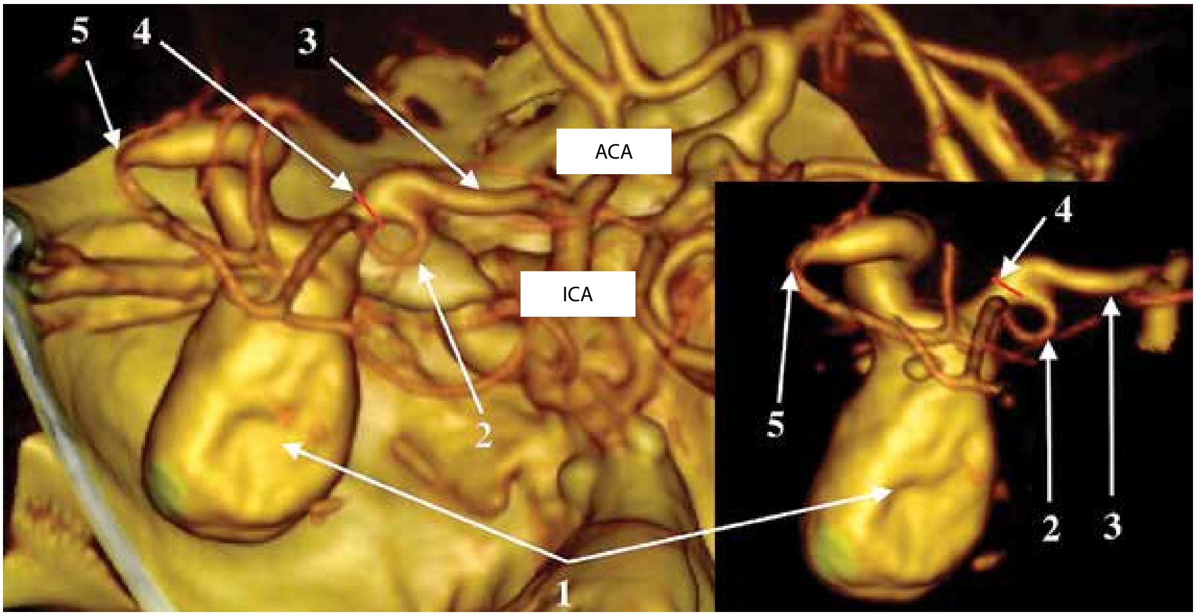

Fig. 2. *SCT-angiography of cerebral vasculature: ACA – anterior cerebral artery; ICA – internal carotid artery; 1 – contrasted part of the cerebral aneurysm (CA); 2 – anterior temporal artery; 3 – M1-segment of the left middle cerebral artery (MCA); 4 – site of the planned trapping of the MCA M1-segment; 5 – parietal trunk of the MCA with significant stenosis*

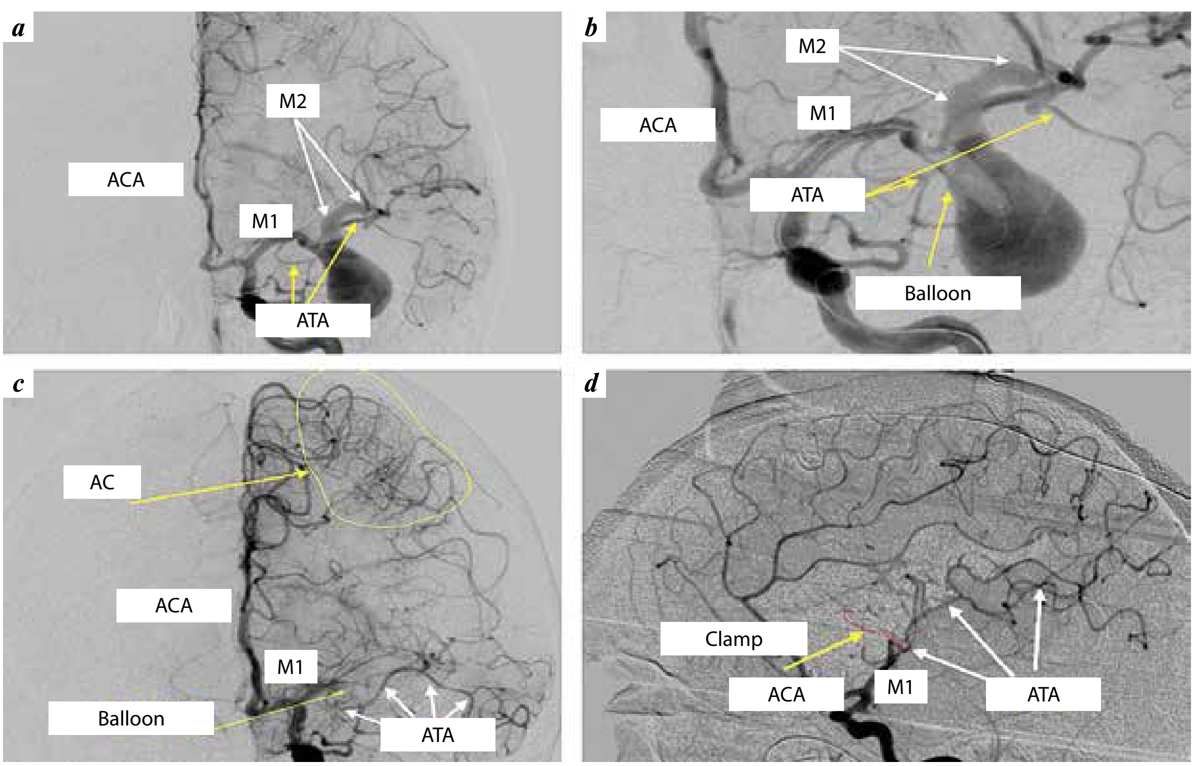

Fig. 3. *Cerebral angiography: a – preoperative cerebral angiography, frontal projection; b – intraoperative balloon occlusion test; c – assessment of collateral blood flow after balloon occlusion of the middle cerebral artery (MCA); d – control cerebral angiography after aneurysm clipping; ACA – anterior cerebral artery; M1, M2 – segments of the MCA; ATA – anterior temporal artery; AC – the area of collaterals between the ATA and MCA*

5 cm) in a functionally important area due to compression of the genu of the corpus collosum (Fig. 4) with afferents from the basins of the right ACA, MCA, superficial and deep outflow into the superior, transverse, straight and cavernous sinuses, basal veins (Fig. 5 a, b). Per the Spetzler–Martin grading system (taking into account AVM size, its location relative to functionally important areas of the brain and characteristics of blood draining), AVM is grade III (SM).

At the 1st stage, AVM was partially endovascularly embolized through accessible largest afferents of the right MCA and

ACA using non-adhesive embolic agent Onyx (Fig. 5 c). Significant decrease in blood flow at the lesion and slowing of blood flow in the largest malformation vein were observed. Filling of AVM remained through small MCA and ACA branches on the right inaccessible for endovascular embolization. Considering impossibility of achieving the stated goals using ES (total embolization of small AVM afferents) and sufficient time for MS treatment, we decided to perform MS removal. Without transfer into another operating room and under singular anesthesia, malformation was totally removed using MS. Control cerebral angiography was performed confirming radical nature of the surgery (Fig. 6). Postoperative period did not have any complications, neurological status of the patient remained on the preoperative level (mRS 0). This case was classified as type II combination surgical intervention.

DISCUSSION

Surgical treatment of neurovascular pathologies involves endovascular and microsurgical approaches. There are some pathologies requiring combination approach using both ES and MS. Limitation of combination of the two approaches is the necessity of patient transfer into another operating room and repeat anesthesia [16–19]. Use of a hybrid operating room allows to perform a combination of ES and MS without these limitations [9, 12, 13].

The main objective of combination surgery in a hybrid operating room in complex CAs was to maximally decrease the risk of complications through combination of placement of vascular bypasses with subsequent endovascular exclusion of CA or carrying vessel after BOT. Operating procedure for combination of the 2 methods was developed and was described in depth by M.T. Lawton et al. [19, 20]. S.C. Shen et al. arranged surgical interventions over several days and performed them in different operating rooms under different anesthesias which could increase the risk of anastomosis thrombosis [21].

In a series of surgeries for complex CAs in the hybrid operating room of our clinic, part of combination interventions

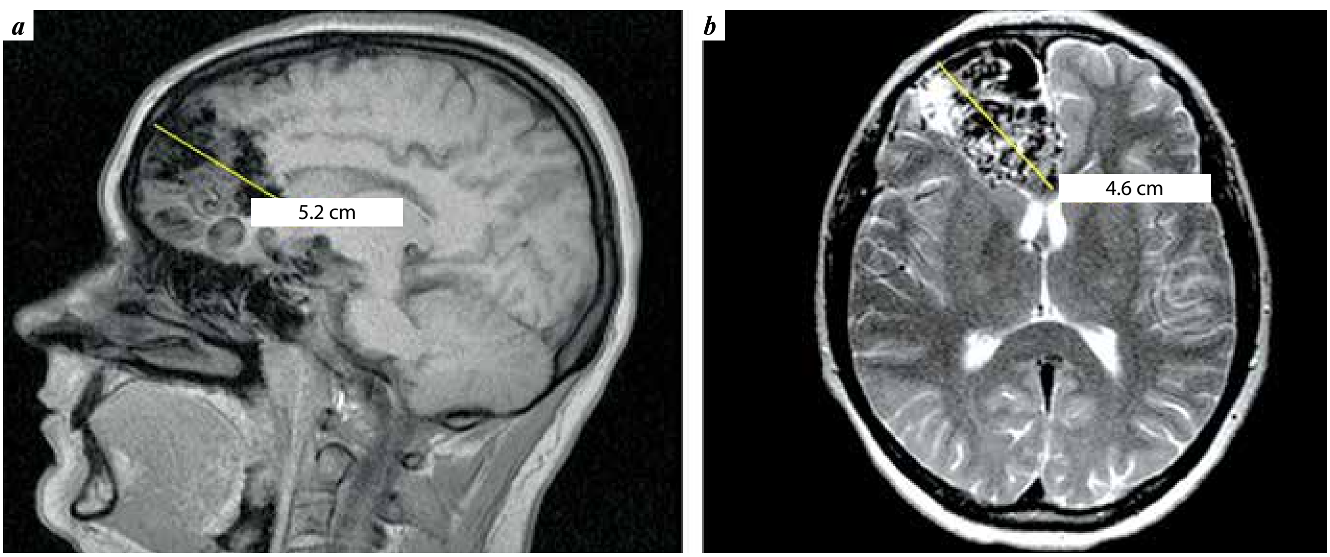

Fig. 4. *Brain MRI: a – sagittal projection, T1-weighted; b – axial projection, T2-weighted*

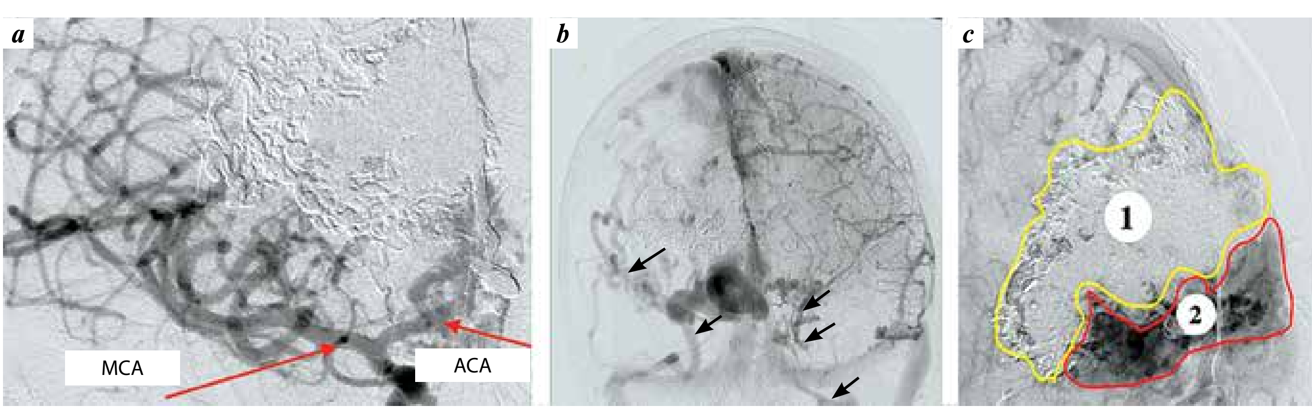

Fig. 5. *Selective cerebral angiography: a – frontal projection of the arterial phase; b – frontal projection of the venous phase (blue arrows show draining veins of the arteriovenous malformation (AVM)); c – embolized and filled parts of the AVM; MCA – middle cerebral artery; ACA – anterior cerebral artery; 1 – embolized part of the AVM; 2 – contrasted part of the AVM*

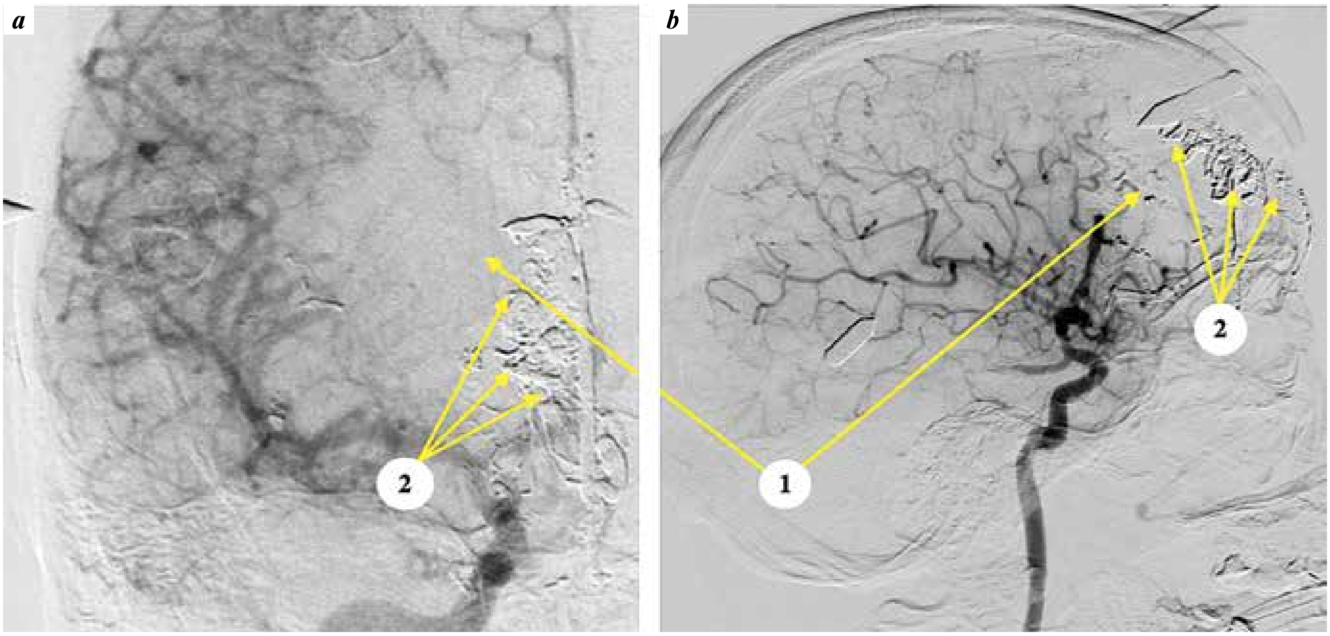

Fig. 6. *Intraoperative control cerebral angiography: a – frontal projection; b – lateral projection; 1 – avascular area of the removed arteriovenous malformation (AVM); 2 – residual parts of the embolizate*

was performed under a single anesthesia which allowed to perform control examination intraoperatively, prevent possible thrombosis, decrease risks of repeat anesthesia [22]. The goal of combination resection of cerebral AVM in the hybrid operating room was decreased intraoperative risk of AVM hemorrhage due to partial endovascular embolization prior to MS resection. Similar problems have been solved in various articles from Swiss and Russian clinics [9, 23]. In one of our cases, intraoperative AVM rupture happened during endovascular embolization. Because there was no necessity in transferring the patient to another operating room, intracerebral hematoma was evacuated, and AVM resected without patient transportation. Specialists of a clinic in Japan [21] noted the possibility of switching from ES to MS during intraoperative AVM rupture during endovascular embolization which can significantly improve the outcome of surgical treatment.

Most of DFs can be effectively and minimally invasively operated on using ES [24]. However, in cases when endovascular access is absent and MS resection is impossible, hybrid intervention is the only option for DF treatment. Various authors note the benefits of using a hybrid operating room when MS access to DF allows to simultaneously endovascularly exclude the fistula [12, 15, 21, 22].

The question of planning the scope and type of surgical intervention depending on neurovascular pathology complexity is insufficiently discussed in the scientific literature. Thus, the authors classified surgical patients into groups of combination intervention, auxiliary techniques, and stereotaxic surgeries [15]. The goal of this classification is to determine cases requiring the use of a hybrid operating room.

We have developed an alternative algorithm of classifying surgery types into groups to standardize the selection of treatment tactics for patients with neurovascular pathologies. Depending on the variant of surgical method combination, we propose 3 types of surgical treatment: I – hybrid, II – combination, III – staged.

Type I – hybrid surgeries: MS and ES are performed simultaneously under 1 general anesthesia, division into stages or separate surgeries is impossible. Type of operative intervention in this group is planned prior to surgery based on neuroimaging and patient medical history. In our series, complex DF was treated using hybrid approach after unsuccessful attempts at MS resection and endovascular embolization. After MS access, embolizate was introduced directly into the fistula in the open brain.

Type II – combination surgery: MS and ES are performed under 1 general anesthesia which increases treatment effectiveness and decreases the risk of complications. In this group, the decision on the type of intervention is made prior to surgery based on neuroimaging data and is confirmed during the surgery. Intraoperatively, time necessary for the 1st type of surgery and the level of achieving the planned surgical scope are evaluated. An example of this (II) type is a case of AVM surgery presented in this article (example No. 2). After ES, significant decrease of blood flow in the AVM body, slowing of the flow in the main draining vein, absence of access necessary for total AVM embolization were observed. This situation had a high risk of AVM rupture in case of staged treatment. The optimal solution was MS resection which increased the effectiveness of the surgery and decreased the risk of AVM rupture between the surgeries, decreased the stress of repeat anesthesia, radiation, and contrast agent administration.

Type III – staged interventions: surgeries under one general anesthesia do not affect the treatment effectiveness.

An example is a case of complex grade IV (SM) cerebral AVM. Though at first total AVM resection under 1 general anesthesia was planned, ES stage took more than 3 hours and the planned goal of decreasing blood flow into the AVM was not achieved. Risks of intraoperative hemorrhage during MS remained. Continuation of embolization could lead to increased operating time and staff fatigue. After 7 days, at the 2nd stage embolization was completed and AVM was radically removed.

We have developed this classification to simplify preoperative planning. Planning of combination surgeries of different types requires continued research with accumulation of more operating material. It will open the possibility for development of an optimal algorithm of patient classification per treatment types, as well as speed up the process of decision making, increase treatment effectiveness, improve outcomes, and decrease the cost of material and human resources.

CONCLUSIONS

Combination of MS and ES in a hybrid operating room allows to unite their positive characteristic: minimal invasiveness of endovascular method and radicalness of microsurgical method. Treatment in a hybrid operating room allows to expand capabilities of intraoperative imaging and monitoring. Classification of surgeries into types of combination interventions will allow to standardize preoperative planning reducing decision making time, improve outcomes of surgical interventions. Accumulation of a large volume of data is required for a deeper comparative analysis of treatment methods in various operating rooms.

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Author's contribution

A.V. Sergeev: obtaining data for analysis, article writing, data statistical analysis;
V.Yu. Cherebillo: research idea and design of the study, editing of the article;
A.V. Savello: research idea and design of the study, editing of the article;
F.A. Chemurzieva: obtaining data for analysis.

ORCID of authors

A.V. Sergeev: https://orcid.org/0000-0002-7603-5838
V.Yu. Cherebillo: https://orcid.org/0000-0001-6803-9954
A.V. Savello: https://orcid.org/0000-0002-1680-6119
F.A. Chemurzieva: https://orcid.org/0000-0002-1461-0286

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