Original Article

Vertebral artery and posterior inferior cerebellar artery aneurysms: Results of microsurgical treatment of eighty patients

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ABSTRACT

Background: The choice of surgical approaches and options for the microsurgical vertebral artery (VA) and posterior inferior cerebellar artery (PICA) aneurysms repair remains controversial.

Methods: A retrospective analysis of the clinical, surgical, and angiographic data of 80 patients with VA and PICA aneurysms treated from 2012 to 2018 was performed.

Results: The aneurysms were saccular in 50 cases (62.5%) and fusiform in 30 cases (37.5%). The median suboccipital craniotomy was the most common approach (73.8%). Retrosigmoid craniotomy was performed in 25% of patients. There were the following types of microsurgical operations: neck clipping (61.25%), clipping with the artery lumen formation (13.75%), trapping (10%), proximal clipping (5%), and deconstruction with anastomosis (10%). Fifty-seven (71.3%) patients were discharged without worsening of the clinical signs after surgery. The most common postoperative neurological disorder was palsy of IX and X cranial nerve revealed in 14 (17.5%) patients. No fatal outcomes or patients in vegetative state were identified. The complete occlusion of PICA and VA aneurysms according angiography was in 77 (96.3%) cases.

Conclusion: Microsurgical treatment is an effective method for VA and PICA aneurysms. The majority of VA and PICA aneurysms do not require complex basal approaches. A thorough preoperative planning, reconstructive clipping techniques, and anastomoses creation, as well as patient selection based on the established algorithms and consultations with endovascular surgeons, may reduce the number of complications and increase the rate of complete microsurgical occlusion in VA and PICA aneurysms.

Keywords: Anastomosis, Aneurysms, Bypass, Clipping, Median suboccipital craniotomy, Posterior inferior cerebellar artery, Retrosigmoid craniotomy, Vertebral artery

INTRODUCTION

The incidence of the aneurysms of the vertebral artery (VA) and posterior inferior cerebellar artery (PICA) is 2–4.5% of all brain aneurysms.[5,8,20] The most common presenting symptoms include subarachnoid and ventricular hemorrhage associated with a high risk of disability and death without surgical treatment.[20,22,27]

The choice of treatment for VA and PICA aneurysms (microsurgical or endovascular surgery) remains controversial.[3,5,21,23,25,26]

This manuscript presents the results of the microsurgical treatment of VA and PICA aneurysms, types of surgical approaches, and options for aneurysm repair according to location and anatomical features.

MATERIALS AND METHODS

A retrospective analysis of the clinical, surgical, and angiographic data of sequential series of patients with VA and PICA aneurysms treated in the N. N. Burdenko National Medical Research Center of Neurosurgery from 2012 to 2018 was performed.

During this period, a total of 4106 patients with intracranial aneurysms underwent surgery in the Center of Neurosurgery. Among them, 130 (3.2%) patients had VA or PICA aneurysms. This group did not include 17 patients who had a combination of aneurysms with arteriovenous malformations of the posterior cranial fossa, as this group of patients had different management and outcomes.

The choice of the surgery type was based on the institutional algorithms for cerebral aneurysms,[9,10] including:
1. Preference for endovascular surgery in patients with aneurysms of the intracranial VA segment
2. Preference for microsurgery for all PICA aneurysms and VA aneurysms with PICA originating from the aneurysm neck or sac.

Contraindications for endovascular surgery included

1. The acute subarachnoid hemorrhage (SAH) requiring stenting and antiplatelet therapy
2. Resistance to or intolerance of the antiplatelet therapy
3. Limited endovascular approach to the aneurysm (VA kinking and atherosclerosis).

In patients with contraindications to endovascular surgery or with unsuccessful endovascular attempts, microsurgery is recommended.

Contraindications for microsurgical treatment included severe decompensated medical conditions and systemic hypocoagulation.

A total of 80 microsurgical operations and 57 endovascular operations were performed.

The outcomes of endovascular surgery are out of the scope of this manuscript.

Clinical characteristics of patients in the study group

Among all patients, 29 (36.3%) were males, and 51 (63.8%) were females. The age of patients ranged from 7 to 68 years (mean, 46.4 years).

A history of SAH was reported in the majority of patients – 75 (93.8%); however, only 12 patients underwent surgery within the first 14 days.

Five patients (6.3%) had no history of hemorrhage: three patients had asymptomatic aneurysms that were incidental findings, and in two patients with giant aneurysms signs of the disease were associated with an increase of the mass effect.

Eight patients (10%) had multiple aneurysms. PICA aneurysms caused hemorrhage in 5 of 7 cases when combined with aneurysms of the anterior circulation.

Anatomical and topographical characteristics of aneurysms in the study group

The intracranial part of the VA can be divided into the three segments: VA proximal to the PICA (VAprox); VA in the area of the PICA origin; and VA distal to the PICA (VAdist).

In accordance with the classification of Lister *et al.*,[14] PICA is divided into the five segments: p1 – anterior medullary segment; p2 – lateral medullary segment; p3 – tonsillomedullary segment; p4 – telovelotonsillar segment; and p5 – cortical segment.

Peerless and Drake classified all PICA as proximal (about 1 cm from the PICA origin) and distal.[20] Similarly, we classified VA aneurysms in the area of the PICA origin and aneurysms of the anterior medullary PICA segment as proximal PICA aneurysms (PICAprox), and all PICA aneurysms in the p2-p5 segments were classified as distal aneurysms (PICAdist).

Thus, we identified four main segments of VA and PICA aneurysm localization: (1) VAprox; (2) VAdist; (3) PICAprox; and (4) PICAdist.

Table 1 shows the aneurysms distribution by segments according to their shape and size, as well as the presence of intra-aneurysmal thrombosis.

Surgical approaches in the study group

Three types of approaches [Figure 1] and four positions of patients on the operating table [Figure 2] were used to repair the aneurysms.

SURGICAL RESULTS

The median suboccipital craniotomy (MSC) with lateralization toward the cerebellum hemisphere according to the location of the aneurysm was the most common approach (73.8%) [Table 2]. In general, a linear incision was appropriate for this craniotomy (*n* = 51). In 8 cases, MSCs involved a hockey stick incision for lateralization and approach to the medial VA-PICA complex (to the anterior

Table 1: Anatomical and topographical aneurysm characteristics.

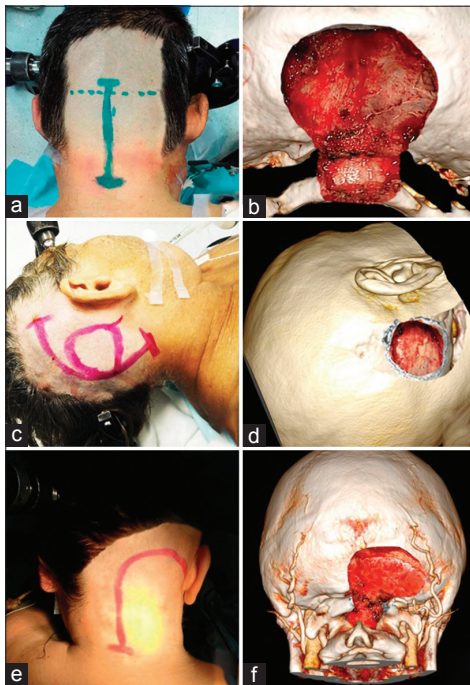| Aneurysm localization	Number of patients (%)	Aneurysm shape		Partial thrombosis	Aneurysm size			
		Saccular	Fusiform		Small	Medium	Large	Giant
VAprox	5 (6.25)		5	2		2	2	1
VAdist	6 (7.5)	3	3		2	4		
PICAprox	46 (57.5)	41	5	4	25	21		
PICAdist								
p2	7 (8.75)	2	5	3	3	3	1	
p3	7 (8.75)	1	6	6	1	2	3	1
p4	8 (10)	3	5	3	2	3	2	1
p5	1 (1.25)		1	1		1		
Total (%)	80 (100)	50 (62.5)	30 (37.5)	19 (23.8)	33 (41.25)	36 (45)	8 (10)	3 (3.75)

Figure 1: Surgical approaches. Linear incision (a) and craniotomy with resection of the posterior arch of the atlas (b) for suboccipital approach. Semioval section (c) and craniotomy (d) for retrosigmoid approach. Hockey stick incision (e) and craniotomy (f) for far-lateral transcondylar approach.

Figure 2: Positions of patients on the operating table. Sitting position (a): can be used for all three approaches; Supine position with contralateral head and operating table rotation (b): is used for retrosigmoid approach; Prone position (c): is used for suboccipital approach; Lateral position (d): is used for far-lateral transcondylar approach.

surface of the medulla oblongata). In several patients, hockey stick incision was used to isolate the occipital artery.

The posterior arch of the cervical vertebrae was also resected through MSC in 40.7% [Table 2].

In 47 patients, the MSC was performed in the sitting position. In 12 cases, where the aneurysm repair with anastomosis creation was considered before the surgery, the MSC was performed in the prone position.

Far-lateral transcondylar approach with resection of the posterior arch of the atlas was performed only in one case with the VAdist aneurysm close to the VA confluence. The approach was made in the lateral position from a hockey stick incision [Figure 2].

Retrosigmoid craniotomy from a linear or arcuate skin incision was performed in 25% of patients [Table 2]. Commonly (n = 16), this approach was performed in the supine position with 90-degree head rotation and a slight additional contralateral rotation of the operating table [Figure 2]. In general, this approach was used for the PICAprox aneurysm surgery [Table 2].

The choice of the aneurysm surgery [Table 2] was based on the aneurysm location, shape, size, and the presence of intra-aneurysmal thrombosis.

In saccular aneurysms, the clipping of the aneurysm neck was performed in the vast majority of patients (49 [98%] of 50) regardless of location. This type of aneurysm surgery was more common in the PICAprox aneurysms [Table 2].

Table 2: Surgical characteristics of the aneurysm surgery by the localization.

Aneurysm localization	Number of patients (%)	Position on the operating table		Incision		Approach			C1 resection	Aneurysm surgery				
		Sitting	Supine/prone	Linear	Hockey stick	MSC	RC	FLT		NC	CALF	Trapping	PC	Deconstruction with anastomosis
VAprox	5 (6.25)	3	2	5		4	1		4		3		1	1
VAdist	6 (7.5)	4	2	5	1	3	2		1	3		1	2	
PICAprox	46 (57.5)	28	18	43	3	29	17	1	18	40	2	1		3
PICAdist														
p2	7 (8.75)	5	2	5	2	7			1	2	3	1		1
p3	7 (8.75)	3	4	7		7			1	1	3	1		2
p4	8 (10)	8		7	1	8				3		3	1	1
p5	1 (1.25)	1		1		1						1		
Total (%)	80 (100)	52 (65)	28 (35)	73 (91.25)	7 (8.75)	59 (73.75)	20 (25)	1 (1.25)	25 (31.3)	49 (61.25)	11 (13.75)	8 (10)	4 (5)	8 (10)

'MSC: Median suboccipital craniotomy, RC: Retrosigmoid craniotomy, FLT: Far-lateral transcondylar approach, NC: Neck clipping, CALF: Clipping with the artery lumen formation, PC: Proximal clipping

In the fusiform aneurysms, complex clipping with the artery lumen formation (CALF) was relatively more common. This operation was aimed at the clipping of the eccentric part of the fusiform aneurysm sparing the blood flow in the parent artery [Table 2]. An example of a CALF is shown in Figure 3.

Only in one of 4 cases with partially thrombosed saccular aneurysms, preoperative thrombectomy from the aneurysm cavity was required for the neck clipping.

In fusiform partially thrombosed aneurysms (n = 15), preliminary thrombectomy before CALF was required in 2 cases with PICAdist aneurysms. In 8 cases of large and giant partially thrombosed PICAdist aneurysms, thrombectomy was performed after aneurysm clipping for decompression of the adjacent brain and nerve structures. In 5 cases with small fusiform aneurysms, thrombectomy was not performed.

Deconstructive surgery (proximal clipping or trapping) was performed in 12 fusiform aneurysms [Table 2]. CALF was unachievable or considered inappropriate due to the significant aneurysm extent or the uniform wall dilation.

The decision about aneurysm occlusion with the PICA segment was made after confirmation of the satisfactory retrograde blood flow through the distal PICA based on the intraoperative video angiography with indocyanine green (ICG) [Figure 4, I]. In the absence of retrograde blood flow, revascularization with the anastomosis creation was performed [Figure 4, II].

Other criteria when PICA deconstruction should be combined with anastomosis may include: large diameter of the involved PICA, hypoplasia of the contralateral PICA or VA, as well as poor enhancement of the ipsilateral PICA and SCA according to angiography.

In most cases (6 of 8), revascularization involved local (*in situ*) anastomoses: "side-to-side" in one patient [Figure 5], "end-to-side" in two patients, and "end-to-end" in three patients. In two patients, PICA revascularization was performed using the occipital artery [Figure 6].

Deconstruction of the artery without anastomosis was possible in the VAdist fusiform aneurysms. The occlusion of this segment through proximal clipping was performed in two patients and trapping in one patient. The requirements for the VAdist occlusion with the aneurysm included PICA sparing (the clip was applied distal to the origin of the artery) and the presence of a second VA with comparable diameter to the main artery. Our attention settled on the fact that in fusiform aneurysms in the VA segment from the PICA origin to the VA confluence there were no large perforating arteries to the medulla oblongata. CALF waiving was due to the close association of this VA segment with the caudal cranial
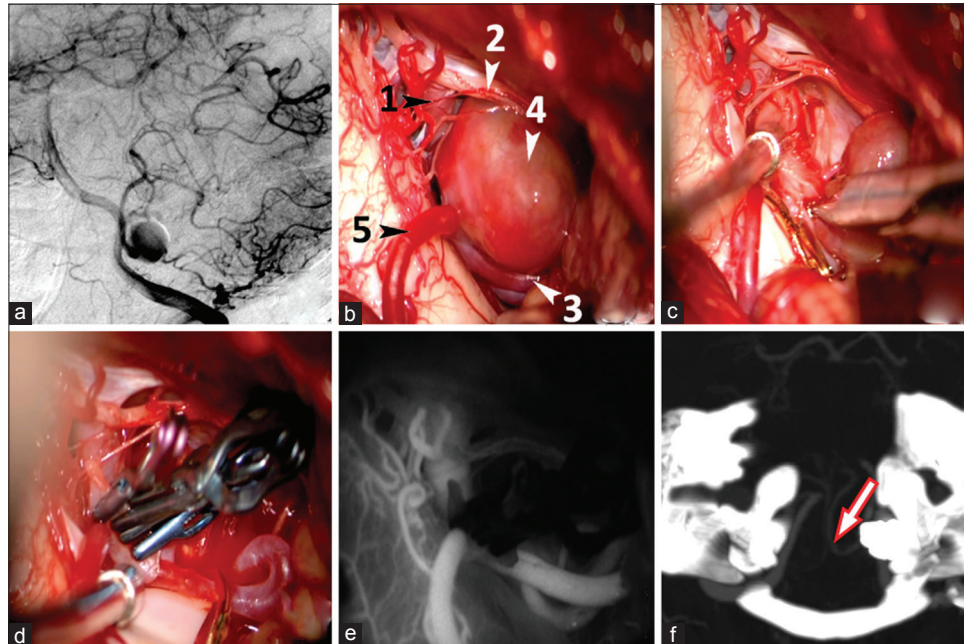
Figure 3: Clipping with artery lumen formation for the eccentric-fusiform partially thrombosed aneurysm of the tonsillomedullary (p3) segment of the left PICA in a 35-year-old female patient. Vertebral angiography, lateral view (a): the functional part of the left PICA aneurysm is enhanced; Surgical view before clipping (b): 1 - proximal intracranial segments of the left VA, 2 - XI cranial nerve, 3 - PICA proximal to the aneurysm, 4 - aneurysm, 5 - PICA distal to the aneurysm; excision of the eccentric thrombosed part of the aneurysm (c); formation of the artery lumen via transverse applying of 4 clips (d); confirmation of PICA patency after clipping via ICG angiography (e); Post-op CT angiography on day 7: the arrow indicates patent left PICA (f).
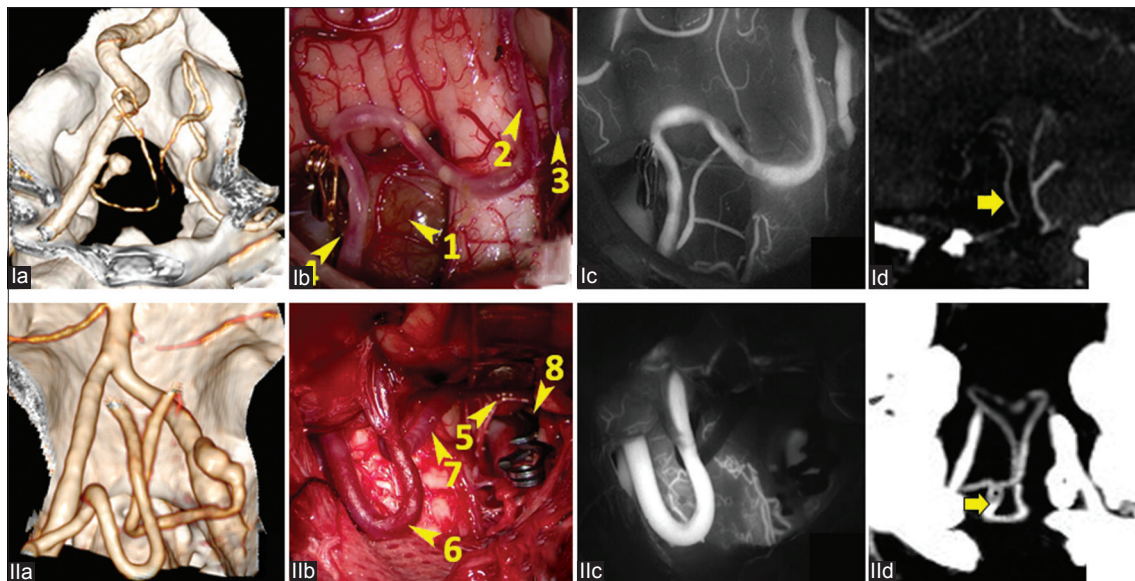

Figure 4: The occlusion test with fluorescein video angiography. I. Patient V., 40 years. Ia. CT-angiography (3D reconstruction): PICAprox fusiform aneurysm on the left; Ib. Surgical view: 1. Aneurysm. 2. Left PICA. 3. Right PICA. 4. Temporary clip on the origin of the left PICA; Ic. ICG video angiography: satisfactory retrograde enhancement of the left PICA indicating good collateral blood flow; Id. CT angiography (MIP) after the aneurysm trapping: retrograde contrast in the left PICA (arrow). II. Patient P., 49 years. IIa. CT-angiography (3D reconstruction): PICAprox fusiform aneurysm on the right; IIb. Surgical view: 5. Aneurysm, 6. Left PICA. 7. Right PICA. 8. Clip on the origin of the right PICA; IIc. ICG video angiography: no retrograde enhancement of the right PICA indicating a lack of collateral blood flow; IId. CT angiography (MIP) after proximal aneurysm clipping followed by the reimplantation of the right PICA into the left PICA: anastomosis is indicated by the arrow.

nerve group, the medulla oblongata, and the narrow surgical corridor [Figure 7].

Intraoperative complications

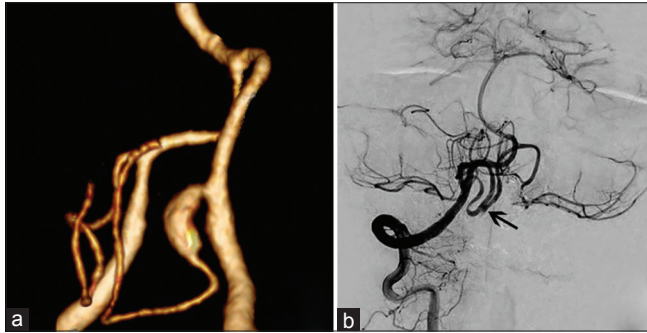Intraoperative aneurysm rupture occurred in 5 (6.3%) cases [Table 3].

Figure 5: "Side-to-side" anastomosis in a 52-year-old patient with PICAprox fusiform aneurysm. a. CT-angiography (3D reconstruction): fusiform aneurysm of the right PICAprox; b. Left vertebral angiography after trapping of the right PICAprox aneurysm and anastomosis creation (arrow) between the right and left PICA.
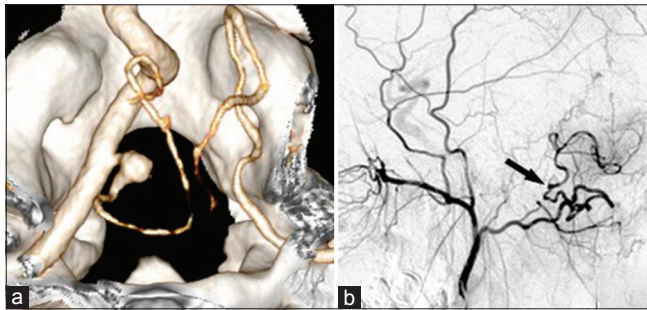

Figure 6: Anastomosis between the occipital artery and the left PICA in a 20-year-old patient with PICAprox fusiform aneurysm. a. CT-angiography (3D reconstruction): fusiform aneurysm of the left PICAprox; b. Angiography of the left external carotid artery after trapping of the left PICAprox aneurysm and anastomosis creation (arrow) between the left occipital artery and PICA.
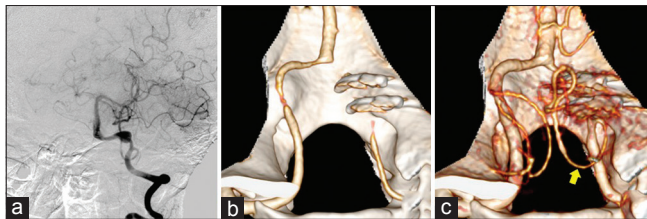

Figure 7: Trapping of the fusiform aneurysm of the right VAdist in female patient M., 43 years old. Vertebral angiography before surgery (a): the fusiform aneurysm of the right VAdist; CT angiography after surgery (b, c): 2 clips in the projection of the cut segment of the right VA and patent right PICA (arrow).

Table 3: Complications and clinical outcomes by the localization of the aneurysm.

Aneurysm localization	Number of patients (%)	Intraoperative complications			Postoperative complications							GOS at discharge		
		Rupture	Artery thrombosis	Air embolism	None	Ischemia Cerebellum	Brainstem	IX, X cranial nerve palsy	XII cranial nerve palsy	Tracheostomy	Hydrocephalus	V	IV	III
VAprox	5 (6.25)				3		1					2	3	
VAdist	6 (7.5)				4			2	1		1	4	1	1
PICAprox	46 (57.5)	4	1	1	31	1	2	11	6	4	8	27	13	6
PICAdist														
p2	7 (8.75)				7						1	4	3	
p3	7 (8.75)		1	1	5	1		1	1	1	1	5	1	1
p4	8 (10)				7	1					2	5	3	
p5	1 (1.25)	1								1	1			1
Total (%)	80 (100)	5 (6.3)	2 (2.5)	2 (2.5)	57 (71.3)	3 (3.8)	3 (3.8)	14 (17.5)	8 (10)	6 (7.5)	14 (17.5)	47 (58.75)	24 (30)	9 (11.25)

Two patients with PICAprox aneurysms and one patient with PICAdist aneurysms had no neurological complications after surgery.

One patient had moderate dysfunction of IX and X cranial nerve after clipping the PICAprox aneurysm.

In one female patient, the surgery was complicated by major intraoperative bleeding requiring clipping of the aneurysm with the right PICA origin that resulted in the postoperative ischemia in this region. Due to severe bulbar impairment, tracheostomy was performed. The patient was discharged from the hospital 90 days after surgery Glasgow outcome scale (GOS 3).

Intraoperative PICA thrombosis was reported in two (2.5%) patients [Table 3].

In one patient with PICAprox aneurysm, a right PICA thrombosis in the area of its origin occurred after repeated clip reposition. An attempt of PICA reimplantation into the proximal VA segments was made; however, this anastomosis did not work. After surgery, the patient had right XII cranial nerve paresis. Postoperative computed tomography (CT) revealed no areas of brain ischemia. The patient was discharged on day 7 after surgery in good condition (GOS 4).

Another patient with a partially thrombosed fusiform aneurysm of the tonsillomedullary (p3) segment of the left PICA developed PICA thrombosis after a CALF attempt. Intraoperative attempts to restore blood flow in the distal PICA were unsuccessful. After surgery, the patient developed massive ischemia in the left hemisphere and the vermis with severe edema in the posterior cranial fossa. Two days after the initial operation, decompressive craniectomy of the posterior cranial fossa was performed. The patient had prolonged sedation with artificial ventilation through a tracheostomy tube. He was discharged on the 47th day after the surgery (GOS 3). At the time of discharge, the patient was conscious, had no movement disorders in the extremities; however, moderate bulbar disorders and severe cerebellar symptoms persisted.

Air embolism during craniotomy was reported in two (3.8%) of 52 patients operated in the sitting position. After hemostasis with occlusion of large veins in both cases, the operation was continued. In the postoperative period, one patient developed bilateral pneumonia in combination with moderate dysfunction of IX and X cranial nerves that required the placement of a tracheostomy tube.

Postoperative complications

Fifty-seven (71.3%) patients were discharged without worsening of the clinical signs after surgery [Table 3]. The mean duration of in-hospital stay in patients without neurological complications was 9.4 days.

Among patients with postoperative neurological disorders, the most common sign was palsy of IX and X cranial nerve (dysphonia, dysphagia, etc.) identified in 14 (17.5%) patients. In 3 cases, these were severe and required the placement of a tracheostomy tube during the recovery period.

In 11 patients, dysfunction of IX and X cranial nerves was observed with PICAprox aneurysms [Table 3]. Thus, among 46 patients with PICAprox aneurysms, the incidence of bulbar disorders due to the caudal cranial nerves palsy was 23.9%.

In three patients with signs of IX and X cranial nerve palsy, XII cranial nerve was also dysfunctional with tongue deviation and dysarthria.

In 3 cases of PICAprox aneurysms, an isolated palsy of the ipsilateral XII cranial nerve was reported.

Postoperative ischemic complications were observed in six patients. In three patients, aneurysm clipping was complicated by the PICA thrombosis and ischemic lesions in the cerebellar hemisphere.

In three patients, MRI showed small ischemic lesions in the medulla oblongata manifested with moderate hemiparesis in one patient and with hemihypesthesia in two others [Table 3].

No postoperative hematomas and other hemorrhagic postoperative complications were reported.

Complicated postoperative wound healing occurred in three patients. In one case, external lumbar drainage was placed for 5 days due to the subcutaneous accumulation of cerebrospinal fluid in the postoperative wound area with subsequent recovery of this complication. Two patients had wound liquorrhea after surgery; revision surgery with the closure of the dura mater defects was performed. Subsequently, meningitis was diagnosed in one of these patients and etiotropic antibiotic therapy was administered with a good outcome.

Postoperative complications associated with SAH were uncommon due to the relatively small number of patients in the acute period (12 patients). In one patient, operated 4 days after SAH, the focal hemispheric neurological signs developed 3 days after the surgery. Angiography revealed severe vasospasm in both MCA vascular regions that caused ischemic lesions in the cerebral hemispheres [Figure 8].

Posthemorrhagic hydrocephalus was reported in 14 (18.7%) of 75 patients with SAH. In six patients, a ventriculoperitoneal shunt was implanted during the hospitalization.

Completeness of aneurysm occlusion

In the postoperative period, follow-up angiography was performed in 46 (57.5%) patients (digital subtraction angiography — 19, and CT-angiography — 27 patients).
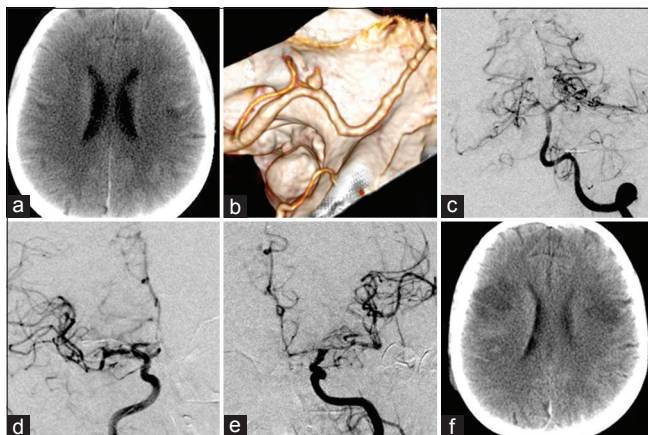
Figure 8: Ischemic lesions in the cerebral hemispheres due to vasospasm after SAH from the PICAprox aneurysm in the female patient P, 60 years old. Brain CT on the day of surgery, 4 days after SAH (a); CT angiography before surgery (b): a small PICAprox aneurysm on the left; Cerebral angiography on day 3 after aneurysm clipping (c, d, e): the aneurysm is occluded, severe vasospasm in both carotid vascular regions; Brain CT on day 5 after surgery (f): ischemic lesions in both cerebral hemispheres.

Complete aneurysm occlusion was confirmed in 43 (93.5%) cases, neck enhancement was revealed in 2 cases (4.3%), and enhancement of the neck and fundus – in one (2.2%) patient.

Patients with a partial enhancement of the aneurysm neck were closely monitored. Endovascular aneurysm coiling was performed in one patient with an enhancement of the aneurysm fundus.

In the other 34 patients without angiography, the complete aneurysm repair was verified by the ICG video angiography followed by opening the aneurysm sac.

Thus, the complete occlusion of PICA and VA aneurysms during microsurgery was achieved in 77 (96.3%) cases.

DISCUSSION

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

Some authors claim that large basal approaches with partial resection of the occipital condyles provide better aneurysm exposure and reduced risk of postoperative dysfunction of the caudal cranial nerves (DCCN).[2,4,8]

In contrast, transcondylar approaches increase the total duration of the operation and increase the risk of poor wound healing, as well as craniocervical instability and neck pain.[8,28]

We agree with those authors who believe that the resection of condyles is unnecessary in the vast majority of cases.[24,28] In some cases, the optimal surgical view may be achieved through intradural jugular tuberclectomy.[2,17,27]

Indeed, the major challenge in the surgery of PICA and VA aneurysms involve neurovascular structures that obscure the neck of the aneurysm rather than bony prominences.[27]

We believe that the need for routine resection of the posterior arch of the atlas to approach the aneurysms of VA and PICA proposed by several authors[4,8,23,24] is somewhat dramatized. In fact, it necessary for the microsurgical approach to VAprox aneurysms and low PICAprox aneurysms. For VAdist and PICAdist aneurysms, resection of the posterior arch of the atlas, in general, is not warranted.

Our recent experience has shown that retrosigmoid craniotomy is an adequate approach to the small PICAprox and VAdist aneurysms that are consistent with other authors.[22,27,28] The benefits of the supine retrosigmoid craniotomy with contralateral head rotation include is the medial and upward gravity-facilitated traction of the cerebellum and brain stem from the base and VA elevation above the skull base. Due to the narrow surgery corridor, we do not use this approach in the large and fusiform aneurysms, especially when anastomosis may be required. Tjahjadi *et al.*[27] recommend a standard retrosigmoid craniotomy (simple lateral suboccipital approach) for PICAprox aneurysms when the PICA-VA complex is 10 mm or more above the great occipital foramen. Otherwise, they recommend to make the craniotomy medial and down to the lateral part of the great occipital foramen.

Actually, even significant bleeding from the VA or PICA aneurysms rare causes microsurgical difficulties. Al-khayat *et al.*[2] noted that this approach results in the relatively small traction of brain structures, and after SAH the involved structures (brain stem and cranial nerves) become swollen less than the cerebral hemispheres.

One of six patients who underwent surgery within 14 days from the SAH event developed ischemic lesions in the cerebral hemispheres due to vasospasm. Estimated risk of angiospastic supratentorial cerebral ischemia in subtentorial SAH originating from the VA or PICA is 1.9–7%.[2,7,15] Intraoperative removal of blood clots from the basal cisterns of the anterior and middle cranial fossa during microsurgery for VA and PICA aneurysms is not possible. Therefore, a number of patients with high linear blood flow velocity in the middle cerebral arteries and progressive clinical deterioration may require cerebral angiography and intra-arterial treatment of vasoconstriction with vasodilators.[17]

Postoperative mortality in the surgical series of patients with VA and PICA aneurysms is 1.8–3.7%.[2,24,28] Poor outcomes were reported to be directly associated with the severity of the patient's condition at admission.[5,23] In our study, the majority of patients were stable at surgery, and no fatal outcomes or vegetative state events were reported.

Ischemic lesions in the cerebellum and brainstem in patients with PICA and VA aneurysms are primarily associated with surgical issues. In one study, postoperative ischemic cerebellar complications were diagnosed in 19% of patients.[27] In general, these were associated with occlusion of the PICA trunk, and the choice of a PICA segment where relatively safe occlusion may be performed is unclear. Many investigators state that ischemia rarely occurs when PICA is occluded distal to the lateral medullary (p2) segment because the stem perforating arteries are more proximal, and the distal blood supply is provided by the collateral branches from the anterior inferior cerebellar artery, the superior cerebellar artery, and contralateral PICA.[6,11,14,19] Our experience has shown that severe ischemic abnormalities in the cerebellum may develop with PICA occlusion at the tonsillomedullary (p3) segment. However, ischemia may not develop even when the PICA origin is cut. Chalouhi *et al.*[7] reported postoperative cerebellar infarction only in 4 (36.4%) of 11 patients with complete PICA clipping.

Unfortunately, there are no accurate predictive criteria of the risk for PICA occlusion yet.

We take guidance from the test with temporary PICA clipping and its retrograde enhancement in the ICG video angiography. However, its evaluation is simple only in extreme cases: the rapid intensive retrograde PICA enhancement along with other intact arteries or the complete absence of the enhancement. Currently, prolonged, mild, or moderate retrograde PICA enhancement may not predict the risk of ischemia. Therefore, we believe that in undetermined cases, revascularization of the target artery may be useful.

Seoane *et al.*[24] have shown that anastomosis in VA and PICA aneurysms should be created in 5.4% of cases. We performed such operations at 10%. In most patients, we preferred to bypass the VA or PICA aneurysm through anastomosis *in situ*. Other clinicians share a similar strategy.[1,12,16] When local anastomosis creation is impossible, an alternative includes revascularization using the occipital artery as a donor.[13,18,24] The main disadvantages of the occipital artery as a "donor" include multiple branches and a significantly smaller diameter in the distal segments. Due to the significant tortuosity, isolating the occipital artery from soft tissues is quite challenging and may result in its damage.

Ipsilateral postoperative DCCN remains the main concern of microsurgery for VA and PICA aneurysms. According to the published data, the frequency of these complications after clipping of the aneurysm of VA and PICA varies from 7.4% to 29%.[5,27,28] According to our data, the incidence of DCCN in the general group of patients with VA and PICA aneurysms was 17.5%, and with PICAprox aneurysms – 23.9%.

There are encouraging data that the rate of DCCN recovery within 6 months is over 76%.[2]

To reduce the risk of DCCN, sharp vasoneural dissection is recommended to prevent the tension of the IX, X, and XII cranial nerve, shorten the time for preventive clipping (up to 6 min) and avoid temporary VA trapping, if possible.[2,27,28]

The risk of DCCN increases with intraoperative ruptures.

The control of intraoperative bleeding in VA aneurysms includes the approachability of the proximal, and, in some cases, distal VA. The distal temporary clipping, especially in the segment between PICA and VA confluence, often requires medial traction of the medulla oblongata and carries the risk of damage to the caudal cranial nerve group.

Our study has shown that microsurgery provides an opportunity to achieve a high rate (95.5%) of the complete occlusion of VA and PICA aneurysms. According to the published data, the microsurgical technique has a high rate of complete aneurysm repair: 90–97.1%,[8,21,27] and in some publications, it reaches 100%.[24,25]

In clinical series, including both microsurgical and endovascular methods, comparable clinical outcomes for aneurysms of VA and PICA were observed.[5,21,23,25]

However, comparison of our data with clinical and angiographic outcomes of endovascular treatment in the VA and PICA aneurysms is inappropriate as we initially included in the study patients selected for microsurgical treatment according to the above criteria rather than consecutive patients. Therefore, it seems promising to use a combined technique in multiple aneurysms, as well as in giant VA aneurysms where the endovascular deconstruction of the parent artery is possible in combination with microsurgical revascularization and elimination of the mass effect.

The limitations of our study included: a retrospective design, the fact that in most patients, SAH was treated on a delayed basis, and the lack of follow-up data beyond discharge.

CONCLUSION

Microsurgical treatment is an effective method for VA and PICA aneurysms.

The majority of VA and PICA aneurysms do not require complex basal approach with resection of the condyles and cervical vertebrae.

A thorough preoperative planning using advanced neuroimaging methods, reconstructive clipping techniques, and anastomoses creation, as well as patient selection based on the established algorithms and consultations with endovascular surgeons, may reduce the number of complications and increase the rate of complete microsurgical repair in VA and PICA aneurysms.

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Conflicts of interest

There are no conflicts of interest.

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