Microneurosurgery for Paraclinoid Aneurysms in the Context of Flow Diverters

Sabino Luzzi, Mattia Del Maestro, and Renato Galzio

Introduction

Paraclinoid internal carotid artery (ICA) lies between the distal dural ring and the origin of the posterior communicating artery. Aneurysms involving this segment pose extraordinary challenges regarding the achievement of proximal hemodynamic control and safe intracranial exposure. The advent of the endovascular era, but especially the implementation of flow diverter (FD) stents in the last few years, have apparently shifted the treatment of paraclinoid aneurysms away from microneurosurgery. However, the not negligible number of reported complications related to endovascular techniques, the lack of randomized clinical trials, the relative brevity of experience with FD stents, their questionable use in hemorrhagic cases, and their yet undefined risk of ophthalmic artery occlusion, cause one to continue to consider microneurosurgery as a valuable option especially in young, visually symptomatic patients harboring large or giant aneurysms.

While admitting the actual achievements of FDs, the present study is aimed to critically review the results of microneurosurgery in a retrospective surgical series of paraclinoid aneurysms to differentiate those more indicated for surgery from those instead of more suitable for endovascular therapy.

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Materials and Methods

The present series employed Barami's classification of paraclinoid aneurysms (Table 1) [1]. Data about demographics, clinical onset, Barami's type site and size, approaches, as well the neurological and visual outcome of 53 patients consecutively operated for one or more paraclinoid aneurysms have been retrospectively reviewed. All the aneurysms were operated by the senior author (RG) in three different hospitals between January 1993 and December 2018. Because of their different natural history and particular characteristics, blister aneurysms were excluded from this study. Type IIIb and IV were also ruled out since nowadays these are certainly best managed by endovascular treatment. Neurological outcome was evaluated with the modified Rankin Scale [3], whereas angiographic outcome was evaluated upon the complete exclusion of the aneurysm at six-month follow-up. Visual outcome was measured based on the perimetry assessment at six-month follow-up.

Results

Demographics and Clinical Data

The Average patient age was 47.2 ± 12.6 years. Admission contrast-enhanced computed tomography (CT) angiography and digital subtraction angiography (DSA) were performed in all aneurysms, the former also providing details of the relationship between the aneurysm and anterior clinoid process. In non-hemorrhagic cases, the need for a DSA balloon test occlusion (BTO) was assessed on a case-by-case basis. A contrast-enhanced MRI was performed in

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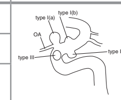
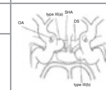
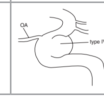
Table 1 Barami classification of paraclinoid aneurysms [1]

Type	Carotid segment (according to Bouthillier Classification) [2]	Surface	Relation	Comments	Scheme
Ia	C6	Superior	Ophthalmic	Medial or lateral to ON	
Ib	C6	Superior	None	Lateral to ON	
II	C6	Ventral	None	Dome projects into CS roof	
IIIa	C6	Medial	SHA	Carotid cave aneurysms Project over DS	
IIIb	C5	Medial	SHA	Transitional aneurysms. Infradiaphragmatic	
IV	C5, C6	Ventral	None	Giant aneurysms extending between C5 and C6 segments. Widen distal dural ring	

CS cavernous sinus, *DS* diaphragma sella, *ON* optic nerve, *SHA* superior hypophyseal artery

all giant aneurysms to reveal eventual intraluminal thromboses. In 21 patients, subarachnoid hemorrhage was the clinical onset, the average admission Hunt-Hess score being 2.1 ± 1 and mean Fisher grade 1.8 ± 0.9 in these patients. Most of the aneurysms (47.4%) ranged between 7 and 12 mm in size, and Barami's type I was predominant. Table 2 reports the prevalence of Barami's types according to size (Table 2). In hemorrhagic cases, patients having an admission Hunt-Hess score ranging between 1 and 3 mainly underwent surgery. Exceptions regarded rare cases of young patients having an impending life hematoma. In these rare instances, the indication for surgery was based mainly upon an evidence-based management algorithm about intracerebral hemorrhages reported by our group [4]. In 94% of cases, an early surgery (within 24 h) was performed, the remaining cases being been deferred because of evidence of vasospasm or poor neurological status. A total of 57 aneurysms were consecutively operated on; six patients had two aneurysms and one patient harbored three different aneurysms. In three patients, surgery was performed after initial endovascular coiling was ultimately incomplete or unsuccessful. Conversely, four previously operated patients underwent an endovascular treatment because of the need for retreatment of the same aneurysm or for a different aneurysm.

Table 2 Prevalence of Barami types according to size

Barami type [1]	*N* (%)	Size			
		Small (7 mm) *N* (%)	Regular (7–12 mm) *N* (%)	Large and very large (13–24 mm) *N* (%)	Giant (25 mm) *N* (%)
Type Ia	35 (61.4%)	7 (20%)	16 (45.7%)	5 (14.3%)	7 (20%)
Type Ib	3 (5.3%)	–	2 (66.7%)	–	1 (33.3%)
Type II	6 (10.5%)	1 (16.7%)	2 (33.3%)	2 (33.3%)	1 (16.7%)
Type IIIa	13 (22.8%)	1 (7.7%)	7 (53.8%)	3 (23.1%)	2 (15.4%)
Type IIIb	–	–	–	–	–
Type IV	–	–	–	–	–
Tot.	57	9 (15.8%)	27 (47.4%)	10 (7.5%)	11 (19.3%)

Surgery

Approach Selection and Proximal Hemodynamic Control

Pterional approach was used as a rule, although in selected cases of complex or giant aneurysms involving the back wall of the ICA, cranio-orbitary approaches were useful to maximize the handling.

Exposure of the cervical ICA was reserved to complex or giant aneurysms, especially if a hemorrhagic onset occurred. It also allowed for both for an eventual temporary occlusion and for the retrograde suction decompression, Dallas technique [5], used in some giant aneurysms. Intradural anterior clinoidectomy was always preferred to that extradural to decrease the risk of aneurysm rupture.

Direct vs. Indirect Treatment

A direct treatment was possible in 52 aneurysms (91.2%) and, in all these cases, it consisted of a clip ligation. In five aneurysms, an extracranial to intracranial high-flow bypass was performed before the trapping. The saphenous vein and the radial artery were the conduits in two and three cases, respectively. During direct treatment, temporary clipping of the parent vessel and bipolar aneurysm shrinking were the most frequently used techniques. Furthermore, stacking-seating clipping technique, retrograde suction-decompression, aneurysmorrhaphy, and aneurysmectomy were commonly employed, particularly for giant aneurysms. A total of 57 aneurysms were successfully treated.

Temporary Clipping and Neurophysiological Monitoring

In all cases of temporary clipping carried out in elective conditions, anesthesia protocol used for burst suppression and intraoperative neurophysiological monitoring was the same already reported by our group for most of the neurovascular pathologies [6–14]. A combined somatosensory-motor evoked potentials and EEG-based monitoring was introduced in 2012 and, since that time, routinely employed for all complex ICA aneurysms electively treated.

Technological Adjuvants and Flow Assessment Techniques

The Endoscope-assisted technique was utilized by default in all the aneurysms involving the back wall of the ICA. A rigid 0° or 30°, 4-mm endoscope was employed in all cases. The details of the endoscope-assisted technique for ICA aneurysms have been described elsewhere by our group [15, 16]. Flow assessment techniques were essential in all cases. They involved micro-Doppler ultrasound (MDU) (20 MHz System, Mizuho Medical Co., Ltd., Tokyo, Japan) since 2007, indocyanine green (ICG) video angiography (Flow 800 Infrared Module, OPMI Pentero 800, Zeiss, Oberkochen, Germany) since 2009, and fluorescein angiography (Yellow 560 Fluorescence Module, Kinevo 900, Zeiss, Oberkochen, Germany) since 2018. Charbel microflow probe (Intracranial Charbel Micro-Flow Probe, Transonic Systems Inc., New York, USA) was also used in some cases.

Neurological Outcome

An overall mRS of 0–2 was achieved in 77.3% of patients, 87.5% of which were elective. The best outcome was achieved in non-hemorrhagic cases and in patients <50 years old. Table 3 reports the overall outcome according to clinical onset (Table 3).

Visual Outcome

In patients suffering a preoperative visual impairment concern, visual field test appeared improved or unchanged in 36.3% and 63.6% of cases, respectively. Campimetry was unchanged also in 76.1% of patients who had a preoperative normal visual field. Table 4 reports the visual overall outcome in unruptured aneurysms according to preoperative visual impairment (Table 4).

Angiographic Outcome

All but four patients underwent postoperative angiography at six-month follow-up. Apart from cases of remnants, all the patients underwent a CT angiography for further follow-ups. The total exclusion of the aneurysms with a single procedure was achieved in 93% of the patients. In four cases, two elective and two hemorrhagic, a remnant of a single aneurysm was revealed, and the patient underwent endovascular treatment. No recurrences were documented during an average follow-up of 54.1 ± 34 months.

Illustrative Cases

Case #1 Unruptured Giant Barami Type II Aneurysm in a Visually Symptomatic Patient. A 34-year-old female suffered a right eye progressive visual impairment (Fig. 1). CT angiography and DSA revealed a right giant Barami type II paraclinoid aneurysm (Fig. 1a–c). She also had a small basilar tip aneurysm (Fig. 1d). The patient passed the BTO of the right ICA and underwent surgery. A right pterional approach, comprehending an intradural anterior clinoidectomy, was performed, and the aneurysm was successfully clipped with three Yasargil standard clips (Fig. 1g). Basilar tip aneurysm was clipped also. The patient was discharged on the fifth postoperative day. At six-month DSA, a very small remnant was revealed, and the patient underwent radiological follow-up (Fig. 1i). Three months after surgery, the patient had completely recovered the preoperative visual field deficit (Fig. 1m, n).

Case #2 Ruptured Very Large Barami Type II Aneurysm. A 37-year-old female was diagnosed with a subarachnoid hemorrhage (Fig. 2). CT angiography and

Table 3 Neurological outcome according to the clinical onset

Clinical onset (*N*/%)		mRS 0–2 (*N*/%)	mRS 3–4 (*N*/%)	mRS 5 (*N*/%)	mRS 6 (*N*/%)
Non-hemorrhagic	32 (60.3%)	28 (87.5%)	3 (9.3%)	–	1 (3.1%)
Hemorrhagic	21 (39.6%)	13 (61.9%)	5 (23.8%)	1 (4.7%)	2 (9.5%)
Tot.	53	41 (77.3%)	8 (15%)	1 (1.8%)	3 (5.6%)

mRS modified Rankin Score

Table 4 Visual outcome in elective aneurysms

Preoperative visual impairment (*N*/%)		Improved (*N*/%)	Unchanged (*N*/%)	Worsened (*N*/%)	De Novo (*N*/%)
Absent	21 (65.6%)	–	16 (76.1%)	–	3 (14.2%)
Present	11 (34.3%)	4 (36.3%)	7 (63.6%)	2 (18.1%)	–
Tot.	32	4 (12.5%)	23 (71.8%)	2 (6.2%)	3 (9.3%)

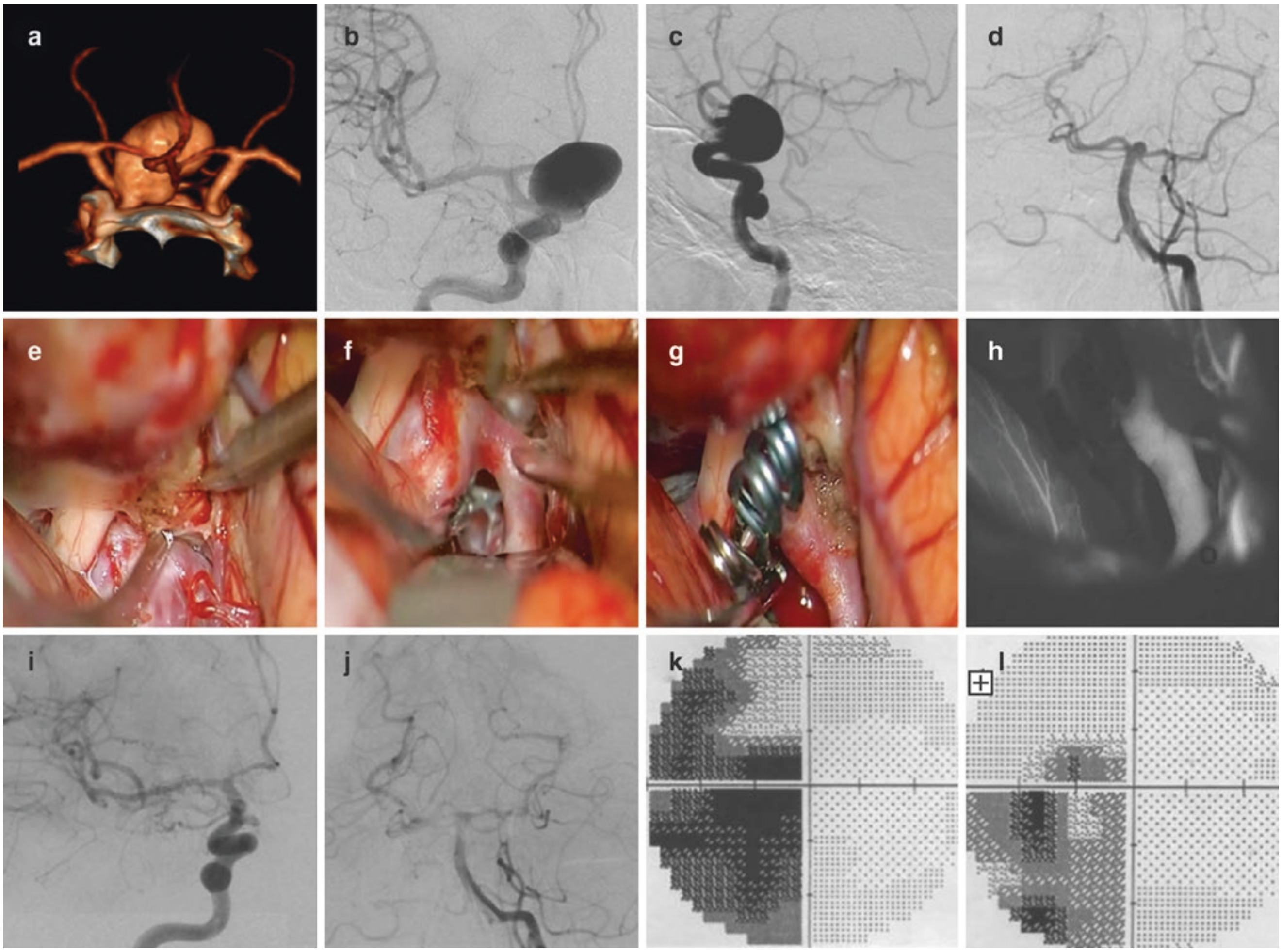


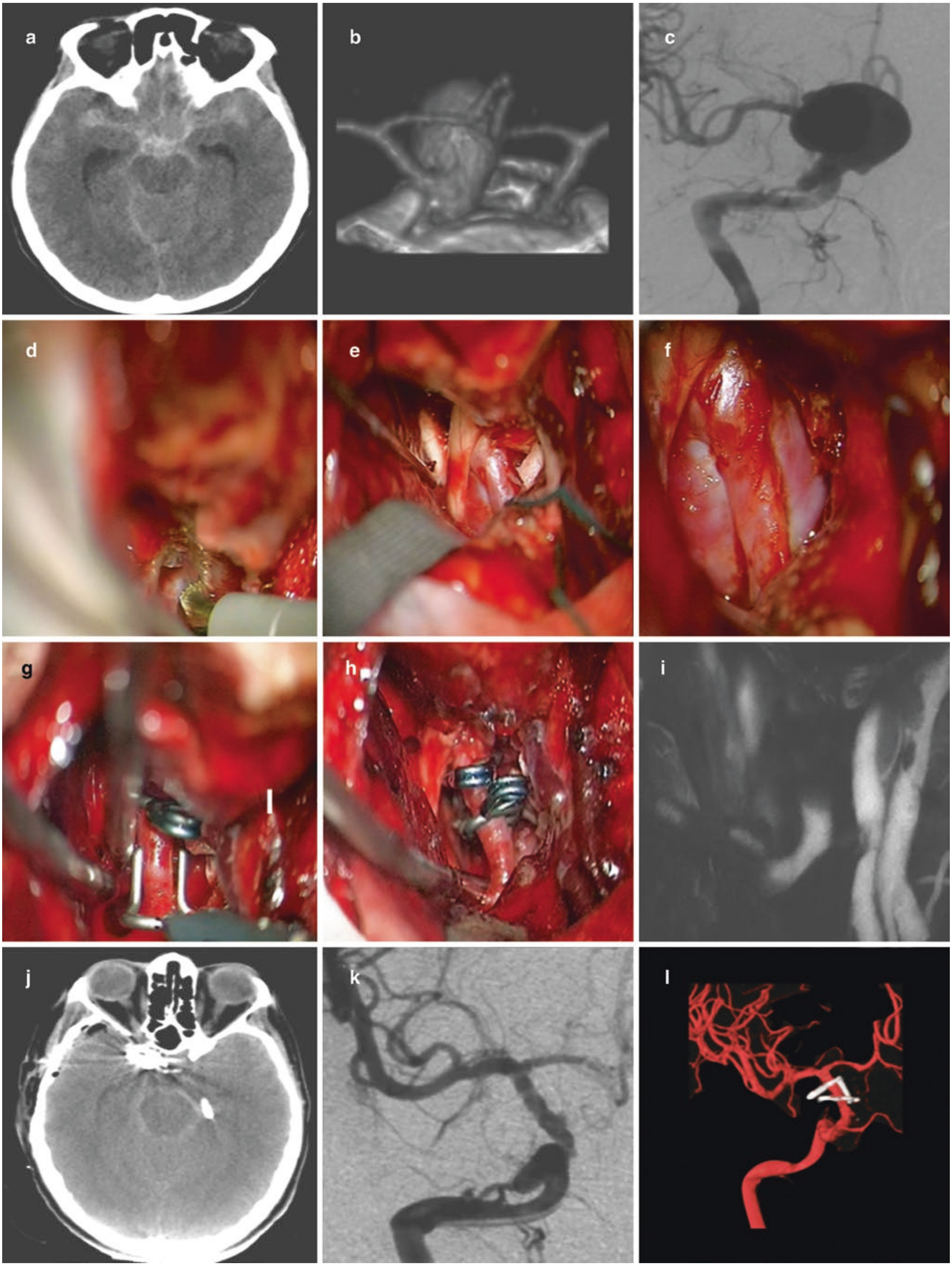
Fig. 1 Illustrative Case #1, regarding a 34-year-old female with a right eye progressive visual impairment. (**a**) CT angiography and DSA (**b**) of the right ICA in anterior-posterior and lateral (**c**) projection showing a right giant Barami type II paraclinoid ICA aneurysm. (**d**) DSA of the left VA showing a basilar tip aneurysm. (**e**) Intradural clinoidectomy during a right pterional approach. (**f**, **g**) Clipping of the aneurysms with the stacking-seating technique. (**h**) Intraoperative ICG videoangiography showing the complete exclusion of the aneurysm. (**i**) Postoperative DSA of the right ICA in anterior-posterior projection showing a very small remnant of the aneurysm. (**j**) DSA of the vertebrobasilar system revealing a complete exclusion of the basilar tip aneurysm. Preoperative (**k**) and postoperative (**l**) visual field test of the right eye, confirming a dramatic improvement

DSA revealed a right very large Barami type II paraclinoid ICA aneurysm (Fig. 2a–c). Early surgery was performed, and the patient underwent a right fronto-temporo-orbitary approach with an intradural anterior clinoidectomy after having exposed the ICA at the neck. The aneurysm was easily clipped with two tandem angled fenestrated clips (Fig. 2d–i). The Postoperative CT scan did not show ischemic complication (Fig. 2l) and the patient was discharged 10 days later without deficits. The six-month DSA confirmed the complete exclusion of the aneurysm (Fig. 2m, n).

Discussion

The natural history of paraclinoid aneurysms is characterized by progressive and slow-growing until it reaches large or giant size without rupture. Hunterian ligation, with or

Fig. 2 Illustrative Case #2, regarding a 37-year-old female who was diagnosed with a subarachnoid hemorrhage (**a**). CT angiography (**b**) and DSA (**c**) of the right ICA showing a right large Barami type II paraclinoid aneurysm. An intradural clinoidectomy with a piezoelectric bone scalpel (**d**) during a fronto-temporo-pterional-orbitary approach allowed to fully expose the aneurysm (**e**, **f**). (**g**, **h**) Clipping of the aneurysm with the tandem angled fenestrated clipping technique. (**i**) Intraoperative ICG videoangiography confirming the complete exclusion of the aneurysm. (**j**) Late postoperative CT scan showing no ischemic complication. (**k**, **l**) DSA of the right ICA in anterior-posterior projection showing the optimal visualization of the paraclinoid ICA and ophthalmic artery and the exclusion of the aneurysm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without revascularization, has in the past been the treatment of choice for most of these lesions. However, as opposed to distal aneurysms, for which it has been reported to be usually decisive [17, 18], the straightforward proximal occlusion of the ICA is associated with an early recanalization of the aneurysm throughout the backflow. Accordingly, surgery shifted toward a direct treatment of this type of the aneurysms. The advent of the endovascular era has dramatically increased the spectrum of possible treatments for intracranial aneurysms, paraclinoid ones included. Moreover, with the introduction of FD stents, which find their main application right in ICA aneurysms, a quiet revolution within the endovascular techniques happened. A wide volume of literature confirms today the effectiveness and safety of FDs, especially for ICA aneurysms, therefore supporting them as the first-line treatment for most paraclinoid aneurysms [19–22]. Recently, FDs have also been associated with a high rate of visual improvement in symptomatic patients, without differences in terms of worsened vision or iatrogenic visual impairment as compared with clipping and coiling techniques [23]. While admitting the practical role of FDs in the treatment of a large part of ICA aneurysms as those wide-necked, fusiform, dissecting, blister-like, or ventral giant, the enthusiastic attitude toward the flow diversion ought to be counterbalanced by a series of drawbacks to be taken into account. First, FDs have been reported to be associated with a not negligible number of serious complications [24]; second, their use in hemorrhagic cases is still pioneering; third, the associated risk of ophthalmic artery occlusion in paraclinoid aneurysms is yet undefined; fourth, their actual effectiveness is not supported by high-quality evidence [25]. Last but far from least, FDs require long-term or chronic anticoagulation, which is extremely inconvenient for patients with a long life expectancy.

All these aspects compel one to consider microneurosurgery as a still valuable option, especially in young and visually symptomatic patients harboring large or giant aneurysms. In addition to the undoubtedly proven durability of the microneurosurgical treatment, the results of the present series documented a very good neurological and visual outcome in patients <50 years old harboring dorsal paraclinoid ICA aneurysms but also type II ventral ones. These cases are essentially those for which microneurosurgery is primarily indicated because it offers some unquestionable advantages compared with flow diversion. Conversely, FDs should be considered as the first option in the superior hypophyseal artery and carotid cave aneurysms, especially if these are small, unruptured, or occur in older and asymptomatic patients. Although not reported in the present series, blister aneurysms also seem to have a clear indication to flow diversions even in hemorrhagic cases [26]. From a technical standpoint, the key aspect in the management of these aneurysms is the anterior clinoidectomy. Regardless of the surgeon's preference for an extradural rather than an intradural approach, it should be stressed that anterior clinoidectomy plays the same role for paraclinoid aneurysms that condylectomy of jugular tuberculectomy play in the vertebro-basilar junction or vertebral artery-posterior inferior cerebellar artery aneurysms: both have been reported as an essential step to achieve the widest and most unobstructed view possible of the target [27, 28]. Indeed, the paramount concept of maximizing the bony removal to avoid mechanical retraction of the neurovascular structures is common to both skull base and neurovascular surgery. Paraclinoid aneurysms constitute a formidable challenging for which the mastery of neurovascular and skull base surgery techniques are mandatory, they being both achievable uniquely by means of a constant microneurosurgical training, as stressed by our group [29].

In conclusion, elective patients <50 years old, visually symptomatic, and harboring a Barami's type Ia, Ib or II paraclinoid aneurysm, especially if large or giant, are the best candidates for microneurosurgery. Conversely, older patients having a superior hypophysial, carotid cave, or blister aneurysm seem to be more likely for endovascular therapy, FDs first. Hemorrhagic cases are still a subject of discussion, however, and worthy of a multidisciplinary evaluation on a case-by-case basis.

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Ethical Approval This study was approved by the Internal Advisory Board.

Conflict of Interest Statement The authors declare that they have no conflict of interest.

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