Optic Foraminotomy versus Anterior Clinoidectomy for Small Superior-Projecting Paraclinoid Aneurysms: Visual and Angiographic Outcome Evaluation

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■ INTRODUCTION: **Optic foraminotomy (OF) has been recently proposed as an alternative to anterior clinoidectomy (AC) for selected types of paraclinoid aneurysms. In this study, OF and AC were compared for small superior-projecting paraclinoid aneurysms assuming visual and angiographic results as outcome measures. Indications for OF are also discussed.**

■ METHODS: **Data of patients who underwent surgery for a paraclinoid aneurysm in the last 10 years were collected across 3 tertiary hospitals. Small to regular-size and superior projecting aneurysms were sorted. Multiple and complex aneurysms were excluded. Records of patients who went through OF were compared with those of patients who underwent AC. Neurologic outcome was reported as a modified Rankin Scale. Aneurysm complete occlusion rate and rate of approach-related worsened vision were selected as outcome measures of efficacy and safety, respectively, of the OF versus AC. Unpaired *t* test and χ^2 test were used for numerical and categorical variables, respectively. A *P* value less than 0.05 was considered statistically significant.**

■ RESULTS: **OF and AC groups involved 18 and 25 patients, respectively. Complication rate, overall neurologic outcome, rate of approach-related worsened vision, and complete occlusion rate did not differ between the groups. The average follow-up was 51 $\pm$ 34 and 60 $\pm$ 41 months in the OF and AC groups, respectively.**

■ CONCLUSIONS: **Compared to AC, OF did not show either a higher rate of approach-related worsened vision or a lower aneurysm complete occlusion rate. OF can be considered a valid alternative to the AC for small superior-projecting dorsal ICA wall paraclinoid aneurysms.**

INTRODUCTION

Carotid-ophthalmic aneurysms, also simply referred to as ophthalmic aneurysms, involve the ophthalmic segment, C6,[1] of the internal carotid artery (ICA) and constitute a specific subtype of superior-projecting paraclinoid aneurysms[2-5] (Figure 1). Ophthalmic aneurysms arise between the distal dural ring and the origin of the posterior communicating artery, pointing superiorly in the direction of the hemodynamic flow.[6] Ophthalmic aneurysms are frequently large to giant, and multiple.[7-9] Their progressive enlargement produces a superomedial compression of the optic nerve against the falciform ligament, thus justifying the inherent visual morbidity characterizing them.[10] These aneurysms are relatively rare, the incidence ranging between 0.5% to 11%, with a higher frequency in female individuals and the left side.[7-16]

Direct repair of ophthalmic aneurysms is classically considered challenging mainly because of the limited proximal control of the ICA, complex anatomy of the anterior clinoid process, difficult aneurysm exposure, anatomical variations of the ophthalmic artery, and superior hypophyseal arteries, as well as risk of

Key words
- Anterior clinoidectomy
- Carotid-ophthalmic aneurysms
- Microsurgical clipping
- Optic foraminotomy
- Optic nerve decompression
- Skull base anatomy

Abbreviations and Acronyms
AC: Anterior Clinoidectomy
CT: Computed Tomography
ICA: Internal Carotid Artery
OF: Optic Foraminotomy
STROBE: Strengthening the Reporting of Observational Studies in Epidemiology

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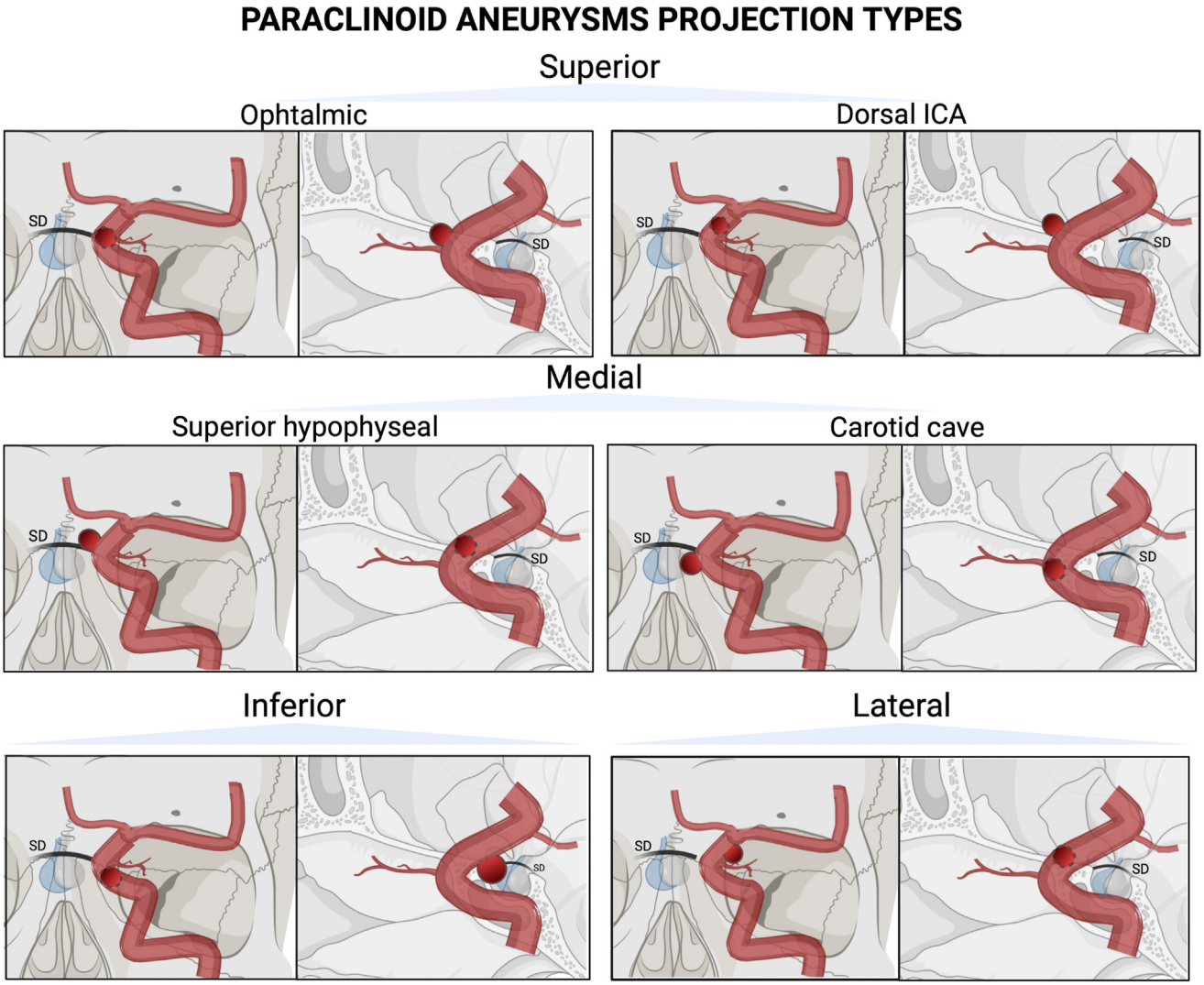

Figure 1. Classification of paraclinoid aneurysms based on the projection. ICA, internal carotid artery.

further worsening or de novo occurrence of visual morbidity. The need for anterior clinoidectomy (AC), requiring a certain dexterity and a detailed knowledge of the anatomy of the paraclinoid region, and the adjunctive risks to the optic nerve deriving from this maneuver explain why visual function remains a significant problem of ophthalmic aneurysms.[12,17-37] Although optic foraminotomy (OF) has been suggested to be advantageous for selected types of ophthalmic aneurysms,[14,38] evidence of its efficacy and safety compared with AC are lacking in the literature.

The present study strives to evaluate the visual and angiographic outcome of OF as an alternative to AC in the surgical management of small superior-projecting paraclinoid aneurysms. A step-by-step description of the OF and its indications are reported.

METHODS

Data of the present study were collected in 3 tertiary hospitals endowed with a neurovascular surgical team and the results were stated according to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement.[39]

Records of patients who underwent surgery for a paraclinoid aneurysm during a reference period ranging from January 2012 to March 2022 were retrospectively analyzed, of which only those with a small to regular-size and superior projecting were definitively selected. Multiple aneurysms arising from the ICA and tandem aneurysms were excluded. Blood blister–like, dissecting, transitional, mycotic, and traumatic aneurysms, as well as those treated previously by endovascular therapy, were also considered ineligible. Demographics, clinical, imaging, and surgical records

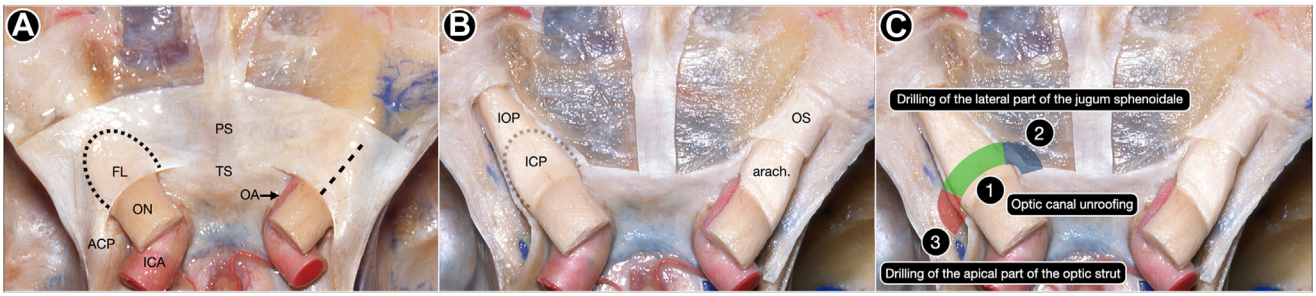

Figure 2. Formalin-fixed and latex injected cadaveric specimen showing the relevant microsurgical anatomy of the paraclinoid region before (**A**) and after (**B**, **C**) optic foraminotomy, cutting of the falciform ligament, and opening of the optic sheath. The curved dotted line indicates the shape of the dural flap. The straight dotted line shows the length of the opening of the optic sheath (10 mm). (**C**) Technical steps of optic foraminotomy. ACP, anterior clinoid process; FL, Falciform ligament; ON, Optic nerve; ICA, Carotid artery; PS, Planum Sphenoidale; TS, Tuberculum sellae; OA, Ophthalmic artery; IOP, Intraorbital segment of the optic nerve; ICP, intracanalicular segment of the optic nerve; OS, Optic sheath; arach., arachnoid of the optic nerve.

of patients where an OF was performed (study group) were compared with that of patients who underwent an AC (control group). Neurologic outcome was reported with the modified Rankin Scale. Aneurysm complete occlusion rate and rate of approach-related worsened vision were outcome measures of efficacy and safety, respectively, of OF versus AC. Continuous variables with normal distributions were reported as mean ± standard deviation and percentages. Unpaired t test and χ^2 test were used for numerical and categorical variables, respectively. A P value less than 0.05 was considered statistically significant. Prism 5 (GraphPad Software, Inc, San Diego, California, USA.) software was used for statistical analysis.

Optic Foraminotomy

The patient was placed supine with the head fixed to the skull clamp and rotated 30° toward the contralateral side. A curvilinear frontotemporal skin incision behind the hairline and interfascial dissection of the temporalis muscle was performed as originally described by Yasargil and recommended by others.[40-43] After pterional craniotomy, flattening of the sphenoid ridge, and dura opening, the sphenoidal compartment of the Sylvian fissure was split under microscopic view to expose the ipsilateral ICA, carotid cistern, and optic nerve. A circumferential dural incision was made above the optic canal. The length of the incision was 10 mm from the free edge of the falciform ligament. A dural flap was reflected and cut. OF involved 3 well-defined steps: (1) optic canal unroofing, (2) drilling of the lateral part of the jugum sphenoidale, and (3) drilling of the apical part of the optic strut (Figure 2). These 3 steps led to achieving a 180° exposure of the content of the optic canal (Figure 3). The latter 2 steps involved the medial and lateral wall of the optic canal and were accomplished using a 3-mm diamond burr. Copious and constant irrigation is critical to avoid thermal damage to the optic nerve. The falciform ligament and optic sheath were then incised observing the release of the cerebrospinal fluid. The optic nerve was gently mobilized away from the ICA with a microdissector to facilitate the aneurysm

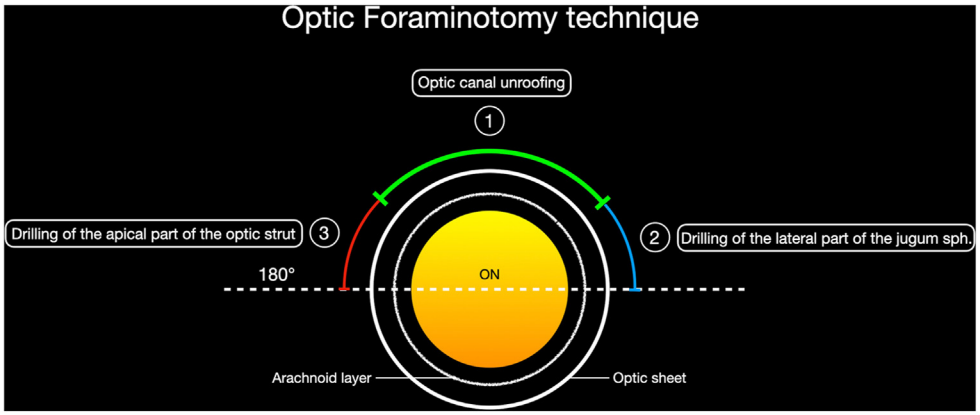

Figure 3. Technical steps of optic foraminotomy. ON, optic nerve; sph., sphenoidale.

exposure and clipping. This maneuver also allowed for an early and effective decompression of the optic nerve and optimization of the angular exposure of the origin of the ophthalmic artery.

RESULTS

OF and AC groups involved 18 and 25 patients, respectively. The frequency of small and regular-sized aneurysms did not differ between the groups. The number of ruptured aneurysms was higher in the AC group with an average Fisher grade of 1.8 ± 1. The exposure of the cervical segment of the ICA was performed in almost all cases of OF. The complication rate and overall neurologic outcome did not vary among the groups. The average follow-up was 51 ± 34 and 60 ± 41 months in the OF and AC group, respectively. Table 1 summarizes patient demographic and clinical data.

Visual Outcome

The rate of approach-related worsened vision did not statistically differ between the groups (Figure 4), although 16.6% of the patients of the OF group experienced a worsening of visual function versus 32% of the control group.

Angiographic Outcome

Aneurysm complete occlusion rate was 88.8% and 92% in the OF and AC group, respectively, with no statistical difference (Figure 5). Three of the 4 patients with a remnant were re-treated with a flow-diverter, whereas the other patient of the AC group underwent angiographic follow-up and remained stable. In all 3 patients treated with the pipeline stent, a delayed complete aneurysm exclusion was achieved within 4 months.

Illustrative Case

A 64-year-old male patient with a visual field deficit in the left eye was diagnosed with a small paraclinoid aneurysm arising from the dorsal wall of the ICA distally to the take-off of the ophthalmic artery. In the light of this angiographic finding, the patient was a candidate for an OF instead of AC considering the adequate hemodynamic control of the C6 segment of the ICA. Through a left pterional approach, an OF was performed. The aneurysm, which severely compressed the inferior aspect of the left optic nerve, was successfully clipped after a gentle elevation of the nerve. Postoperative computed tomography (CT) angiography documented the complete exclusion of the aneurysm. The patient was discharged on the third postoperative day, and the visual deficit appeared completely recovered on the fifteenth day (Figure 6) (Video 1).

Video available at www.sciencedirect.com

DISCUSSION

Ophthalmic aneurysms are considered a challenge in neurovascular surgery due to their close anatomical relationships with important surrounding structures such as the optic nerve and ICA. The results of the present study demonstrated that in small superior-projecting paraclinoid aneurysms OF was not associated with a worse visual outcome compared with AC. Conversely, the rate of approach-related worsened vision was even better in the former. The angiographic outcome also did not differ between the groups.

The surgical management of ophthalmic paraclinoid aneurysms goes through 3 distinct points, namely, the decision-making process delineating the indication for microneurosurgery versus endovascular therapy, the selection of a specific technique for proximal control of the ICA, and the consequent choice between the AC versus OF; this latter with precise indications as discussed below.

Decision-Making Process of Ophthalmic Aneurysms

While recognizing the pivotal role of the flow diverters in the management of most elective paraclinoid aneurysms, mainly attributable to their reported safety profile and good visual outcome,[44-57] microneurosurgery, and especially clipping, has proved to offer a complete and durable exclusion of the ophthalmic aneurysms with acceptable morbidity and mortality, regardless from the clinical onset. These data have been confirmed in large series, where the rate of complete aneurysm exclusion and good neurologic outcome was 93% and 88%, respectively.[12,18-37,58-61] Recently, based on their very good results in terms of neurologic and visual outcomes in 2 different studies, Otani and Matano stressed the surgical indication for superior-projecting paraclinoid aneurysms in young patients.[36,62] Several factors should be considered in the choice between surgery versus endovascular therapy, namely, the clinical onset, neurologic status, patient age, comorbidities, aneurysm size, angioarchitecture, navigability of the ICA, balloon test occlusion, and patient preference. In the current flow diverter era, our indications for microneurosurgery in ruptured ophthalmic aneurysms are mainly (1) Hunt-Hess grade ≤3, and (2) age ≤55 years. We still consider microsurgery as the best option for broad-based unruptured ophthalmic aneurysms affecting young and visually symptomatic patients. Sentinel headaches and reduced navigability of the cervical or intracranial ICA because of excessive tortuosity or occlusion are further indications of microneurosurgery.

Proximal Control of the ICA

The achievement of the proximal control of the ICA is a key aspect of ophthalmic aneurysm surgery. Different techniques have been proposed for this purpose, each one having pros and cons. These include the cervical, petrous, or clinoidal ICA exposure, endovascular balloon-assisted occlusion, suction-decompression technique, adenosine-induced cardiac standstill, and intracavernous control.[63-72] Some authors have depicted the control of the petrous ICA as particularly difficult and often inadequate.[71-76] Endovascular techniques require a trained endovascular team or a hybrid operative room. Cardiac standstill is characterized by certain morbidity and mortality. Intracavernous ICA exposure, according to the Krisht technique,[2] needs a consolidated experience regarding the management of the venous bleedings from the cavernous sinus. We prefer the exposure of the cervical ICA in dealing with those ophthalmic aneurysms where an OF is indicated. In the authors' experience, the modern implementation of the neuromonitoring techniques, indocyanine green and fluorescein videoangiography, micro-Doppler ultrasonography, Doppler flowmetry, endoscopic assistance, and intraoperative digital subtraction angiography

Table 1. Patients' demographic Clinical and Data

Variable	Data		
	Of Group	AC Group	*P* Value
Number of patients	18	25	
Age, years ± SD	43.7 ± 17	51.3 ± 18	0.1939
Sex, no. (%)			
Male	7 (38.9)	13 (52)	0.5375
Female	11 (61.1)	12 (48)	
Aneurysm size, no. (%)			
Small	6 (33.3)	7 (28)	0.7622
Regular	12 (66.7)	18 (72)	
Hemorrhagic onset, no. (%)	9 (50)	13 (52)	0.0298*
Fisher grade average ± SD	1.6 ± 1	1.8 ± 1	0.0441*
Cervical ICA exposure, no. (%)	17 (94.4)	11 (21.1)	0.0003†
Complications, no. (%)			
Intraoperative	3 (16.6)	6 (24)	0.5707
Aneurysm rupture	2 (11.1)	5 (20)	>0.9999
ICA thrombosis/occlusion	1 (5.5)	1 (4)	
Postoperative nonvisual	6 (33.3)	9 (36)	0.8605
mRS average ± SD	1.6 ± 1	1.6 ± 2	
Angiographic outcome, no. (%)			
Complete exclusion	16 (88.8)	23 (92)	>0.9999
Remnant	2 (11.1)	2 (8)	
Visual outcome			
Improved/unchanged	15 (83.3)	17 (68)	0.3090
Worsened	3 (16.6)	8 (32)	
Average follow-up, months ± SD	51 ± 34	60 ± 41	0.4239

AC, anterior clinoidectomy; ICA, internal carotid artery; mRS, modified Rankin Scale; OF, optic foraminotomy; SD, standard deviation.
*P value < 0.05.
†P value < 0.001.

significantly improved the reliability of the intraoperative checking of the blood flow for most neurovascular pathologies, including the ophthalmic aneurysms.[77-82]

Anterior Clinoidectomy for Ophthalmic Aneurysms

Extradural AC was first pioneered by Dolenc for intracavernous vascular lesions and later modified by Yonekawa.[12,83] Hauser treated an optic compression due to a carotid-ophthalmic aneurysm by unroofing the optic foramen, while Drake performed a removal of the anterior clinoid through a subfrontal route.[7,84] AC is universally considered necessary for superior and lateral paraclinoid aneurysms, and advantageous also for ventral and medial ones.[6,7,11,12,18-20,83,85-91] AC has some unquestionable strengths as it allows us to (1) expose and cut the distal dural ring,

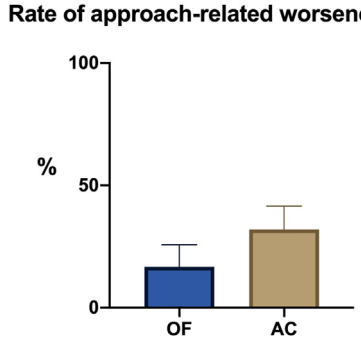

Figure 4. Bar graph showing the rate of approach-related worsened vision in the optic foraminotomy (OF) and anterior clinoidectomy (AC) groups.

(2) achieve optimal proximal control of the ICA at the level of the clinoid segment, (3) mobilize the ICA, (4) visualize the superior hypophyseal branches, and (5) optimize the angular exposure of the ophthalmic aneurysms, as the clinoid process hinder the superolateral aspect of the ICA similarly to what the condyle and jugular tubercle do for the anterior medullary segment of the vertebral artery.[92,93] However, the rate of postoperative severe visual complications in ophthalmic aneurysms ranges between 0% and 19% in the literature and AC accounts for an important part of this visual morbidity.[12,19,27,28,30,32,34] It has been reported that preoperative visual deficit may be worse after clipping of ophthalmic aneurysms because of potential iatrogenic damages to the optic pathway during AC aside from aneurysm exposure and clipping.[94] The drilling of the anterior clinoid becomes a source of visual morbidity especially because of the thermal injury to the optic nerve. Contusions of the optic pathway and imbalances of the blood flow into the ophthalmic and retinal

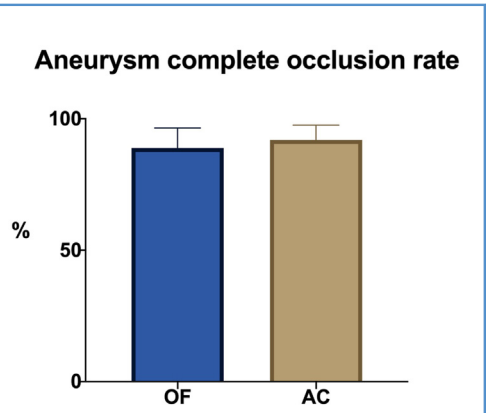

Figure 5. Bar graph showing the aneurysm complete occlusion rate in the optic foraminotomy (OF) and anterior clinoidectomy (AC) groups.

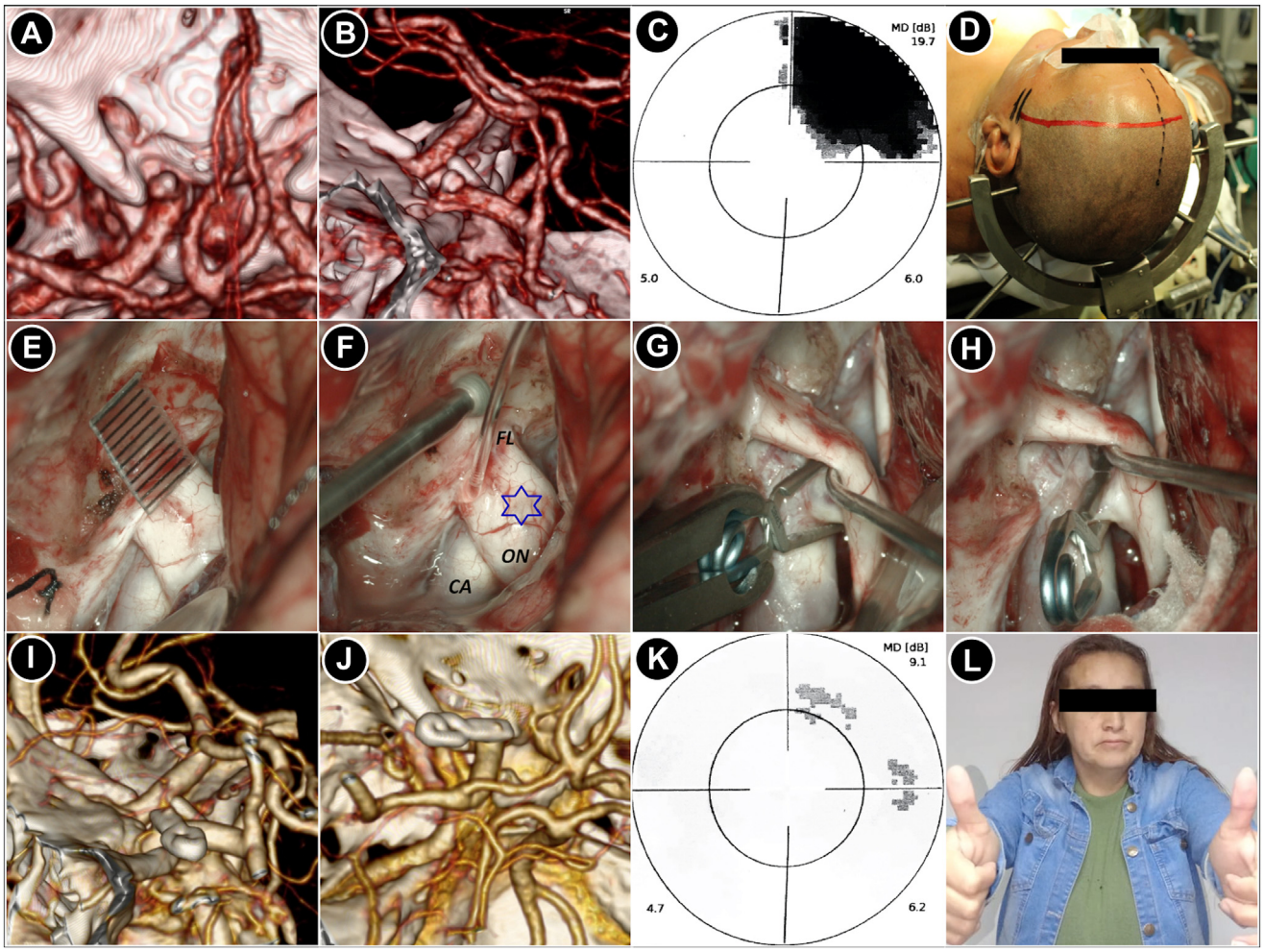

Figure 6. Preoperative 3-dimensional CT angiography in axial (**A**) and lateral (**B**) orientation. (**C**) Preoperative visual field test. (**D**) Surgical position for left pterional approach. (**E**, **F**) Optic foraminotomy. The *blue star* marks the projection of the aneurysm and the point of greater compression beneath the optic nerve. FL, falciform ligament; ON, optic nerve; CA, carotid artery. (**G**) Mobilization of the left optic nerve before the clipping of the aneurysm. (**H**) Complete exclusion of the aneurysm after clipping. Postoperative visual field test (**K**) and postoperative picture of the patient (**L**) 2 weeks after surgery.

artery secondary to the handling of the clinoid segment of the ICA are further potential causes of blindness.[17,95]

Optic Foraminotomy for Ophthalmic Aneurysms

In 1978, Iwabuchi et al. described in detail the unroofing of the optic canal, a concept similar but not overlapping to the OF, reporting 6 consecutive cases of ophthalmic aneurysms successfully treated with this technique.[14] OF differs from the simple optic canal unroofing as, apart from the roof, it also involves the medial and lateral wall of the optic canal. The rationale of the OF in selected types of small superior-projecting paraclinoid aneurysms lies in avoiding unnecessary drilling of the anterior clinoid process, thus decreasing the risk of visual and vascular complications. Our group has already reported the advantages of the OF compared with AC that is synthesizable as follows[96]: (1) the drilling is carried out over a flat surface and the risk of slippage of the drill is lower than AC; (2) OF does not involve the handling of the ICA, this aspect is associated with a lower risk of bleeding from the ICA itself or cavernous sinus; (3) it lets an early visualization of the ophthalmic artery; (4) it allows for an earlier decompression of the optic nerve; (5) the gentle mobilization of the optic nerve widens the working space for clipping, thus avoiding the need for manipulation of the ICA and decreasing the risk of intraoperative rupture; and (6) OF is faster to be performed than AC, this point probably justifying the reduced risk of thermal damage to the optic nerve and the lower, although not statistic, rate of approach-related worsened vision that we had in the study group. We used the free edge of the falciform ligament rather than the superior edge of the optic canal as a landmark to perform the 10-mm incision of the dura of the

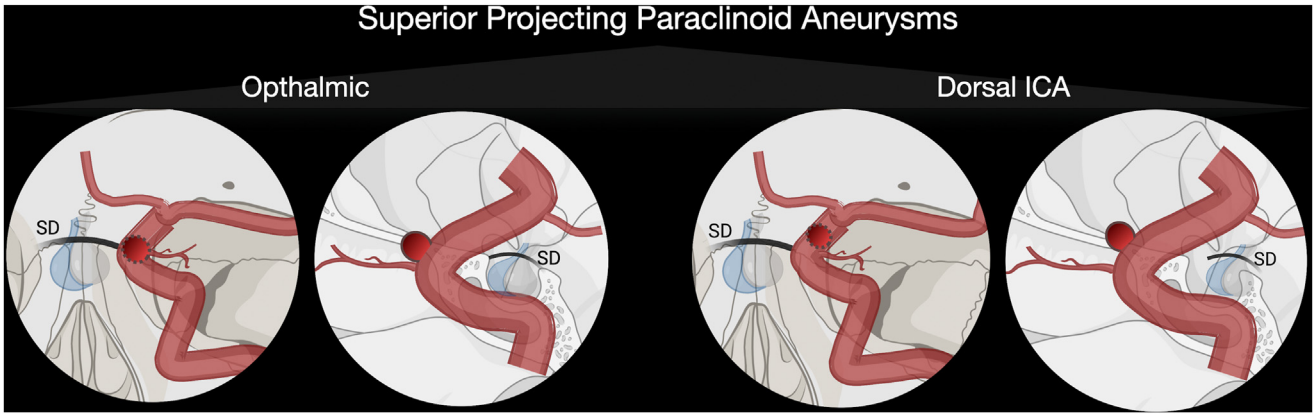

Figure 7. Types of superior projecting paraclinoid aneurysms. ICA, internal carotid artery.

optic nerve; this is because the falciform ligament has a negligible rate of anatomical variation compared with the bony edge of the optic canal.

Indications for Optic Foraminotomy

The profiling of the indications to OF for superior-projecting paraclinoid aneurysms rests entirely on the distinction between the so-called "true" ophthalmic aneurysms, characterized by the direct involvement of the ophthalmic artery by the aneurysmal neck, and those instead arising distally to the origin of the ophthalmic artery, commonly referred to as dorsal ICA aneurysms[97] (Figure 7). While in the former the exposure of the clinoid (C_5) segment of the ICA achieved through the AC is mandatory to obtain the proximal hemodynamic control, in the latter the skeletonization of the ophthalmic (C6) segment is sufficient to clip the aneurysm safely, as long as it is small (Figure 8). It derives that OF is indicated for superior-projecting dorsal ICA wall aneurysms of sizes from small to regular.

Limitations of the Study

The retrospective nature, small number of patients, heterogeneity of the surgical teams, and patients' cohorts are the main limitations of the present study.

CONCLUSIONS

OF consists of a 180° exposure of the content of the optic canal. Compared to AC, OF was not found to have either a higher rate of approach-related worsened vision or a lower complete aneurysm occlusion rate.

OF is selectively indicated in small superior-projecting dorsal ICA wall paraclinoid aneurysms.

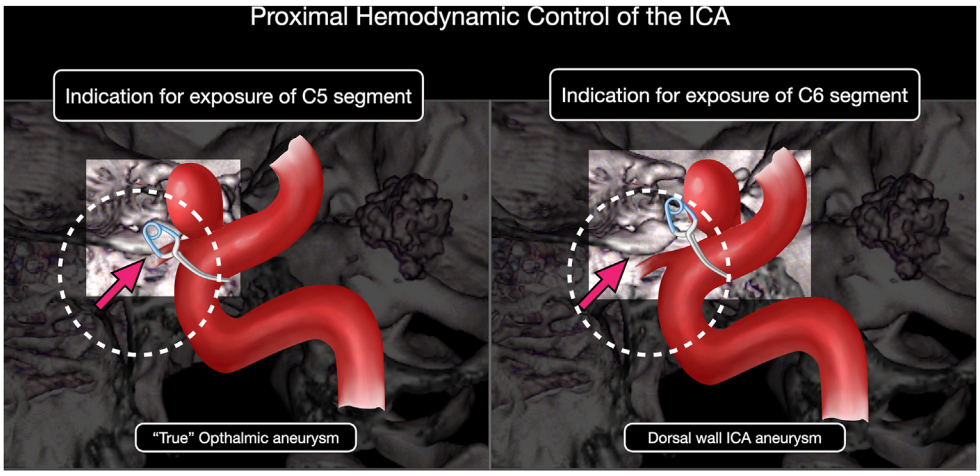

Figure 8. Proximal hemodynamic control of the internal carotid artery (ICA) and need of anterior clinoidectomy in "true" ophthalmic and dorsal ICA wall aneurysms.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Sabino Luzzi: Data curation, Formal analysis, Writing — review & editing, Supervision, Validation. **Alice Giotta Lucifero:** Conceptualization, Investigation, Methodology, Writing — original draft. **Matias Baldoncini:** Conceptualization, Formal analysis, Writing — review & editing. **Alvaro Campero:** Formal analysis, Writing — review & editing, Supervision, Validation. **Renato Galzio:** Conceptualization, Formal analysis, Writing — review & editing, Supervision, Validation. **Michael T. Lawton:** Conceptualization, Supervision, Validation.

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