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TECHNICAL NOTE

The extradural minipterional approach for the treatment of paraclinoid aneurysms: a cadaver stepwise dissection and clinical case series

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Abstract

Minipterional (MPT) craniotomy has recently been added to the neurosurgical armamentarium as a less invasive alternative to the pterional craniotomy for the treatment of parasellar lesions. However, its clinical applicability in the treatment of certain complex aneurysms, such as those arising in the paraclinoid region, remains unclear. To illustrate the microsurgical anatomy of a modified extradural MPT approach, which combines a classic MPT craniotomy with an extradural anterior clinoidectomy, and to demonstrate its clinical applicability in the treatment of complex paraclinoid aneurysms. A stepwise extradural MPT approach is illustrated in a cadaver study. Clinical outcome data from a series of 19 patients with 20 paraclinoid aneurysms treated surgically using the extradural MPT approach between 2016 and 2018 were retrospectively collected. In 95% of the cases, complete aneurysm occlusion was achieved. No aneurysm recurrences were seen during follow-up with a median length of 21 months. The outcome, according to the modified Rankin Scale, was 0 points in 12 patients (63%), 1 point in 6 patients (32%), and 2 points in 1 patient (5%). Four out of 6 patients (67%) with initial visual symptoms showed improvement following treatment, whereas in two (11%), vision became worse. The extradural MPT approach ensures a sufficiently large exposure of the paraclinoid region that is comparable with conventional approaches with the advantage of being minimally invasive. Our case series demonstrates the feasibility of this approach for the treatment of complex paraclinoid aneurysms.

Keywords Pterional · Minimally invasive · Skull base · Dolenc · Hakuba

Introduction

Pterional craniotomy, initially described by Professor Yasargil [42] (Fig. 1a), is one of the most utilized approaches for the clipping of anterior circulation aneurysms. It provides surgical access to the anterior and middle cranial fossas, the superior aspect of the posterior cranial fossa, the sellar and parasellar regions, and the superior orbital fissure, as well as the cavernous sinus (Fig. 1) [42, 43]. Since its first description, many variations of the original technique, such as the orbitozygomatic or transzygomatic approaches, have emerged [9, 38]. Nonetheless, the aforementioned approaches bear complications such as frontal sinus opening, masticatory difficulties, as well as esthetic problems secondary to temporal muscle atrophy, and paralysis of the frontal branch of the facial nerve [5, 31]. Less invasive approaches, such as the minipterional (MPT) craniotomy described by Figueiredo et al. [16] (Fig. 1b), have been shown to be equally safe and

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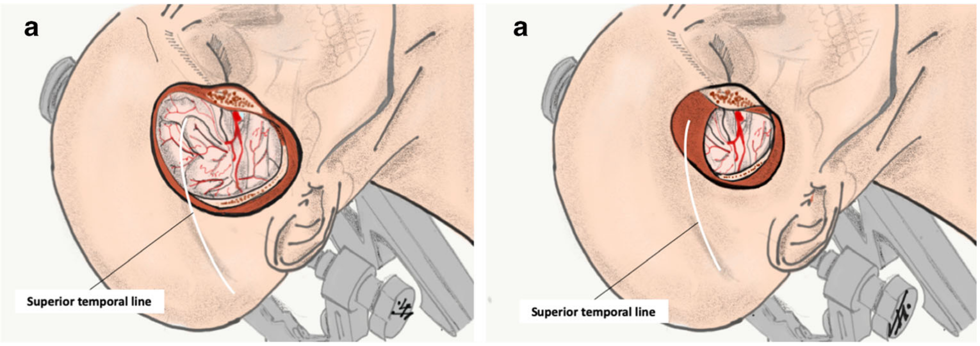

Fig. 1 Schematic representation pterion-centered craniotomies. **a** The pterional craniotomy (Yasargil 1975[1], blue line) is a variably sized craniotomy comprising the frontal, parietal, temporal, and sphenoid bone. Its superior limit extends above the superior temporal line. **b** The minipterional (MPT) craniotomy (Figueiredo 2007[8], orange line) measures 3 to 4 cm with a superior limit constituted by the superior temporal line

effective as the pterional craniotomy, in terms of microsurgical dissection of the Sylvian fissure and aneurysm visualization for most of the cerebral aneurysms. However, the MPT craniotomy requires less muscular retraction and bone removal, which results in shorter surgical times and better cosmetic outcomes [16, 18, 19]. Additionally, some authors have expressed their concerns about its applicability and safety in the treatment of aneurysms located deep in the basal cisterns that require extended splitting of the Sylvian fissure [11, 16]. After all, the reported clinical experience in cerebrovascular neurosurgery using this approach is mostly limited to small non-ruptured superficial aneurysms, such as those arising from the middle cerebral and posterior communicating cerebral arteries. Thus, the body of literature for the treatment of paraclinoid aneurysm is scarce [34].

In 1981, Hakuba et al. described their technique of sectioning the meningorbital band (MOB) in order to extradurally remove the anterior clinoidal process and reach the cavernous sinus [21]. Later, Dolenc and colleagues popularized the extradural anterior clinoidectomy as a mainstay of treatment to gain access to vascular lesions located in the cavernous sinus and in the paraophthalmic region [12].

We propose a combination of the MPT craniotomy with the extradural anterior clinoidectomy for the microsurgical treatment of paraclinoid aneurysms. Thus, the objectives of this study are (1) to illustrate the microsurgical anatomy of the dissection of this modified extradural MPT approach in a stepwise fashion using a cadaver model and (2) to demonstrate its clinical feasibility in the treatment of complex paraclinoid aneurysms.

Materials and methods

Cadaveric study

Three cadaveric embalmed heads were injected with colored silicone. MPT craniotomies were performed using a high-speed drill (Medtronic Midas Rex, Fort Worth, TX). Microscopic anatomical dissections were performed with × 3 to × 40 optical magnifications under an operating microscope (OPMI; Zeiss, Oberkochen, Germany). The photographs were obtained with a digital camera (Canon EOS 80D DLSR, Canon, Tokyo, Japan).

Participants

Between March 2016 and March 2018, 19 patients harboring 20 paraclinoid aneurysms were treated surgically by the senior author using the extradural MPT approach. Patients with follow-up less than 6 months were not included in the analysis. Patients' demographic parameters, aneurysm characteristics, and clinical outcome were collected from the medical records and the pre- and postoperative radiological images. Functional status was assessed by means of the modified Rankin Scale (mRS). Aneurysms of the paraclinoid region were classified according to the anatomical considerations by Kim et al. [24] (Fig. 2).

Informed consent was not deemed necessary by the local ethics in view of the retrospective design of the study and the application of strict patient privacy regulations operating in our center.

Results

Cadaveric study: stepwise dissection of the MPT extradural approach

1. MPT craniotomy

At the beginning of the case and for all aneurysms within the paraclinoid region, the authors dissect the ipsilateral neck of the cervical internal carotid artery (ICA) to gain proximal control. Then, an arcuate scalp incision is made 1 cm above the zygoma, extended superiorly to 1 cm behind the hairline

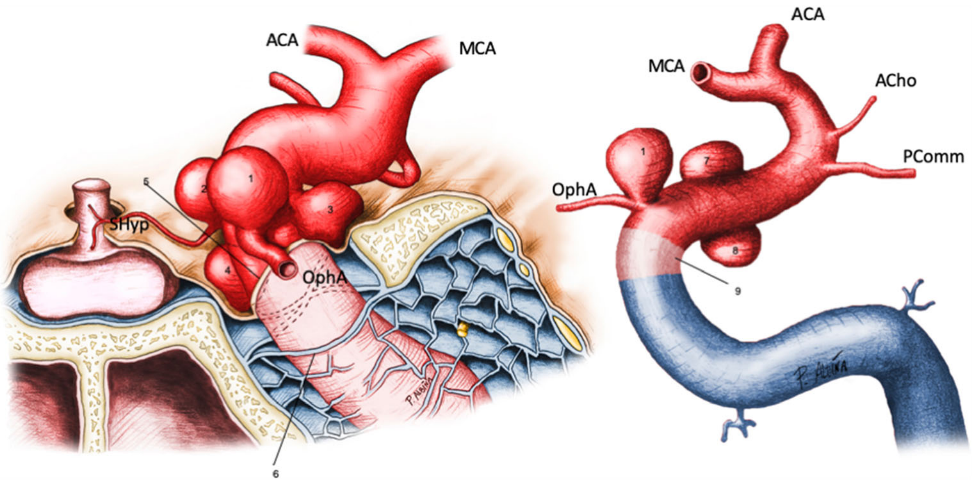

Fig. 2 Schematic representation of different subtypes of paraclinoid region aneurysms from an anterior and lateral perspective. 1, carotid-ophthalmic type aneurysm; 2, superior hypophyseal aneurysm; 3, lateral wall-type aneurysm; 4, medial wall-type/cavum-type aneurysm; 5, distal dural ring; 6, proximal dural ring; 7, superior wall-type aneurysm; 8, posterior wall-type aneurysm; 9, clinoidal segment of the internal cerebral artery. ACA, anterior cerebral artery; ACho, anterior choroidal artery; MCA, middle cerebral artery; OphA, ophthalmic artery; PComm, posterior communicating artery

and gradually curved toward the ipsilateral midpupillary line (Fig. 3a). We always keep the incision away from the midline for better cosmetic results.

The scalp is retracted anteriorly and an interfascial dissection is fashioned to avoid injury to the frontal branch of the facial nerve [43] (Fig. 3b). The frontal fascia and muscle are detached from the superior temporal line and the upper lateral orbital rim using the Bovie electrocautery. The muscle flap is then dissected subperiostally using a No. 5 Penfield dissector and pulled downward until the pterion is visualized. The keyhole is placed anteriorly to the pterion. A craniotomy is fashioned with the craniotome directed superiorly and posteriorly just underneath the superior temporal line. When the craniotome reaches the coronal suture, a smooth down turn should be made toward the temporal bone. At the temporal base, the craniotome is directed anteriorly to connect with the keyhole (Fig. 3c–e). Once the craniotomy is done, small holes are placed along the bone of the superior temporal line for re-approximation of the temporal muscle at the end of the procedure.

2. Sphenoid ridge drilling

The sphenoid ridge is drilled flat so that the MOB and the superior orbital fissure can be exposed (Fig. 3f). The MOB is an important anatomical structure in anterolateral approaches. It is constituted by a fold of the superficial dura mater, which binds the dura propria of the temporal pole and the periorbita through the superior orbital fissure [1, 32]. Once envisioned, the MOB is followed in the direction of the superior orbital fissure and finally coagulated using bipolar cautery (Fig. 3f). Cutting the MOB allows for mobilization of the temporal pole and facilitates the mini-peeling of the temporal base, providing a better surgical corridor to reach the anterior clinoid process (ACP) [20].

3. Unroofing the optic canal and extradural anterior clinoidectomy

Anatomically, the ACP forms the posteromedial border of the lesser sphenoid wing. It covers the cavernous sinus superiorly and has a triangular shape with its base oriented anteriorly. At its base, it is connected to the sphenoid wing by 3 pillars: lateral, medial, and inferomedial. The lateral pillar consists of the extension of the lesser sphenoid wing, while the medial pillar forms the roof of the optic canal. The inferomedial pillar, or optic strut, is a small bone with a rounded anterior aspect and a posterior sharp edge that forms the lateral wall of the optic canal, thereby separating the optic nerve medially from the ICA [25, 31].

Once the superior orbital fissure is reached, the lateral wall of the orbit is drilled until the lateral pillar of the ACP is gone (Fig. 3g). This maneuver is aided by Kerrison Universal Rotating Rongeurs (Sontec Instruments, CO, USA). Next, the roof of the optic canal is removed using angulated rongeurs (Sontec Instruments, CO, USA); thus, optic nerve decompression is performed at its superior margin (Fig. 3h). We avoid using high-power drills in the vicinity of the optic nerve for anterior extradural clinoidectomy, since local heat could cause damage. Once the ACP is disconnected from its attachment at the optic strut and the roof of the optic nerve, its tip and body are removed using a curved rongeur (Sontec Instruments, CO, USA) (Fig. 3h). Gentle movements are required to liberate the entire ACP from the petroclival ligament in order to prevent excessive manipulation of the third nerve.

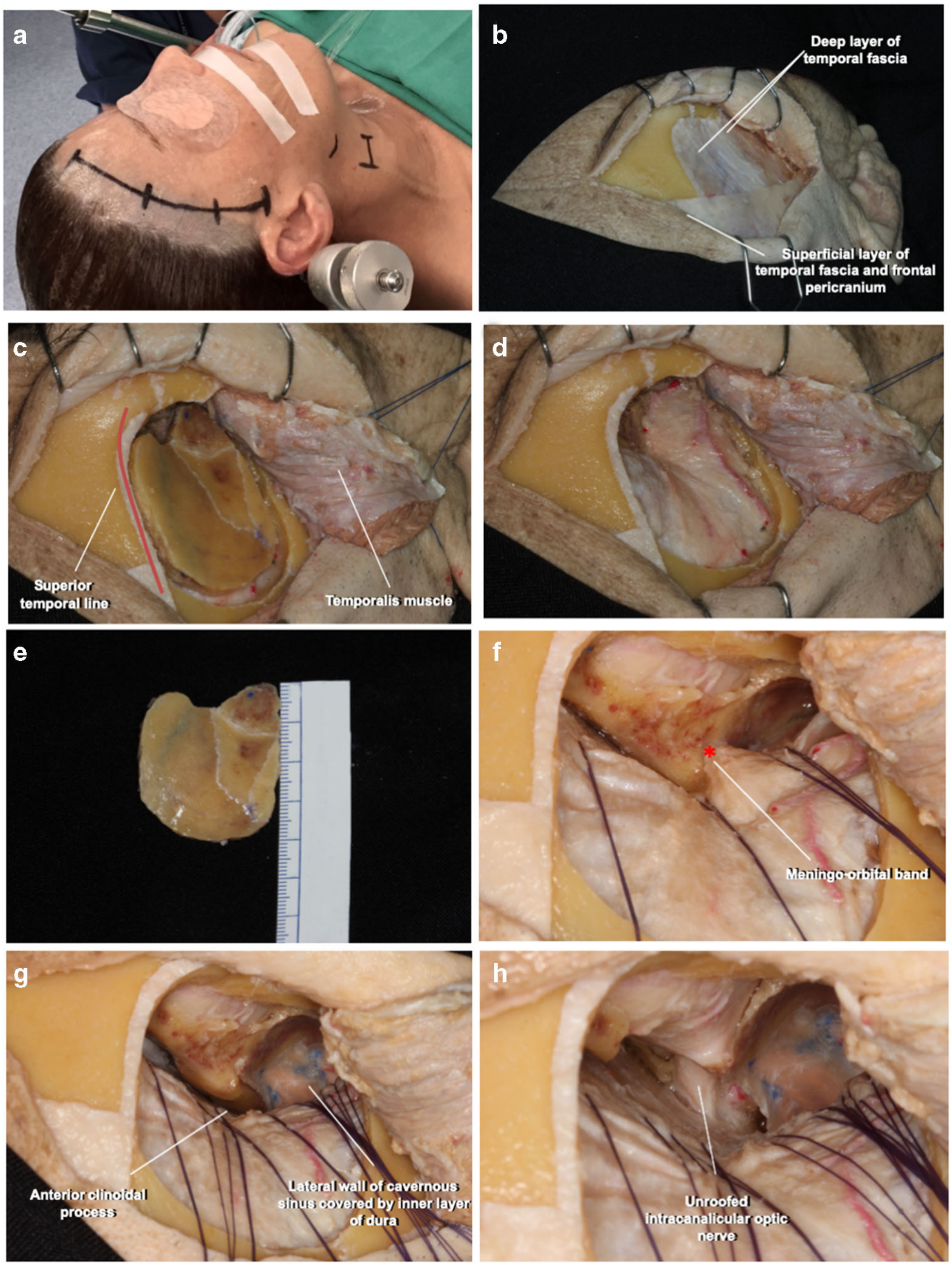

Fig. 3 Stepwise dissection of an extradural minipterional (MPT) approach. **a** Patient positioning in supine position with the head slightly extended and fixated using the Mayfield clamp. A 2-cm horizontal incision at the level of C5, anterior to the sternocleidomastoid muscle, is delineated to expose the carotid bifurcation. An arcuate scalp incision is started 1 cm above the base of the zygomatic arch and extended superiorly to 1 cm behind the hairline and curved gradually toward the ipsilateral midpupillary line. **b** The scalp is retracted anteriorly and an interfascial dissection is fashioned to avoid injury of the frontal branch of the facial nerve. **c** The muscle flap is dissected subperiostally and is then retracted inferiorly. **d** A minipterional craniotomy beneath the superior temporal line is performed. **e** The bone flap has an approximate diameter of 4 cm. **f** The sphenoid ridge is drilled away until its base is flattened and the lateral meningo-orbital band (MOB) is exposed. **g** The MOB is coagulated and dissected and a mini-peeling of the temporal fossa is performed to gain access to the lateral wall of the cavernous sinus and the tip of the anterior clinoid process. **h** The optic canal is unroofed using a number 1 Kerrison and the anterior clinoid process is gently liberated from its attachments

4. Dome isolation and clipping

The dura is opened linearly along the axis of the Sylvian fissure ending between the optic nerve and the ICA (Fig. 4a, b). Once the arachnoid plane is exposed, the optico-carotid cistern is opened to help brain relaxation. At this point, the dissection is continued by splitting the proximal portion of the operculoinsular compartment of the Sylvian fissure.

Extradural anterior clinoidectomy aids in obtaining a complete exposure of most paraclinoid aneurysms (Fig. 4c). Nevertheless, section of the distal dural ring is recommended during dome liberation of transitional-type aneurysms in order to gain a better view of the aneurysm neck shoulders. This maneuver reduces the risk of ICA stenosis or kinking after clip deployment. At this point, further considerations regarding the origin of the aneurysm in relation to the distance to the proximal and distal dural ring are mandatory for the next surgical step: While an extradural anterior clinoidectomy might suffice for the majority of the superior hypophyseal aneurysms, transitional aneurysms with intra- and extradural extension may require additional opening of the proximal and distal dural ring to entirely free their neck. Mild venous bleeding from the cavernous sinus is often encountered at this stage, for which hemostasis is achieved with fibrin glue sealant

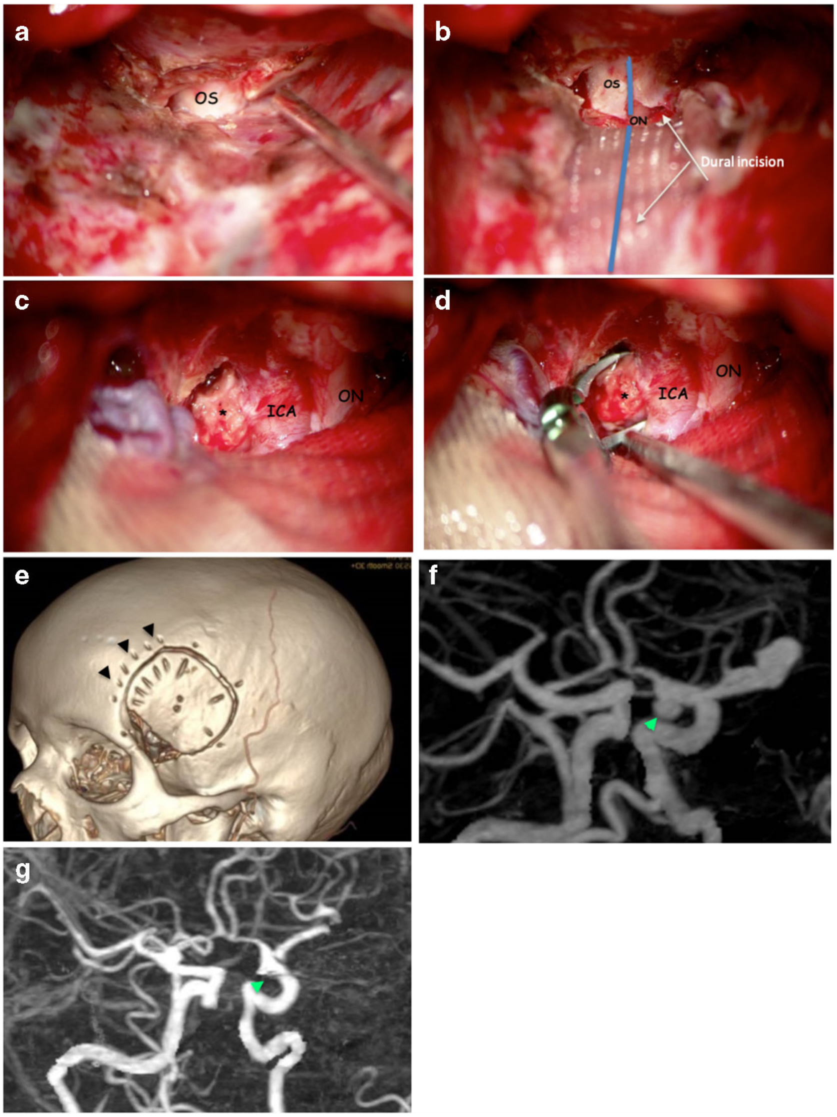

Fig. 4 Intraoperative views of an unruptured 6-mm left paraclinoid aneurysm surgically accessed through an extradural minipterional craniotomy combined with an anterior clinoidectomy. **a** Operative view after performing the extradural anterior clinoidectomy. The optic sheath (OS) is exposed as a result of removing the roof of the optic canal. **b** The dura is opened linearly (blue lines) over the OS along the Sylvian fissure, and the optic nerve (ON) is exposed. **c** Thereafter, the aneurysm dome (*) is dissected and the external dural ring opened, if needed (see also main text; ICA, internal carotid artery). **d** A low profile semi-curved clip is deployed across the neck of the aneurysm. **e** Postoperative CT bone scan showing the size of the minipterional craniotomy surrounded by small bony holes for re-approximation of the temporal muscle (arrow heads). **f** Preoperative 3-dimensional computed tomography (CT) angiogram showing a postero-inferior wall wide-neck aneurysm (arrow head). **g** The postoperative 3-dimensional CT angiogram shows the occlusion of the aneurysm by the clip (arrow head)

(Beriplast, CSL Behring GMBH, Marburg, Germany) and a small cottonoid [26]. We avoid the use of oxidative-cellulose products since engorgement of this material may be responsible for delayed third nerve damage [26].

The clip should be selected in advance based on angiographic and surgical considerations. We recommend a laterally curved clip for superiorly pointing carotid-ophthalmic aneurysms (i.e., Peter Lazic-45-747, Peter Lazic GmbH, Tuttlingen, Germany). By its orientation, this clip avoids kinking of the parent vessel and optic nerve compression. A low profile head clip facilitates manipulation within the surgical field. In most other instances, (superior hypophyseal, posterior wall or cavum-type aneurysms), an angled fenestrated clip can be chosen. A curved or bayonet-type clip might also be used for posterior wall and cavum-type aneurysms (Fig. 4d).

Once the first clip is placed across the neck, the tips must be visualized to rule out inadvertent clamping or kinking of surrounding neurovascular structures (Fig. 4c, d). If needed, a second clip can be applied in order to increase stability. In order to achieve optic nerve decompression and guarantee complete aneurysm occlusion, we recommend opening the aneurysm dome. However, we refrain from removing it completely since small perforators could be disrupted, especially in superiorly directed carotid-ophthalmic aneurysms. Patency of the distal branches is finally confirmed with indocyanine green (Aurolab, Madurai, India).

5. Closure

The dura is closed in a water-tight fashion distally at the level of the Sylvian fissure, using 3/0 silk. Proximally, at the level of the optic nerve and distal dural ring, dural ends are approximated, and gaps are sealed using temporalis muscle free flaps and fibrin glue. The bone flap is brought back in, fixed with 0 silk or miniplates and screws. The temporalis muscle is then re-attached at the three to four small holes along the temporal line with 2/0 silk (Fig. 4e). As a result, the keyhole defect is covered. Pre- and postoperative angiographic studies are needed to assess complete occlusion of the aneurysm and patency of the parent vessel (Fig. 4f, g).

Participants

Patients' demographic data, aneurysm characteristics, and clinico-radiological outcomes are summarized in Table 1. Nineteen patients with 20 aneurysms underwent surgery via the extradural MPT approach. Mean age at presentation was 45 years. Two men (11%) and 17 women (89%) were included in the analysis. Median follow-up was 21 months (range 12–23 months). Good exposure of all neurovascular structures of the paraclinoid region was obtained in every case. Complete aneurysm occlusion was achieved in 19 (95%) cases. In one patient (5%), clipping was subtotal given the inclusion of the ophthalmic artery in the neck of a carotid-ophthalmic aneurysm. Three patients were treated in the context of a subarachnoid hemorrhage (SAH), while 16 had unruptured aneurysms that were treated electively. Aneurysm diameter varied in the range from 6 to 23 mm (median 10 mm). Six out of 19 patients (32%) presented with visual symptoms, 4 of which (67%) improved after surgical treatment. Two patients (11%) without prior visual symptoms experienced a decline of their visual acuity. No infection, infarction, hydrocephalus, or other complications were observed. There was no mortality in our series. Outcome according to the mRS was 0 points = 12 patients (63%), 1 point = 6 patients (32%), and 2 points = 1 patient (5%). Thus, all patients reached an independent status at last follow-up (mRS ≤ 2). Among the three patients who presented in the acute phase of a SAH, all of them were asymptomatic (mRS = 0) at the last follow-up visit. There were no SAH recurrences during the time of follow-up.

Discussion

Key results

The principle of minimally invasive techniques entails a balance between minimal tissue trauma and maximum anatomic exposure [15]. The benefits of the MPT craniotomy were previously highlighted in recent publications [8, 15, 16, 27, 31, 40]: reduced trauma to the myocutaneous and bony structures while the transylvian access is non-inferior to the one obtained by a classic pterional craniotomy. However, the MPT has never been shown to be feasible in pathologies that require bone drilling in the depths of the operative field. Moreover, some authors have put forward concerns regarding insufficient working space and a reduced view angle, especially when managing ruptured aneurysms [7, 11]. Our results with the extradural MPT approach are very promising in terms of functional outcome, occlusion rate, and safety for a wide range of paraclinoid aneurysms. The fact that our series included large (> 15 mm) and ruptured aneurysms demonstrates how the extradural MPT is applicable in those types of aneurysms as well.

Along with this work, we review the anatomic aspects of the paraclinoid region and discuss the indications, technical nuances, and pitfalls of the extradural MPT approach for a variety of paraclinoid aneurysms.

Interpretation of our results and indications for the extradural MPT approach in the treatment of paraclinoid aneurysms

Given the complex anatomical location and surrounding neurovascular structures, the treatment of paraclinoid region aneurysms represents a challenge from both a microsurgical and an endovascular point of view. Along with symptoms related with subarachnoid hemorrhage in the case of rupture, clinical presentation in non-ruptured aneurysm is influenced by aneurysm size and location. As such, giant superior hypophyseal aneurysms might induce pituitary insufficiency, or aneurysms arising from the ophthalmic segment of the ICA can cause visual symptoms when they affect the optic nerve.

Similarly, surgical manipulation can also be the cause of impairment to the third cranial nerve during anterior clinoidectomy. As it was previously described in the technical note, oculomotor nerve is particularly at risk during the maneuver of the detachment from the petroclinoidal ligament. Hence, this maneuver should be carried out carefully, using sharp dissection if needed to avoid excessive traction. On the other hand, removal of the ACP enhances the visualization of the third cranial nerve piercing the dura at the oculomotor membrane, which can be used to liberate the nerve from excessive manipulation during aneurysm dissection. To reduce complications associated with ACP removal, some authors have proposed using a contralateral supraorbital approach as alternative for clipping medially and superiorly pointed aneurysms [3, 35]. However, the surgical exposure afforded by the supraorbital approach is inferior to that provided by the MPT approach and the proximal control is not such as feasible as when the external dural ring is opened [14, 22, 41]. All these considerations should be interpreted and anticipated in the preoperative plan, in order to choose the best operative approach.

Endovascular treatment is becoming more important given the recent technical advances and development of new assisting devices [13]. While endovascular treatment is still considered a safer alternative to microsurgical clipping [13], higher rates of recanalization and visual deterioration secondary to aneurysm thrombosis or the increased mass effect after coiling have been reported by others [6, 13, 39]. In a series of 83 patients with ophthalmic aneurysms, Beretta et al. [6]

Table 1 Patients' demographic data, aneurysm characteristics and clinico-radiological outcomes of the cohort (*patient number 2 harbored two aneurysms on the right side; f, female; m, male; mRS, modified Rankin Scale; SAH, subarachnoid hemorrhage

N	Age at presentation	Gender	Initial symptoms	Hunt Hess classification	Fisher grade	Aneurysm type	Visual function	Aneurysm diameter (mm)	Occlusion grade	mRS at follow-up	Complications	Follow-up (months)
1	56	F	Visual impairment	0	1	Carotid-ophthalmic	U	14	Complete	1	None	23
2*	33	F	Headache and visual impairment	0	1	Lateral wall	I	15	Complete	0	None	23
				0	1	Superior hypophyseal (same side)		11			None	
3	38	F	Incidental	0	1	Lateral wall		8	Complete	0	None	23
4	41	F	Headache	0	1	Carotid-ophthalmic		5	Subtotal (> 95%)	0	None	22
5	40	F	Tinnitus	0	1	Superior hypophyseal		5	Complete	1	Partial III CN palsy with complete recovery at 2 weeks	22
6	52	F	Incidental	0	1	Carotid-ophthalmic	I	8	Complete	1	None	22
7	43	F	Incidental	0	1	Medial wall	S	12	Complete	2	None	22
8	62	F	Incidental	0	1	Superior hypophyseal		21	Complete	0	None	21
9	41	M	Headache	0	1	Carotid-ophthalmic		5	Complete	0	None	21
10	45	F	Incidental	0	1	Carotid-ophthalmic		5	Complete	1	None	20
11	31	F	Headache	0	1	Superior hypophyseal		6	Complete	0	None	20
12	47	F	Visual impairment	0	1	Superior hypophyseal	U	23	Complete	1	None	20
13	56	F	Facial hypoesthesia	0	1	Carotid-ophthalmic		14	Complete	0	None	19
14	39	F	SAH	2	3	Carotid-ophthalmic	I	11	Complete	0	None	19
15	47	F	SAH	3	3	Superior hypophyseal		6	Complete	0	None	16
16	58	F	Headache	0	1	Carotid-ophthalmic	M	19	Complete	1	None	15
17	42	F	Incidental	0	1	Carotid-ophthalmic		6	Complete	0	None	15
18	41	M	Cefalea	0	1	Superior hypophyseal		6	Complete	0	None	15
19	40	F	SAH	2	3	Carotid-ophthalmic	I	10	Complete	0	None	12

Visual function: *U* preoperative deficit, unchanged; *I* preoperative deficit, improved; *W* preoperative deficit, worsened; *M* (new) postoperative deficit, mild; *S* (new) postoperative deficit, severe reported an incidence of visual decline in 38% of the patients treated with endovascular coiling, while it was only 6% after microsurgical clipping. Turner et al. [39] reported 6 patients with large paraclinoid aneurysms who underwent coiling and experienced delayed visual deterioration. In a recent meta-analysis [13], visual improvement in patients with clipped paraclinoid aneurysms was 14% higher than in the coiling group. Furthermore, the need for re-treatment is lower after surgical clipping. In a direct comparison of endovascular and open surgical treatment of ophthalmic aneurysms, Sherif et al. reported a combined 4% re-treatment rate after clipping [36]. This rate was as high as 30% in patients treated with coiling and increased to over 80% in the patient subgroup with ruptured aneurysms. Flow diversion has emerged as a new promising alternative for wide neck aneurysms. However, delayed re-hemorrhages and acute in-stent occlusion with devastating consequences have been reported as well [33]. Furthermore, definitive clipping prevents from using antiplatelet therapy, reducing the risk of complications at long term, especially in young patients.

We still consider endovascular treatment and flow diversion as effective and safe treatment alternatives in paraclinoid aneurysms. Hence, selecting which patients are the best candidates for each technique has become a matter of importance, and each case needs should be assessed on an individual patient basis. For the reasons outlined above, regardless surgeon's preferences and experience, we particularly support the surgical clipping of paraclinoid aneurysms in cases with mass effect and visual decline, and in those aneurysms occurring in young patients. In experienced hands, excellent and definitive results can be obtained with the microsurgical technique [13, 29].

Technical aspects of the extradural MPT approach

A good balance between a wide exposure and avoiding unnecessary damage of the cortex and soft tissues is key for the different anterolateral approaches. The extradural anterior clinoidectomy, along with the detachment of the MOB, enables a good overview of the paraclinoid region through a minipterional craniotomy. As opposed to the intradural anterior clinoidectomy, the extradural technique also allows for a prompt and full length optic nerve decompression, which might account for the excellent visual outcomes in this series (67% visual improvement). Moreover, the no-drilling technique for decompressing the optic canal might contribute to improve the visual outcome, as the risk of optic nerve thermic damage by drilling is reduced [23]. Still, two of our patients experienced some decline in their visual function. Although any cause can be ruled out after analyzing cases from a retrospective perspective, we believe that the manipulation of a large and complex aneurysm close to an already impaired optic nerve is the main responsible of such decline.

Potential criticisms of the MPT craniotomy—and our technical nuances in particular—are (1) reduced frontal exposure limiting the possibility of frontal lobe retraction and (2) limited distal Sylvian fissure dissection [11]. However, we were able to demonstrate how MOB detachment, extradural work, and the anterior clinoidectomy can create ample room to compensate for these drawbacks. All these steps are key to provide enough surgical maneuverability through an already narrow craniotomy, such as the minipterional craniotomy. In contrast to previous discussions, obviating frontal lobe exposure might be advantageous as it reduces brain retraction and subsequent damage [30]. Moreover, Figueiredo et al. [17] noted that the greatest exposure could be obtained when the microsurgical dissection is continued posteriorly to the anterior ascending ramus. Thus, extended opening of the Sylvian fissure has no extra benefit. Alternative minimally invasive approaches such as the extended lateral supraorbital approach [4] require additional effort to retract the frontal lobe and to expose the paraclinoid region [30]. Additionally, the limited brain exposure and the linear opening of the dura reduce the risk of unintentional injury to the cortex. Clipping trough the extradural MPT approach can result particularly challenging when accessing aneurysms from the non-dominant hand side. We consider that the use of new-generation clip appliers and bayonet instruments, and anticipating the clip selection for each aneurysm are key to be successful in narrow craniotomies. Alternatively, minimal posterior enlargement of the craniotomy, respecting the superior temporal line superiorly, would enhance surgical maneuverability in non-dominant side, without excessively compromising esthetic results.

The extradural MPT craniotomy has some additional advantages. We already stressed the importance of the superior temporal line as the upper margin of the MPT craniotomy, since it constitutes a safety margin for undesirable frontal sinus violation [8]. Avoiding the frontal sinus reduces the incidence of cerebrospinal fluid leaks and potential infectious complications [16]. Likewise, when the skin incision is carried out anteriorly enough, there is no risk to inadvertently injure the superficial temporal artery. Lastly, diminishing muscle retraction also reduces temporal muscle atrophy [16, 40]. Damage of the frontal branch of the facial nerve and the temporalis muscle is common complications, likely underreported in most previous surgical series [28]. Submuscular and subfascial approaches were proposed as safer alternatives [2, 10, 37]. The use of these techniques reduces the risk of facial nerve palsy. However, this comes at the expense of anterior exposure especially when the temporal muscle is bulky [37]. Like Figueiredo et al., we use the interfascial dissection as it allows for better retraction of the temporal muscle, which provides more space for a more anteriorly placed craniotomy with good access to the sphenoid ridge [16]. All these steps are mandatory for opening a wide surgical corridor and being successful in accessing deeper lesions.

Besides the limitations (retrospective design, single-institution case series, lack of a control group), this work presents the extradural MPT technique as a valuable alternative in the treatment of paraclinoid aneurysms. Previous indications of the MPT craniotomy can be expanded to ruptured and large paraclinoid aneurysms.

Conclusion

As demonstrated from cadaveric studies and clinical data, the extradural MPT approach offers a feasible and safe "attack corridor" for paraclinoid region aneurysms. The limited brain exposure can be compensated by a sufficiently wide working angle that guarantees access to the vast majority of paraclinoid aneurysms.

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Compliance with ethical standards

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

Ethical approval and informed consent Informed consent and ethical approval were not deemed necessary by the local ethics in view of the design of the study (retrospective) and the application of strict patient privacy regulations operating in our center (cadavers were unidentified).

References

1. Ammirati M, Bernardo A (2007) Anatomical study of the superior orbital fissure as seen during a pterional approach. J Neurosurg 106(1):151–156
2. Ammirati M, Spallone A, Ma J, Cheatham M, Becker D (1993) An anatomicosurgical study of the temporal branch of the facial nerve. Neurosurgery 33(6):1038–1043 discussion 1044
3. Andrade-Barazarte H, Kivelev J, Goehre F, Jahromi BR, Hijazy F, Moliz N, Gauthier A, Kivisaari R, Jääskeläinen JE, Lehto H, Hernesniemi JA (2015) Contralateral approach to internal carotid artery ophthalmic segment aneurysms: angiographic analysis and surgical results for 30 patients. Neurosurgery 77(1):104–112 discussion 112
4. Andrade-Barazarte H, Jägersberg M, Belkhair S, Tymianski R, Turel MK, Schaller K, Hernesniemi JA, Tymianski M, Radovanovic I (2017) The extended lateral supraorbital approach and extradural anterior clinoidectomy through a frontopterio-orbital window: technical note and pilot surgical series. World Neurosurg 100:159–166
5. Badie B (1996) Cosmetic reconstruction of temporal defect following pterional [corrected] craniotomy. Surg Neurol 45(4):383–384
6. Beretta F, Andaluz N, Zuccarello M (2004) Aneurysms of the ophthalmic (C6) segment of the internal carotid artery: treatment options and strategies based on a clinical series. J Neurosurg Sci 48(4): 149–156
7. Chalouhi N, Jabbour P, Ibrahim I, Starke RM, Younes P, El Hage G, Samaha E (2013) Surgical treatment of ruptured anterior circulation aneurysms: comparison of pterional and supraorbital keyhole approaches. Neurosurgery 72(3):437–441 discussion 441-442
8. Chiarullo M, Mura J, Rubino P, Rabelo NN, Martinez-Perez R, Gadelha figueiredo E, Rhoton A (2019) Technical description of minimally invasive extradural anterior clinoidectomy and optic nerve decompression. Study of feasibility and proof of concept. World Neurosurg S1878875019314731
9. Conway JE, Raza SM, Li K, McDermott MW, Quiñones-Hinojosa A (2010) A surgical modification for performing orbitozygomatic osteotomies: technical note. Neurosurg Rev 33(4):491–500
10. Coscarella E, Vishteh AG, Spetzler RF, Seoane E, Zabramski JM (2000) Subfascial and submuscular methods of temporal muscle dissection and their relationship to the frontal branch of the facial nerve. Technical note. J Neurosurg 92(5):877–880
11. Davies JM, Lawton MT (2014) Advances in open microsurgery for cerebral aneurysms. Neurosurgery 74(Suppl 1):S7–S16
12. Dolenc VV (1999) A combined transorbital-transclinoid and transsylvian approach to carotid-ophthalmic aneurysms without retraction of the brain. Acta Neurochir Suppl 72:89–97
13. Durst CR, Starke RM, Gaughen J, Nguyen Q, Patrie J, Jensen ME, Evans AJ (2014) Vision outcomes and major complications after endovascular coil embolization of ophthalmic segment aneurysms. AJNR Am J Neuroradiol 35(11):2140–2145
14. Eroglu U, Shah K, Bozkurt M et al (2019) Supraorbital keyhole approach: lessons learned from 106 operative cases. World Neurosurg. https://doi.org/10.1016/j.wneu.2018.12.188
15. Esposito G, Dias SF, Burkhardt J-K, Fierstra J, Serra C, Bozinov O, Regli L (2019) Selection strategy for optimal keyhole approaches for middle cerebral artery aneurysms: lateral supraorbital versus minipterional craniotomy. World Neurosurg 122:e349–e357
16. Figueiredo EG, Deshmukh P, Nakaji P, Crusius MU, Crawford N, Spetzler RF, Preul MC (2007) The minipterional craniotomy: technical description and anatomic assessment. Neurosurgery 61(5 Suppl 2):256–264 discussion 264-265
17. Figueiredo EG, Deshmukh P, Zabramski JM, Preul MC, Crawford NR, Spetzler RF (2008) The pterional-transylvian approach: an analytical study. Neurosurgery 62(6 Suppl 3):1361–1367
18. Figueiredo EG, Teixeira MJ, Spetzler RF, Preul MC (2014) Clinical and surgical experience with the minipterional craniotomy. Neurosurgery 75(3):E324–E325
19. Figueiredo EG, Welling LC, Preul MC, Sakaya GR, Neville I, Spetzler RF, Teixeira MJ (2016) Surgical experience of minipterional craniotomy with 102 ruptured and unruptured anterior circulation aneurysms. J Clin Neurosci 27:34–39
20. Fukuda H, Evins AI, Burrell JC, Iwasaki K, Stieg PE, Bernardo A (2014) The meningo-orbital band: microsurgical anatomy and surgical detachment of the membranous structures through a frontotemporal craniotomy with removal of the anterior clinoid process. J Neurol Surg B Skull Base 75(2):125–132
21. Hakuba A, Nishimura S, Shirakata S, Tsukamoto M (1982) Surgical approaches to the cavernous sinus. Report of 19 cases (author's transl). Neurol Med Chir (Tokyo) 22(4):295–308
22. Heros RC (2011) The supraorbital "keyhole" approach. J Neurosurg 114(3):850–851 discussion 851
23. Iwasaki K, Toda H, Hashikata H, Goto M, Fukuda H (2018) Extradural anterior clinoidectomy and optic canal unroofing for paraclinoid and basilar aneurysms: usefulness of a no-drill instrumental method. Acta Neurochir Suppl 129:39–42
24. Kim JM, Romano A, Sanan A, van Loveren HR, Keller JT (2000) Microsurgical anatomic features and nomenclature of the paraclinoid region. Neurosurgery 46(3):670–680 discussion 680-682
25. Komatsu F, Komatsu M, Inoue T, Tschabitscher M (2011) Endoscopic extradural anterior clinoidectomy via supraorbital

keyhole: a cadaveric study. Neurosurgery 68(2 Suppl Operative): 334–338 discussion 337-338

26. Krayenbühl N, Isolan GR, Hafez A, Yaşargil MG (2007) The relationship of the fronto-temporal branches of the facial nerve to the fascias of the temporal region: a literature review applied to practical anatomical dissection. Neurosurg Rev 30(1):8–15 discussion 15
27. Martínez-Pérez R, Hernández-Álvarez V, Maturana R, Mura JM (2019) The extradural minipterional pretemporal approach for the treatment of spheno-petro-clival meningiomas. Acta Neurochir 161:2577–2582. https://doi.org/10.1007/s00701-019-04064-3
28. Mathias RN, Lieber S, de Aguiar PHP, Maldaun MVC, Gardner P, Fernandez-Miranda JC (2016) Interfascial dissection for protection of the nerve branches to the frontalis muscles during supraorbital trans-eyebrow approach: an anatomical study and technical note. J Neurol Surg B Skull Base 77(3):265–270
29. Mattingly T, Kole MK, Nicolle D, Boulton M, Pelz D, Lownie SP (2013) Visual outcomes for surgical treatment of large and giant carotid ophthalmic segment aneurysms: a case series utilizing retrograde suction decompression (the "Dallas technique"). J Neurosurg 118(5):937–946
30. Mura J, de Oliveira E (2017) Letter to the editor regarding "The Extended Lateral Supraorbital Approach and Extradural Anterior Clinoidectomy Through a Frontopterio-Orbital Window: Technical Note and Pilot Surgical Series.". World Neurosurg 107: 1035
31. Nathal E, Gomez-Amador JL (2005) Anatomic and surgical basis of the sphenoid ridge keyhole approach for cerebral aneurysms. Neurosurgery 56(1 Suppl):178–185 discussion 178-185
32. Natori Y, Rhoton AL (1995) Microsurgical anatomy of the superior orbital fissure. Neurosurgery 36(4):762–775
33. Rouchaud A, Brinjikji W, Lanzino G, Cloft HJ, Kadirvel R, Kallmes DF (2016) Delayed hemorrhagic complications after flow diversion for intracranial aneurysms: a literature overview. Neuroradiology 58(2):171–177
34. Rychen J, Croci D, Roethlisberger M, Nossek E, Potts M, Radovanovic I, Riina H, Mariani L, Guzman R, Zumofen DW (2018) Minimally invasive alternative approaches to pterional craniotomy: a systematic review of the literature. World Neurosurg 113:163–179
35. Serrano LE, Archavlis E, Ayyad A, Schwandt E, Nimer A, Ringel F, Kantelhardt SR (2019) Comprehensive anatomic assessment of ipsilateral pterional versus contralateral subfrontal approaches to the internal carotid ophthalmic segment: a cadaveric study and three-dimensional simulation. World Neurosurg 128:e261–e275
36. Sherif C, Gruber A, Dorfer C, Bavinzski G, Standhardt H, Knosp E (2009) Ruptured carotid artery aneurysms of the ophthalmic (C6) segment: clinical and angiographic long term follow-up of a multidisciplinary management strategy. J Neurol Neurosurg Psychiatry 80(11):1261–1267
37. Spetzler RF, Lee KS (1990) Reconstruction of the temporalis muscle for the pterional craniotomy. Technical note. J Neurosurg 73(4): 636–637
38. Sturiale CL, La Rocca G, Puca A, Fernandez E, Visocchi M, Marchese E, Sabatino G, Albanese A (2017) Minipterional craniotomy for treatment of unruptured middle cerebral artery aneurysms. A single-center comparative analysis with standard pterional approach as regard to safety and efficacy of aneurysm clipping and the advantages of reconstruction. Acta Neurochir Suppl 124:93–100
39. Turner RD, Byrne JV, Kelly ME, Mitsos AP, Gonugunta V, Lalloo S, Rasmussen PA, Fiorella D (2008) Delayed visual deficits and monocular blindness after endovascular treatment of large and giant paraophthalmic aneurysms. Neurosurgery 63(3):469–474 discussion 474-475
40. Welling LC, Figueiredo EG, Wen HT, Gomes MQT, Bor-Seng-Shu E, Casarolli C, Guirado VMP, Teixeira MJ (2015) Prospective randomized study comparing clinical, functional, and aesthetic results of minipterional and classic pterional craniotomies. J Neurosurg 122(5):1012–1019
41. Yagmurlu K, Safavi-Abbasi S, Belykh E, Kalani MYS, Nakaji P, Rhoton AL, Spetzler RF, Preul MC (2017) Quantitative anatomical analysis and clinical experience with mini-pterional and mini-orbitozygomatic approaches for intracranial aneurysm surgery. J Neurosurg 127(3):646–659
42. Yasargil MG, Fox JL (1975) The microsurgical approach to intracranial aneurysms. Surg Neurol 3(1):7–14
43. Yaşargil MG, Reichman MV, Kubik S (1987) Preservation of the frontotemporal branch of the facial nerve using the interfascial temporalis flap for pterional craniotomy. Technical article. J Neurosurg 67(3):463–466