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ORIGINAL ARTICLE - TUMOR - MENINGIOMA

Endoscopic endo- and extra-orbital corridors for spheno-orbital region: anatomic study with illustrative case

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Abstract

Background and objective Management of selected spheno-orbital meningiomas via the endoscopic transorbital route has been reported. Surgical maneuverability in a narrow corridor as that offered by the orbit may be challenging. We investigate the additional use of an extra-orbital (EXO) path to be used in combination with the endo-orbital (EO) corridor.

Material and methods Three human cadaveric heads (six orbits) were dissected at the Laboratory of Surgical Neuroanatomy at the University of Barcelona. The superior eyelid endoscopic transorbital approach was adopted, introducing surgical instruments via both corridors. Surgical freedom analysis was run to determine directionality of each corridor and to calculate the surgical maneuverability related to three anatomic targets: superior orbital fissure (SOF), foramen rotundum (FR), and foramen ovale (FO). We also reported of a 37-year-old woman with a spheno-orbital meningioma with hyperostosis of the lateral wall of the right orbit, treated with such combined endo-orbital and extra-orbital endoscopic approach.

Results Combining both endo-orbital and extra-orbital corridors permitted a greater surgical freedom for all the targets compared with the surgical freedom of each corridor alone (EO + EXO to SOF: 3603.8 $mm^2 \pm 2452.5$ mm^2; EO + EXO to FR: 1533.0 $mm^2 \pm 892.2$ mm^2; EO + EXO to FO: 1193.9 $mm^2 \pm 782.6$ mm^2). Analyzing the extra-orbital pathway, our results showed that the greatest surgical freedom was gained in the most medial portion of the considered area, namely the SOF (1180.5 $mm^2 \pm 648.3$ mm^2). Regarding the surgical case, using both pathways, we gained enough maneuverability to nearly achieve total resection with no postoperative complications.

Conclusion An extra-orbital corridor may be useful to increase the instruments' maneuverability, during a pure endoscopic superior eyelid approach, and to reach the most medial portion of the surgical field from a lateral-to-medial trajectory. Further studies are needed to better define the proper indications for such strategy.

Keywords Endoscopic transorbital · Extra-orbital corridor · Superior eyelid approach · Spheno-orbital meningiomas · Skull base surgery

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Introduction

Spheno-orbital meningiomas (SOMs) arise from the dura mater covering the sphenoid wing, representing approximately 9% of all the intracranial meningiomas [3, 9, 24, 25, 38, 42]. Typically, these tumors present two components: a meningeal "en plaque" mass and a hyperostotic part, the latter resulting from the pathological modification of the bone at the tumor attachment level. The hyperostosis can be quantitatively more representative than the tumor itself and it may be responsible for the patient's symptoms. Patients suffering of spheno-orbital meningiomas typically present with proptosis, visual impairment, and ocular movement disorders as well as headache to be mostly addressed to the presence of the hyperostotic bone.

Nowadays, transcranial approaches represent the most viable surgical routes for the treatment of SOMs, however being burdened by a certain risk of perioperative and/or postoperative complications, mainly related to brain manipulation and retraction [24, 26]. Open craniotomy approaches were employed to reach regions of anterior and middle cranial fossa, and only in the last decades, thanks to refinements of the surgical techniques and technological advancements, endo-orbital corridors and several different procedures were described [7, 34, 40, 41, 49].

During the last decades, minimally invasive endoscopic and ventral approaches have been emerging as a valid option for the management of skull base tumors, according to the concept of "keyhole" surgery [12, 13]. The advantages of these procedures reside primarily on the avoidance of brain manipulation, thus reducing potential approach-related morbidity and, furthermore, dealing directly with the tumor and its attachment. Eventually, this leads to obtain an early tumor devascularization, very useful when performing meningioma surgery.

Endoscopic endonasal approaches thoroughly fit this scenario and currently can be considered among the strategies of surgical treatment for the management of several skull base tumors [35, 45, 48]. Although recent extension toward lateral aspects of the ventral skull base, different tumors originating far off the paramedian areas are not amenable to the endonasal corridor.

For these reasons, the endoscopic superior eyelid transorbital approach has been gaining ground recently for the management of selected lateral skull base lesions [4, 14–16, 28, 39, 50]. Different anatomic studies have demonstrated that the orbit is a possible route to get to anatomical regions such as anterior cranial fossa, middle cranial fossa, lateral cavernous sinus up to the petrous apex region in a minimally invasive fashion [4, 10, 11, 15, 23, 27, 37]. Besides, the feasibility and safety of the purely endoscopic endo-orbital approach has been proven in selected spheno-orbital meningiomas [16, 50].

However, it must be taken into account that the surgical corridor is quite narrow and this could hinder surgical maneuverability, especially at the deepest portion of surgical field [36]. Some authors have reported different modifications of this approach in order to overcome the spatial limitation of the surgical field [5, 7, 21, 37].

Having in mind this background, we present a technical variation of the purely endo-orbital endoscopic superior eyelid approach taking advantage of an extra-orbital pathway, underneath the temporalis muscle and lateral to the orbital rim that has been preserved. The aim is to get an extra space and to create a lateral-to-medial pathway that may be useful for reaching the most medial portion of the surgical field. Anatomical quantitative analysis of the surgical freedom is provided and, accordingly, we report of a case of spheno-orbital meningioma who was treated with such combined endo-orbital and extra-orbital endoscopic approach.

Materials and methods

Anatomic dissection

Anatomic dissections were performed at the Laboratory of Surgical Neuroanatomy of the Human Anatomy and Embryology Unit, University of Barcelona (Barcelona, Spain), on three embalmed cadaveric heads (six orbits), where the arterial system had been injected with red latex. This study was approved by the IRB of the University of Barcelona.

Endoscopic transorbital approaches were performed using a rigid 4-mm-diameter endoscope, 18 cm long, with a 0° and 30° rod lens (Karl Storz). The endoscope was connected to a light source (300 W Xenon, Karl Storz) through a fiber optic cable and to a high-definition camera (Endovision Telecam SL; Karl Storz).

Prior to the dissection, all specimens underwent a multislice helical computed tomography (CT) scan (Siemens SOMATOM Sensation 64, Malvern, PA) with 0.6-mm-thick axial spiral sections and 0° gantry angle. Five screws were implanted in the specimen's skull as permanent bone reference markers to allow co-registration with the neuronavigation system. Imaging data were transferred to the laboratory navigation-planning workstation and point registration was performed. A registration correlation tolerance of 2 mm was considered acceptable.

Endoscopic superior eyelid approach—endo-orbital corridor

Endoscopic superior eyelid transorbital approach to the middle cranial fossa was performed as already described in previous reports, published in the pertinent literature [4, 15, 19]. A skin incision was made through one eyelid wrinkle and extended laterally beyond the lateral canthal angle—the lateral

extent was meant to realize the extra-orbital corridor. The incision in this region was planned to be as horizontal as possible, according to the relative "safety zone" free of nerve branches (max 2.5 cm off the lateral canthus) [1, 44]. The orbicularis oculi muscle was spared, and the dissection continued in a plane between the orbicularis oculi and the underlying orbital septum.

The skin-muscle flap was raised superolaterally until the lateral bony orbital rim and frontozygomatic suture were identified. The dissection proceeded in subperiosteal and subperiorbital plane (the periosteum continues with the periorbital layer inside the orbital cavity) and orbital contents covered by the periorbit were displaced medially. From this point, the endoscope was inserted into the field: superior and inferior orbital fissures were the relevant anatomic landmarks.

Extensive drilling of the greater sphenoid wing and lesser sphenoid wing was performed until middle cranial fossa dura was reached. Once the temporal pole dura was reached, extradural dissection allowed to reach the middle cranial base floor and the anatomical targets, i.e., foramen rotundum and foramen ovale.

Endoscopic superior eyelid approach—extra-orbital corridor

The extra-orbital corridor was obtained extending laterally the superior eyelid incision in order to expose the anterior and superior portions of the temporalis muscle. Subperiosteal dissection of the temporalis muscle was performed until the extracranial surface of the greater sphenoid wing and the pterion were exposed [1, 44].

Afterwards, instruments were inserted underneath the temporalis muscle, laterally, and the zygomatic bone/greater sphenoid wing, medially, without detaching the muscle from its natural insertion on the superior temporal line (Figs. 1, 2, and 3). The orbit was entered via its lateral wall, namely the lateral aspect of the greater sphenoid wing.

Quantitative analysis

To determine the surgical freedom and the possible gain/improvement of the extra-orbital corridor when used in combination with the endo-orbital—according also to their different trajectories (straight the endo-orbital, lateral-to-medial the extra-orbital), we selected three key anatomic targets, oriented in a medial-to-lateral direction, the superior orbital fissure (SOF), foramen rotundum (FR), and foramen ovale (FO). Surgical freedom analysis was performed as previously described in the pertinent literature [17, 18, 22, 32]. For each point, we assessed the surgical freedom by fixing the tip of a straight instrument on the target point and moving its handle in four directions, superior, inferior, medial, and lateral, until the movement was hindered by a deep or superficial obstacle. Each position reached was registered with the neuronavigation pointer, placed on the distal end of the instrument handle, and Cartesian coordinates of each point were registered. Thus, we obtained three areas via both the two corridors, endo-orbital and extra-orbital. The assessment of the surgical freedom was then achieved and compared. Reference value to which comparison can be made is represented by the entire surface of a sphere whose radius corresponds to the length of the instrument used (i.e., 180 mm).

An additional area, represented by the arithmetic sum of surgical freedom areas calculated with both the endo-orbital and extra-orbital corridor, was considered as well for each target (SOF, FR, FO).

The virtual three-dimensional model of the surgical freedom related to each route was created using Amira 3D for life sciences (ThermoFisher Scientific, Hillsboro, OR, USA). Bony structures were segmented, and surgical freedom areas were then represented using advanced instruments for measurement and quantification provided by the Amira workstation.

All data were uploaded into Microsoft Excel, and the paired Student *t* test function was used to calculate statistical differences among approaches ($p < 0.01$ was considered as statistically significant).

Volumetric analysis

Volumetric analysis of tumor and bone removal, after surgical procedure, was achieved by means of BrainLab® software. First, tumor and hyperostotic bone volumes were calculated on the preoperative MRI and CT scans, respectively. Then we calculated the volume of tumor and hyperostotic bone removed using the postoperative MRI and CT scans, respectively. Finally, we calculated the extent of removal by comparing the post- and preoperative volumes and expressed the results as percentage.

Results

Surgical freedom evaluation

Our results showed that endo-orbital corridor offers a greater surgical freedom for all the targets considered when compared with the extra-orbital corridor. Such results did not reach a statistical significance. In particular, the surgical freedom analysis showed the following results that are summarized in Table 1: superior orbital fissure (2423.31 $mm^2 \pm 2104.8$ mm^2 vs 1180.5 $mm^2 \pm 648.3$ mm^2); foramen rotundum (1066.4 $mm^2 \pm 844.6$ mm^2 vs 466.5 $mm^2 \pm 132.1$ mm^2); and foramen ovale (731.0 $mm^2 \pm 619.2$ mm^2 vs 462.9 $mm^2 \pm 291.6$ mm^2).

For the extra-orbital corridor, surgical freedom at the level of the superior orbital fissure, which is located at the most

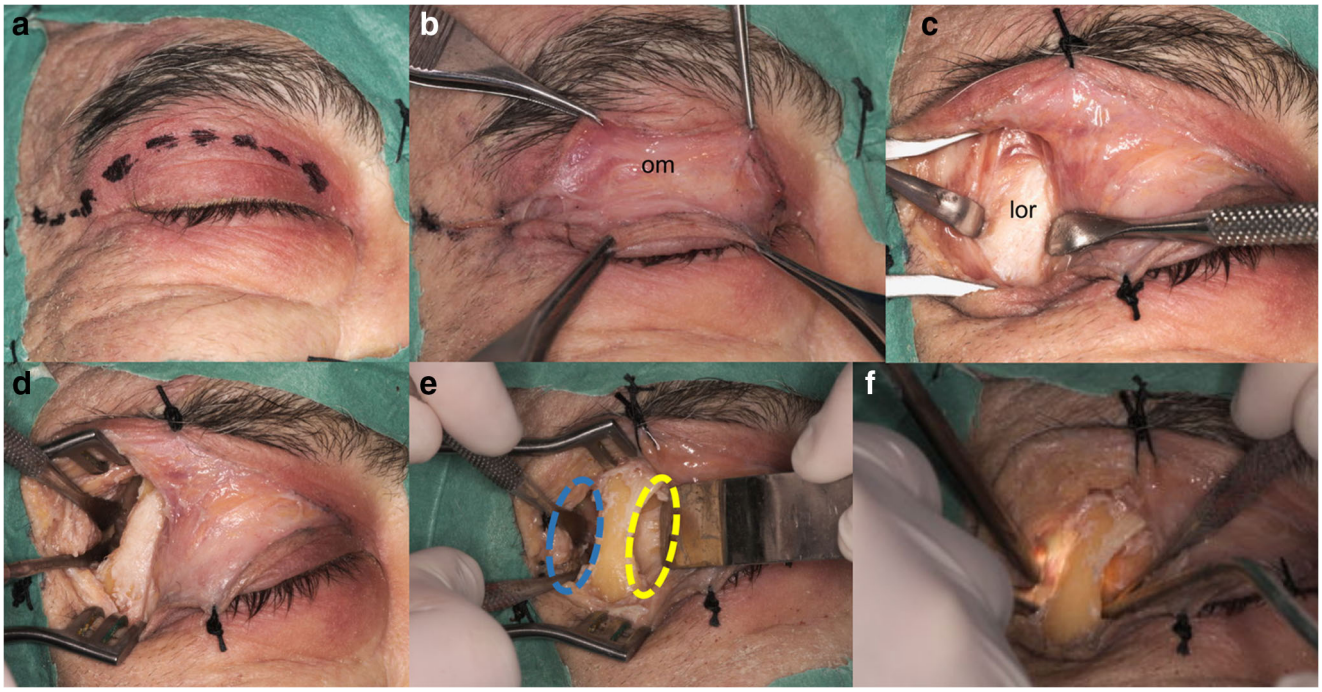

Fig. 1 Palpebral phase. Superior eyelid incision is marked from the median aspect of the superior eyelid to the lateral aspect of the lateral canthus and extended superiorly, in a curved shape (**a**). Skin incision continues until orbicular muscle is identified (**b**) then dissection proceeds along his fibers, into a preseptal orbital plane. Lateral orbital rim is then identified and completely skeletonized (**c**, **d**). Medial endo-orbital (yellow dotted line) and lateral extra-orbital (blue dotted line) corridors are identified (**e**, **f**). om orbicularis muscle, lor lateral orbital rim

medial aspect of the area we considered, was the greatest compared to the other targets (SOF: 1180.5 $mm^2 \pm 648.3$ mm^2; FR: 466.5 $mm^2 \pm 132.1$ mm^2; FO: 462.9 $mm^2 \pm 291.6$ mm^2).

Finally, the sum of surgical freedom areas obtained for each target, with the endo- (EO) and extra-orbital (EXO) corridors, was greater when compared to the each single corridor alone ($SOF_{(eo + exo)}$: 3603.8 $mm^2 \pm 2452.5$ mm^2; $FR_{(eo + exo)}$: 1533.0 $mm^2 \pm 898.2$ mm^2; $FO_{(eo + exo)}$: 1193.9 $mm^2 \pm 782.6$ mm^2).

Three-dimensional representative reconstructions of the surgical freedom calculated at these three middle cranial fossa targets (superior orbital fissure, foramen rotundum, and foramen ovale, via both endo-orbital and extra-orbital corridors) have been provided (Figs. 4 and 5).

Case report

A 37-year-old woman complaining of a 4-month history of right eye proptosis was diagnosed of a spheno-orbital meningioma. Upon the admission at the Division of Neurosurgery of the University of Naples "Federico II," neurological examination showed slight right proptosis, lateral nystagmus, and hypoesthesia along the territory of distribution of the ophthalmic branch of the trigeminal nerve, while visual acuity and visual field were preserved (Fig. 6).

MRI scans demonstrated a mass expanding from the greater and lesser sphenoid wing with infiltration of the superior orbital fissure and expansion into the homolateral cavernous sinus. Computed tomography scans demonstrated signs of hyperostosis of the greater and lesser sphenoid wings (Fig. 7).

Accordingly, we proposed surgical treatment of the lesion via an endoscopic superior eyelid transorbital approach.

Surgical procedure

The patient was placed supine under general anesthesia, with her head slightly elevated and fixed with a Mayfield head holder. A protective antibiotic ointment was placed in both eyes. An endoscopic superior eyelid transorbital approach was performed. The procedure started with a skin incision of approximately 2.5 cm in length, at the level of an eyelid wrinkle. The orbicularis muscle was reached and dissected along his fibers so that a skin-muscle flap was obtained and raised superolaterally. The skin incision was extended more laterally than the standard, endo-orbital, approach and the detachment of the temporalis muscle fascia from the lateral orbital rim was achieved. The lateral orbital rim was completely skeletonized, up to the lateral canthal tendon. With a malleable retractor, the periorbita was retracted inferomedially to create a subperiorbital plane of dissection and an endo-orbital corridor in which the endoscope could be inserted. With the lateral retraction of the temporalis muscle, a lateral extra-orbital

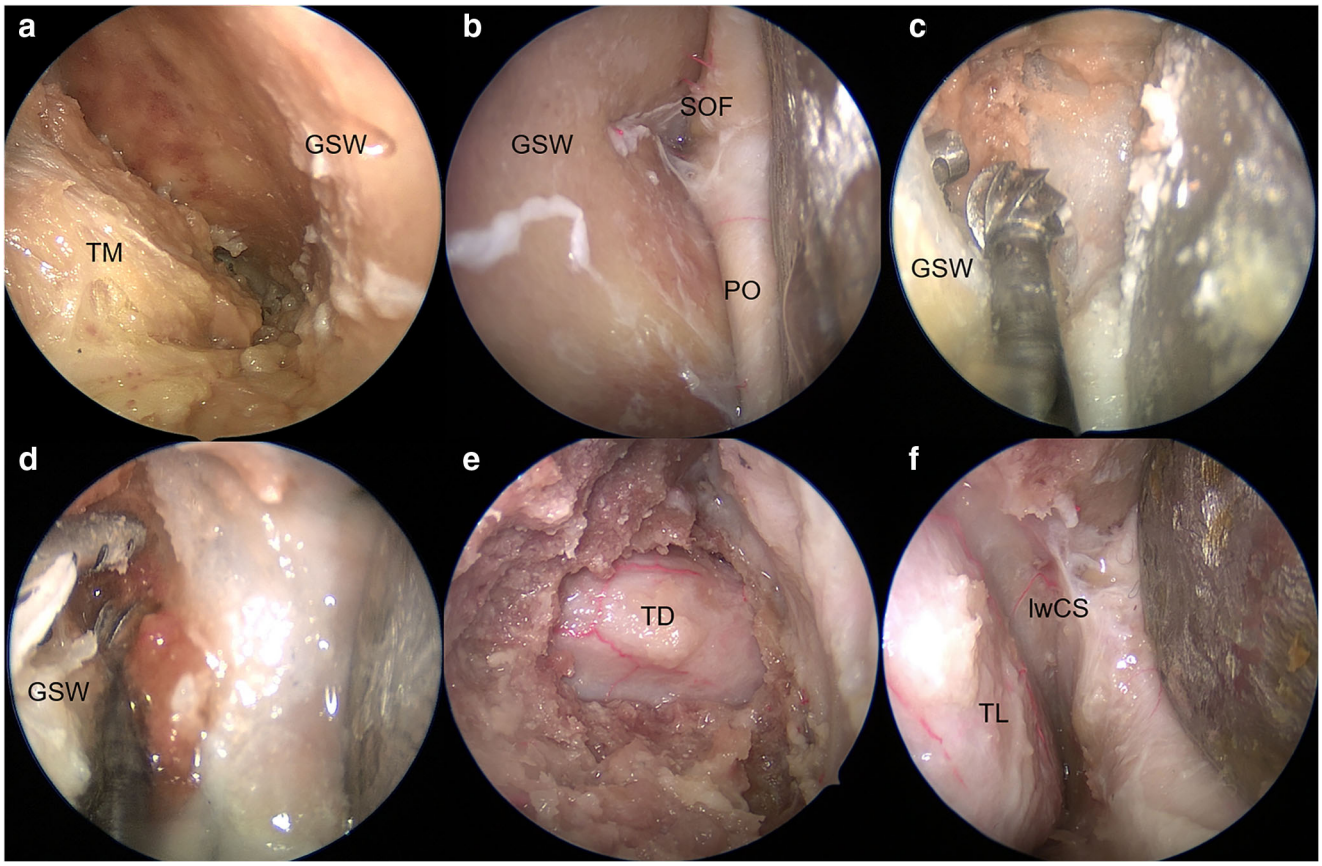

Fig. 2 Endoscopic view of the extra-orbital corridor after lateral retraction of temporalis muscle (**a**). Endoscopic view showing endo-orbital corridor and landmarks, after inferomedial retraction of the periorbit (**b**). Both corridors are used to reach middle cranial fossa and expose lateral wall of the cavernous sinus (**c**–**f**). GSW greater sphenoid wing, lwCS lateral wall of the cavernous sinus, PO periorbit, SOF superior orbital fissure, TD temporal dura, TL temporal lobe, TM temporalis muscle

corridor was also created (Fig. 8). In order to avoid ophthalmologic complications due to compression of the optic nerve, intermittent relief from retraction of the periorbit was applied during surgery and maximum limit for retraction of the globe was set at < 10 mm, as reported by previous publications [8, 34, 36].

Exposure and drilling of the hyperostotic bone was achieved via both endo-orbital and extra-orbital corridor; afterwards, dura of the middle cranial fossa was reached and the dural attachment of the tumor was coagulated. The intracranial portion of the meningioma was then resected (Fig. 9).

The dural defect was filled with dural substitute layers and Tisseel glue (Baxter®). The empty spaces, left by the drilling of the hyperostotic bone, were filled with a fat graft, harvested from the abdomen's patient (Video 1). Referring to the volumetric analysis, we found a preoperative volume of the hyperostotic bone of 20,113 cm^3 with a postoperative amount of bone removed corresponding to a volume of 13,612 cm^3, with a percentage of bone removal of 67.67%. Preoperative volume of the *en-plaque* tumor was 4,100 cm^3 while the volume of tumor removed was 2,076 cm^3, with a percentage of tumor resection of 50.63% (Fig. 10).

No substantial modifications of the clinical scenario occurred, and patient was discharged at POD#4. Risk of orbital complications (enophthalmos, ptosis, epiphora, necrosis of the superior eyelid, diplopia, V1 and V2 hypoesthesia, periorbital emphysema, soft tissue edema) has been reported after endoscopic transorbital approach [16, 28, 34, 39]. In recent series, it has been reported a 0.72% of enophthalmos. Indeed, in 2010, Moe et al. described 20 cases of different pathologies managed with a pure endoscopic transorbital approaches with 1 patient developing postoperative enophthalmos. In 2016, Ramakrishna et al., in a follow-up of the original study of Moe, presented 40 cases treated with pure endoscopic transorbital approach with 3 of them complaining persistent complications (enophthalmos, ptosis, and epiphora). Dallan et al. presented a series of 14 patients with SOM, 9 of which were treated with a purely endoscopic superior eyelid approach with none of them presenting enophthalmos. Finally, Kong et al. recently published a case series of 18 patients, 14 of which were treated with pure endoscopic transorbital

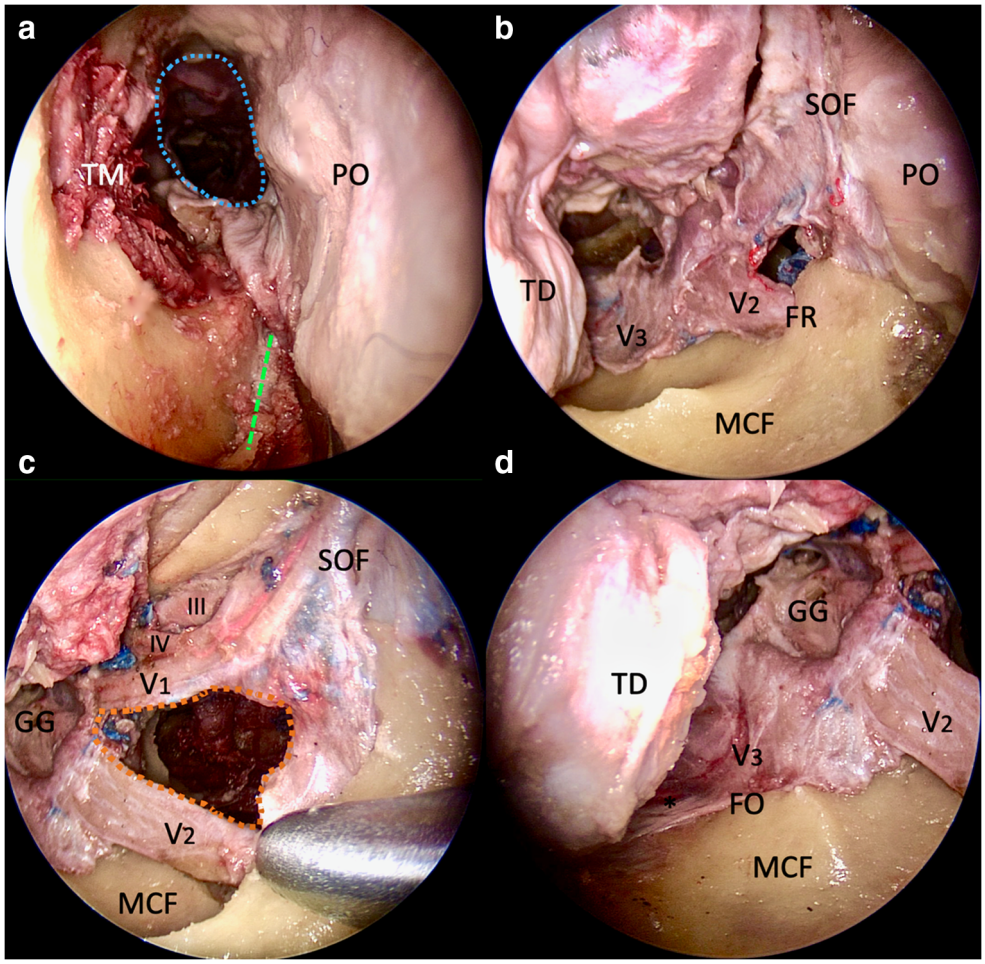

Fig. 3 Endoscopic transorbital approach to the cavernous sinus. Right side, cadaveric dissection. Exposure of the inferior orbital fissure (IOF, dotted green line) via the endo-orbital corridor (**a**); the IOF represents the inferior limit of the transorbital middle fossa approach. Complete exposure of the cavernous sinus lateral wall (**b**); the superior orbital fissure, foramen rotundum, and foramen ovale (mandibular branch of the trigeminal nerve entering the foramen ovale) are visible. The endoscope can be inserted in the exo-orbital corridor, thus obtaining a more lateral-to-medial view of the cavernous sinus (**c**); a dissector is inserted in the endo-orbital corridor and is pointing at the foramen rotundum; the orange dotted line indicates the anteromedial triangle of the cavernous sinus. With the endoscope placed in the exo-orbital corridor and the lens turned downward, a close-up view of the foramen ovale, located medially to the middle meningeal artery (*), can be obtained (**d**). TM: temporal muscle; PO: periorbit; TD: temporal dura; V1-V2-V3: trigeminal nerve branches; SOF: superior orbital fissure; FR: foramen rotundum; FO: foramen ovale; GG: gasserian ganglion; MCF: middle cranial fossa floor; III: third cranial nerve; IV: fourth cranial nerve; asterisk: middle meningeal artery; blue dotted line: middle fossa approach via the transorbital route; dotted green line: inferior orbital fissure; orange dotted line: anteromedial triangle of the cavernous sinus

approach with 9 of them patients complaining postoperative transient ptosis, but no case of enophthalmos was reported. A late postoperative ophthalmological evaluation, with a computerized visual field evaluation and a Hess-Lancaster test, confirmed the absence of deficits of the visual acuity, extrinsic eye muscles, and orbicularis muscle (Fig. 11). Early postoperative CT and 3-month MRI scans confirmed subtotal removal of the "en plaque" portion of the tumor and extensive removal of the hyperostotic bone. Although we could not get a quantitative assessment of the degree of preoperative exophthalmos and so a quantification of the amount of correction, patient's proptosis clinically improved during the follow-up and 6-month MRI did not show radiological signs of progression of the residual lesion (Fig. 12).

Discussion

First of all, results of surgical freedom showed that endo-orbital corridor offers the greatest surgical freedom for all the targets considered.

Secondly, among the areas calculated for the extra-orbital corridor, the surgical freedom at the level of the superior orbital fissure, which is located at the most medial aspect of the area we considered, was the greatest.

Thirdly, it stands clear that the sum of surgical freedom areas obtained for each target, with the EO and EXO corridors, was greater.

Discussing our first result, it has to be highlighted that starting from an anatomical scenario, recent experience

Table 1 Quantitative analysis of surgical freedom obtained for endo-orbital and extra-orbital corridors to specific anatomic targets, i.e., superior orbital fissure (SOF), foramen rotundum (FR), and foramen ovale (FO)

	Endo-orbital (EO) [mean (SD) mm^2]	Extra-orbital (EXO) [mean (SD) mm^2]	Combined endo-orbital + extra-orbital (EO + EXO: COM) [mean (SD) mm^2]	EO vs COM	EXO vs COM	EO vs EXO
Superior orbital fissure (SOF)	2423.31 (2104.8)	1180.5 (648.3)	3603.8 (2452.5)	*t*-Stu, 0.8168	*t*-Stu, 21361	*t*-Stu, 12618
				df, 8	*df*, 8	*df*, 8
				p, 0.4377	*p*, 0.0652	*p*, 0.24
Foramen rotundum (FR)	1066.4 (844.6)	466.5 (132.1)	1533.0 (898.2)	*t*-Stu, 0,8461	*t*-Stu, 26267	*t*-Stu, 15692
				df, 8	*df*, 8	*df*, 8
				p, 0.4221	*p*, 0.0303	*p*, 0.15
Foramen ovale (FO)	731.0 (619.2)	462.9 (291.6)	1193.9 (782.6)	*t*-Stu, 10373	*t*-Stu, 19572	*t*-Stu, 0.8758
				df, 8	*df*, 8	*df*, 8
				p, 0.3299	*p*, 0.0860	*p*, 0.40

SD standard deviation, *t-Stu t* value of the Student *t* test, *df* degree of freedom

confirmed the possibility of extending the areas explored through the endoscopic endo-orbital approach reaching the cavernous sinus [15]. This was achieved by means of an interdural dissection of the meningo-orbital band without the need to enter the cavernous sinus' venous compartment and thus potentially avoiding massive bleedings. Then, case series have been reported of intracranial lesions with or without extension into the cavernous sinus managed with a pure endo-orbital approach [16, 28, 29] demonstrating the feasibility of treating such lesions even with a good hemostasis control, avoiding postoperative complications. It has to be underlined that, at the authors' best knowledge, only one case of fibrous dysplasia, treated with a multiportal combined endoscopic endonasal and transorbital approach, has been reported in literature with a clear example of a good control of hemostasis in the cavernous sinus region by means of a small amount of FloSeal (Baxter International Inc., Deerfield, IL, USA) [47]. We are perfectly acknowledged that hemostasis control in this critical area still remains an important issue in the neurosurgical *scenario*. Furthermore, it should be stressed that even if the route to access the cavernous sinus region is full of critical neurovascular structure, the presence of a lesion dislocating such structures could "make the route" by itself, providing the surgeon more maneuverability. However, even if the results of surgical freedom analysis of the present study showed that endo-orbital corridor offers the greatest surgical freedom for all the targets considered, it has to be said that the endo-orbital corridor is narrow, and overcrowding this space with surgical instruments may be a relevant problem during this kind of surgery, further limited by the lateral orbital rim. Accordingly, in this paper, with the aim of overcoming these limitations and concurrently to gain further maneuverability without removing the lateral orbital rim, we focused our attention to the possibility of extending our approach laterally, taking advantage of an extra-orbital corridor, between the temporal muscle (laterally) and the orbital rim (medially).

Although not statistically significant, our data related to the second main result herewith presented showed that the greater maneuverability for the extra-orbital corridor is offered when SOF is reached, which means that this corridor can provide a better maneuverability of instruments when the most medial target is reached with a lateral-to-medial trajectory (1180.5 $mm^2 \pm 648.3$ mm^2 for SOF; 466 $mm^2 \pm 132.1$ mm^2 for FR; 462.9 $mm^2 \pm 291.6$ mm^2 for FO). Of utmost interest, these two corridors provide the surgeon with different instrumental trajectories to the middle fossa. Indeed, while the endo-orbital corridor allows for a straight dissection, the extra-orbital path permits to achieve a more lateral-to-medial trajectory that can be useful to work medially, i.e., near the superior orbital fissure.

Thirdly, when applied together, the two corridors provide the surgeon with greater spaces for instrument insertion and dissection compared with each corridor when used alone. This

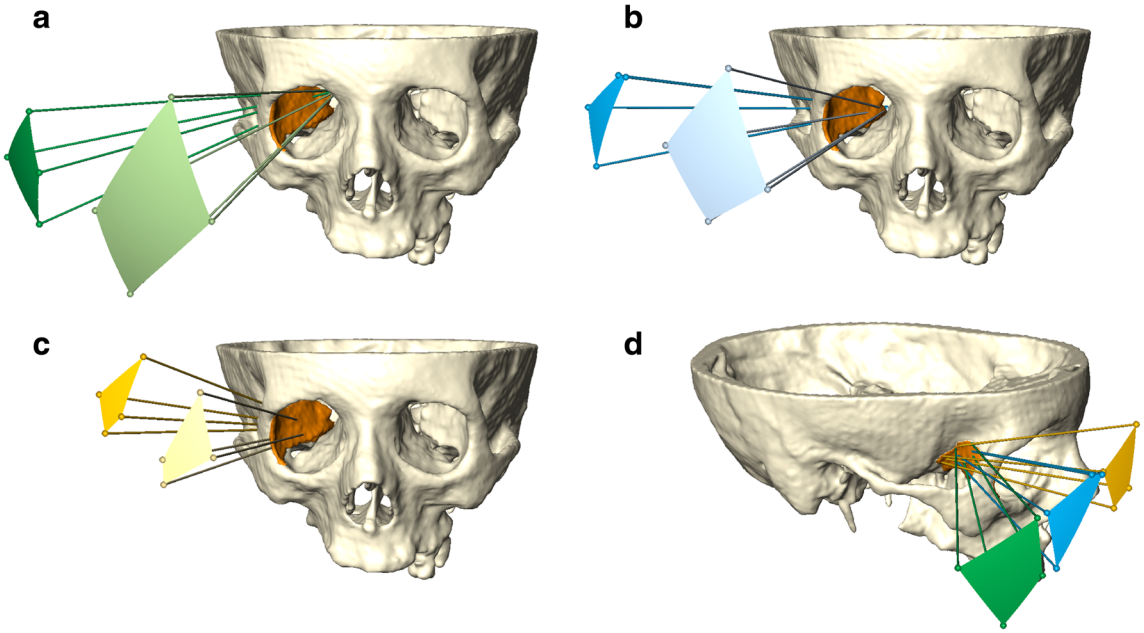

Fig. 4 Three-dimensional reconstruction of the surgical freedom calculated at three middle cranial fossa targets: superior orbital fissure (**a**), foramen rotundum (**b**), and foramen ovale (**c**), via both endo-orbital and extra-orbital corridors. Pictures are obtained with Amira

implies that the greater maneuverability can be gained when the two corridors are used simultaneously, without the need of removing the lateral orbital rim.

Backing upon our findings in the cadaveric dissection, we applied such novel approach, as a "proof of principle," in a patient with a spheno-orbital meningioma. Surgical management of these kinds of tumors has been traditionally achieved by means of open transcranial approaches, i.e., pterional approach, fronto-temporal approach, and fronto-orbito-zygomatic approach, with already described outcome and complications [2, 33, 43, 46]. Minimally invasive approaches have been suggested recently like transorbital extradural approach [30], lateral orbitotomy, with or without removal of lateral orbital rim [6, 31], and, more recently, pure endoscopic transorbital approaches via the superior eyelid approach [28]. These minimally invasive approaches offer the chance of avoiding some complications related to open craniotomy with the main disadvantage of working in a narrow space, with a subsequent limitation of the surgical maneuverability. The goal of our surgery was tailored on patient's symptom, which was right eye proptosis due to hyperostosis associated with the spheno-orbital meningioma, which, in reverse, was very small in size. We planned our surgery in order to relieve patient's symptoms being less

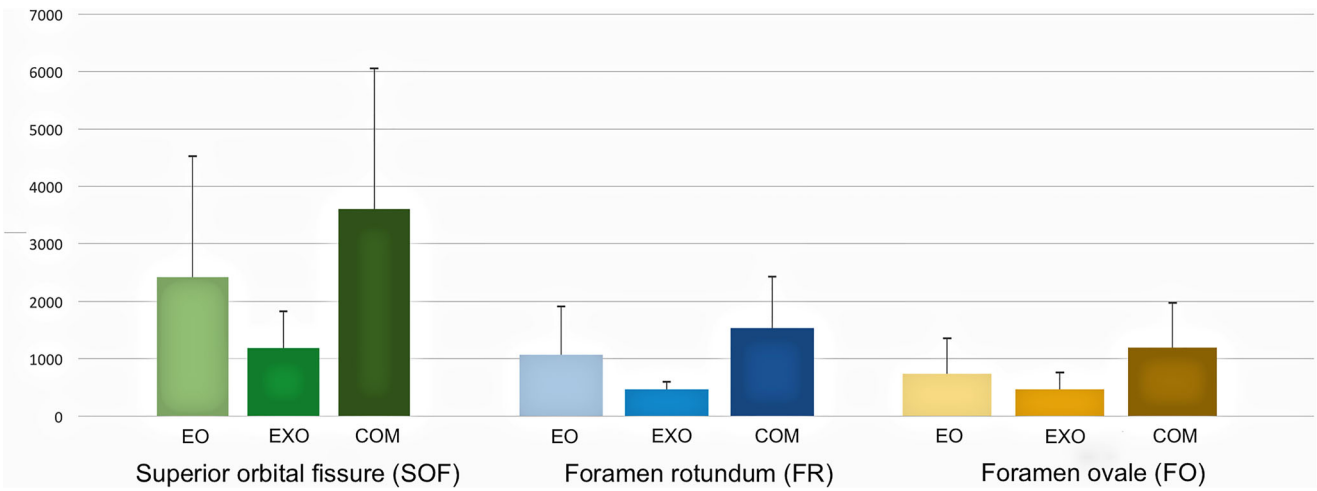

Fig. 5 Graph showing results of surgical freedom (expressed in mm^2) calculated at three middle cranial fossa targets, superior orbital fissure (SOF, represented in green), foramen rotundum (FR, represented in blue), and foramen ovale (FO, represented in brown) for the endo-orbital corridor (EO), the extra-orbital corridor (EXO) and for the two corridors combined (COM)

Fig. 6 Preoperative pictures showing right eye proptosis

invasive as we could. So, in line with recent literature, which proposes the endoscopic transorbital approach as a valid option in the management of these kinds of tumors, and in line with surgeon's experience in endoscopic surgery, we decided to approach the lesion by means of an endo-orbital endoscopic approach. As described in the case report section, in order to overcome the main limitation offered by this approach and so to get an extra-space during the neuroendoscopic surgery, we used the extra-orbital corridor in addition to the endo-orbital one. The extra-orbital corridor allowed us to introduce one instrument in the surgical field with a lateral-to-medial trajectory, thus permitting a good maneuverability in the most medial portion of the surgical field, as confirmed by our laboratory analysis. This area corresponds in the cadaveric dissection to the superior orbital fissure (that is the most medial of the anatomic target of the middle cranial fossa where we calculated the surgical freedom). Accordingly, using a four-handed technique, while the assistant surgeon is holding the endoscope in the upper portion of the endo-orbital corridor (12 o'clock position), the operating surgeon can use two instruments that can be inserted in the bottom part of the endo-orbital corridor as well as in the extra-orbital corridor (with a lateral-to-medial trajectory, thus dissecting the tumor from the most medial middle cranial fossa region). Accordingly, our experimental findings were validated by our case experience.

Finally, extra-orbital corridor may not offer, when used alone, a greater maneuverability and a more comfortable control of the instruments when comparing it to the endo-orbital corridor; nevertheless, it could provide the surgeon with an extra space for sliding instruments, therefore reducing the overcrowding of the instruments within the endo-orbital corridor and limiting the degree of medial retraction of the orbital contents [20]. Indeed, it has to be underlined that even if the extra-orbital corridor alone adds little in terms of surgical maneuverability, when used together with the endo-orbital corridor in this novel variation of the superior eyelid neuroendoscopic surgery, it can improve the whole surgical freedom, especially in the medial aspect of the surgical field, serving as an adequate complement to the endo-orbital route. Hence, we completely recognize that the extra-orbital corridor alone is not enough to reach the cranial base; however, used as a complement to the endo-orbital one, the intended surgical target regions within the skull base can be approached in a coplanar manner, thereby requiring fewer angled endoscopes, decreasing disorientation; multiple instruments can be used, thus helping pathology dissection from the vital neurovascular structures. The contribution developed need to be interpreted as a possible step forward in the evolution of minimally disruptive surgery of the skull base in which a combination of a multiportal endoscopic surgery is

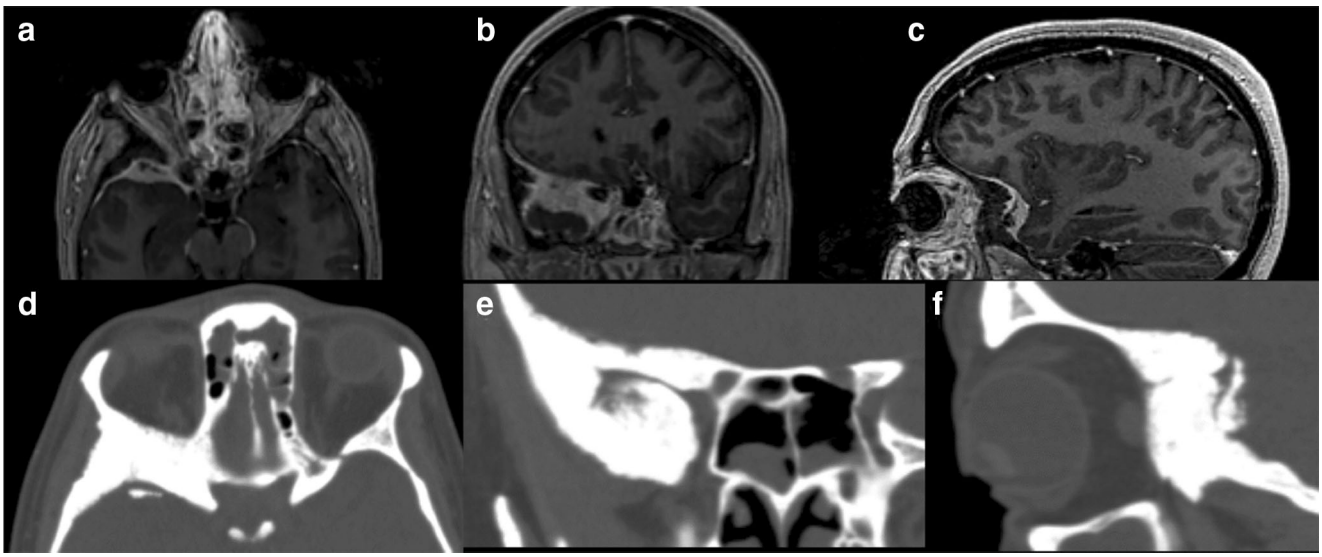

Fig. 7 Preoperative axial (**a**), coronal (**b**), and sagittal (**c**) MRI scans showing a "en plaque" growing mass in the anterior portion of the right middle cranial fossa. Preoperative axial (**d**), coronal (**e**), and sagittal (**f**) CT scans demonstrating extensive hyperostosis involving greater and lesser sphenoid wings, lateral orbital wall, and frontal and zygomatic bones

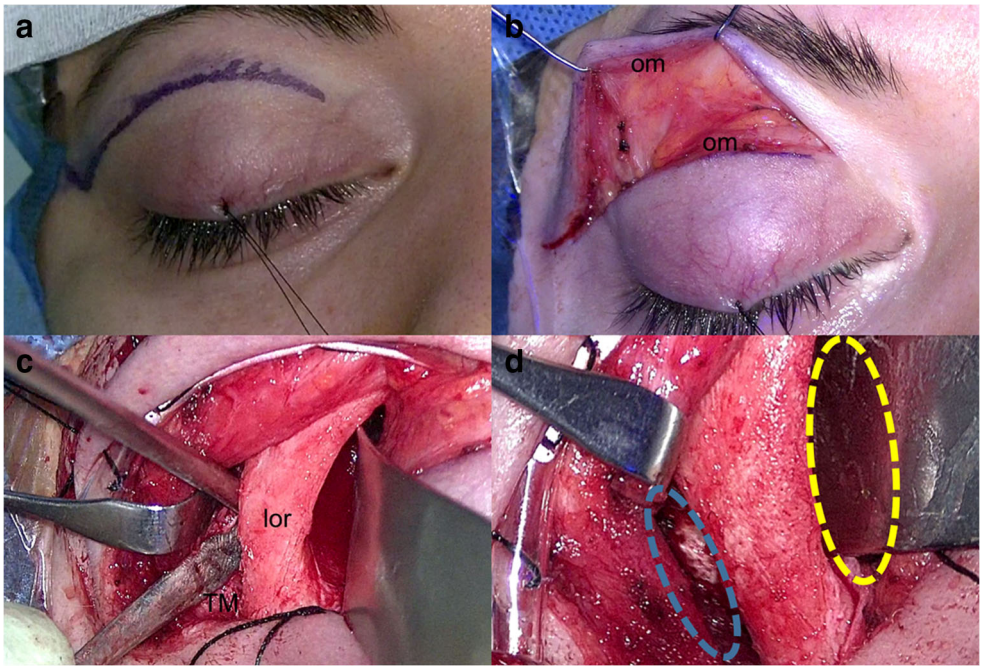

Fig. 8 Intraoperative images showing the superior eyelid approach. Skin incision is done along a superior eyelid wrinkle, orbicularis muscle fibers are dissected, and levator palpebrae muscle is identified (**a**, **b**). Lateral orbital rim is completely skeletonized (**c**). Orbital contents contained by periorbita are retracted inferomedially to expose endo-orbital corridor (yellow dotted line). Skin incision is extended laterally, and temporalis muscle is retracted laterally to expose extra-orbital corridor (blue dotted line) (**d**). Om orbicularis muscle, lor lateral orbital rim, tm temporalis muscle

researched and studied in detail via both anatomic investigations and clinical cases. In our opinion, SOM in which hyperostosis is predominant could be addressed with an endoscopic endo-orbital approach combined with an extra-orbital corridor in order to gain more maneuverability, especially in the medial and depth of the surgical field.

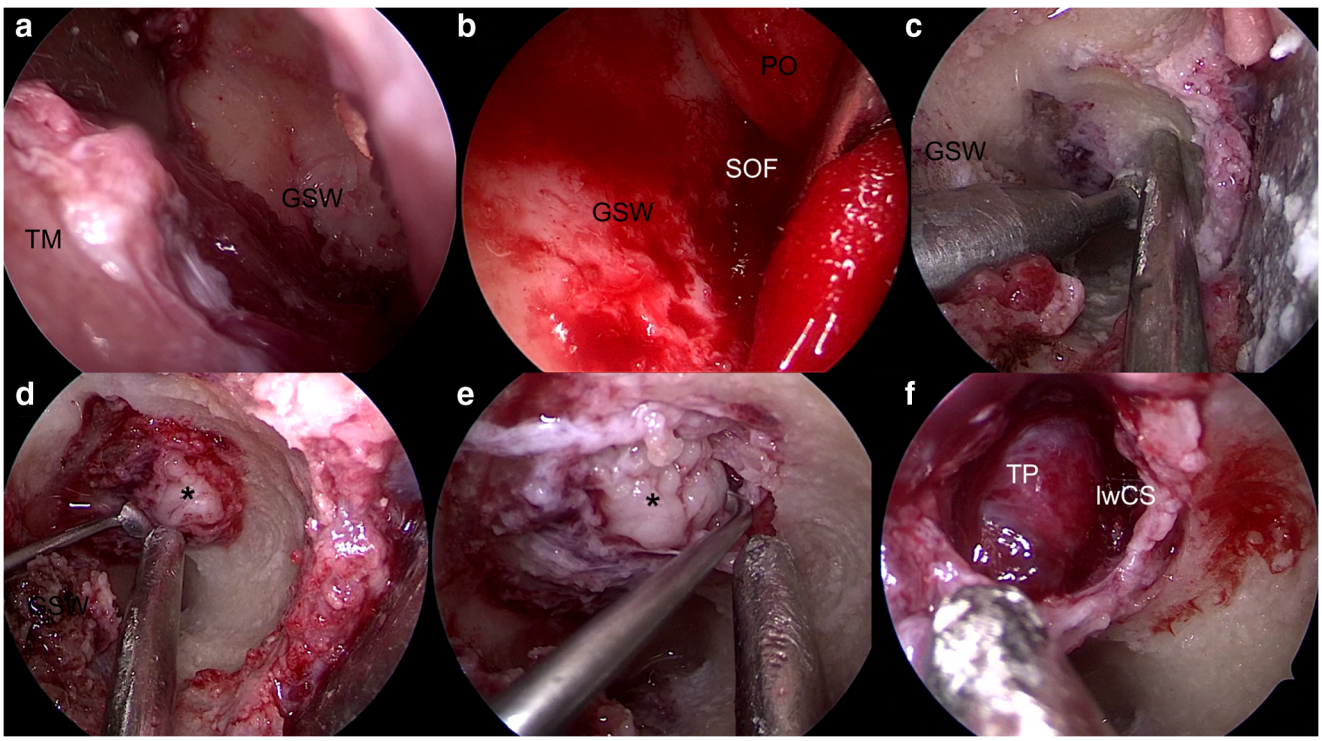

Fig. 9 Intraoperative endoscopic view showing exposure of the extra-orbital corridor, whose lateral limit is represented by the temporalis muscle (**a**), and of the endo-orbital corridor, limited laterally by the lateral wall of the orbit (**b**). Superior orbital fissure is the superomedial limit of the approach. Intraoperative endoscopic pictures showing extensive drilling of the hyperostotic bone (**c**), exposure of the middle cranial fossa dura, and dissection of the tumor via both endo-orbital and extra-orbital corridors (**d**, **e**). Dura mater of the temporal pole and lateral wall of the cavernous sinus are shown (**f**). GSW: greater sphenoid wing; lwCS: lateral wall of the cavernous sinus; PO: periorbit; SOF: superior orbital fissure; TM: temporalis muscle; TP: dura of the temporal pole; asterisk: tumor

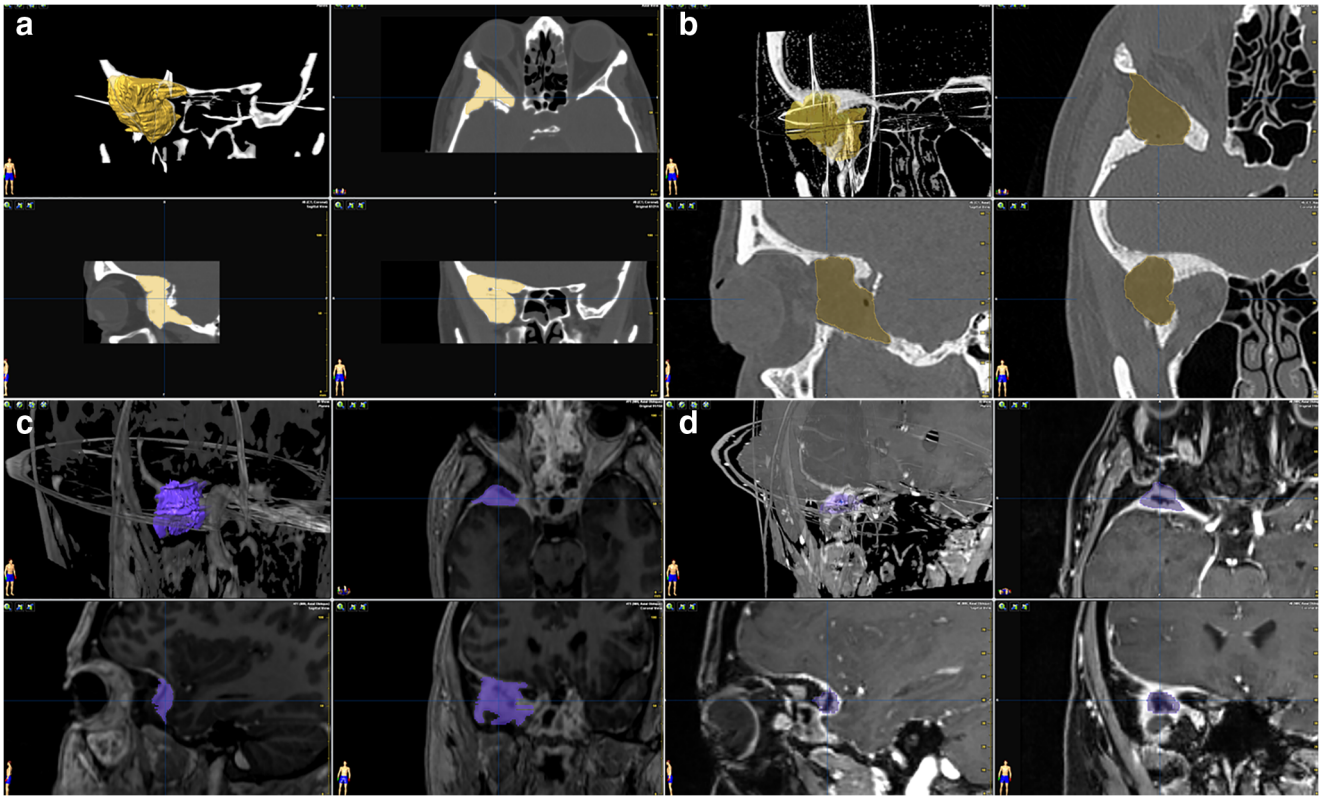

Fig. 10 Illustrative pictures obtained with BrainLab® showing computer-based reconstruction of the amount of preoperative hyperostotic bone (**a**) and tumor (**c**) and postoperative amount of bone (**b**) and tumor (**d**) removed

Study limitations

As for all anatomic investigations based on cadaveric dissection, our study suffers from some limitations that should be discussed.

Our results in terms of surgical freedom may be affected by great variability due to the modification of the elasticity of specimens' tissues, modifications related to the methods of preparation and storage of the specimens. This represents a real drawback in translating our results into a clinical scenario. Furthermore, it has to be underlined that, as often occurs when quantitative analysis is applied to anatomic studies, our results are represented by rough values, hardly to interpret by strict statistical methods. Anyway, since our data did not reach statistical significance, they have to be considered as representative but that can support the clinical case.

Concerning the clinical case, our purpose is to show an example of feasibility in taking advantage of a latero-medial trajectory and the greater maneuverability offered by the combined use of extra-orbital and endo-orbital corridors during the management of a spheno-orbital meningioma, with no need of removal of the lateral orbital rim. Still, this remains a limited case with no purpose of standardize and/or generalize this kind of approach for any clinical scenarios. Consequently, since we reported only an example case, no general conclusions and proper indications can be drawn. Further cases and even series are needed to establish the effectiveness of this technique in the neurosurgical armamentarium.

Conclusions

The creation of a novel extra-orbital corridor, without removal of the lateral orbital rim, and its combination with an endoscopic endo-orbital approach, may provide the surgeon an additional space to insert instruments,

Fig. 11 Pictures showing clinical outcomes of patient 6 months after surgery. Clinical improvement of her right exophthalmos was observed, with no postoperative esthetic disfigurement

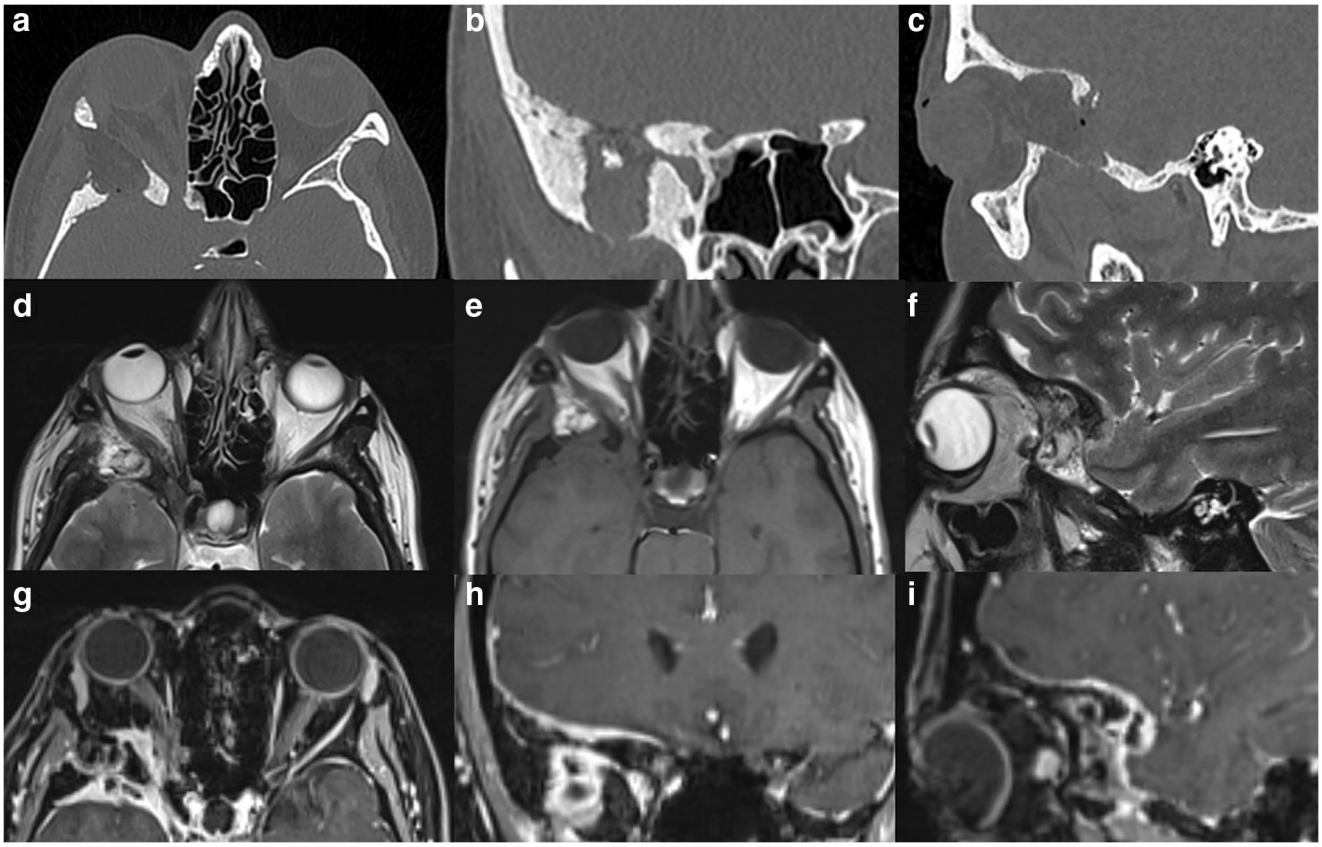

Fig. 12 Early postoperative axial (**a**), coronal (**b**), and sagittal (**c**) CT scans demonstrating decompression of the lateral orbital wall after extensive debulking of the hyperostotic bone. Three-month postoperative T2-weighted axial (**d**), contrast-enhanced axial (**e**), and T2-weighted sagittal (**f**) MRI scans showing the normal evolution of the surgical field with inflammatory tissue. Temporal lobe appears decompressed after removal of the "en plaque" component of the tumor. Six-month postoperative contrast-enhanced axial (**g**), coronal (**h**), and sagittal (**i**) MRI scans demonstrating the radiologic stability of the residual lesion together with resolution of the patient's right eye exophthalmos

avoiding cluttering during endo-orbital surgery, and an additional latero-medial trajectory to better manage the most medial portion of the surgical field. Our quantitative analysis shows that the endo-orbital corridor offers the greater maneuverability when accessing the middle cranial fossa, compared with the extra-orbital corridor. In addition, the extra-orbital corridor provides the greater surgical freedom, when the most medial portion of the middle cranial fossa is reached. Further anatomic studies and surgical series will be necessary to compare this variation of the technique with the conventional endo-orbital approach as well as with a recently reported variation of the procedure that include the removal of the lateral orbital rim [36]. In this way it will be possible to validate the advantages and limitations of using endoscopic extra-orbital corridors during endoscopic endo-orbital surgery.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Human and animal rights and informed consent This study was approved by the IRB of the University of Barcelona. Written informed consent has been obtained from the patient presented in this study.

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