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ORIGINAL ARTICLE

Following the canyon to reach and remove olfactory groove meningiomas

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ABSTRACT

BACKGROUND: Olfactory groove meningiomas (OGMs) represent approximately 10% of all intracranial meningiomas. They arise in the olfactory fossa, a variable depression delimited by the lateral lamella and perpendicular plate. The cribriform plate with the lateral lamella and ethmoidal and orbital roof could be viewed as a 'canyon' with the frontal sinus as the main entrance.

METHODS: Between January 2000 and December 2013, 32 consecutive patients underwent removal of OGMs through this 'canyon' at the Department of Neurosurgery of Brescia and Turin. Complete removal was achieved in all patients with this trans-frontal sinus subcranial approach (Simpson grade I; mean lesion volume, 46.6 cm^3).

RESULTS: Five patients (15.6%) experienced nasal CSF leakage, treated with external lumbar drain positioning for 4 days and resolved in all cases but one, which was re-operated. Two patients (6.2%) during the CSF leakage experienced meningitis at day 7 after surgery, both successfully treated by intravenous antibiotic therapy. After one month, one patient developed hydrocephalus, treated with a ventricular peritoneal shunt. In one patient, traction on the OGM caused bleeding of the callosomarginal artery, which was coagulated with superior frontal gyrus ischemia without neurological consequences. Glasgow Outcome Scale Score at 6 months was V in 29 patients, IV in one patient, and I in two patients.

CONCLUSIONS: Advantages with this approach may include easy and early control of blood supply from its insertion in the skull base, minimal frontal lobe retraction, preservation of the frontal veins draining to the sagittal sinus, and a satisfactory aesthetic outcome.

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Key words: Meningioma - Skull base - Surgery.

Olfactory groove meningiomas (OGMs) represent approximately 10% of all intracranial meningiomas.[1] They arise in a depression delimited by the lateral lamella and perpendicular and cribriform plates, called the olfactory fossa. The combination of olfactory fossa and the ethmoidal and orbital roofs could represent a sort of 'canyon' with the frontal sinus as the main entrance. The OGM blood supply derives from anterior and posterior ethmoidal arteries, anterior branches of the middle meningeal artery, and the meningeal branches of the ophthalmic artery. Usually the olfactory nerves and bulbs are displaced by smaller OGMs, while with larger ones, they can be stretched or included in the tumor. If reached, the optic nerve and chiasm can be displaced infero-laterally.[1] Because meningiomas are generally slow-growing tumors and the basal frontal lobe is a "non-functional area", the mass can become significantly extended before clinical symptoms arise. Clinical signs and symptoms usually include headache, dyskinesia, and personality changes such as apathy.[2]

OGMs grow in the center of the anterior cranial fossa and thus lie in the paths of growth manifolds but always below the brain, which is an obstacle for their removal, primarily in cases of small OGMs. Several approaches for removing OGMs have been proposed with various positive and negative aspects.[3, 4] Some authors have previously described surgical removal of OGMs starting directly from the skull base dural attachment, moving from below as in an endoscopic endonasal route,[5-7] or anteriorly and tangentially to the anterior skull base through the "canyon", as in the trans-frontal sinus subcranial approach,[8-10] with minimal brain manipulation.

Here we present our surgical experience with removal of OGMs using the trans-frontal sinus subcranial approach, emphasizing the technical advantages based on anatomic considerations.

Materials and methods

Thirty-two consecutive patients, undergoing surgical intervention between January 2000 and December 2013 at the Department of Neurosurgery of Brescia and Turin, were included in the study. Each patient was informed of the risks and benefits of this approach and signed the consent form, in accordance with current Italian laws regarding the consent form for surgical procedures (art. 30: Code of Ethics of the Italian doctors; Articles 13 and 32 of the Italian Constitution).

All patients had a meningioma arising in the olfactory groove, diagnosed by brain CT scan and/or MRI. The only exclusion criterion was the presence of frontal sinusitis whereas the dimension of the frontal sinus in relation to the extent of the tumor was never considered a contraindication for this approach. A neuroradiologist reviewed radiological exams before and after surgery. The extent of meningioma resection was expressed using Simpson grading. All but one patient had a preoperative brain MRI and postoperative brain CT scan within 6 hours after surgery. Neuroradiological evaluation and follow-up consisted of MRI after 4 months and then 1 year after surgery. In one patient, a diagnostic radiological exam and neuroradiological follow-up were performed using brain CT scan because of the presence of a pacemaker.

The Glasgow Outcome Scale was administered in an outpatient setting to all patients at 6 months after surgery. All patients were also invited to complete a questionnaire we designed, at least 6 months after surgery, with a subjective rating scale regarding aesthetic impact, as follows:

— I (No): no aesthetic changes compared with the pre-operative situation;

— II (Mild): small changes, but none experienced as an aesthetic problem (no requirement to change hairstyle, absence of visible scar);

— III (Medium): some discomfort due to the scar, hairstyle change, swelling of subcutaneous and muscular tissues. Not completely satisfied with the cosmetic outcome;

— IV (High): a significant degree of dissatisfaction due to depressions on the skin, visible or hairless scars, asymmetry between the two sides of the head, alopecia;

— V (Severe): aesthetic aspect heavily influenced by surgery due to facial deficits or temporal muscle atrophy with visible depressions of skin for bone gaps.

Surgical technique

Preoperative prophylaxis with antibiotic therapy was performed in all patients (intravenous cefotaxime 12.5 mg/kg and metronidazole 25 mg/kg). The patient was placed in a supine position with the head lying on a horseshoe-shaped pillow and fixed with a patch. A shaved line of 2 cm was obtained by shaving the hair, and a bicoronal skin incision was performed. A bilateral interfascial approach of the temporal muscle was performed preserving the fronto-temporal branch of the facial nerve. The scalp was elevated in the subgaleal plane with subsequent harvesting of the pericranial flap pedicle on supratroclear and supraorbital vessels on both sides. Finally, the flap was detached from the calvaria and anteriorly reversed together with the scalp to reveal the nasal bones and orbital rims. Frontal sinus boundaries were defined using a neuronavigator or by measuring the size calculated from an X-ray obtained in Caldwell projection. If the frontal sinus was hypoplasic or absent, craniotomy was tailored based on the dimension of the meningioma, but always bilaterally within supraorbital notches and the nasofrontal suture inferiorly. A large free graft of periosteum was prepared up to the posterior edge of the skin incision. Osteotomy was achieved using a reciprocating saw, with the blade directed obliquely to reduce the risk of dural damage and improve bone support and fusion, or with a piezosurgery system that creates an effective osteotomy with

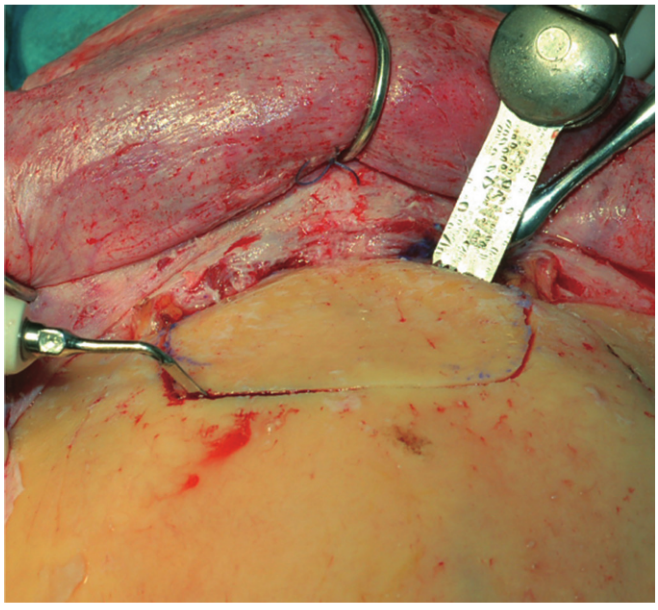

Figure 1.—Size and modality of the osteotomy.

minimal or no trauma to dura mater (Figure 1). The superior extension of the osteotomy was adjusted according to the size of the frontal sinus and meningioma. Furthermore, inferiorly, both the orbital ridges and the nasofrontal suture were cut; for more space, even the most antero-medial part of orbital roof can be cut. The anterior wall of the sinus was lifted up, and the intersinus septa were removed. The sinus was carefully demucosized in every recess.

The posterior wall was drilled, and the dura mater was dissected from the skull base and the crista galli removed. At the beginning of the intracranial phase of the procedure, it is strongly suggested to not open the dura over the frontal poles because they may swell due to edema and a meningioma compression effect. The dura was then cut over the skull base behind the insertion of crista galli so that the dural attachment of the meningioma was accessible and detached after coagulation of the anterior and posterior ethmoidal arteries. At this stage, the olfactory bulbs and nerves can be highlighted and dissected from the meningioma, keeping them intact when possible. The tumor was debulked by an ultrasonic aspirator to achieve its collapse and reach the optic and carotid cisterns for CSF drainage. After brain collapse, the dura mater was opened linearly on both frontal poles, the longitudinal sinus was tied, and the falx was cut. The frontal poles with the anterior, medial orbital gyrus and the superior frontal gyrus were preserved (Figure 2). Therefore thus, the residual tumor was removed with minimal bleeding.

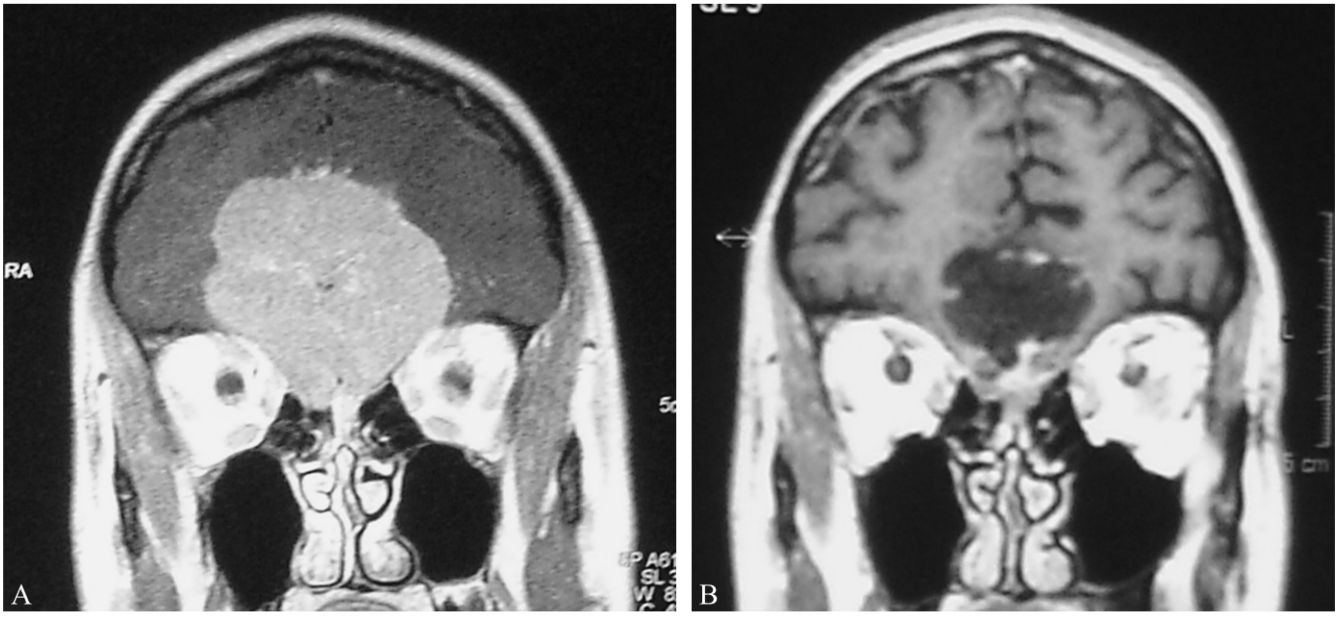

Figure 2.—A) Coronal MRI T1-weighted images after gadolinium injection reveals a large OGM with the adjacent frontal gyri laterally dislocated; B) repositioning of the superior and orbital frontal gyri after tumor removal.

An arachnoidal dissection plane was always identified posteriorly, and the meningioma was separated from the anterior communicant and cerebral anterior and pericallosal arteries. The removal of the superior portion of the lesion was handled with caution moving along the falx between the two frontal poles, exposing if necessary the frontopolar, fronto-orbital, or marginal callosal branches and avoiding vascular injuries. Closure was achieved with a free graft of periosteum positioned to fill the previously demucosized frontal recesses. The pedicled periosteal flap previously harvested was positioned intradurally, passing over the filled frontal recess to reconstruct the dura mater defect with a tight closure. The frontal bone defect was reconstituted by repositioning the anterior wall of the frontal sinus fixed by suture threads. After surgery, patients were administered prophylactic antibiotic (cefotaxime) for 7 days.

Results

A total of 32 patients affected by OGM (mean age, 58.7 years) underwent a frontal trans-sinus subcranial approach at the Neurosurgical Department of the Universities of Brescia and Turin between January 2000 and December 2013. Patient characteristics are shown in Table I. In all cases, clinical presentation prompted neuroradiological examination. Five patients complained of a first symptom of anosmia, but another eighteen patients had an unrecognized disturbance of smell on admission during neurological examination. Regarding the other nine patients, six (66%) had a postoperative reduction in smell, and three had intact smell before surgery that was maintained after surgery. None of the patients had increased smell function compared with pre-operative perception.

All patients underwent Simpson grade I resection. In

TABLE I.—*Patients' characteristics.*

N°	Sex	Age	Clinical presentation	Axial. sagittal. coronal diameter (cm)	Elipsoid Volume (cm^3)	Frontal sinus presence	Glasgow Outcome Scale	Extension into ethmoid sinuses	Satisfaction of cosmetic result
1	M	38	Headache	5.0 × 6.1 × 5.2	79.3	Yes	5	No	Yes
2	M	67	Headache	4.1 × 4.3 × 3.9	34.3	Yes	5	No	Yes
3	M	71	Frontal syndrome	4.4 × 4.7 × 4.2	43.4	Yes	5	No	Yes
4	F	51	Anosmia	3.7 × 4.2 × 3.4	26.4	No	5	Yes	Yes
5	M	31	Frontal syndrome	3.9 × 4 × 4.3	33.5	Yes	5	No	Yes
6	F	41	Headache	4.1 × 3.4 × 4.5	31.3	Yes	5	No	Yes
7	M	70	Frontal syndrome	5.1 × 4.8 × 4.7	57.5	Yes	4	No	Yes
8	M	68	Anosmia	3.4 × 4.1 × 3.9	27.1	No	5	No	Yes
9	M	55	Headache	5.1 × 5.3 × 4.7	63.5	No	5	No	Yes
10	M	59	Frontal syndrome	4.7 × 4.9 × 5.1	58.7	Yes	5	No	Yes
11	F	45	Anosmia	4.2 × 6 × 4.3	54.1	Yes	5	Yes	Yes
12	F	60	Visual field disturbance	5.9 × 5.2 × 4.9	75.1	No	5	No	Yes
13	F	57	Frontal syndrome	4.8 × 5 × 6	72	Yes	5	No	Yes
14	M	62	Frontal syndrome	6.8 × 6.2 × 4.5	94.8	Yes	5	Yes	Yes
15	M	66	Headache	6 × 5.2 × 5.5	85.8	Yes	5	No	Yes
16	F	52	Seizures	4.2 × 3.5 × 4.0	29.4	Yes	5	No	Yes
17	M	72	Frontal syndrome	5.1 × 5.4 × 4.5	61.9	Yes	5	No	Yes
18	F	68	Seizures	3.2 × 4.5 × 4	28.8	Yes	5	No	Yes
19	F	74	Frontal syndrome	5.3 × 5.5 × 6	87.4	Yes	5	No	Yes
20	F	60	Frontal syndrome	4.5 × 5.2 × 4.8	56.1	Yes	1	No	-
21	M	36	Seizure	5.9 × 6.1 × 5.2	93.5	Yes	5	No	Yes
22	M	66	Headache	3.5 × 4 × 3.8	26.6	Yes	5	No	Yes
23	F	42	Seizure	4 × 3.5 × 3	21	Yes	5	No	Yes
24	F	48	Headache	2 × 2.5 × 1.5	3.7	Yes	5	No	Yes
25	M	60	Frontal syndrome	3 × 3.5 × 3	15.7	Yes	5	No	Yes
26	M	75	Headache	3.2 × 3 × 3.1	14.8	Yes	5	No	Yes
27	F	37	Anosmia	2 × 3 × 3.1	9.3	Yes	5	No	Yes
28	F	67	Accidental discover	1 × 2 × 1	1	Yes	5	No	Yes
29	M	74	Visual field disturbance	5 × 2 × 3	15	Yes	1	No	-
30	M	52	Anosmia	5 × 7 × 6	105	Yes	5	Yes	Yes
31	F	88	Frontal syndrome	4 × 6 × 5.5	66	Yes	5	No	Yes
32	F	69	Headache	3.5 × 3 × 4	21	Yes	5	No	Yes

eight cases, because of the absence or limited dimension of the frontal sinus, the size of the fronto-nasal bone flap was tailored to the width of the OGM but in all cases was bilaterally within the supraorbital notches. Extension into the ethmoidal sinus (4 cases) changed the strategy of the approach only in one case, in which a combined endoscopic endonasal and trans-frontal sinus subcranial approach was used. Compared to an ellipsoid, the mean volume of OGM was 46.6 cm^3 (range: 1-105 cm^3). Immediate postoperative brain CT with contrast showed complete removal of the tumor in all patients.

Complications included a superior frontal gyrus ischemia without neurological consequences due to traction on the meningioma caused by the rupture of the right callosomarginal artery. Five patients (15.6%) experienced nasal CSF leakage that was treated with external lumbar drain positioning for 4 days and resolved in all cases but one, which was re-operated. Two patients (6.2%) during the CSF leakage developed meningitis at day 7 after surgery. The CSF culture was positive for methicillin-resistant *Staphylococcus aureus*, and treatment was vancomycin for 15 days. After one month, one patient developed hydrocephalus that was treated with a ventricular peritoneal shunt. Eleven (34.3%) patients had postoperative fever treated with cefotaxime for a mean period of 7 days: three of these had lumbar puncture, and both CSF culture and blood tests excluded meningitis. Two patients died, the first after a completely uneventful surgical operation and who, while he was moving in the postoperative awakening room, developed a sudden bilateral mydriasis. He was immediately brought back into the surgical room for a re-operation but developed a malignant pseudohypoxic brain swelling that led to his death after three days. We found no anesthesiological or surgical explanation for this sudden event. The other patient died 10 days after discharge as a result of myocardial infarction.

Brain MRI confirmed complete resection during follow-up in 29 patients; one had a one-year contrast CT scan with complete removal. A reduction of brain edema was documented in 25 cases (Figure 3). At the

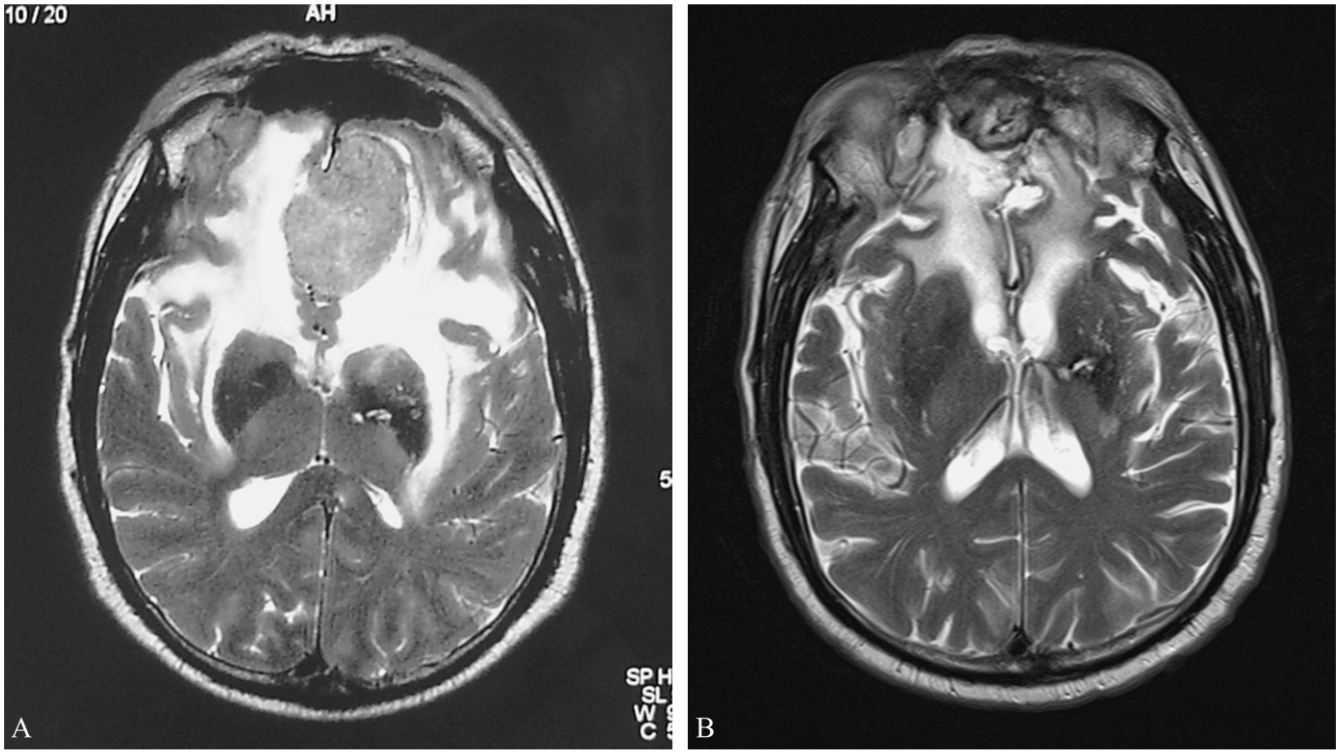

Figure 3.A) Axial MR T2-weighted images showing massive edema in the frontal white matter surrounding an OGM, extending posteriorly to the insulas and external capsules; B) reduction of edema after surgery, limited to fronto-orbital areas, with expansion of ventricles.

6-month follow-up, the Glasgow Outcome Scale score was V in 29 patients, IV in one patient, and I in two patients. There was no aesthetic impact (grade I) in 26 patients; four male patients ages, 72, 70, 67, and 55 years, respectively, all of whom were bald, reported a mild (grade II) impact.

Discussion

Ideal features of the surgical approach to OGMs are limited craniotomy and a short route to reach the meningioma, early surgical control of feeding vessels, absence of brain retraction, preservation of neural structures, sparing of veins and arteries in contact with or encased by the tumor, and the opportunity for a complete removal. The best surgical approach for OGM removal remains controversial; however, no single approach completely incorporates the above-mentioned characteristics. Many authors have described the strengths and weaknesses of different approaches.[11-15] Taking into account the site of the skull base dural attachment and the usually large dimension of OGMs, it is unlikely that they can be safely removed using approaches such as pterional, lateral supraorbital, interhemispheric, or bilateral frontobasal craniotomy and its variations.[16] As an OGM increases in size, it tends to push up and displace the frontal lobes, expanding the interface between the brain and the skull base and creating a natural corridor through which the meningioma can be debulked and finally removed.

The trans-frontal sinus subcranial approach, described for the first time by Raveh in 1978 as a subfrontal approach for treating a traumatic anterior skull base fracture,[17-19] was subsequently adapted for tumor resection.[20] It may be considered as a less invasive modification of the bi-frontal craniotomy approach in which the frontal sinus is routinely opened. Indeed, thanks to the inferior osteotomy at the level of the nasal bones, this approach allows directly exposing the olfactory groove and approaching it in a tangential way with a direct view of the meningioma skull base insertion. The depth of the olfactory groove is determined by the height of the lateral lamella of the cribriform plate, which exhibits great variability, as demonstrated in the Keros classification [21] type I (<3 mm), type II (4-7 mm), and type III (8-16 mm); this issue needs to be carefully addressed in the preoperative setting to select the proper approach. In fact, the deeper the olfactory fossa is, the more difficult the complete removal of the meningioma and its dural attachment by a lateral approach such as a supraorbital or pterional approach; furthermore, brain retraction is mandatory to achieve the best control of this deeper site. In case of an olfactory groove of Keros type III, it is easy to consider the midline of the anterior fossa as a 'canyon' with the frontal sinus as the access point.

Only two approaches allow detaching of OGMs from the skull base with a large area of OGM insertion while decreasing the need for brain retraction. These are the endoscopic endonasal approach, which allows management of the skull base from below, and the trans-frontal sinus approach, which enables control of the skull base insertion of the tumor antero-posteriorly in a tangential fashion.

OGM removal by an endoscopic endonasal approach has been described by some groups,[5, 6, 22] who have emphasized the not-negligible length of the learning curve and the need for proper instrumentation and interdisciplinary cooperation. This approach offers direct midline access from below, without brain retraction or manipulation of neurovascular structures. In 2007, Webb-Myer *et al*.,[7] in the first report on OGM resection by an endoscopic endonasal route, affirmed that "*the endoscopic endonasal approach to OGM is a new development that requires specialized instrumentation and training in order to manage potential complications and difficulties*". In 2008 Gardner *et al*.[6] published the first series of 35 anterior cranial fossa meningiomas removed by endoscopic endonasal resection. Fifteen patients had an OGM with a mean volume of 47.6 cm^3 (range 3.1 to 109.3 cm^3); 80% of patients had complete removal, and 27% had postoperative CSF fistulas treated with lumbar drain. In 2009, Fernandez-Miranda *et al*. [23] affirmed that an endoscopic endonasal approach to OGM allows removal of the involved bone and dura mater "as a part of the approach" and permits early tumor devascularization, direct tumor access without brain retraction or damage, and if needed early, complete optic canal decompression. Furthermore, although the initial rate of CSF fistula was as high as 40%, the use of a pedicle naso-septal flap for skull base reconstruction reduced the risk to 5.4%.[24] Liu *et al*.[22] stressed that the limits of an endonasal endoscopic approach are represented by a dural attachment extending laterally over the orbital roofs and by tumor adherence to critical vascular struc-

tures. In either case, tumor removal cannot be complete, and these authors thus prefer a trans-frontal sinus approach that allows not only primary devascularization of the tumor coagulating feeding vessels coming from the ethmoidal pathway, but also safe control of the interface between the lesion and the brain after proper cavitation. Several elements must be taken into account when choosing this approach. These include the length of the operation,[25] the need for expertise and a team trained in extended endoscopic surgery, the close relationship of the OGM with the back wall of the frontal sinus,[26] the lateral extension beyond the lamina papyracea, the difficulty of reaching a Simpson grade I resection for large OGMs (>40 mm),[25] knowledge of refined endoscopic skull base reconstruction techniques, the permanent and unavoidable loss of olfaction that also affects taste, and finally, the risk of repeated surgery.[25] In cases of OGM extending into the ethmoid sinus, a combined trans-frontal sinus and endoscopic endonasal approach should be considered to ensure total removal and the best anterior skull base reconstruction technique.

In 2001, Hallacq *et al*.[9] published a first report describing the trans-frontal sinus approach in a small series of six patients. The OGMs were limited to one side of olfactory groove in four cases and extended to both side in two cases. After surgery, three patients suffered from visual disturbances, but normal visual activity was later recovered. Furthermore, these authors reported no post-operative complications. Spektor *et al*.[16] in 2005 published their experience with the management of OGMs using different surgical approaches; they used a "subcranial" approach in 11 cases only when the meningioma had a paranasal sinus extension. Pepper *et al*.[10] describing 19 patients undergoing excision of OGM through a subcranial approach, most of whom had evidence of extension into the paranasal sinuses, and reported that the subcranial approach "offers excellent surgical access for excision, particularly for recurrences that involve the paranasal sinuses and optic apparatus". Boari *et al*.[8] described the surgical technique of the trans-frontal sinus subcranial approach on a cadaveric specimen.

Our series of OGMs removed through a trans-frontal sinus subcranial approach is the largest reported to date. Thirty-two cases were treated, with complete removal and satisfactory aesthetic results due to the scar being hidden under the hair and no cases of partial or total necrosis of the bone flap. Few patients (33%) with preoperative intact smell had preserved olfaction after surgery, and the sparing of olfaction was strongly correlated with meningioma volume.[27] This approach seems to allow for good management of the olfactory nerves, early identification of the olfactory pathway, and the ability to work between the two nerves.

The use of the trans-frontal sinus subcranial approach in cases of large OGMs may be criticized because of the limited transcranial surgical corridor for exposure of the neurovascular complex and for the exposure of both frontal poles.

A small surgical opening may allow for the application, under microscope guidance, of multiple oblique trajectories in the removal of even large meningiomas extended over the orbital roofs (Figure 4). At the beginning of the procedure, before opening the dura on the frontal poles, this technique provides detachment of the OGM from the base of the implant with minimal debulking to reach and open the optic and carotid cisterns early. In this way, both significant devascularization of the meningioma and exposure of both optic nerves and carotid arteries can be obtained. Through CSF suction at the level of the above-mentioned cisterns, brain collapse is achieved, and the dura of the frontal pole can be safely opened. This approach requires minimal retraction of the frontal lobes, thus preserving their anatomical integrity and respecting the bridging veins to the longitudinal sinus, decreasing the risk of postoperative cerebral infarction that, in our series, was never highlighted to the post operative brain CT scan and follow up MRI. It also permits radical surgical removal (Simpson grade I) through direct, short, and easy access tangential to the skull base insertion of the lesion. If necessary, it also allows an interhemispheric approach to the upper part of an OGM. Furthermore, the size of the tumor does not affect the extent of the tumor resection.

The prevalence of CSF leakage through the nose (16.6%) was higher in this patient group in comparison to data reported in the literature on OGM resection by a craniotomic approach (6.0%).[4] This complication occurred at the beginning of the learning curve, before an appropriate and codified dural closure technique was developed, as confirmed by the fact that no cases of CSF leakage arose in the last 22 cases.

Whatever the size of the OGM [small (<3-cm), medium (3-6 cm)] or large (>6 cm)], the peculiarity of the

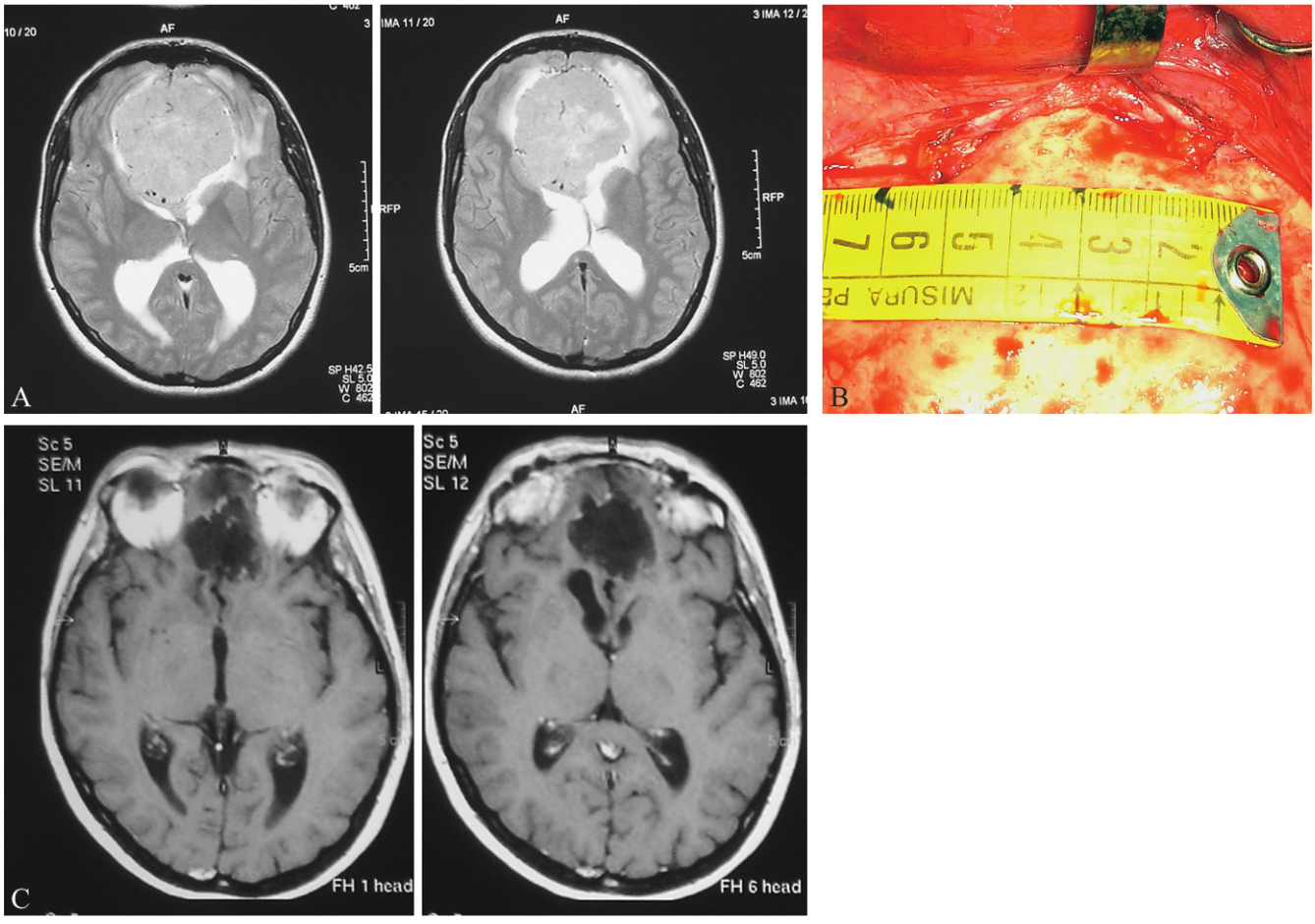

Figure 4.~~A)~~ Preoperative axial MRI showing a large OGM; B) the osteotomy was tailored according to the size of the frontal sinus and the men - ingioma as measured by MRI; C) postoperative axial MRI.

frontal trans-sinus approach is the almost lack of a need for brain retraction to reach the meningioma, such as the modest retraction done to get to the optic-carotid cisterns and obtain a slack brain. Moreover, crossing through a non-sterile surgical site, such as the frontal sinus, did not lead to meningitis or surgical wound infection by microbes that normally colonize the frontal sinus. In fact, the only case of infection reported was due to methicillin-resistant *Staphylococcus aureus* from the skin. Thus, taking into consideration the meningitis rate reported by many authors in pure trans-nasal skull base surgery,[24, 28] access through a non-sterile route can no longer be considered a valid argument against this approach.[29] These technical benefits may be considered in the selection of the most proper transcranial approach in the treatment of OGMs.

This study has many limitations, including its retrospective nature. Other limitations are the absence of pre- and postoperative neuropsychological investigations, which could confirm that the removal of OGM improves frontal lobe function, as other authors have demonstrated,[30] and the absence of pre- and postoperative quantitative and qualitative evaluation of smell.

Conclusions

The trans-frontal sinus subcranial approach is a safe alternative to "traditional" approaches for OGM removal. The main advantages are no need for brain retraction, preservation of the anatomical integrity of the frontal poles, easy and early vascular deafferentation of the lesion that allows safe debulking and removal, and pres-

ervation of smell. The complication of this approach is essentially nasal CSF leakage, which can be prevented by adopting proper multilayer skull base reconstruction techniques. Passage through a non-sterile surgical site should no longer be an argument against this approach.

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