Advanced paranasal sinuses osteomas: a retrospective multicentric analysis on surgical management outcomes and intra- and post-surgical complications

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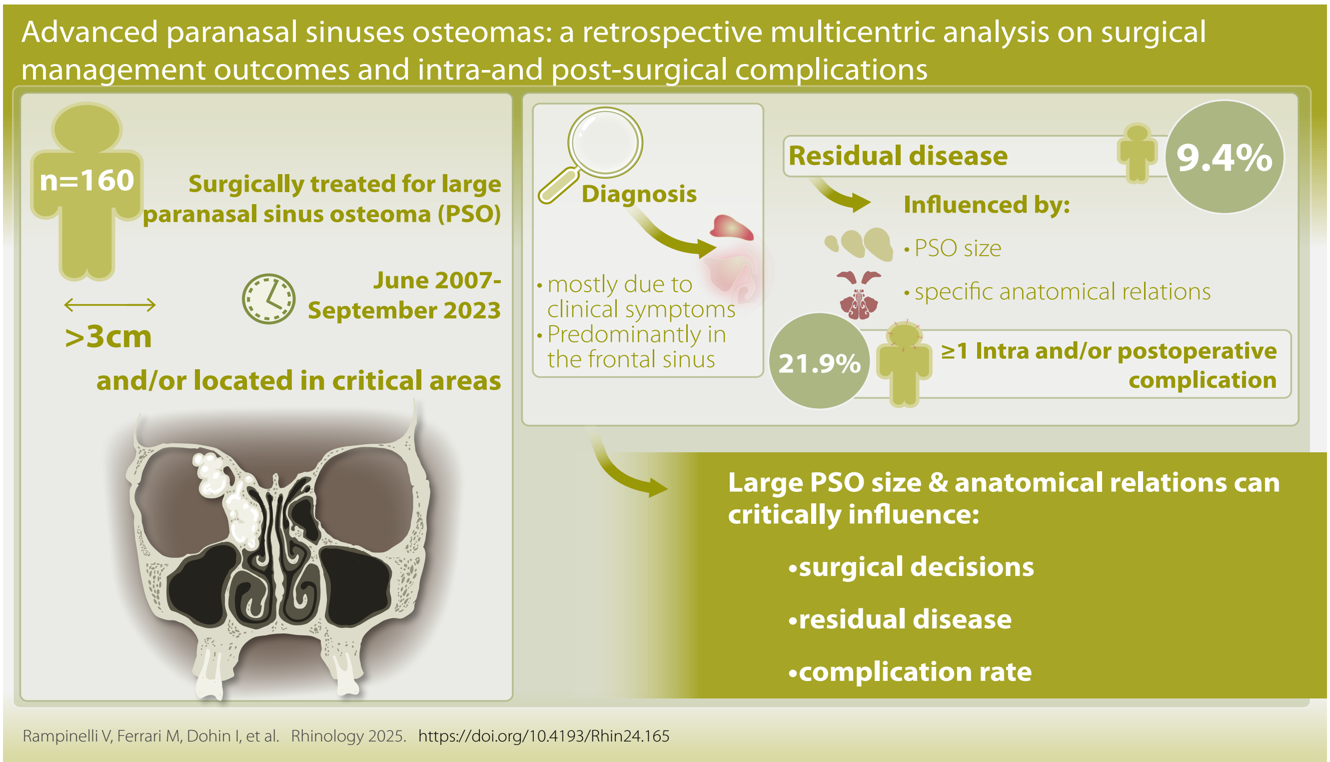

Abstract

Background: This study examines the management and outcomes of large paranasal sinus osteomas (PSO), especially those abutting or encasing critical structures of the skull base and orbit.

Methodology: A multicentric retrospective analysis was conducted between June 2007 and September 2023. The study included surgically treated (regardless the type of approach chosen) PSO, exceeding 3 cm in diameter and/or located in critical anatomical areas. An analysis was performed to assess the association between the critical relationships, size, presence of residual disease, and incidence of intra- and postoperative complications.

Results: The series included 160 patients. Most PSO were diagnosed due to clinical symptoms, predominantly for those located in the frontal sinus. Residual disease was observed in 9.4% of patients, with its occurrence influenced by PSO size and relationships with specific anatomical structures. Thirty-five/160 (21.9%) of patients experienced one or more intra- and/or postoperative complications. Intraoperative complications were associated with the proximity of PSO to the cribriform plate. Long-term complications were more frequently observed in cases involving the anterior and posterior plate of the frontal bone.

Conclusions: This study highlights the complexities involved in managing large PSO, demonstrating that size and anatomical relationships of these osteomas can critically influence surgical decisions, residual disease, and complication rate. The study's retrospective design limited the collection of standardized symptom outcomes, highlighting the need for future studies to address this apect.

Key words: paranasal sinuses, osteomas, complications, skull base, outcomes assessment

Introduction

Osteomas are common benign tumors of the sinonasal tract, with the frontal sinus being the most frequently involved. Typically, osteomas are discovered incidentally [1]. They become symptomatic in about 10% of cases, usually presenting with pain due to soft tissue compression (typically orbital content and facial tissues) and/or obstruction of the paranasal sinus drainage pathway [2-4].

Over the last 30 years, surgical techniques evolved significantly with the introduction of advanced endoscopic equipment and navigation systems. The introduction of navigation systems has improved surgical precision by providing guided orientation and intraoperative quantification of any residual disease. The development of dedicated instruments, such as proficient curved drills and ultrasound bone emulsifier, and advanced surgical techniques, such as orbital transposition, has also enabled the endoscopic control of osteomas in critical locations within the frontal sinus. With the increased confidence in advanced endoscopic approaches to the skull base for malignant pathology and reconstructive techniques, even selected osteomas with critical relationships to the dura mater and the brain have become accessible endoscopically [5-7].

Several factors influence clinical presentation, management, and potential perioperative complications. Among them, size is one of the most reported key factors [8, 9]. Osteomas are defined as "giant" if they exceed the diameter of 30 mm [9, 10]. These lesions are complex to be addressed, and the challenge posed to the surgeon is mainly steric, due to their encumbrance in the narrow spaces of nasal cavities.

Large lesions of the frontal sinus require favorable anatomical conditions to be endoscopically resected. A narrow antero-posterior distance between frontal beak and anterior skull base limits endoscopic possibilities, as well as lateral extension over the meridian of the orbit. Moreover, the ratio between the distance from the midline to the lateral end of the frontal sinus and and the distance from the midline to the medial orbital wall have been demonstrated to influence frontal sinus exposure [4, 11]. An open or combined approach could solve the issue, allowing for complete resection and saving operative time, but at the cost of higher morbidity [12-14].

Aside from mere dimensions, the location and relationships with critical anatomical subunits are the main contributors to the complexity of the specific case. Osteomas with extension into the orbit and anterior skull base, either by abutting or crossing bony boundaries, may result in ocular movement impairment, proptosis, spontaneous pneumocephalus [15], CSF leak, cerebral abscess, or meningitis, necessitating prompt intervention [16, 17]. Conversely, if a critical relation with an anatomical structure is identified on preoperative imaging with no inherent severe symptoms, then the goal of surgery is to remove the lesion while preventing relevant complications that could worsen the symptom burden with respect to the preoperative situation. In general, when dealing with advanced osteomas, the surgeon must be prepared to undertake demanding surgery, which can be burdened with severe potential complications.

To date, given the rarity of challenging osteomas, their definition and the evidence concerning their global management are based on small series, often with controversial conclusions. Hence, the aim of this study is to analyze the experiences gathered by different referral centers in managing advanced paranasal sinus osteomas (APSO), defined as those exceeding 3 cm and/or involving critical adjacent structures, irrespective of the size. Special emphasis has been placed on assessing the relation with the skull base, orbit, and anterior ethmoidal artery (AEA). Analysis of the association between critical anatomical relations, dimensions, residual disease, and incidence of intra- and postoperative complications has been performed.

Materials and methods

A multicentric retrospective evaluation of patients treated for paranasal sinus osteomas between June 2007 and September 2023 was conducted, regardless of the type of surgical approach used.

The centers involved in the study were:

- Unit of Otorhinolaryngology – Head and Neck Surgery, ASST Spedali Civili of Brescia, Brescia, Italy;
- Unit of Otorhinolaryngology – Head and Neck Surgery, "Azienda Ospedale Università di Padova", Padova, Italy;
- Otorhinolaryngology and Skull Base Center, AP-HP, Hospital Lariboisière, Paris, France;
- Unit of Otorhinolaryngology, American Hospital, Tirana, Albania;
- Division of Otorhinolaryngology, Department of Surgical Specialties, ASST Sette Laghi, Ospedale di Circolo, Varese, Italy;
- Department of General Otorhinolaryngology, Head and Neck Surgery, Medical University of Graz, Graz, Austria;
- Hospital Clinic Barcelona, Rhinology and Skull Base surgery unit. Otorhinolaryngology, Barcelona, Spain;
- Department of Otorhinolaryngology, Department of Surgery, ASST Lariana, University of Insubria, Como, Italy.

Bone lesions other than osteomas were excluded from the analysis.

The study included osteomas of more than 3 cm in maximum diameter and/or involving at least one of the following anatomical areas:

- Anterior, posterior, and/or orbital plate of the frontal bone;
- Cribriform plate (CP);
- Ethmoidal roof (ER);
- AEA (the degree of encasement was classified as either less than 180°, more than 180°, or 360°);

Table 1. Clinical presentation and osteomas characteristics.

		n	%
Clinical presentation	None	14/160	8.8%
	Frontal and/or orbital pain	120/160	75.0%
	Proptosis	12/160	7.5%
	Diplopia	2/160	1.3%
	Meningitis	3/160	1.9%
	Deformity	6/160	3.8%
	Orbital cellulitis	3/160	1.9%
	Nasal obstruction	5/160	3.1%
	Epiphora	1/160	0.6%
	CSF leak	1/160	0.6%
	Vision loss	1/160	0.6%
	Cutaneous fistula	1/160	0.6%
	NS	6/160	3.7%
Density at CT Scan	Ivory	53/160	33.1%
	Low-density	27/160	16.9%
	Mixed	64/160	40.0%
	NS	16/160	10.0%
Bilateral involvement	Yes	29/160	18.1%
	No	131/160	81.9%
Sinonasal localization	Anterior ethmoid	40/160	25.0%
	Posterior ethmoid	8/160	5.0%
	Frontal sinus	86/160	53.8%
	Anterior + posterior ethmoid	5/160	3.2%
	Anterior ethmoid + frontal sinus	17/160	10.6%
	Anterior ethmoid + posterior ethmoid + frontal sinus	4/160	2.5%
Gil-Carcedo Classification (for frontal osteomas only – 107/160) [18]	Stage I	0/107	0.0%
	Stage II	8/107	7.4%
	Stage II	99/107	92.5%
Dimensions	Mean axial diameter: 24.9 mm [11-42 mm^3] Mean coronal diameter: 20.8 mm [9-33 mm^3] Mean volume: 11382,26 mm^3 [696-38729 mm^3]		

- Crista galli;
- Dura of the anterior cranial fossa;
- Lamina papyracea (LP);
- Periorbit.

The critical relationship with a structure was defined as abutment (i.e., simple contact) or involvement/encasement (i.e., when the structure is invaded or partially/totally encased), the latter being characterized by obvious change of shape or interruption of the bony/fascial anatomical boundaries. These data were derived by revising preoperative computed tomography (CT) scans and magnetic resonance imaging (MRI). Exposure and involvement of dura and periorbit were additionally defined according to intraoperative findings.

The following anonymized data were extracted from institutional databases:
- Patient-related variables (age, gender);
- Tumor-related variables (presentation, texture, Gil-Carcedo classification [18], location and type of relation with adjacent structures, dimensions);
- Treatment-related variables (surgical approach, reconstructive strategy);
- Adverse events and complications related to surgical treatments (intra- and postoperative);
- Residual disease (assessed with postoperative imaging).

Within frontal sinus lesions, lateral involvement was defined if the plane of the meridian of the orbit was crossed (Figure S1). Lesion dimensions were assessed in the axial and coronal planes by measuring the greatest diameter. The volume was calculated by equating the shape of the osteoma to a sphere and using the axial diameter at the point of greatest dimension.

Statistical analysis

Statistical analysis was performed with SPSS version 24 (IBM Corp. in Armonk, NY, USA). Data are reported as mean ± standard deviation or range. The distribution of open vs endoscopic approaches through the study period was assessed with a Chi-Square Test of Independence. The associations of complications (classified in intra-operative, post-operative <24 h, post-operative >24 h and late complications occurring >30 days) and residual disease with a number of factors (unilateral vs bilateral osteoma, localization, involved anatomical structures,

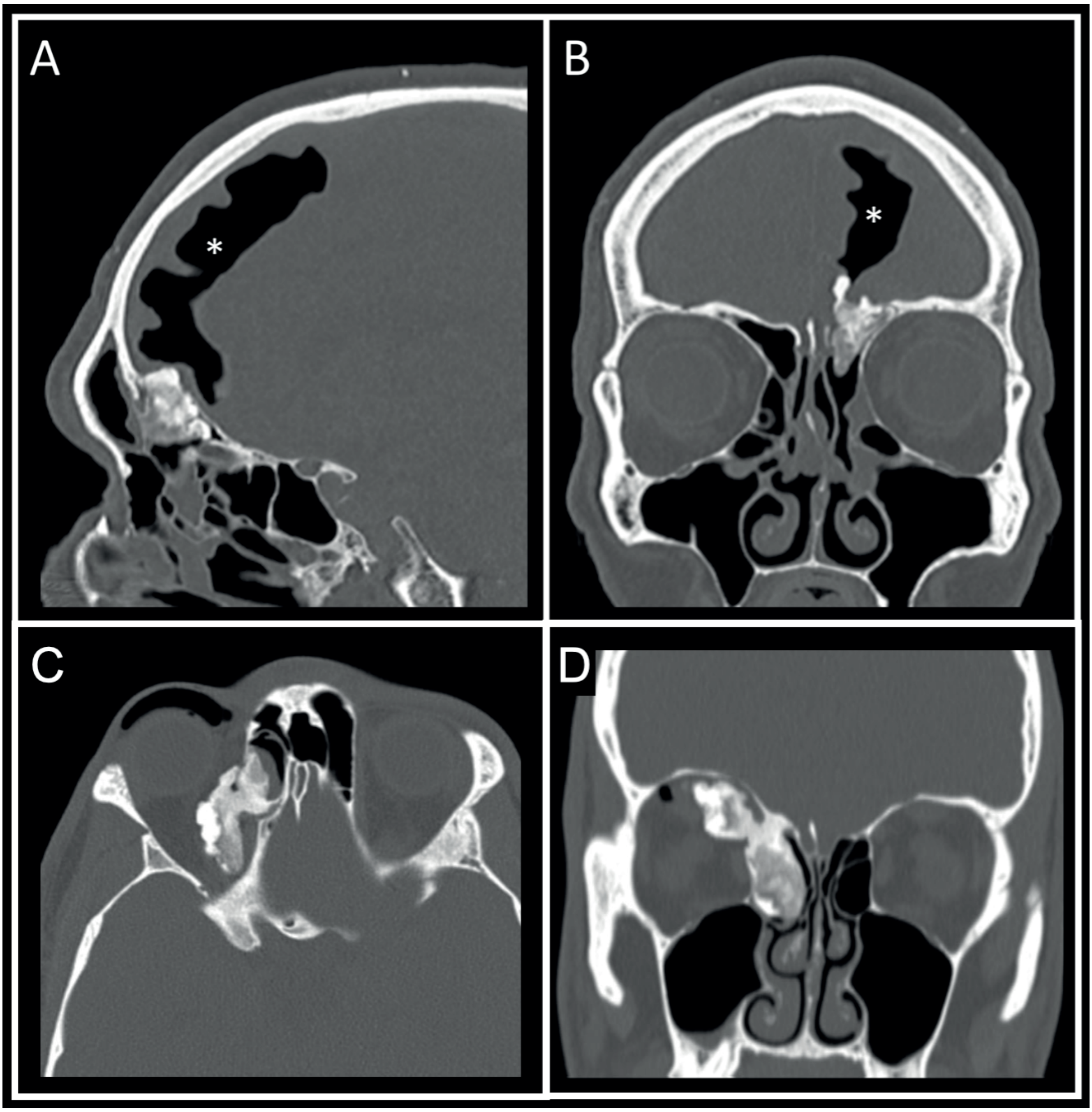

Figure 1. A, B) Preoperative CT-scan images (A coronal, B sagittal) showing a case of osteoma with intracranial extension complicated with spontaneous pneumocephalus due to valve mechanism (white asterisk). C, D) Orbital emphysema due to valve mechanism of an osteoma with intraorbital extension (C axial, D coronal) (pictorial case not included in the analysis).

age, axial diameter, surgical approach) were evaluated using a chi-square test or t-test, as appropriate. Multivariable logistic regression analysis was employed to investigate the association between the abovementioned variables with complications and residual disease. The level of statistical significance was set at $p < 0.05$. Patient with a specific missing data were excluded from the statistical analysis of interest.

This study was approved by the Institutional local Ethics Committees if needed, based on local legislation (study coordinator: ASST Spedali Civili di Brescia e University of Brescia: protocol NP3616).
The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki. Written informed consent was obtained from each participant/patient for study participation and data publication.

Results

Population

One hundred and sixty patients were included in the study. The mean age at surgery was 42.6 years (range 13-83). Sixty-three patients were female (39.4%) and 88 were males (55%) (data not available for 9 cases, 5.6%).

Diagnosis and location

Clinical presentation data are reported in Table 1. Symptoms were reported in 125/160 patients (78.1%), while incidental diagnosis was made in 23/160 cases (14.4%); data were not available in 12/160 (7.5%; Figure 1). Osteomas of patients complaining with pain showed a frontal involvement in 69.8% of cases (67/96). Radiologic signs of sinusitis due to sinonasal drainage occlusion were detected in 33/160 (20.6%) patients. Lateral location in the frontal sinus was described in 46/160 cases (28.8%). Maximum diameter under 3 cm was observed in 130/160 (81.2%) of patients.
Table S1 shows the relationships between the osteomas and critical anatomical areas (Figure 2).

Treatment

Treatment consisted of endoscopic resection in 103/160 patients (64.4%), open surgery in 10/160 (6.3%), and combined surgery in 47/160 (29.4%).
Open approaches of (alone or in combination with endoscopic approach), consisted in coronal, Lynch, or superior eyelid approaches in 42 (73.7%), 3 (5.3%), and 2 (3.5%) cases, respectively (data missing in 10/57 cases, 17.5%).
During the study period, no statistically significant difference was found in the distribution between open and endoscopic approaches.
Frontal sinus involvement was reported in all the patients treated with an open approach and in all but 2 patients treated with combined approach (45/47, 95.7%). Among patients treated with an endoscopic approach the frontal sinus was involved in 52/103 cases (50.5%).
Among patients with lateral frontal sinus involvement, treatment consisted of endoscopic surgery in 12/46 cases (26.1%), open surgery in 5/46 cases (10.9%) and combined surgery in 29/46 cases (63.0%). Dura, periorbit, and anterior ethmoidal artery management is detailed in Table 2.
Intraoperative surgical navigation has been used in 59/160 patients (36.8%, data missing for 45/160 patients).

Follow-up and complications

The presence of residual disease after surgery was described at post-operative imaging in 15/160 patients (9.4%) (Table S2). Residual disease was reported in 7.4% of patients treated endoscopically (7/95), in 14.3% of those receiving combined surgery (8/56), and in no case treated with purely open surgery. Among these patients, radiological follow-up was available in 10/15 cases and all the residues showed stability over time (mean FU duration: 23 months; range: 3 – 58 months).
At the univariate analysis, no significant association between the presence of residual disease and osteoma localization, density at CT scan (p=0.52) and relation with the CP, ER, crista galli, AEA, and the brain was found at the chi-square test. Conversely, bilaterality of the lesion (p=0.003), relation with anterior plate of the frontal sinus (p=0.047), posterior plate of the frontal sinus (p=0.001), orbital plate of the frontal sinus (p=0.008), LP (p=0.030), dura (p=0.018), and axial diameter (p=0.05) were significantly associated with the presence of residual disease. Multivariable analysis did not identify any covariate with an independent impact on presence of residual disease.
Thirty-five/160 (21.9%) of patients experienced one or more intra and/or postoperative complications, detailed in Table 3. Skull base reconstruction was performed in cases with intraoperative finding of dura breaching and in selected cases of dural exposure. Dural reconstruction was performed in 29/160 cases (18.1%), with either a single-layer (15/29 cases, 51.7%) or a multilayer technique (14/29 cases, 48.3%). When a single-layer technique was used, autologous material was used in 13/15 (86.7%) of the cases, with mucoperiosteal graft being the most frequently used. If a multilayer reconstruction was performed, local mucosal pedicled flaps (7/14, 50%) were most frequently used compared to the regional flaps (5/14, 35.7%; data non-available for 2/14 patients).
Table 2 reports the reconstruction rate of the periorbit. No cases of orbital content postoperative infection were observed.
The 2 cases of CSF leak observed in the postoperative periods were attributed to failure of the skull base reconstruction.
At univariate analysis, intraoperative complications were more frequent when the osteoma had a critical relation with the CP (p=0.003).
Intraoperative and postoperative <24h AEA bleeding was managed with intraoperative or bedside lateral canthotomy and inferior cantholysis, followed by endonasal hemostasis and orbital decompression, in 3/5 cases. Two/5 cases, in absence of major intraorbital hematoma, were managed with endonasal hemostasis and orbital decompression.
No relevant factors influencing the occurrence of postoperative complications <30 days have been found.
Involvement of the anterior (p=0.009) and posterior plate (p=0.018) of the frontal sinus were associated with an increased rate of late postoperative complications.
Multivariable analysis did not identify any covariate with an independent impact on complication occurrence.

Discussion

In this study, we sought to examine how size and critical anatomical relationships of paranasal sinus osteomas affect their

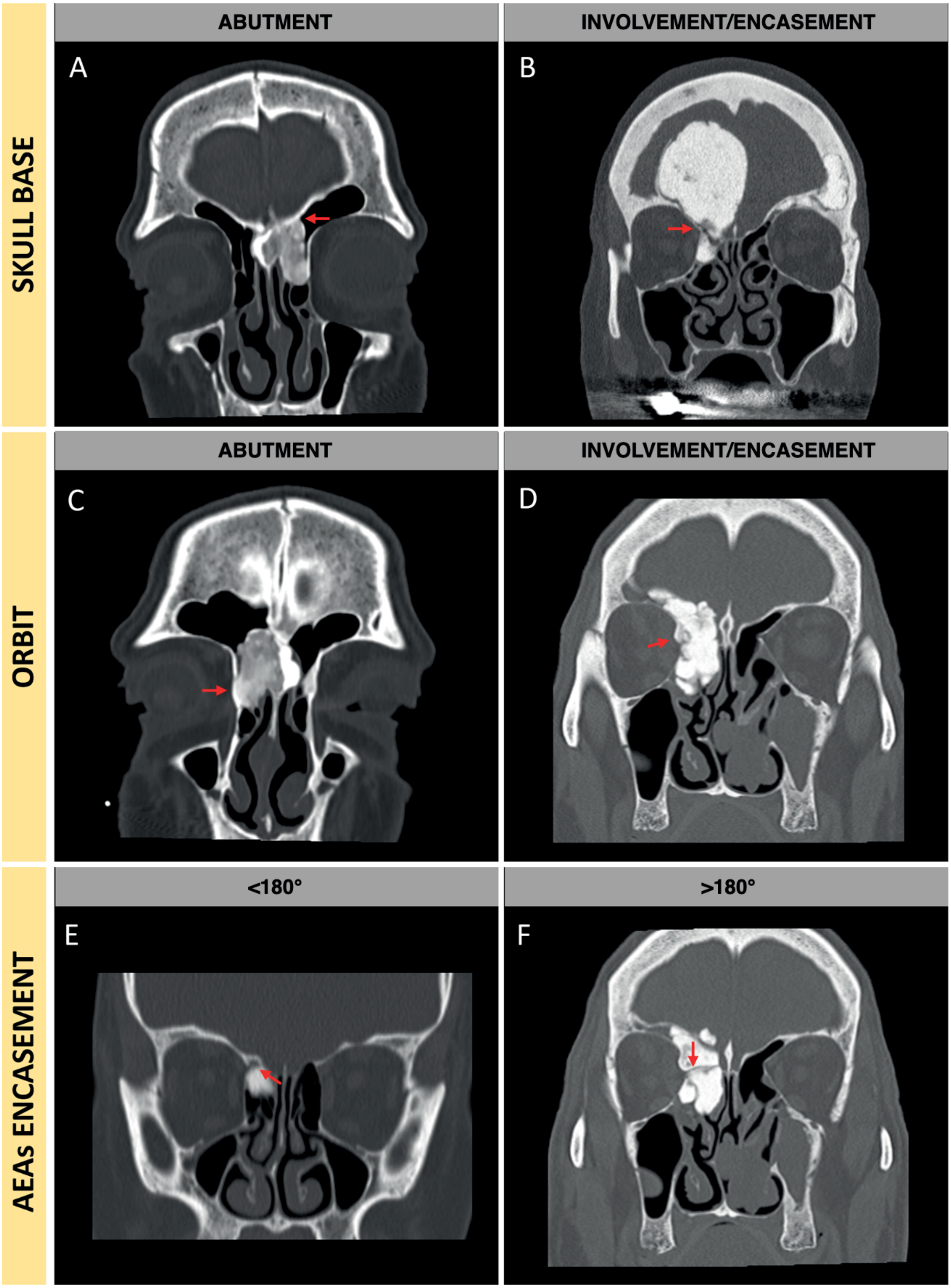

Figure 2. CT-scan imaging showing osteomas' radiological relationships (red arrows) with critical structures: osteomas in abutment (A) and involvement/encasement (B) of the anterior skull base; osteomas in abutment (C) and involvement/encasement (D) the papyracea; osteomas encasing <180° (E) or >180 (F) the anterior ethmoidal artery.

Table 2. Dura, periorbit and anterior ethmoidal artery management.

	Dural exposure (41/160)		Dural breaching (20/160)		Skull base reconstruction (29/160)			
	n	%	n	%	n	%		
Radiological relationship with the ER and/or CP								
ER/CP abutment (n=80)	23/80	28.8	10/80	12.5	13/80	16.3		
ER/CP involvement/encasement (n=5)	3/5	60.0	2/5	40.0	2/5	40.0		
No relation (n=75)	15/75	20.0	8/75	10.7	14/75	18.7		
Radiological relationship with the dura								
Dural abutment (n=12)	9/12	75.0	6/12	50.0	6/12	50.0		
Dural involvement/encasement (n=2)	2/2	100	2/2	100	2/2	100		
No relation (n=145)	29/145	20.0	11/145	7.6	20/145	13.8		
NS (n=1)	1/1		1/1		1/1			
Radiological relation with the papyracea	**Periorbit exposure (54/160)**		**Periorbit breaching (24/160)**		**Periorbit reconstruction (3/160)**			
	n	%	n	%	n	%		
Papiracea abutment (n=47)	15/47	31.9	4/47	8,70	0/47	0		
Papiracea involvement/encasement (n=33)	27/33	81.8	12/33	36.4	2/33	6.1		
No relation (n=80)	12/80	15	8/80	10	1/33	3		
Radiological relation with the AEA	**Dural exposure (41/160)**		**Dural breaching (20/160)**		**Periorbit exposure (54/160)**		**Orbital content exposure (24/160)**	
	n	%	n	%	n	%	n	%
Encasement <180°	12/42	28.6	3/42	7.1	18/42	42.9	5/42	28.6
Encasement >180°	2/7	28.6	1/7	14.3	1/7	85.7	1/7	14.3
Encasement 360°	7/12	58.3	6/12	50	6/12	50	4/12	33.3

AEA, anterior ethmoidal artery; CP, cribriform plate; ER, ethmoidal roof.

management and the incidence of perioperative complications. Our analysis focused exclusively on APSOs, defined as osteomas exceeding 3 cm and/or with critical extension towards the orbit and/or anterior skull base. Tumors with these specific anatomical features were included regardless of dimensions, since a small tumor in a tricky location can potentially increase the complexity of surgery more than a larger, more accessible lesion. We retrospectively analyzed clinical data from 160 patients, collecting experiences from high-volume referral centers. Despite the typical biases of such research type, several noteworthy observations emerged.

Diagnosis and localization

In most cases, the diagnosis of osteomas was prompted by clinical symptoms, a finding that diverges from existing literature where incidental discovery is noted in 90% of cases [19-21]. This variation can be attributed to the characteristics of the osteomas included in our study, which naturally increase the likelihood of symptoms and complications. However, it is possible that a selection bias may have occurred. The clinical series includes patients who underwent surgery, and therefore likely symptomatic, and does not consider patients who were under radiological surveillance.

The most common symptom was pain, usually resulting from sinus drainage compression and subsequent sinusitis. Headache is certainly not specific symptom. However, we believe that a frontal headache in the presence of an osteoma is strongly suggestive of a correlation between the symptom and the expansive lesion, even in the absence of clear signs of sinusitis on CT. Proptosis was the second most frequent symptom, caused by the mass effect of the lesion on the orbital contents. Of note, at Gil-Carcedo classification [18], almost all patients were staged in the third category, due to extension within the frontal sinus and presence of symptoms.

Our findings align with the topographic distribution reported in literature, indicating the frontal sinus as the most common site of osteoma occurrence [2]. Interestingly, we observed an ethmoidal extension in 46.2% of cases (exclusive or in combination with frontal sinus). The ethmoid complex, being a crossroad between the orbit and anterior skull base, has thin bony walls (LP and CP), which serve as potential pathways for lateral and cranial extension. We found that the LP was involved in 20.6% of all osteomas and 44.6% of ethmoid-centered lesions, whereas the CP was crossed in only 3.8% of cases (8.1% of ethmoid-centered osteomas). This pattern may reflect the pathogenesis and evolution of ethmoidal osteomas reported by Pons et al. [22]. The Authors reported an origin from the lateral part of the ethmoid sinus roof in all the cases of a series of 25 ethmoidal osteomas.

Table 3. Complications rates and details.

	n	%		n	%
Intraoperative	23/160	14.4	CSF leak Orbital content exposure AEA bleeding	11/26 11/26 1/26	42.3 42.3 3.8
Postoperative <24h	12/160	7.5	AEA bleeding Visual impairment* Proptosis* Pneumocephalus Frontal paresthesia	5/12 3/12 2/12 1/12 1/12	41.7 25 16.7 8.3 8.3
Postoperative <30 days	5/160	3.1	Mucocele Epistaxis Surgical site infection Visual impairment Proptosis	1/5 1/5 1/5 1/5 1/5	20 20 20 20 20
Late postoperative >30 days	23/160	14.4	Mucocele Frontal sinus stenosis Synechiae formation Septal perforation Cutaneous fistula Trigeminal nevralgia CSF leak Visual impairment Surgical site infection Headache	6/23 7/23 1/23 1/23 1/23 1/23 1/23 1/23 1/23 2/23	26.1 30.4 4.3 4.3 4.3 4.3 4.3 4.3 4.3 8.7

*2 cases of temporary visual impairment and 1 case of proptosis were observed in orbital hematoma due to intraorbital AEA bleeding.

The consequent extension towards the orbit may be due to the thinness of the LP, which does not constitute a resistant barrier to the expansive growth of the osteoma [22]. Consistent with these observations, the most common contact point in ethmoid lesions was the ER, followed by the LP and CP.

Treatment

The treatment strategy for osteomas typically depends on their clinical presentation and characteristics. In symptomatic patients, surgical removal is preferred. Conversely, management of asymptomatic (14.4% of our cohort) or small osteomas remains debated, with radiological surveillance as a potential option also for selected APSOs. Most literature on osteoma treatment focuses on large osteomas [8, 23-25], highlighting lesion size as a key factor in treatment decisions. However, location of the lesion and its relationship with critical anatomical structures should be considered as relevant as size in determining surgical management and its inherent risks.

In absence of symptoms, ethmoid osteomas warrant surgery more frequently than frontal lesions, due to the proximity to orbit and skull base. In these cases, a watchful waiting approach might not be advisable, as the occurrence of a complication could potentially be severe irrespective of dimension. In parallel, indications for surgical intervention in frontal osteomas vary among authors [22, 26]. Savic and Djeric advocated treating all osteomas extending beyond the frontal sinus, showing growth, exhibiting signs of chronic sinusitis, and/or located near the nasofrontal duct [26]. Georgalas et al. suggest surgery for large osteomas, defined as those occupying over 50% of the frontal sinus [19]. Interestingly, the mean diameter of the osteomas included in the study was around 2 cm, which is below the 3 cm threshold that is necessary to define a "giant" osteoma [8]. This suggests that indication to surgery was mainly dictated by symptoms and critical relationships, rather than large dimensions.

The choice of surgical approach – open, endoscopic, or combined – depends on the need for exposure, complete resection, management of potential complications, and experience of the surgeon. In this light, location and dimensions weight heavily on the type of procedure selected [19, 27]. Ethmoidal osteomas have been preferentially addressed with purely endoscopic techniques, benefiting from the favorable geometry for disease control despite critical relations with the orbit, AEA, ER, and CP. Conversely, frontal sinus osteomas pose greater geometric challenges. Lateral extension beyond the orbit meridian and a narrow frontal ostium on the sagittal plane may necessitate open or combined approaches [19, 28, 29]. In our series, an open or combined approach was selected for most cases with lateral frontal extension (73.9%). Of these, 85.3% underwent combined approach, to reduce the risk of stenosis addressing the frontal recess from below.

In our opinion, it is not possible to identify a system of objective factors that can invariably guide the choice of the approach. There are conditions that heavily influence the treatment choice, such as the laterality in relation to the orbital meridian,

the width of the frontal recess, and the percentage of frontal occupation [29]. However, these must be balanced with the surgeon's experience and the size of the tumor. For example, a lateral tumor of small size might, in experienced hands, undergo an attempt of endoscopic excision with orbital transposition. Therefore, each patient must be evaluated flexibly, conducting thorough counseling with the patient and being ready to switch from one approach to another if necessary.
Interestingly, no change in the distribution between open and endoscopic approaches was observed during the study period. This can be explained by the fact that the latter is relatively recent and the innovations in technique and technology aimed at favoring endoscopic approaches have been substantially available, albeit with recent improvements, throughout the entire analysis period.
Intraoperative navigation has been used in a significant percentage of cases, with more systematic use in recent years. Improvements in technology in terms of precision and ease of use have enabled its more extensive application, offering the advantage of greater surgical accuracy with the assessment of anatomical boundaries and estimation of residual disease.

Residual disease

In our cohort, residual disease was reported in less than 10% of cases, slightly higher than typically reported in the literature [12]. However, it is important to consider the inclusion criteria of the study. The primary aim of surgical resection is complete removal to prevent further complications without exacerbating the current condition [4, 8]. Nevertheless, if a safe dissection plane is unattainable and critical anatomical relationships are present, considering subtotal resection to minimize the risk of complications might be viable [22]. It is important to highlight that the potential for residual disease should be anticipated preoperatively and weighed against the invasiveness of the surgery upfront [30]. Based on our results, although not confirmed at multivariable analysis, involvement of CP suggests the need of a careful balance of risks and benefits provided by complete surgery, given the considerable association with intraoperative complications.
A higher incidence of residual disease was observed in frontal combined procedures, likely because these approaches were selected for more complex lesions. As reported in Table S2, the typical reason reported by the surgeon for incomplete resection was skull base involvement, confirming the previous statement about the possibility of intentionally leaving residual disease in cases involving the CP. This was confirmed by univariable analysis, where skull base relationships were significantly associated with residual disease. This is associated with the significant impact of axial diameter on incomplete resection. Combined approaches should ease the ablative phase of surgery, allowing complete exposure and control of the most lateral aspect of the osteoma. However, large osteomas are intuitively prone to critical relationships with the skull base that may lead the surgeon to stop the procedure.
In our series, none of the residual diseases showed a tendency to grow, resulting in the occurrence of symptoms and/or complications. This is in line with the results of Nguyen and Nadeau. In their series of "giant" osteomas, only 1 out of 6 residual diseases required a second surgery [8]. Similarly, Pamuk et al. reported a 6/40 residual tumor rate, with need of reintervention in 2 cases [31]. It must be underlined that the authors do not specify whether the reoperations were performed due to tumor growth or complications. Given the slow growth of osteomas, a long-term follow-up may be indicated in those selected patients in whom critical relationships and residual disease are observed, to potentially intervene in advance to prevent severe complications.

Complications

Intraoperative complications were significantly higher when the osteoma had a close relationship with the CP, with cerebrospinal fluid leak being a relatively common occurrence.
When abutment or frank involvement of CP and/or ER was anticipated at preoperative imaging, dural exposure occurred in 28.8% and 60% of cases, respectively. Dural tearing was reported in 40% of cases with CP and ER involvement. Despite being slow growing lesions with limited invasive potential, osteomas with critical relationship with skull base must be managed carefully, since their removal is associated with dural tearing and subsequent CSF leak in a non-negligible proportion of cases. Moreover, when dura involvement or abutment were suspected preoperatively, tearing occurred in all cases and half of the cases, respectively. These findings indicate a strong correlation between radiological assessment of the osteoma relationship with the skull base and intraoperative findings, suggesting the possibility of reliably predicting the need for reconstruction before starting the procedure. In our series, large dural defects were primarily reconstructed using a multilayer technique, while smaller defects were typically repaired using nasal mucoperiosteum grafting.
Periorbit tearing and orbital content exposure occurred as frequently as CSF leak but generally did not pose significant issues. Indeed, exposure of the orbital content typically does not require reconstruction, as the intraorbital fat rapidly heal without need of covering.
Early complications were predominantly orbital, attributed to bleeding from the AEA. Endoscopic surgery of osteomas is particularly subject to this eventuality, given the need to work extensively with drills and traction, even vigorously, on nasal structures, especially the orbit. Ethmoidal bleeding did not correlate with the degree of encasement on the artery, indicating the importance of surgeons being prepared to manage orbital hematoma in all cases. Procedures such as orbital decompres-

sion, lateral canthotomy, and inferior cantholysis must be performed promptly to avoid long-term visual impairment, both intraoperatively and bedside in the immediate postoperative period. An adequate training is therefore required. In any case, a careful check of the state of the ethmoidal arteries at the end of the procedure, regardless of active bleeding, is essential to minimize these events.

Additionally, the cavitation of the osteoma's core facilitates the gentle fracturing and removal of the thin peripheral bony shell. This technique diminishes the lever force required to dissect the bone from the surrounding tissues, thereby minimizing damages to the dura, periorbita, and ethmoidal arteries [12].

Long-term complications occurring beyond 30 days were notably associated with anterior and posterior plate of the frontal sinus involvement, with osteoma in the frontal sinus posing a higher risk for mucoceles and ostium stenosis. Careful management of the new frontal opening is essential. Given the need for extensive drilling of the bony boundaries, the progression towards a process of cicatricial stenosis or osteitis is a likely occurrence. A wise use of mucosal rotation flaps, grafts, or medicated stents could improve long-term outcomes in this regard [32, 33].

Interestingly, the size of the lesion did not appear to impact complication rates. The correct selection of the surgical approach likely minimizes the impact of the osteoma size on the development of complications, whose rate is nonetheless influenced by critical anatomical relationships.

According to our findings, none of the predictive variables highlighted at univariable analysis showed an independent impact on the occurrence of complications and residual disease at multivariable study. The complexity of each case may be influenced by several factors, claiming for a case-by-case discussion of criticisms and treatment strategies.

The primary limitation of this study lies in its retrospective design, which did not allow for the inclusion of standardized symptom-related outcome measures, such as SNOT-22 or VAS. Future studies should incorporate validated symptom-related outcomes to provide a more comprehensive understanding of the impact of osteoma resection on patient quality of life. Moreover, the sample size is relatively small considering the number of confounders and events analyzed. Expanding the cohort may validate these findings and offer further insights.

Conclusion

Our research highlights that dimensions and critical anatomical relationships impact the surgical management of paranasal sinus osteomas and its inherent morbidity. Radiologic assessment of the osteoma relationship with the skull base proved valuable in predicting intraoperative challenges, with special reference to intraoperative CSF leak and need for dural reconstruction.

By focusing on APSO, we demonstrated that the selection of surgical approach and the occurrence of residual disease are influenced by both dimensions and critical anatomical relationships. Interestingly, complication rates were not correlated with the osteoma diameter. Furthermore, relationships with the CP and anterior and posterior plate of frontal sinus were associated with intraoperative and long-term complications, respectively.

Provided that the goal of surgery remains gross total resection whenever achievable, the present study demonstrated that leaving a residue whose removal would imply high risk of morbidity represents a valuable option in selected cases.

While our study provides valuable insights, its limitations emphasize the need for further research to validate and expand upon these findings.

Authors' contributions

Conceptualization: VR MF AV BV, Data collection: ID TS GT CC CF GA PG DC TS ADA LN AW CRVS; Data analysis: VR MF AV BV; Draft preparation: VR MF AV DM DB; Supervision and paper revision: AA MTZ EE AS PB FP MB CP PC NP PH.

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Conflicts of interest

The authors declare no conflict of interest.

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This manuscript contains online supplementary material

SUPPLEMENTARY MATERIAL

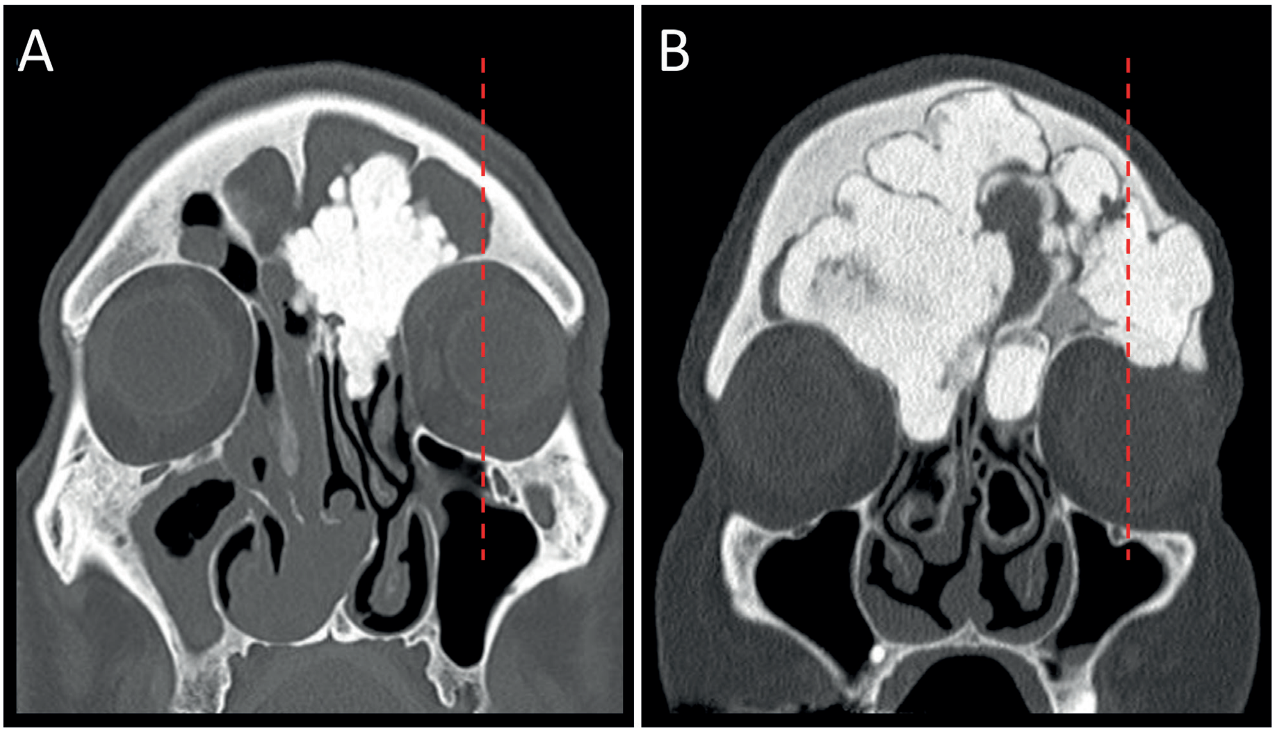

Figure S1. Coronal CT scan showing the medio-lateral extension of frontal sinus osteomas with respect to the meridian of the orbit (red dotted line). Images A and B depict a medial and a lateral osteoma, respectively.

Table S1. Critical relations at preoperative imaging.

		Abutment		Involvement/encasement	
		n	%	n	%
Skull base and orbit relations	Anterior plate of frontal sinus	75/160	46.9%	12/160	7.5%
	Posterior plate of frontal sinus	83/160	51.9%	14/160	8.8%
	Orbital plate of frontal sinus	74/160	46.3%	18/160	11.3%
	Cribriform plate	26/160	16.3%	6/160	3.8%
	Ethmoidal roof	70/160	43.8%	5/160	3.1%
	Crista galli	27/160	16.9%	2/160	1.3%
	Dura	12/160	7.5%	2/160	1.3%
	Brain	4/160	2.5%	4/160	2.5%
	Papiracea	47/160	29.4%	33/160	20.6%
	Periorbit	39/160	24.4%	3/160	1.9%
AEA relations	No abutment with the ethmoidal artery	99/160	61.9%		
	Encasement <180°	42/160	26.3%		
	Encasement >180°	7/160	4.4%		
	Encasement 360°	12/160	7.5%		

Table S2. Residual disease details. NS – Not specified.

n=15	Critical relations								Surgery	Reasons for intentional residual disease
	Location	Cribriform plate	Fovea ethmoidalis	Crista galli	AEA encasement	Dura	Papyracea	Lateral location in the frontal sinus		
1	Frontal	Abutment	Abutment	Abutment	No	No	Abutment	No	Combined	NS
2	Frontal + ethmoid	Involvement/encasement	Abutment	No	360°	Abutment	Involvement/encasement	Yes	Combined	NS
3	Frontal	None	No	No	No	No	No	Yes	Combined	NS
4	Frontal	Abutment	No	No	360°	No	Abutment	No	Endoscopic	Critical relation with orbit and skull base
5	Ethmoid	Abutment	No	No	No	No	No	No	Endoscopic	Critical relation with skull base
6	Frontal + ethmoid	Abutment	Abutment	Involvement/encasement	>180°	Abutment	Involvement/encasement	No	Endoscopic	Critical relation with skull base
7	Frontal	No	No	No	No	No	Involvement/encasement	No	Combined	Surgery consisted in a debulking for sinusitis, a second-look was planned but the patient refused
8	Frontal + ethmoid	No	Involvement/encasement	No	<180°	Abutment	Involvement/encasement	No	Endoscopic	Emergency surgery for sinusitis with posterior frontal plate erosion, a second-look surgery planned but the patient refused
9	Ethmoids	No	Abutment	No	<180°	No	Abutment	No	Endoscopic	Critical relation with the skull base
10	Frontal	No	No	No	No	No	No	Yes	Endoscopic	Critical relation with the skull base
11	Frontal	No	No	Abutment	<180°	No	Involvement/encasement	Yes	Endoscopic	Lateral location in the frontal sinus
12	Frontal	No	Abutment	Abutment	<180°	Abutment	Involvement/encasement	Yes	Combined	Presence of intracranial component
13	Frontal	No	No	No	<180°	No	Abutment	Yes	Combined	NS
14	Frontal	No	Abutment	Abutment	<180°	No	Abutment	No	Combined	NS
15	Frontal + ethmoid	No	Abutment	No	No	No	Abutment	Yes	Combined	NS