Frontal sinus ablation (Riedel-Mosher's procedure): indications and role in the endonasal endoscopic era*

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Abstract

Background: The aim of this article is to describe the Riedel-Mosher's surgical technique and identify its current role in the endoscopic endonasal era based on the experience of a tertiary care medical centre. It also provides a brief excursus on materials available for frontal reconstruction.

Methods: A retrospective review of patients submitted to Riedel-Mosher's procedure from 2005 to 2018 at a single tertiary care centre was carried out. Details of the surgical technique along with data on frontal reconstruction timing and materials used were collected.

Results: A total of 21 patients (16 males and 5 females) underwent the Riedel-Mosher's procedure. The age of the patients ranged from 15 to 84 years. The underlying pathology was represented mainly by chronic osteitis of the frontal bone (17 cases), followed by benign tumours (3 cases) and malignancy (1 case). Perioperative complications occurred in 3 patients. Cranioplasty was carried out only on 16 cases and delayed by an average time of 10 months. Materials for reconstruction included titanium, ceramic, plastic and free flap .

Conclusions: Nowadays, Riedel-Mosher's procedure is still indicated in selected cases of benign and malignant pathologies of the frontal sinus and/or frontal bone. Surgical expertise is key to approach the frontal sinus safely. Its reconstruction requires proper planning and a wide variety of materials to perform it is now available.

Key words: frontal sinus ablation, frontal sinus reconstruction, frontal osteitis, cranialization, cranioplasty

Introduction

The endoscopic endonasal approach represents the gold standard of various frontal sinus pathologies[(1)], as even selected far lateral frontal lesions can be now approached in selected cases by combining a Draf III procedure with an endoscopic endonasal orbital transposition[(2)]. At any rate, the endoscopic endonasal technique is a valid alternative both for disease biology and frontal sinus morphology, as it offers additional benefits

such as minimal aesthetic and/or cosmetic discomfort, reduction of postoperative morbidity and patient hospitalization[1]. However, in some cases an external approach stands as the only option for complete clinical resolution. The invasiveness of such approaches is also related to the disease nature and extension. Surgical options range from osteoplastic frontal flaps o cranialization of the frontal sinus or even more aggressive interventions, such as Riedel's procedure, that consists in removing the anterior wall and floor of f ontal sinus, and its modific tion according to Mosher's, with removal of the sinus posterior wall [3-5]. Following Riedel-Mosher's procedure, the residual large cranial bony defect will lead to cranio-facial disfigu ement and possible neurologic disorders. Reconstruction is therefore necessary to protect the brain, normalize intracranial pressure, alleviate neurologic signs and provide acceptable cosmetic results[6].
Materials used for frontal cranioplasty should be biocompatible, osteoconductive, resistant to infections, robust, light, radiolucent, pliable, non-magnetic, inexpensive and ready to use. Various materials have been recommended and employed[7], although none can be considered the perfect solution for obvious reasons. Of course, revascularized autogenous calvarial bone represents the most suitable material for anterior frontal sinus wall reconstruction; other options include alloplastic bone, Hydroxyapatite (HAP) ceramic, metals and alloys, carbon fib e reinforced polymers[8].
Timing of reconstruction represents another key issue when dealing with this type of surgery as it depends on various factors related to both the patient and the pathology treated.
The aim of this study is to provide our experience through practical surgical notes and discuss indications and complications related to the Riedel-Mosher's procedure and subsequent cranioplasty.

Materials and methods

A retrospective evaluation was conducted on patients submitted to Riedel-Mosher's procedure at the Otorhinolaryngology and Neurosurgery Department of the University of Insubria Varese, Italy, from 2005 to 2018. Clinical data, demographics, surgical details, pre- and post-operative images, duration of surgery, complications, time to cranioplasty, reconstruction materials and follow-up information on treated patients were collected from a specific d tabase. Approval for the study was granted by the Insubria Board of Ethics.
Preoperative assessment was based on nasal endoscopy and computed tomography performed on every patient object of the study. Selected cases underwent a contrast-enhanced magnetic resonance imaging to obtain additional information on the lesion nature (i.e., pattern of enhancement, solid or fluid content) and to better outline the frontal sinus involvement and relationship with the adjacent skull base (i.e., dura, brain, orbits). Every patient was thoroughly informed about the treatment method and gave his/her written consent to the surgical procedure. Patients were followed up closely after surgery through serial clinical and radiological evaluation to identify early or late complications and detect possible recurrence of the disease.

Surgical technique

Resection

Prior to surgery, an autoclave template of the frontal sinus outline is obtained from a 6-ft Caldwell view cranial X-ray or, as an alternative, a magnetic navigation system is set up using the pre-operative CT scan, as described by Volpi et al.[9].
Surgery is performed on patient under hypotensive general anaesthesia, in slight anti-Trendelenburg position. Local anaesthesia is injected before incision to reduce bleeding. A coronal incision is made from ear to ear, about 5 cm behind the hairline for a non-visible scar. An anterior peak in the incision can be designed to help approximation of the scalp flap t end of surgery. Raney clips are applied on the scalp incision to improve haemostasis. The incision is carried down to the subgaleal plane as far as the loose areolar tissue. The scalp is pulled down caudally on both sides through blunt dissection as far as the superior orbital rims and the nasion, paying attention to preserve the supraorbital and supratrochlear nerve, the vessels at supraorbital rim level and the frontal division of the facial nerve, running inside the subgaleal fat pad between the tempoparietal fascia and the temporalis muscle fascia[10]. A large periosteal/pericranial flap is then created, keeping it pedicled caudally at the bone. Some authors recommend using a pericranial-frontalis muscle flap rather than a pericranial fla , even in patients with skin fistula , as pericranial flaps m y not retain a suffici t blood supply after previous operations and infections[11]. The shape of the frontal sinus is outlined by the template or by the magnetic navigation system. The diseased bony anterior wall of the frontal sinus is then drilled bilaterally as far as the supraorbital ridge while preserving a bony lid to hinge the periosteal fla . The sinus is fully exposed, including supraorbital cells, and the bony borders are smoothed with a diamond burr.
The entire diseased tissue is removed according to the pathological findings as far as the pos erior wall of the frontal sinus (pwFS). The pwFS is then thinned, fractured and gradually removed to expose the dura mater (Figure 1). Crista galli is resected as well, along with the floor of the f ontal sinus bilaterally to create a wide Draf III sinusotomy, and the bony orbital roofs if necessary. In case of accidental incision, the dura can be repaired with silk sutures. After removing the pathology completely and smoothing all bony edges, the pericranial/pericranial-frontalis muscle flap is everted to cover the Draf III sinusotomy, excluding the nasal fossae, and, further above, the exposed dura of the anterior cranial fossa. The pericranial flap is stabili ed to the dura with stitches, Surgicel (Johnson & Johnson Medical, Arlington, TX, USA) and fib in glue. There should be no mucosal

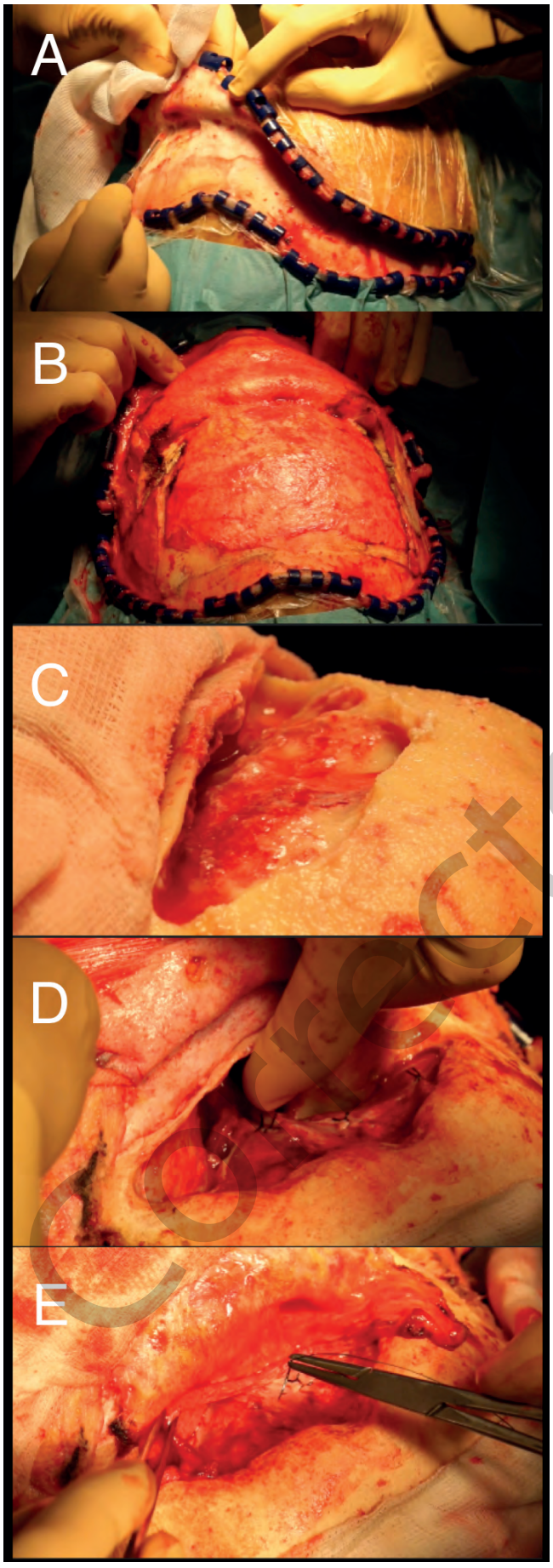

Figure 1. Surgical steps of frontal sinus ablation: after harvesting galeal (A) and pericranial (B) flaps, anterior (C) and posterior (D) walls of the sinus are removed to expose the dura mater; at the end of the procedure the pericranial flap is sutured to the dura mater (E) to separate the nose from the intracranial compartment.

residue above the reconstructed frontal sinus floor to prevent mucocele. This can be achieved either by extirpating completely the mucosal lining and drilling the underlying bone or by inverting the residual mucosa of the frontal outflow tract into the nose[11]. At the end of this operation, the scalp is flipped back and sutured with single stiches or staples. In addition, a drain is inserted and then removed on the 2nd post-operative day.

Reconstruction

The reconstructive technique may vary slightly depending on the material used, but the principles are generally the same. Some authors advocate immediate reconstruction (single stage) [12, 13], but in our experience an adequate period of time is recommended between the two surgery stages, generally 6 months, although the current literature gives no shared opinion about the ideal timing for cranioplasty[14].

Prior to surgery, all patients undergo a CT scan to help mould a custom-made template or to evaluate the anatomy of the residual frontal bone and possibly measure the frontal defect (see below). A thorough clinical examination is also performed to identify possible signs of systemic or local infection along with a blood test to evaluate inflammatory markers, such as white blood cell (WBC), erythrocyte sedimentation rate (ESR), C-reactive protein (CRP) and procalcitonin (PCT).

The initial surgery stage corresponds to resection time, i.e. coronal incision and harvesting of scalp flap. Dissection of the scalp should be carried out with great care to prevent scarring and potential damage to the dura.

Once the defect is fully exposed, some authors recommend cutting the pedicle of the pericranial flap which covers the bony supraorbital rim and may interfere when fitting the template[11]. However, this has never occurred in our experience and the template could always be fitted with ease.

Depending on the material used to reconstruct, the template can be pre-formed, made to measure based on post-resection imaging of the patient (CT scan), or modelled during the operation according to the outline of the resulting defect. The former technique is based on a 3D computed reconstruction of the defect based on radiologic imaging (Computed Aided Design, CAD) and subsequent creation of a three-dimensional implant through additive processes, such as stereolithography (SLA), selective laser sintering (SLS) or fused deposition modelling (FDM), depending on the various materials available and/or required, thanks to the so-called Computer Aided Manufacturing (CAM).

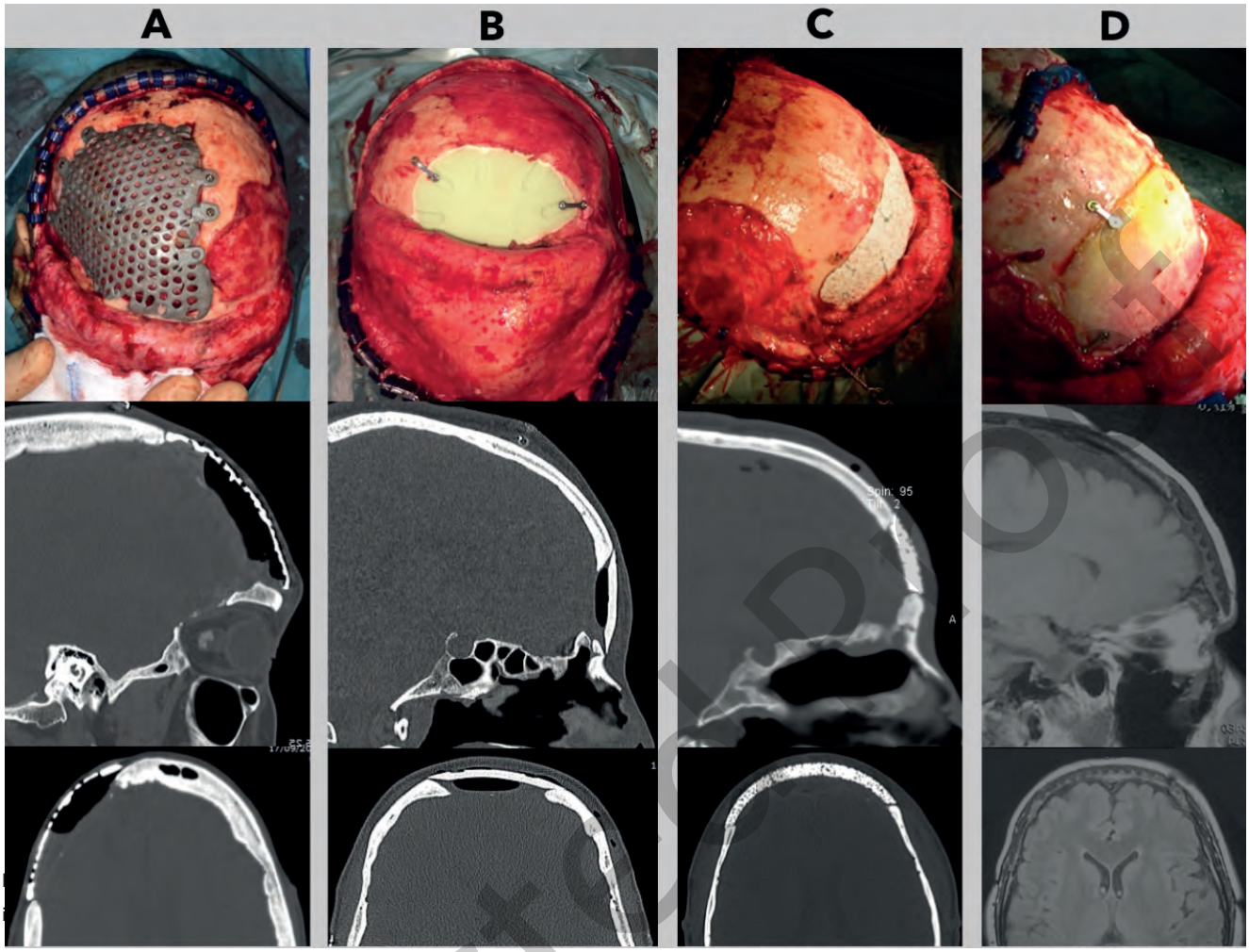

Figure 2. Intraoperative view of the different types of implants after fitting and stabilization: titanium (A), PMMA (B), ceramic (C) and Medpor (D). Radiologic controls show excellent outcomes both on first post-operative day (A and B, CT scan) and one year after surgery (C, CT scan; D, MRI T1 weighted scan).

All made-to-measure implants are provided sterile with a sterile spare device. On the other hand, the latter technique allows the surgeon to fit the emplate accurately even when widening or correcting the bony defect, but it is less accurate. In this case the template is realized intraoperatively by combining a predefined amou t of powder and liquid to obtain a homogenous paste, which is then applied directly on the skull or poured into a custom-made mould, stamped and let dry for a few minutes (e.g. 12-15 minutes for PMMA). The mould is made based on the preoperative CT scan and provided unsterile with a stamp; both pieces need to be sterilized prior to surgery.

After fittin , the template needs to be stabilized in the residual frontal bone with silk stitches or miniplates and screws at the angles to prevent displacements (Figure 2). Finally, the scalp flap is flipped back and sutu ed, while drainage is inserted subcutaneously and maintained for two days.

Materials used for reconstruction

An in-depth review of alloplastic materials available for skull base reconstruction was carried out by Maier[8], while an even more detailed description of biomaterials for craniofacial reconstruction was published by Neuman and Kevenhoerster[7].

In our series, all reconstructions were performed using 3 materials: titanium, ceramic and plastic, either poly-methyl methacrylate (PMMA) or high-density porous polyethylene (HDPE or Medpor®).

Titanium is a corrosion-resistant and biocompatible metal which presents high stability at light mass and very low toxicity[15, 16]. Sensitization to titanium is very rare and type-IV reactions have not been experienced in cranio-facial implants so far. Downsides of titanium implants include impossibility to reprocess made-to-measure implants, vital tissue required as cover, sensitivity to heat and cold and creation of artefacts during radiological imaging (CT/MRI)[8].

Glass-ceramic is a bioactive material able to induce osteostimulation at surface level[17]. It consists of silicon dioxide and sodium oxide (45% each), while the remaining 10% is composed by calcium oxide and phosphorus oxide. The material is never

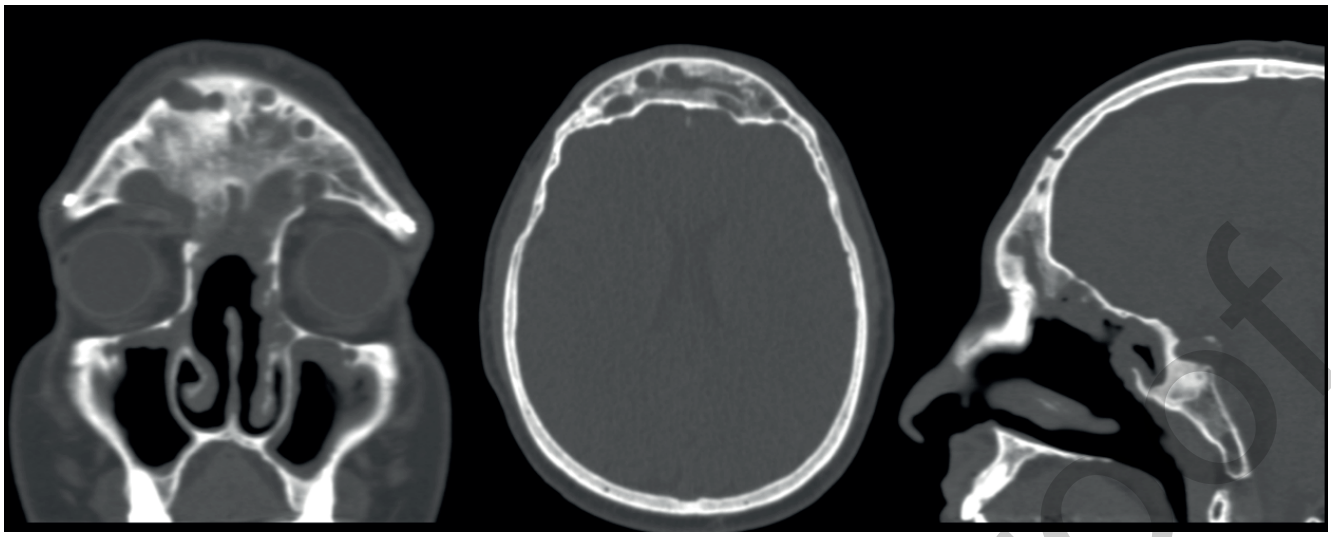

Figure 3. CT aspect of chronic osteitis of the frontal bone. Note the diffuse thickening with ground glass appearance, sparse mucoceles and areas of bony erosion.

replaced after implantation, even when tenacious bonds form between the bone and the implant. Drawbacks of ceramic implants may include extrusion, possibly caused by poor vascularization, and fractures by minor trauma[18].

Poly-methyl methacrylate (PMMA) is part of the so-called hard tissue replacement (HTR) sintered polymers, which include poly-hydroxyethyl methacrylate (pHEMA) and calcium hydroxide. Among HTR benefits a e: porosity, which enables ingrowth of blood vessels and connective tissue while enhancing implant fix tion; hydrophilic surface; negative surface tension and high compressive strength. Following implantation, PMMA remains stable in size, is not absorbed and is well tolerated[19].

The materials described above are available as pre-formed (or mesh in case of titanium) or made-to-measure implants, based on the preoperative CT scan. The latter is always more expensive to produce, that is why it may not be the first choi e for a budget-centred healthcare policy; yet it represents the most convenient solution for patients in terms of aesthetics and tolerance.

Results

A total of 21 patients, 16 males and 5 females, were treated with the so-called Riedel-Mosher's procedure, but only 16 (76%) underwent subsequent cranioplasty. 4 patients are currently awaiting reconstruction, 2 of which are still monitored clinically and radiologically for oncological reasons; the last patient was lost during follow up after ablation. Age at the time of resecting surgery ranged between 17 and 84 years, with an average of 48. All patients, except one (meningioma of olfactory groove), had undergone surgery in the past targeting the frontal sinus: endoscopic only (2 cases), external only (7 cases) or combined/sequential (11 cases). The time span from the previous surgery varied extremely, ranging from 1 month to 9 years. One single patient affected by squamous cell carcinoma had been exposed to adjuvant chemoradiation after the initial endoscopic endonasal surgical procedure as part of the overall treatment.

The pathology leading to the surgical procedure was mainly represented by chronic frontal osteitis with possible resorption of the frontal wall (17 cases, 81%) (Figure 3), followed by benign tumours (1 frontal osteoma, 1 frontal fib ous dysplasia, 1 meningioma of the olfactory groove, 5%) and 1 case of malignancy (squamous cell carcinoma of frontal sinus). In 17 cases (81%) the frontal sinus was involved bilaterally, while in 4 cases (19%) it was involved unilaterally (2 on the left and 2 on the right).

Main pre-operative problems reported by patients were frontal skin fistula (8 case , 40%) and headaches (7 cases, 35%). Riedel-Mosher's surgical procedure lasted on average 206 minutes (ranging from 67 to 332 minutes). When available, samples for cultural examination were positive to methicillin-resistant *Staphylococcus aureus* (MRSA) in 2 cases, non-aureus *Staphylococcus* (NAS) in 3 cases (with 2 methicillin-resistant species) and other bacteria in 3 cases (*Pseudomonas Aeruginosa, Bacteroides Bivius, Serratia Marcescens*).

Following frontal sinus ablation, 3 patients (14%) experienced complications: 2 had a CSF subcutaneous collection that was treated conservatively with compressive bandaging; 1 developed initially a fronto-basal purulent collection, treated conservatively with antibiotic therapy, and later a delayed CSF leakage, requiring duraplasty, and a CSF subcutaneous collection, which was treated with transcutaneous drainage and lumbar puncture to reduce intracranial pressure.

As specified ab ve, 16 patients took cranioplasty. Reconstruction time ranged from 3 to 25 months with a median value of 10. In one specific cas , reconstruction was contextual to ablation

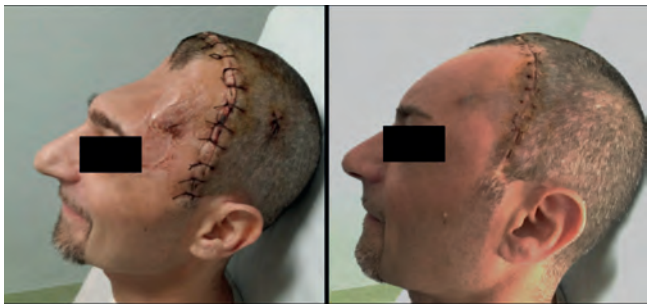

Figure 4. Aesthetic results of frontal sinus ablation (left) and subsequent cranioplasty with ceramic template (right) in a 40-year-old male affected by chronic osteitis of the frontal bone.

due to the complex post-surgical anatomy of the patient, who had undergone a previous craniofacial resection. Various materials were used for reconstruction: made-to-measure ceramic was employed in 6 cases (Figure 4); PMMA (polymethylmethacrylate) intraoperatively prepared and modelled in 6 cases; preformed pliable high-density polyethylene (Medpor®) in 1 case; titanium mesh in 2 cases; a latissimus dorsi free flap (LDFF) as used on the patient who was reconstructed contextually. After cranioplasty, 4 patients experienced complications: 1 patient developed a frontal and supraorbital mucocele 4 years later and required marsupialization plus duraplasty; 2 patients suffered delayed infection of the PMMA template, which needed to be removed respectively 3 and 6 years after fittin , but they refused further reconstruction; 1 patient suffered an early post-operative extradural hematoma which required removal of the ceramic template and repositioning after a couple of months; the same patient later suffered a template fracture after head trauma, and the template was eventually replaced with PMMA. To note, this patient was the same who suffered multiple complications after Riedel-Mosher's procedure.

Follow up ranged from 12 months to 11 years, with an average of 50 months. It is pointed out herein that our department's policy provides for discharging patients after 10 years of uneventful follow up and recommending further consultation in case of new symptoms.

Details about the patients' individual characteristic and surgical outcomes are summarized in Table 1.

Discussion

Nowadays, the frontal sinus is generally approached endoscopically through the endonasal route, which provides the surgeon with direct access to the sinus and magnific tion of the operative fiel , along with the possibility to restore physiological ventilation by removing obstacles along the ethmoidal drainage pathway and shaping the frontal ostium to prevent unnatural routes and facial scars. Nonetheless, several transfacial/craniofacial techniques have been codified in the past, d ting back as far as the 18th century[4]. Although they have lost their popularity along the years for their association with limited benefits and major complications - including death - external surgical approaches to the frontal sinus are still strongly recommended for complicated rhinosinusitis, extensive benign tumours, malignancies or trauma with fracture of the frontal sinus walls[20, 21]. In fact, the endoscopic endonasal approach alone would be inappropriate and inconclusive for all the above situations.

The so-called Riedel-Mosher's procedure, also known as frontal sinus ablation, was introduced in 1933 by Dr Harry P. Mosher who modified iedel's original technique[3]. The surgical invasiveness of the latter and the double-stage intervention (ablation and reconstruction) lead to a considerable rate of complications that must be taken into account. In our series, post-operative adverse events were experienced by 3 patients (3/21, 14%) after ablative time and by 4 patients (4/16, 25%) after reconstruction time, but only 1 major event occurred in the end (1/21, 5%), a CSF leakage. There were no damages to cerebral parenchyma or local extensive infections, as described by Van Dijk et al. during a similar surgical procedure (cranialization), which resulted in a total of 5 major or minor complications out of 17 cases (33%)[22]. In the past, other authors reported similar types and rates of unfavourable events (6/21, 29%, including 4 cases of CSF leakage)[23]. To note, complications after ablation, such as subcutaneous collections, seemed to occur at an early stage after surgery and they were treated conservatively in all but one case; on the contrary, complications after reconstruction generally presented a later onset (mucocele, template infection) and all of them required surgical treatment.

Considering its invasiveness and possible complications, Riedel-Mosher's procedure in modern sinus and skull base surgery must follow strict indications, which, in our opinion, may be summarized as follows:

- complications of acute or chronic frontal sinusitis, such as osteomyelitis of anterior and posterior walls (with or without skin fistula
- extensive Pott's puffy tumour (subpe iosteal abscess of the frontal bone) with associated common intracranial complications
- resorption of the frontal bone after previous craniotomy
- malignant tumours of the frontal sinus
- benign tumours with extensive involvement of anterior and/or posterior walls of frontal sinus
- comminuted fractures of anterior/posterior walls

In our series, the most frequent indication for Riedel-Mosher's procedure was represented by chronic degenerative processes of the frontal bone, namely chronic osteomyelitis possibly caused by subacute infection and/or vascular impairment of the bony tissue, often developed some time after a previous craniotomy. While in acute suppurative complications of frontal sinusitis, such as Pott's puffy tumour , there is a clear indica-

Table 1. Patients' characteristics and surgical details.

Patient	Sex	Age (years)	Disease	Previous surgery	Side	Time to re-construction (months)	Material for reconstruction	Complications of ablation	Complications of reconstruction
C.G.	F	54	CO	YES	BIL	6	Medpore	/	/
P.U.	M	38	CO	YES	BIL	16	Ceramic	Purulent collection CSF leak	Extradural hematoma Template fracture
S.E.	M	84	CO	YES	BIL	8	PMMA	/	Template infection
I.C.	M	49	CO	YES	BIL	16	Ceramic	/	Frontal mucocele
B.G.	M	19	CO	YES	L	3	Ceramic	/	/
D.A.	M	62	CO	YES	BIL	/	/	/	/
D.P.	M	51	CO	YES	BIL	14	Ceramic	/	/
P.A.	M	21	CO	YES	BIL	5	Ceramic	/	/
S.G.	M	44	CO	YES	BIL	12	PMMA	/	/
P.G.	M	15	FO	YES	R	15	Titanium	/	/
P.L.	F	45	CO	YES	BIL	3	PMMA	/	Template infection
C.A.	M	81	CO	YES	L	Concurrent	LDFF	/	/
E.E.	M	48	FD	YES	BIL	/	/	/	/
F.F.	M	27	CO	YES	BIL	3	PMMA	/	/
C.A.	M	55	CO	YES	BIL	8	PMMA	/	/
R.S.	M	40	CO	YES	BIL	8	Ceramic	/	/
R.E.	M	68	SCC	YES	BIL	/	/	CSF collection	/
L.M.	F	69	OGM	NO	BIL	/	/	CSF collection	/
P.A.	F	47	CO	YES	BIL	25	PMMA	/	/
I.G.	F	46	CO	YES	R	22	Titanium	/	/
C.R.	M	47	CO	YES	BIL	/	/	/	/

CO, chronic osteitis; FO, frontal osteoma; FD, fibrous dysplasia; OGM, olfactory groove meningioma; SCC, squamous cell carcinoma; LDFF, latissimus dorsi free flap; R, right; L, left; BIL, bilateral; CSF, cerebrospinal fluid; PMMA, poly-methyl methacrylate.

tion to immediate surgical treatment, dictated by the frequent intracranial complications associated (e.g. epidural/subdural/cerebral abscess)[24], management of chronic osteomyelitis is often based on ineffective medical therapy or conservative surgery and ablation is erroneously postponed. Under such circumstances, rehabilitation of the patency of the frontal ostium through an endoscopic endonasal approach is insufficient as the disease affects the bone itself. On the other hand, antibiotic therapy cannot eradicate the infectious foci, because of poor penetration into the avascular or sequestered bone, for the excessive extension of the pathological degeneration or even inadequate drug and/or regimen applied. Typically, patients report recurrent episodes of headache, forehead and/or supra-orbital swelling and tenderness, possible purulent discharge intranasally or through cutaneous fistula, which may all regress with a short course of antibiotic and steroid therapy, but never cease completely. CT scan typically shows erosion or resorption of variable parts of the frontal sinus walls, with possible bony sequestration and/or distortion of the cancellous bone occupied by amorphous radiopaque tissue. It is therefore mandatory to remove the affected walls until normal bone is reached and implement post-operative treatment with a prolonged antibiotic regimen[25-27]. Although a less radical surgery, such as the simple Riedel's procedure, may seem sufficient, in case of long-standing disease complete ablation provides better chances of eradicating the infection completely, even where it is not clinically but only microscopically apparent[3], because of the possible spread through the diploic veins of Breschet. Moreover, disfigurement resulting from complete ablation of the frontal sinus is the same resulting from Riedel's classic procedure.

Malignancies of the frontal sinus are extremely rare[28] and require radical treatment, which includes necessarily unilateral or bilateral removal of the frontal sinus walls involved to achieve oncological free margins of resection[4]. In such cases, resection

may be extended even further, as far as the orbital roof or adjacent bony components of the skull, based on the pre-operative radiological-documented extension of disease or intraoperative frozen sections with evidence of neoplastic infiltration. The likely advanced stage at diagnosis generally requires adjuvant radiation or chemoradiation and prognosis remains poor[28], that is why timing of reconstruction is a matter of debate.

Similarly, extensive benign tumours of the frontal sinus, more specifically fibrous-osseous lesions causing total or subtotal substitution of the whole bone, compel complete removal of the walls affected by the disease and lead to reconstruction of the frontal defect[29-31].

Severely comminuted fractures of the frontal sinus anterior and posterior walls may represent another indication to Riedel-Mosher's procedure. In such cases, it may not be possible to wire the bone fragments with miniplates, as this is usually performed in case of gross fracture of the anterior wall[32], and there may be bony losses which prevent conservation of the remaining frontal osseous components[33]. In addition, given the traumatic origin of this clinical scenario with possible associated neurological morbidity, brain decompression by removal of the frontal bone may be necessary, thus making delayed reconstruction with wired bony fragments unrealistic[34].

Of course, restoration of the frontal contour is essential for sinus ablation. There are various materials available, each with pros and cons. In our opinion, ceramic and PMMA provide the best results in terms of both aesthetic and function: they are biocompatible, light, heat-insensitive and induce bone growth. Nonetheless, they are burdened by a few shortcomings which we experienced first-hand: ceramic is fragile, so a minor trauma may cause fractures; PMMA may induce local reactions or may be prone to infection in case of contact with nasal mucosa or residual undetected foci of osteomyelitis[8].

Autologous calvarial bone is not a valid option for the morbidity of the donor site and the significant rate of later complications extensively described by literature, consisting of infection or resorption[35, 36].

Although the patient's health is the main goal, cost of the various materials and processes to produce them is key when making the final choice. This standpoint overlooks the idea of patient-tailored medicine, which aims at providing each person with the best-fitting treatment, in favour of a generalized and cost-effective solution, that is giving the surgeon the cheapest material that can satisfy, more or less adequately, the highest number of patients.

Timing of cranioplasty needs to be properly evaluated to avoid additional complications, namely infection. In our series, reconstruction time ranged from 3 to 16 months, save for a contemporary reconstruction in an exceptional patient. Prior to cranioplasty, in case of chronic osteomyelitis, we recommend completing an extended post-operative antibiotic regimen based on cultural exam, whenever available, to eradicate possible residual infective foci. Literature indicates a 3-month course as the most effective treatment[37]. A delayed post-operative CT scan (e.g. at 3 months) is useful not only to confirm positive evolution of the surgical field and non occurrence of late complications, but also to guide possible preparation of a pre-modelled template. Given this minimal lapse, timing should ultimately be established based on the patient's clinical conditions, especially in case of chronic osteomyelitis: absence of local or general signs of infection, normal values of inflammatory markers (CRP and ESR) and negative CT scan are positive elements for frontal reconstruction[14]. The role of radionuclide imaging during follow up is undetermined in case of frontal chronic osteomyelitis. Numerous techniques are available for diagnosis and monitoring of skull base osteomyelitis[38] or for general osteomyelitis[39]. Bone scintigraphy with ^{99m}Tc MDP, ^{67}Ga scintigraphy and labelled leukocyte scintigraphy are the most common techniques, but evidence to support one over the others in diagnosis or post-operative follow up is scanty, and the clinical picture, along with inflammatory markers (WBC, CRP, ESR, procalcitonin), is still the most reliable indicator for resolution of the infection. However, a recent metanalysis pointed toward the use of ^{67}Ga scintigraphy for post-treatment surveillance and assessment of healing as it reverts to normal with resolution of the disease[40].

Conclusion

Surgery of the frontal sinus has always been and still is challenging. Endoscopic sinus surgery has revolutionized the modern approach and allowed for implementation of our anatomy and physiology knowledge of paranasal sinuses, making possible and effective a minimally invasive procedure. Nonetheless, in some instances, endoscopy is inadequate to target and treat the pathology affecting the frontal sinus properly. There are various external approaches, with ablation of the frontal sinus (Riedel-Mosher's procedure) being the most radical. While indications are limited, it is still required in case of a chronic complicated inflammatory pathology, benign or malignant tumours and fracture of the frontal bone. The ensuing frontal defects can be restored with multiple materials which offer satisfactory long-lasting results.

As a conclusion, treatment of frontal sinus pathologies requires a versatile surgeon, familiar with different types of techniques and thus able to identify the most suitable approach for a specific disease.

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nology, Biosciences and Surgical Technologies at the University of Insubria, Varese, Italy.

Authorship contribution

GP contributed to the study design, data collection and analysis and he wrote the paper. MB contributed to the study design, reviewed the drafts and supervised the work. AP contributed to the study design, data collection, analysis and writing. FB contributed to the study design, data collection and analysis. SG contributed to the study design and reviewed the drafts. AP contributed to the study design, data collection and analysis. HB contributed to the study design, data collection and analysis. DL contributed to the study design and supervised the work. AK contributed to the study design, supervised the work, reviewed the drafts and supervised the bibliographic research. PC contributed to the study design, supervised the work and reviewed the drafts.

Conflict of interest

The authors state that they have no confli t of interest or fina - cial relationship with the entities mentioned in this paper.

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