EGAS MONIZ SCHOOL of HEALTH & SCIENCE | INSTITUTO UNIVERSITÁRIO EGAS MONIZ

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MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

MANAGEMENT OF SINUS MEMBRANE PERFORATION DURING MAXILLARY SINUS ELEVATION TECHNIQUES

Trabalho submetido por

Rami Matri

para a obtenção do grau de Mestre em Medicina Dentária

julho de 2024

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Trabalho orientado por:

Prof. Doutor Jorge Rebola

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RESUMO

A elevação do seio maxilar, descrita em 1977 por Tatum, é uma técnica cirúrgica comumente utilizada em medicina dentária para adicionar osso e colocar com segurança implantes dentários. No entanto, o procedimento encerra o risco de perfuração da membrana sinusal, o que pode levar a complicações.

O manejo da perfuração da membrana sinusal durante as técnicas de elevação do seio é de crucial importância. O diagnóstico precoce e a comunicação transparente com o paciente são essenciais. Diferentes abordagens podem ser utilizadas para reparar a perfuração, como o uso de membranas de reforço, enxertos ósseos ou materiais de preenchimento.

Neste contexto, a digitalização do planeamento e a transição para o digital desempenham um papel cada vez mais importante. Os avanços tecnológicos possibilitam o uso de planeamento virtual e navegação assistida por computador para melhorar a precisão e a segurança dos procedimentos de elevação do seio. Scanners 3D, software de planeamento e guias cirúrgicos personalizados oferecem uma melhor visualização e maior previsibilidade dos resultados.

Ao integrar a técnica de Digital Workflow, os profissionais podem avaliar melhor a anatomia pré-operatória, planear com precisão o procedimento e antecipar possíveis complicações. Isso permite uma gestão mais eficiente da perfuração da membrana sinusal e reduz os riscos relacionados com o procedimento.

Em conclusão, a gestão clínica da ocorrência da perfuração da membrana sinusal durante as técnicas de elevação do seio maxilar é crucial para o sucesso dos implantes dentários. A integração das novas tecnologias digitais oferece benefícios significativos em termos de planeamento preciso e redução de complicações. Usando ferramentas avançadas de visualização, como scanners intraorais e software de modelagem 3D, os dentistas podem prever com precisão a localização da membrana sinusal e desenvolver uma abordagem cirúrgica em conformidade. Essa abordagem ajuda a minimizar o risco de perfuração da membrana sinusal e a reduzir as complicações da cirurgia de forma a melhorar os resultados clínicos e a satisfação do paciente

Palavras-Chave

perfuração da membrana sinusal, elevação do seio maxilar, piezocirurgia , Fibrina rica em plaquetas.

ABSTRACT

The sinus lift, described in 1977 by Tatum, is a commonly used surgical technique in dental medicine to add bone and safely place dental implants. However, this procedure carries the risk of sinus membrane perforation, which can lead to complications.

The management of sinus membrane perforation during sinus lift techniques is of crucial importance. Early recognition and transparent communication with the patient are essential. Different approaches can be used to repair the perforation, such as the use of reinforcing membranes, bone grafts, or filling materials.

In this context, the digitisation of planning and the transition to digital play an increasingly important role. Technological advances enable the use of virtual planning and computer-aided navigation to improve the accuracy and safety of breast lifting procedures. 3D scanners, planning software and custom surgical guides provide better visualization and greater predictability of results.

By integrating the Digital Workflow technique, professionals can better assess preoperative anatomy, accurately plan the procedure and anticipate possible complications. This allows for more efficient management of sinus membrane perforation and reduces risks related to the procedure.

In conclusion, the clinical management of the occurrence of sinus membrane perforation during maxillary sinus elevation techniques is crucial for the success of dental implants. The integration of new digital technologies offers significant benefits in terms of precise planning and reduction of complications. Using advanced visualization tools such as intraoral scanners and 3D modeling software, dentists can accurately predict the location of the sinus membrane and develop a surgical approach accordingly. This approach helps minimize the risk of sinus membrane perforation and reduce complications of surgery to improve clinical outcomes and patient satisfaction.

Keywords

sinus membrane perforation, elevation of the maxillary sinus, piezosurgery , Fibrin rich in platelets

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ABREVIATION

AAA : Alveolar Antral Artery

PRF : Platelet rich fibrin

SCA : Sinus Crestal Approach

CBCT : cone beam computed tomography

CAD : computer-aided design

CAM : computer-aided manufacturing

I Introduction

In the last four decades, the field of implantology has witnessed significant advancements, leading to the incorporation of this discipline into the array of therapeutic options for prosthetic rehabilitation of posterior maxillary edentulism.

Nevertheless, the prolonged absence of teeth and the phenomenon of sinus floor pneumatization present notable challenges in implantology due to the consequential reduction in bone height. The techniques introduced by Tatum in 1977 (the lateral approach technique) and by Summers in 1994 (the less invasive crestal approach technique) have undergone considerable refinement, rendering them reliable, straightforward, and feasible under local anesthesia. (Jensen et al., 1998a)

Both methodologies involve the elevation of the Schneiderian membrane, which demarcates the sinus, to create a sub-sinus space that can be filled with bone substitutes to facilitate implant placement.

However, these procedures are not without risk, as sinus membrane perforation may occur, potentially resulting in complications such as sinus infections, hemorrhage, and bone dehiscence. Therefore, it is imperative to adopt precautionary measures to mitigate this risk, including meticulous tissue handling, precise utilization of surgical guides, and a comprehensive grasp of regional anatomy . (Mlouka et al., 2021a)

Modern advances in dentistry, particularly the integration of digital workflow techniques, offer the potential to prevent sinus membrane perforation preemptively, even prior to the surgical phase. This involves harnessing digital technologies to design and strategize dental procedures, including sinus augmentation. By leveraging advanced visualization tools such as intraoral scanners and 3D modeling software, dentists can accurately anticipate the location of the sinus membrane and devise tailored surgical plans accordingly. This proactive approach not only minimizes the likelihood of sinus membrane perforation but also reduces associated surgical complications. (Morgan et al., 2023)

The search was performed in the databases Pubmed, b-on, Google scholar, Sciencedirect and Mendeley search. The terms used for the consultation were: sinus membrane perforation, sinus elevation, prevention, guided surgery and data were available from December 2023 to March 2024.

The objective of our study is to elucidate the diverse techniques, delineate risk factors, and the consequences of sinus membrane perforation.

Additionally, we will explore strategies for managing intraoperative breaches of the sinus mucosa, empowering practitioners with adaptable management protocols tailored to the specific characteristics of the perforation. Finally, alternative approaches to accessing the sinus window will be discussed.

II Development

1 Anatomy of the maxillary sinus

The maxillary sinus takes on the shape of a pyramid, with a medial base and a lateral apex, comprising four walls and a sinus floor (Figure 1-2):

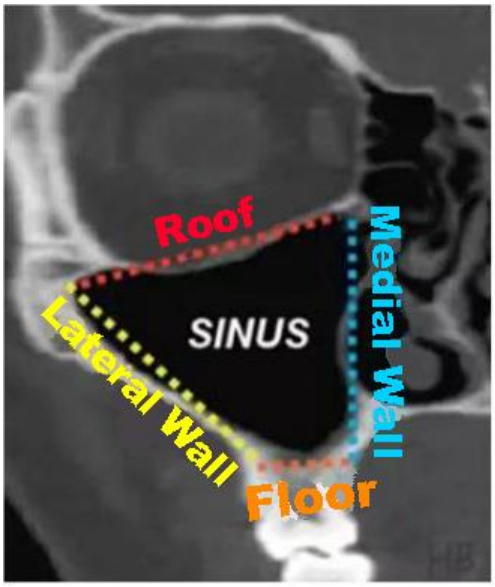

Figure 1 The walls of the maxillary sinus. Adapted from (A. RAFII & J. KISSA, 2019)

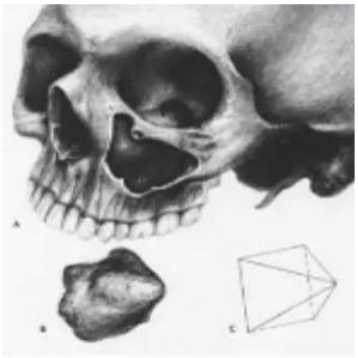

Figure 2 The pyramidal shape of the maxillary sinus. Adapted from (A. RAFII & J. KISSA, 2019)

1.1 Wall Structures

1.1.1 Anterolateral Wall:

This wall, corresponding to the buccal surface, exhibits a trapezoidal configuration with its base positioned inferiorly. It displays thickness at its lower aspect, gradually thinning towards the inferior orbital rim, and is marked by the prominence of the canine.

1.1.2 Posterolateral Wall:

Quadrangular in shape, this wall relates to the infratemporal and pterygopalatine fossae. It houses the posterior superior alveolar canals, facilitating passage for the corresponding neurovascular bundle destined for the molars and the sinus mucosa.

1.1.3 Superior Wall:

Forming the roof of the sinus and encompassing most of the orbital floor, this wall presents a triangular, delicate structure traversed by the infraorbital groove and canal.

1.1.4 Medial Wall:

This wall serves as the intersinuso-nasal septum, separating the maxillary sinus from the nasal cavities. It is distinguished by the presence of the maxillary ostium, which opens into the middle nasal meatus, facilitating sinus drainage.

1.2 Sinus Floor:

This aspect, constituting the most inclined portion of the maxillary sinus, forms an elongated trough oriented anteroposteriorly. Positioned approximately 15 mm above the tooth apices (Figure 3), it may exhibit a close association with the roots of the molar group (second molar, third molar, and then the first molar).

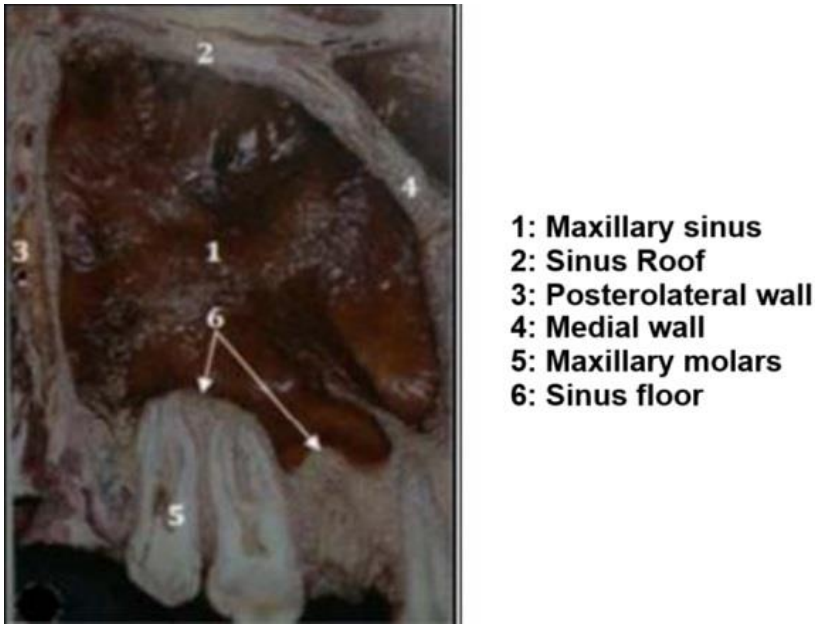

Figure 3 Frontal section illustrating the maxillary sinus walls. Adapted from (Mlouka et al., 2021c)

1.3 Internal Configuration:

The internal configuration of the maxillary sinus varies considerably among individuals, with some sinuses featuring a smooth, uniform appearance, while others present septa, rare partitions that may divide the sinus cavity into multiple compartments. These bony septa can complicate sinus lift procedures and heighten the risk of sinus membrane perforation by up to 52%. (Schwartz-Arad et al., 2004)

Thus, comprehensive knowledge of their number, dimensions, and topography is crucial before undertaking any sinus lift surgery. (Kao & DeHaven, 2011)

1.4 Physiology of the Sinus Membrane:

1.4.1 Composition:

The walls of the maxillary sinus are lined with a thin, respiratory-type mucosa firmly adherent to the underlying bone. Comprised of a pseudostratified columnar epithelium endowed with cilia that facilitate the movement of mucus and debris towards the naso-sinus ostium, this epithelium is supported by a delicate layer of elastic fibers associated with the underlying periosteum. The scarcity of elastic fibers accounts for the membrane's ease of detachment from the bone. (Davarpanah M & Szmukler S, 2011)

1.4.2 Thickness:

Various thickness variations are observed in the sinus membrane among individuals and even within the same person, depending on the specific location being examined. An example of this can be found in the research conducted by Dr. Simone, Janner, and their colleagues in 2011. Their study, titled "Characteristics and Dimensions of the Schneiderian Membrane: An Analysis Using Cone Beam Computed Tomography in Patients Requiring Posterior Maxillary Implant Surgery," utilized cone beam computed tomography (CBCT) scans to reveal differing membrane thicknesses across different regions: anterior, middle, posterior, as well as medial, middle, or lateral. Their findings led to several conclusions:

- The average thickness in the anterior and medial sectors was 1.6mm, 2.47mm in the middle sector (at the level of the alveolar crest), and 0.96mm in the lateral sector.
- Medially, in the middle sector, the average thickness measured 1.84mm, 3.11mm in the middle sector, and 1.11mm in the lateral sector.

- In the posterior sector, the average thickness was 0.99mm medially, 2.16mm in the middle sector, and 0.9mm in the lateral sector. (Janner et al., 2011)

Similarly, a study from 2008 by Mario Aimetti et al. examined 20 patients and established a relationship between sinus membrane thickness and gingival phenotype. Their findings suggested that gingival thickness could serve as a reliable predictor for sinus membrane thickness. (Gouët E, 2017)

2 Sinus augmentation

The elevation of the maxillary sinus floor has emerged as a pivotal procedure in pre-implant treatment planning, especially in cases where the remaining bone height is inadequate (<10 mm). Initially proposed by Tatum and further refined by Boyne and James in 1980, there are presently two primary techniques employed for sinus floor elevation:

- Lateral sinus lift: a conventional, direct method.

- Crestal sinus lift: a less invasive indirect method. (Alshamrani et al., 2023)

2.1 Contraindications of Sinus augmentation:

Contraindications for sinus lift procedures are typically categorized into two primary groups: general contraindications and local contraindications. Furthermore, each of these categories is subdivided into relative or absolute contraindications.(Singh Gill et al., 2020)

2.1.1 Absolute contraindications:

2.1.2 General Considerations:

- Cardiovascular conditions posing a risk of infectious endocarditis.

- Hematologic disorders, particularly erythrocyte abnormalities.

- Untreated or uncontrolled endocrine disorders like diabetes.

- Hepatic ailments.

- Bone pathologies (such as Paget's disease), multiple myeloma, fibrous dysplasia.

- Maxillary radiotherapy within the last 12 months.

- Significant immunodeficiency.

- Severe addictions: alcohol, tobacco, illicit drugs.

- Psychiatric disorders.

- Patient non-cooperation.

2.1.3 Local Considerations:

- Maxillary sinus infections such as empyema.

- Acute sinusitis.

- Excision of alveolar scars.

- Sinus hypoplasia or aplasia.

- Maxillary cysts and tumors.

- Severe, untreated periodontal diseases.

- Excessive inter-crestal distance.

2.1.4 Relative considerations:

2.1.4.1 General Considerations:

- History of myocardial infarction within the past 6 months.

- Well-managed systemic pathologies like diabetes.

- Osteoporosis.

- Pregnancy.

- Moderate tobacco use (smoking cessation required two weeks pre-surgery).

- Chronic alcoholism.

- Severe allergic rhinitis.

2.1.4.2 Local Considerations:

- Expansive maxillary mucoceles.

- Chronic sinusitis.

- Oroantral communication.

- Sinus infections originating from dental issues.

2.2 Techniques for Sinus augmentation:

2.2.1 Lateral Approach Sinus augmentation:

2.2.1.1 Indications

This procedure is indicated for oral rehabilitation with implant prostheses in atrophied posterior maxillary regions. It can address single or multiple edentulism and complete edentulism reconstruction.

The lateral sinus lift, or direct technique, pioneered by Tatum in 1977, involves a modified Caldwell-Luc approach. (Hunter et al., 2009)

It's a well-established procedure, offering predictability in correcting vertical bone defects in the posterior maxilla.

The 1996 consensus conference delineated the indications for each sinus lift technique based on infra-sinus bone height. The crestal approach is suitable for moderate bone defects (height ≥ 7mm), while the lateral approach is recommended for more advanced vertical bone defects (height ≤ 6mm). (Gouët E, 2017) Simultaneous implant placement may be considered when sufficient bone quantity ensures adequate anchorage and primary stability (height ≥ 4mm) (Table 1). (Jensen et al., 1998b)

Table 1 Jensen classification following the consensus conference (1996)

Residual Ridge Height	Implantation	Case Management
≥10 mm (Type A)	Direct Implant Placement	-
7 to 9 mm (Type B)	Crestal Approach	Sinus Lift and Simultaneous Implant Placement
4 to 6 mm (Type C)	Lateral Approach	Sinus Lift and Simultaneous Implant Placement
1 to 3 mm (Type D)	Lateral Approach	Delayed Sinus Lift and Implant Placement

(Jensen et al., 1998c)

2.2.1.2 Principle:

This approach necessitates surgical access through the maxillary lateral wall, followed by sinus membrane elevation and bone grafting under direct visualization. (Gandhi, 2017)

2.2.1.3 Surgical Protocol:

2.2.2 Patient preparation

Patient preparation includes periodontal debridement a few days before the surgery and reinforcement of oral hygiene practices to eliminate potential infection sources that may infect the bone graft. (Antoun et al., 2020)

2.2.3 Pre-medication

Pre-medication serves a threefold purpose:

1. It aids in reducing bacterial contamination throughout the entirety of the procedure via prophylactic antibiotic therapy (Antoun et al., 2020). This typically involves:

- Administering Amoxicillin + Clavulanic acid at 2g/day for 7 days, one hour before the intervention. (Bouchard PH, 2015)

- In case of penicillin allergy, prescribing pristinamycin at 1g, one hour pre-intervention.

It assists in mitigating postoperative swelling and improving patient comfort by prescribing corticosteroids, such as prednisone, at a dosage of 1mg per kg as a morning single dose.

It addresses patient anxiety through oral sedation:

- Administering Hydroxyzine at 1mg per kg, one hour before the intervention (Atarax® 25mg: 1mg/kg).

- Providing Benzodiazepine (Valium® 20mg) on-site. (Antoun et al., 2020)

The surgical steps will be elaborated upon based on a clinical case managed by Dr. Mohamed Tlili, an assistant practitioner at the outpatient department of the dental clinic in Monastir, Tunisia. The case pertains to a 25-year-old patient in good overall health seeking implant rehabilitation following the extraction of tooth 16 due to carious complications (Figure 4). (Mlouka et al., 2021b)

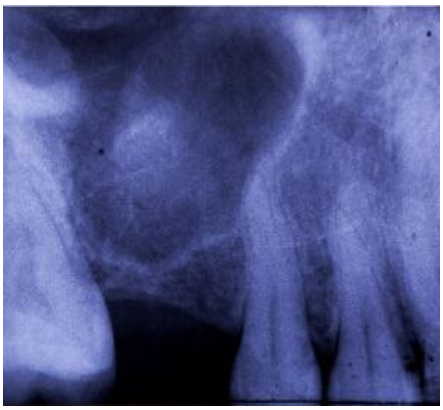

Figure 4 Preoperative retroalveolar X-Ray. Adapted from (Mlouka et al., 2021c)

2.2.4 Anesthesia

During chairside grafting procedures, local anesthesia is administered using an anesthetic solution containing a vasoconstrictor (if there are no contraindications), aiming to minimize bleeding. The dosage of the anesthetic solution varies based on the duration of the procedure and the patient's anatomical characteristics (Figure 5). (Antoun et al., 2020)

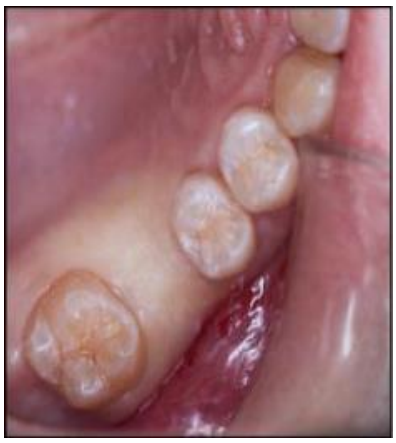

Figure 5 Periapical anesthesia. Adapted from (Mlouka et al., 2021c)

2.2.5 Incisions

There are several possible incision techniques. Typically, a slightly palatal crestal incision is made, accompanied by one or two vertical releasing incisions diverging upward. (Antoun et al., 2020)

2.2.6 Flap

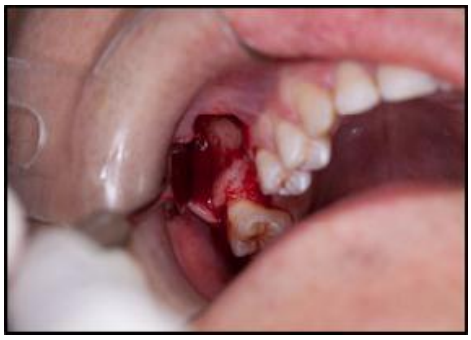

Figure 6 Incision and detachment of the full-thickness flap.
Adapted from (Mlouka et al., 2021c)

A trapezoidal-based full-thickness flap is raised, exposing an adequate portion of the anterolateral aspect of the maxillary sinus to facilitate the creation of the bone window (Figure 6). (Lisa Nour, 2019)

2.2.7 Osteotomies:

To access the sinus membrane, a bone window must be created, with its shape (rectangular, trapezoidal, or oval) determined by the sinus anatomy and extent of edentulism. Preoperative radiological assessment is essential to gauge the thickness of the maxillary sinus's lateral wall, identify any bony septa, ascertain the course of the alveolo-antral artery, and measure the alveolar bone height beneath the sinus. The contours of the window are delineated using a round bur (Figure.7).

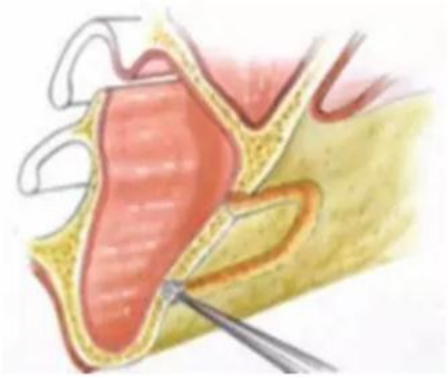

Figure 7 Osteotomy with a ball burr (front view)
. Adapted from (Davarpanah M et al., 2012)

- To prevent sinus membrane perforation, a diamond-tipped insert is preferable for piezosurgery.

- Ensuring rounded corners for the window minimizes the risk of perforation (Figure.8). (Bouchard PH, 2015)

- Gentle pressure is applied with an instrument to mobilize the bone flap. (Davarpanah M et al., 2012)

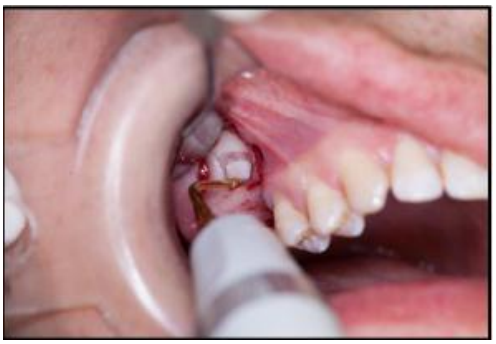

Figure 8 Tracing the bone window using an OT5 piezoelectric insert (MECTRON®). Adapted from (Davarpanah M et al., 2012)

2.2.8 Membrane Detachment

This step typically employs broad, rounded-edge curettes to prevent tearing. The curette tip maintains constant contact with bone during detachment (Figure 9) . Ultrasonic instruments may initiate detachment. Constant curette contact with bone walls minimizes membrane perforation risk. Detachment proceeds gradually to create membrane laxity, guided by the implant project's parameters. Detaching beyond planned implant sites is unnecessary. Membrane integrity is verified once detachment is sufficient. (Ali et al., 2014)

Membrane integrity can be assessed during the procedure. Patient breathing movements help indicate membrane status (elevation, descent). If perforated, the membrane loses these movements.

Membrane cleavage forms a submembranous space.

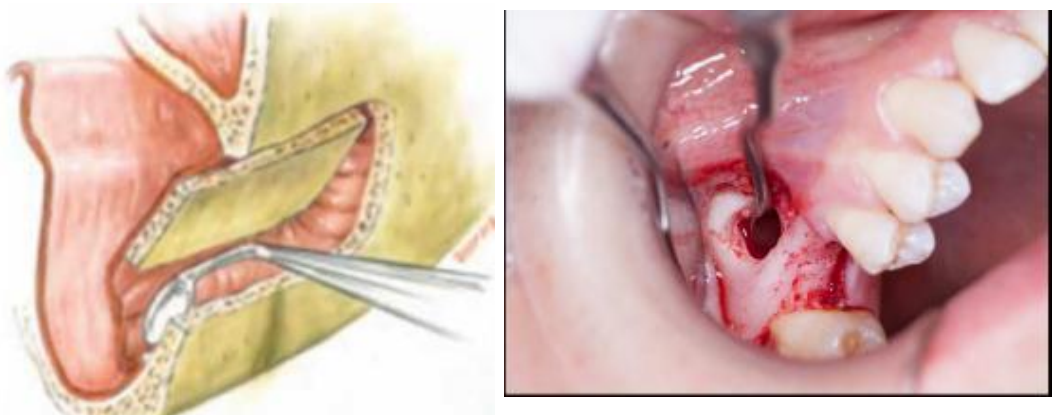

Figure 9 Membrane detachment reaching the nasal wall. Adapted from (Langer B & Langer L, 1999; Mlouka et al., 2021c)

2.2.9 Placement of Bone Graft Material

A variety of bone graft materials are available for use, including autogenous bone, allogeneic bone, xenografts, and alloplastic materials. Studies indicate that the success of sinus floor augmentation procedures is not significantly influenced by the specific type of bone graft material employed. The graft material is administered using a syringe. Initially, it is gently packed and then firmly compacted to achieve direct bone contact (Figure 10). Care is taken to ensure the preservation of the Schneiderian membrane's integrity during this process.

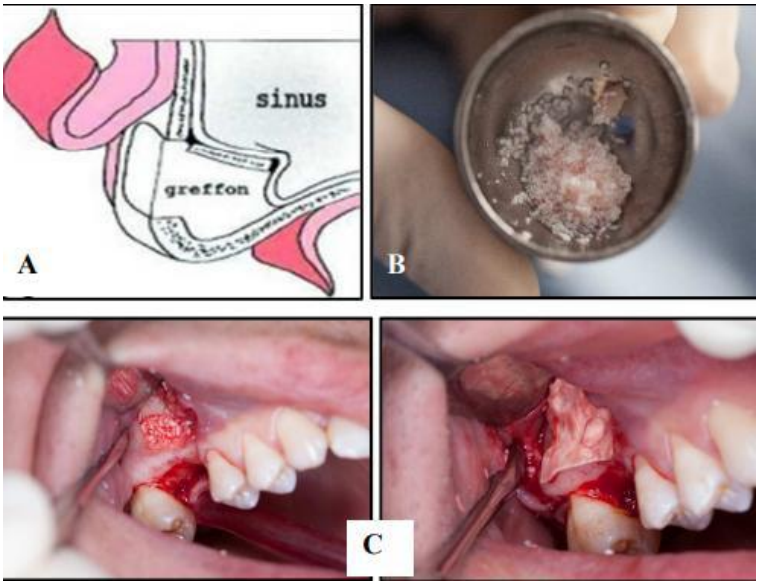

Figure 10 A-graft, B-bone filling, C-absorbable collagen membrane . Adapted from (Langer B & Langer L, 1999; Mlouka et al., 2021c)

2.2.10 Flap Repositioning and Suturing:

Following graft placement, the flap is repositioned, and a resorbable or non-resorbable membrane is applied, followed by meticulous suturing of the crestal and relief incisions (Figure 11-12). (Antoun et al., 2020)

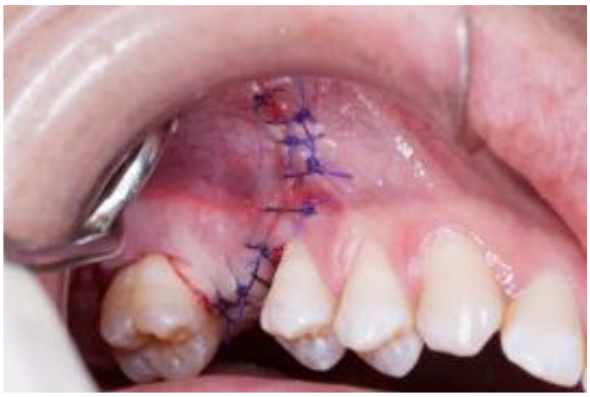

Figure 11 : Sutures with discontinuous O-stitches. Adapted from (Mlouka et al., 2021c)

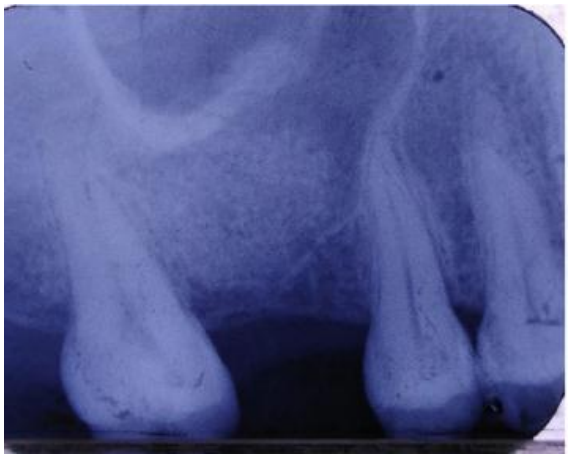

Figure 12 : Postoperative X-Ray: note the condensed appearance of the filling material and the level of the apically translating sinus floor after sinus augmentation. Adapted from (Mlouka et al., 2021c)

2.2.11 Implant Placement :

- Delayed Approach : Implant placement occurs subsequent to bone regeneration, typically after :
    - 4.5 months for autogenous bone,
    - 7 to 9 months for allografts or xenografts (Figure 13),
    - Over 9 months for alloplastic materials. (Alfred Seban, 2008)
- Immediate Approach: If residual alveolar bone height is adequate to ensure primary implant stability, implants are placed before sinus floor bone grafting. (Alfred Seban, 2008)

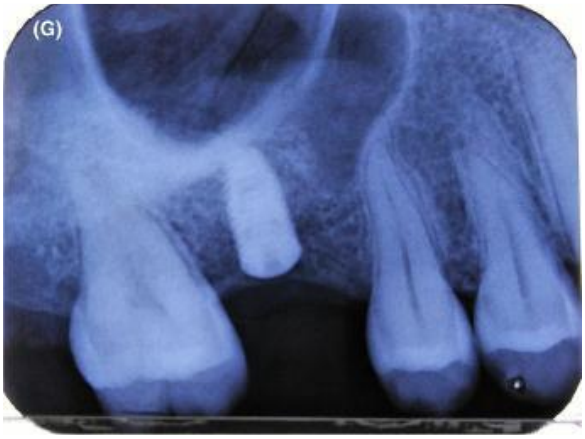

Figure 13 Retroalveolar X-Ray 6 months after sinus lift . Adapted from (Mlouka et al., 2021c)

2.3 Crestal Approach Sinus augmentation:

2.3.1 Indications:

This refers to an indirect method via the alveolar pathway, famously known as the Summers technique (1994). (Deffrennes et al., 2013)

The consensus conference held in 1996 played a significant role in delineating the indications for each sinus lift technique based on the height of the bone beneath the sinus. Specifically, the crestal approach is recommended for addressing moderate bone deficiencies (height ≥ 7mm), whereas the lateral approach is favored for more advanced vertical bone defects (height ≤ 6mm). (Jensen et al., 1998b; M. TLiLi et al., 2021)

Simultaneous implant placement may be considered when sufficient residual alveolar bone height ensures primary implant stability (height ≥ 4mm).

This technique is considered simpler and less burdensome for patients compared to the lateral approach. (Jensen et al., 1998b)

2.3.2 Principle:

It involves lifting the sinus floor and membrane over the implant site using osteotomes. (Deffrennes et al., 2013)

This technique allows for crest expansion, reducing surgery time and costs (Jensen et al., 1998b). This osteotomy technique has undergone various modifications.

2.3.3 Surgical Procedure

2.3.3.1 Preoperative Medication:

There is a divergence among authors regarding the necessity of preoperative antibiotic prophylaxis. While some advocate for the administration of Amoxicillin + Clavulanic Acid (Augmentin®) (2g) orally 1 to 2 hours before surgery, others argue against its use.

2.3.3.2 Surgical Steps:

- Summers' Original Osteotome Technique with Simultaneous Implant Placement (Figure 14) :

a. The crestal cortical bone is perforated using a round bur.

b. Site preparation is performed using osteotomes, which are 1mm smaller in diameter than the implant and positioned 1-2mm from the sinus floor. (Antoun et al., 2020)

- In cases of denser bone, osteotomes with a rounded conical end are utilized. (Davarpanah M et al., 2012)

c. The sinus floor is fractured by tapping the lower end of the osteotome, which is smaller than the last osteotome used. Subsequently, the integrity of the sinus membrane is checked using a gauge or the Valsalva test. Detection of air escaping from the implant site indicates membrane perforation.

d. Graft material is introduced and compacted into the newly formed space using the osteotome, followed by implant placement. (Antoun et al., 2020) According to a systematic review and meta-analysis, in cases where the residual height is between 5 and 9 mm, indirect sinus floor elevation without the use of graft material can be effective. This approach results in a bone gain of 3.43 ± 0.09 mm and implant survival rates ranging from 93.5% to 100%. Bone regeneration can be facilitated by the blood clot alone. (Wimalarathna, 2021)

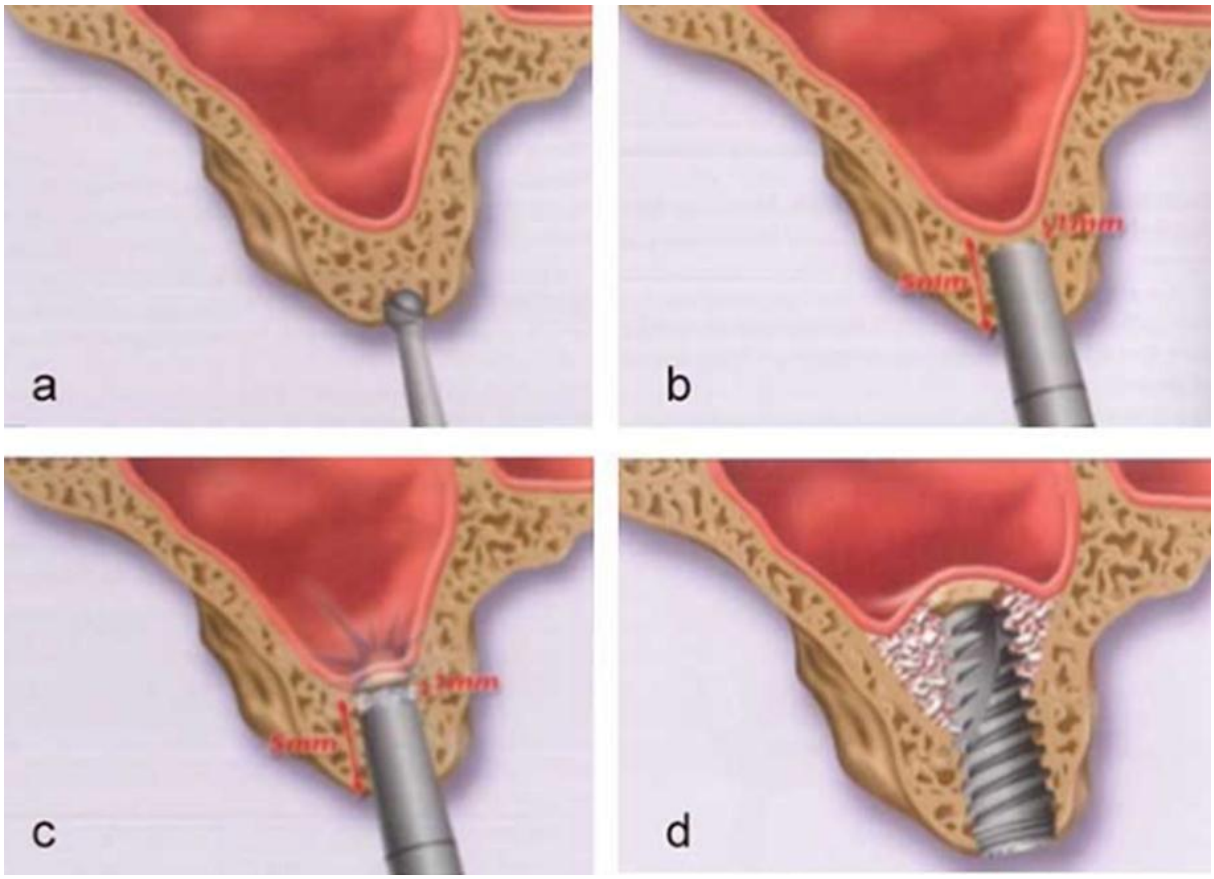

Figure 14 Steps in the osteotome technique described by Summers a- Milling of the cortical bone using a ball burr. b- Preparation of the implant site using osteotomes. c- Fracture of the cortical bone of the sinus floor using the osteotome (a biomaterial can be interposed between the osteotome and the cortical bone). d- Introduction of the biomaterial into the newly-formed space with placement of an implant of satisfactory height. Adapted from (Davarpanah M et al., 2012)

- Sinus Lift using the SCA Crestal Approach Kit (M. TLiLi et al., 2021):

The SCA Kit (Sinus Crestal Approach Kit, Neo-Biotech®, South Korea) includes S-reamers designed with an "S"-shaped tip to penetrate the sinus floor without damaging the Schneiderian membrane (Figure 15). Additionally, it contains height-adjustable stops, supports for graft material, and condensers.

Figure 15 S-reamer drill with S-shaped blunt end.
Adapted from (M. TLiLi et al., 2021)

- A crestal incision is made, supplemented by two intrasulcular incisions at the implant site : 17 .

- A full-thickness flap is raised (Figure 16).

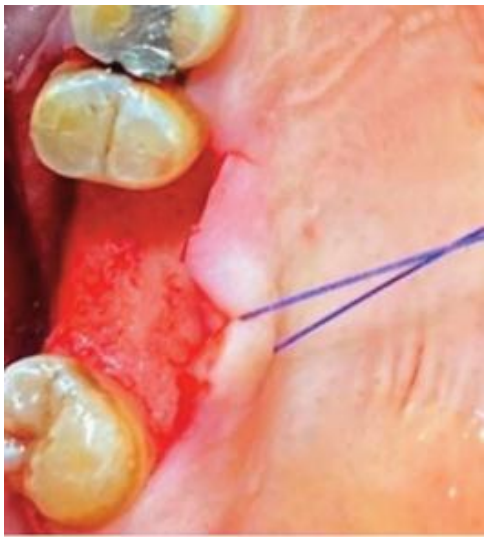

Figure 16 Flap detachment. Adapted from
(M. TLiLi et al., 2021)

- At the implant site of the 17, the SCA system is utilized. It begins with a pilot drill (diameter 2 mm) with a stop corresponding to h-1mm.

- Subsequently, the first S-reamer (diameter 2.8 mm) is employed at the same length.(Figure 17) The progressive millimetric use of this reamer, with increasing height stops, safely perforates the sinus floor.

Figure 17 "S-reamer" drill. Adapted from (M. TLiLi et al., 2021)

- The second S-reamer (3.2 mm) is then introduced to widen the implant site. After each pass, a flat-surfaced depth gauge is inserted to ensure drilling quality and membrane integrity (Figure 18 and 19).

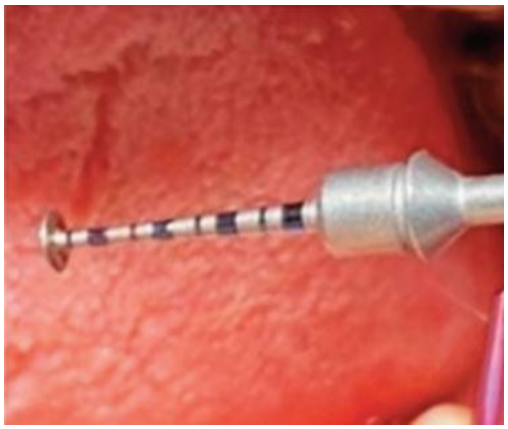

Figure 19 Checking for sinus floor intrusion using a depth gauge. Adapted from (M. TLiLi et al., 2021)

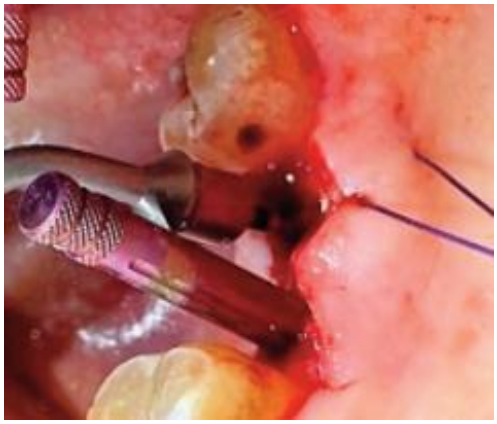

Figure 18 Depth gauge . Adapted from (M. TLiLi et al., 2021)

- Graft material is condensed into the sinus cavity

the SCA system (Bone carrier and Bone condenser). (Figures 20)

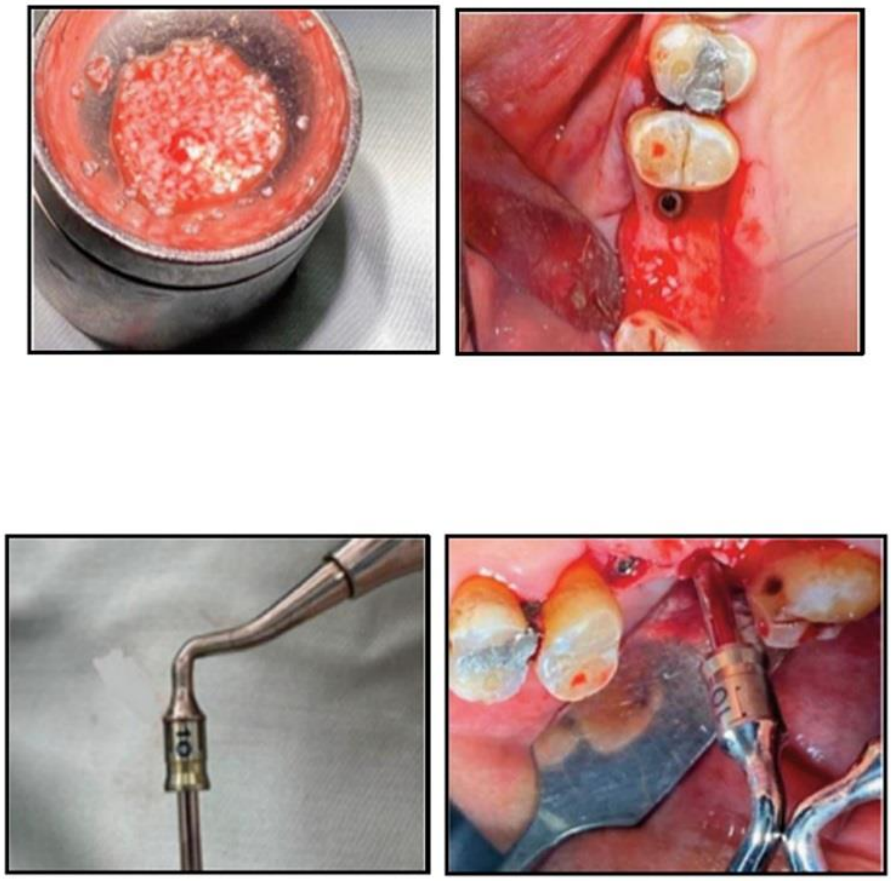

Figure 20 Graft material is condensed into the sinus cavity using appropriate instruments from the SCA system. Adapted from (M. TLiLi et al., 2021)

Implant placement is performed, ensuring excellent primary stability (>35 N), and a healing screw is immediately placed on the same day (Figure 21)

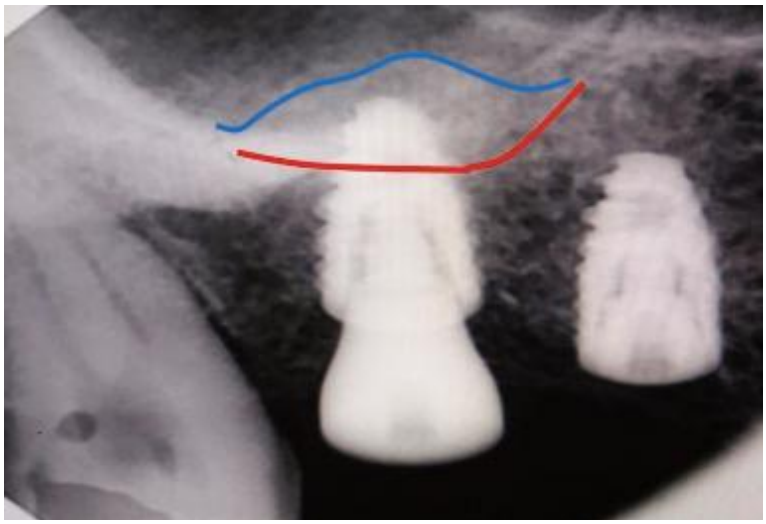

Figure 21 Postoperative X-ray showing the level of the sinus floor Sinus floor before (red) and after (blue) surgery. Adapted from (M. TLiLi et al., 2021)

3 Contributing Factors to Sinus Membrane Perforation

It is essential to understand the various risk factors associated with sinus membrane perforation to anticipate sinus elevation surgery and minimize the likelihood of this complication.

3.1 Sinus Polyps

Sinus polyps refer to soft tissue aggregations that increase in thickness within the nasal cavity. Initially described by Bourjat and Braun in 1924 as "benign epithelial hyperplasia, regardless of histological type, presenting as a soft and mobile swelling." These polyps are benign outgrowths of mucosal tissue and represent a macroscopic term. Most samples diagnosed as nasal and/or sinus polyps by Otolaryngologists correspond to edematous and inflammatory thickenings of the nasosinusal mucosa in patients suffering from chronic rhinosinusitis. (Costes et al., 2011)

The formation of polyps is influenced by allergies and infections, although the exact pathophysiological process remains poorly understood. Polyps can manifest as multiple (more than ten) and large, measuring up to 5 cm. Surgical treatment is typically warranted only for advanced and extensive forms. The surface epithelium typically exhibits a respiratory type, characterized by hyperplasia of goblet cells and, occasionally, hyperproduction of mucus leading to mucous cyst formation. Squamous metaplasia foci are often present, and the epithelium rests on a basal membrane, which is frequently thickened and hyaline, imparting a glassy appearance. (Alfred Seban, 2008)

3.2 Intra-Sinus Septum

Intra-sinus septa, also known as Underwood's septa, are bony partitions that partially or completely divide the sinus cavities, sometimes resulting in the formation of smaller accessory sinuses. These septa serve as bony reinforcements to masticatory forces during the dentate phase of life and tend to diminish gradually with tooth loss. (Alfred Seban, 2008; Pommer et al., 2012)

Their shape is often likened to that of an inverted gothic arch, extending from the internal, anterolateral, or inferior walls and can be found in anterior, middle, or posterior positions (Figure.22) .

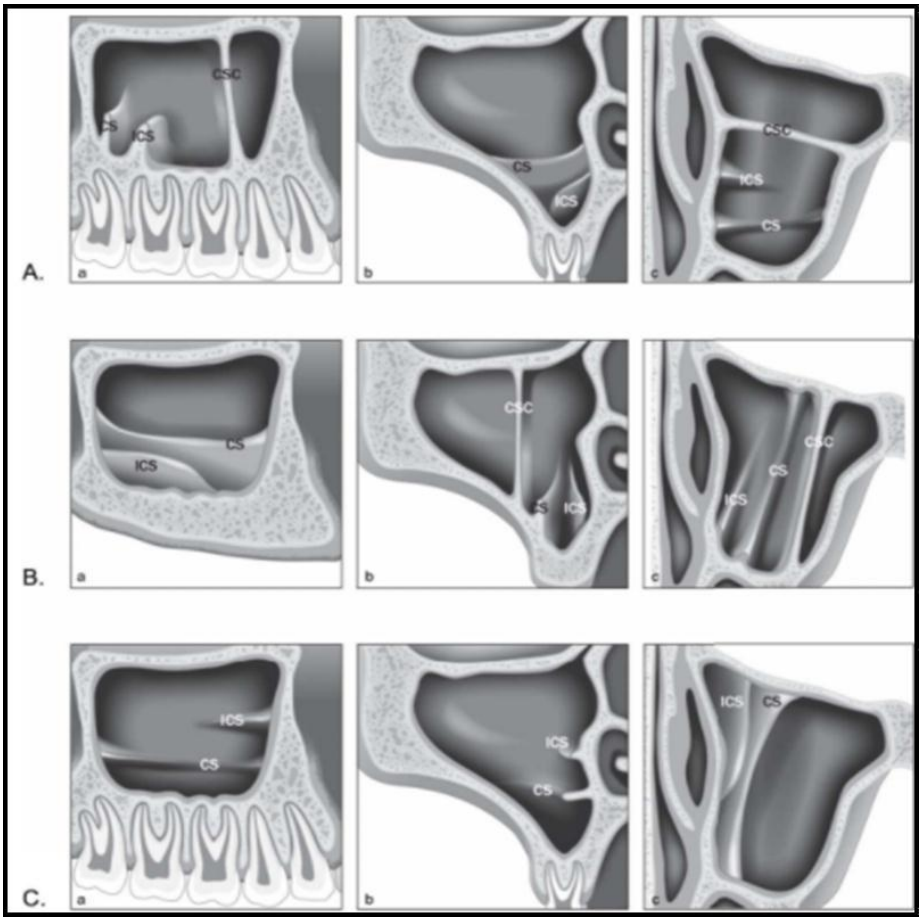

Figure 22 Schematic representation of different partition conformations: (A) coronal, (B) sagittal, (C) transverse, in the (a) sagittal, (b) coronal, (c) axial planes CS: complete partition, CSC: complete partition with compartmentalization, ICS: incomplete partion. Adapted from (Ammar F, 2022)

Some authors have proposed a classification of septa based on their origin:

- Primary septa develop concurrently with maxillary development and are present during the dentate phase.

- Secondary septa appear following tooth loss and are associated with selective resorption of the sinus floor, resulting in protrusions and depressions.

The primary septa are notably longer than the secondary septa and can lead to complete sinus partitioning. They exhibit various types, determined by their size and orientation (sagittal or frontal), potentially complicating the preservation of the Schneiderian membrane. (SOUZA et al., 2019)

Research indicates that these septa are present in approximately 30.85% of cases (ranging from 24% to 36.6% according to different studies) and are observable through CBCT examinations. (Ammar F, 2022)

It's crucial to highlight that three-dimensional CBCT radiographic assessments are indispensable for identifying intra-sinus septa. Several studies have demonstrated the occurrence of false negatives in panoramic dento-maxillary radiography (with a false negative rate of 21% when comparing CBCT and 2D radiography), rendering OPT examinations only capable of providing an estimation of septal size and location (Altayar et al., 2023). Their positioning varies, with an intermediate majority of 44%, followed by 22% for the anterior region and 34% for the posterior region. On average, septal height measures 6.9 mm. (Ammar F, 2022)

However, there's no discernible correlation between septal presence and gender, age, or side. Nonetheless, septa are more frequently singular than multiple within a given sinus (two septa in 3.7% of cases, three septa or more in 0.5% of cases) (Figure 23). Regarding orientation, the majority of the 3154 septa considered are coronal, accounting for approximately 89.1% (Ammar F, 2022). Sagittal septa follow at 9.2%, while horizontal septa are considerably less common and typically more transverse than sagittal. It's also noteworthy that septal thickness typically increases from the lateral to the medial portion. Moreover, these septa may occur unilaterally (80.48%) or, less commonly, bilaterally (19.52%). Their presence can impede the creation and movement of the lateral bony flap during lateral approach sinus lift procedures, thereby heightening the risk of Schneiderian membrane perforation. (Ammar F, 2022)

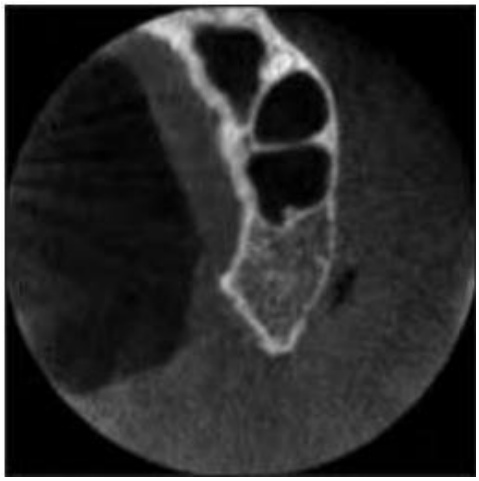

Figure 23 Cross-section of intrasinusal septa.
Adapted from (Pommer et al., 2012)

Krennmair et al., in 1997 and 1999, categorized septa into two distinct groups based on their formation mechanisms:

- Primary septa, originally described by Underwood, are innate structures resulting from the persistence of these bony walls after tooth eruption.

- Secondary septa, acquired, arise from incomplete and irregular sinus pneumatization, particularly following the loss of one or more teeth. (SOUZA et al., 2019)

More recently, in 2017, Irinakis et al. proposed a novel classification of these septa that no longer considers their origin but focuses solely on their conformation, relating it to the risk of membrane perforation and thus the complexity of the corresponding sinus surgery (Table II). (Irinakis et al., 2017)

Table 2 Septa classification according to (Irinakis et al., 2017).

Classification	Orientation	Incidence	Risk of perforation
Class I	Coronal	Common	Low
Class II	Sagittal	Average	Moderate
Class III	Transverse	Rare	High
Class IV	Complex	Common	Very high

(Irinakis et al., 2017)

The surgical approach will be tailored based on all collected information about the present bony septa, necessitating (M. Kim et al., 2006):

- Inclusion of the septum in the lateral flap osteotomy.

- Creation of two bony windows on either side of the septum.

- Limitation of the extent of filling by avoiding the septum.

- If the septum is poorly defined, the membrane can be lifted palatally or vestibularly from the septum.

- Fracture of the septum at its base: initially, the mucosa is detached from the mesial wall of the septum, then the septum is fractured at its base distally using wide osteotomes.

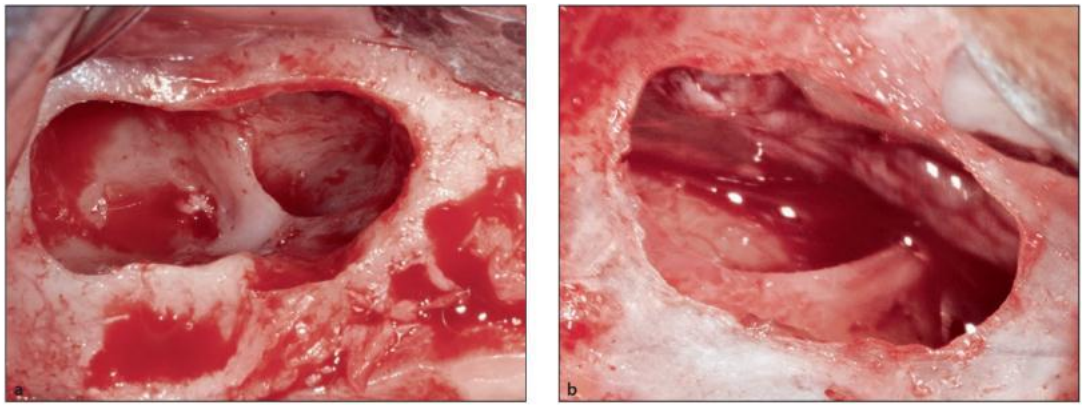

Figure 24 Maxillary sinus floor elevation in the presence of sinus septa. Adapted from (Testori et al., 2020)

3.3 Thin membrane

Sinus membrane perforation remains one of the most prevalent complications during sinus floor elevation.

The thickness of the sinus membrane varies among individuals and within individuals depending on different anatomical areas. The incidence of perforations varies according to the surgical approach. Thus, in a lateral approach, the risk of sinus membrane perforation ranges from 20% to 44%, while in a crestal approach, this risk varies from 0% to 25%; this is due to differences in thickness between different approach zones.

It has been suggested that among all factors influencing sinus membrane perforation, membrane thickness plays a significant role. Lum et al. found that patients who experienced membrane perforation during sinus floor elevation had a thinner membrane compared to patients without membrane perforation (0.84 mm versus 2.65 mm, respectively) (Figure 25). (Testori et al., 2020)

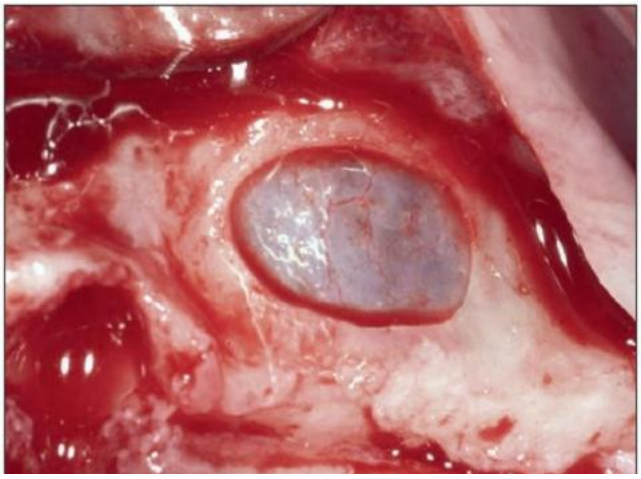

Figure 25 Lateral window approach showing a thin sinus membrane. Adapted from (Testori et al., 2020)

However, it is important to note that the CBCT may not be the most accurate method for evaluating sinus membrane thickness, as a systematic review concluded that CBCT tends to overestimate membrane thickness by 2.5 times compared to histological results. It should also be noted that membrane thickness may be influenced by gingival phenotype and age, but not by gender or weather conditions at the time of examination, and excessive thickness may indicate a pathological condition associated with a higher risk of perforation (e.g., sinusitis). According to Shanbhag et al., increased membrane thickness (> 5 mm) is positively correlated with a higher risk of ostium obstruction, which is a contraindication for sinus floor augmentation. (Wen et al., 2015a)

According to a previous review article, a membrane thickness of 1.5 to 2.0 mm may be considered favorable for sinus floor elevation, while a thickness < 0.8 mm and > 3 mm may be associated with a higher risk of perforation (Table 3).

Table 3 Classification of sinus membrane thickness and percentage of associated perforations

Group	Membrane thickness	Average	Max (mm)	Min (mm)	Percentage	Proportion of perforations (%)
A	<1mm	0,64 +/- 0,19	0,9	0,2	38,92	18,06
B	1 to <2mm	1,36 +/- 0,27	1,9	1,0	35,14	13,85
C	>2mm	4,07 +/- 2,88	11,8	2,0	25,95	20,83

(Wen et al., 2015b)

3.4 Angulation Between Vestibular and Palatal Walls (Sinus Floor Width)

The angle formed between the vestibular and palatal walls of the maxillary sinus is a crucial factor contributing to the risk of membrane perforation. Studies by Cho et al. have revealed that narrow sinus anatomy may correlate with a heightened risk of membrane tearing. Specifically, when the angle between the lateral and medial walls of the sinus measures less than 30 degrees, the incidence of membrane tear significantly increases (62.5%). (Testori et al., 2020)

Conversely, sinuses with wider angles, ranging between 30 and 60 degrees, or even greater than 60 degrees, exhibit reduced rates of perforation, measured at 28.6% and 0%, respectively. A classification system devised by Drs. WILEY and JOHN categorizes sinuses based on this angulation into three groups (Table IV) (Niu et al., 2018):

- Less than 30° (approximately 4.8% of the population)

- Between 31 and 60° (approximately 42.8% of the population)

- Greater than 61° (approximately 52.4% of the population)

It's important to note that there appears to be no discernible correlation between this angle, patient age, or gender.

Table 4 Influence of sinus floor angulation on sinus membrane perforations in sinus fillers

Angulation between vestibular and palatal walls (°)	**<30°**	**30°<x<60°**	**>60°**
Percentage of perforations	**37,5%**	**28,5%**	**0%**

(Baumann & Ewers, 1999)

3.5 Previous Oroantral Communication

Oroantral communications may arise during oral surgical procedures, such as extractions. In such instances, the sinus membrane typically heals over time, leaving behind a scar at the site of the communication.

However, this scar tissue presents a weaker section of the sinus membrane and thus poses a risk during sinus lifting procedures involving membrane detachment. Hence, careful consideration of this history is imperative during the medical evaluation. (Becker et al., 2008)

3.6 Alveolar Antral Artery (AAA)

Excessive bleeding during sinus lifting procedures can complicate the creation of the antrostomy, leading to reduced visibility and an increased risk of membrane laceration. Injuries to major blood vessels adjacent to the lateral sinus wall can contribute to this complication.

The relationship between the lateral wall of the maxillary sinus and the anastomosis between the posterior superior alveolar artery and the infraorbital artery has been extensively studied. Research by Solar et al. has indicated that the AAA is predominantly intraosseous, with approximately 44% of cases presenting as extraosseous. (Testori et al., 2020)

Rosano et al. found that the anterior superior alveolar artery (AAA) can manifest in three distinct patterns: fully intraosseous, partially intraosseous, or located beneath the periosteum of the postero-lateral sinus wall. Similarly, their study revealed that behind the second premolar area, the artery tends to be adherent to the sinus membrane.

Moreover, the AAA's position relative to the alveolar crest and sinus floor varies, with estimates ranging from 11.25 to 26.9 mm from the alveolar crest and 5.8 to 10.4 mm from the sinus floor (Testori et al., 2020). However, these measurements should be interpreted cautiously due to the AAA's variability in course. A thorough preoperative CBCT assessment is therefore recommended.

CBCT studies have reported that the diameter of the AAA is typically less than 1 mm (62.2%), while diameters ≥ 2 mm are rare (4.3%). Ella et al. have noted that AAA diameters between 0.5 and 1 mm contribute to intraoperative bleeding in approximately 10% of cases, whereas diameters of 1 to 2 mm increase the likelihood of hemorrhage to about 57% (Testori et al., 2020). Therefore, the AAA's diameter, especially when located near the planned antrostomy site, can impact the complexity of sinus lifting procedures (figure 26).

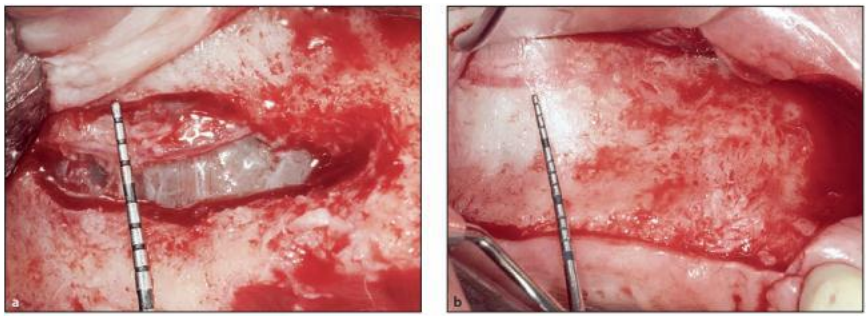

Figure 26 (a) Large and (b) small antral alveolar artery passing through the osteotomy window area. Adapted from (Testori et al., 2020)

3.7 Sinus Osteoma

Certain benign tumors can develop inside the paranasal sinuses, such as osteomas. These are slow-growing lesions, typically asymptomatic, characterized by a proliferation of compact or spongy bone tissue.

Craniofacial osteomas can arise on any bone of the skull or face, including within a paranasal sinus. They are relatively rare within the paranasal sinuses, occurring in approximately 0.01% to 0.43% of patients, with a predominance in the frontal sinus (96% of cases), followed by the ethmoid (2%) and maxillary (2%) (Mlouka et al., 2021a). The sphenoidal sinus is rarely affected. When an osteoma develops within the maxillary sinus, it typically appears on the postero-lateral wall, which may interfere with creating the lateral window required for a planned bone augmentation procedure.

To remove the lateral window and the portion of the osteoma obstructing it, piezoelectric instruments can be used to minimize the risk of Schneiderian membrane perforation (Figure 27).

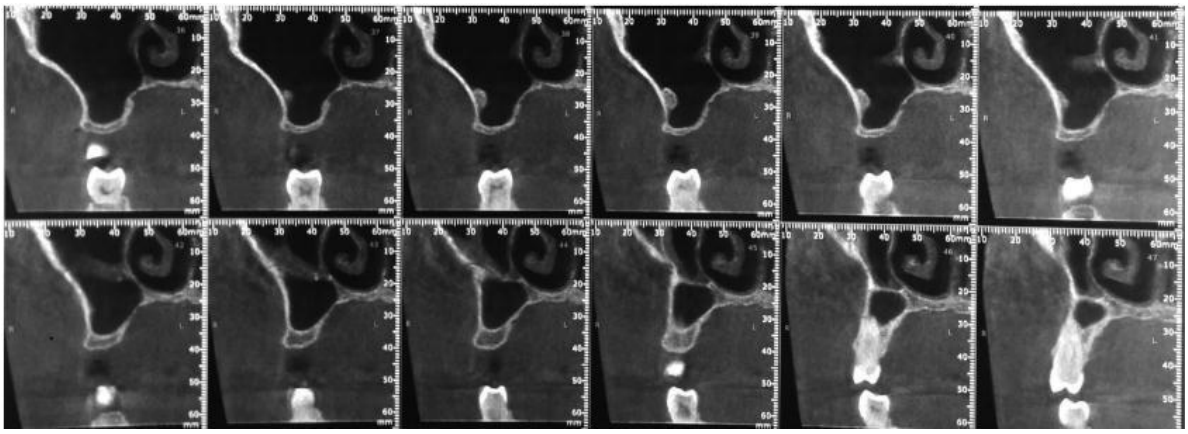

Figure 27 CBCT oblique coronal sections showing vertical defect and sinus osteoma (Mlouka et al., 2021c)

4 The consequences of sinus membrane perforation

The sinus membrane, a delicate barrier separating the maxillary sinuses from the oral cavity, is vital for maintaining healthy sinus function. Unfortunately, dental procedures like implant placement or sinus augmentation can sometimes lead to a perforation, or tear, in this membrane. While most perforations are small and heal uneventfully, some can lead to a cascade of complications. Let's explore the potential consequences of a perforated sinus membrane:

4.1 Bone graft infection

4.1.1 Diagnosis

Infection is a complication that can occur following any surgical procedure. Although the incidence is low, infection after sinus augmentation can occur and have deleterious effects on the survival of the graft and implant. In a study involving immediate implants placed in augmented sinuses, Peleg et al found that 61.4% of failed implants exhibited postoperative infection, making it the main cause of implant failure. (Katranji et al., 2008)

In situations where the infection has contaminated the graft, emergency treatment is necessary to prevent the spread of this infection to the sinus cavity and adjacent anatomical structures. (Urban et al., 2012)

Symptoms of bone graft infection include (Figure 28) (On et al., 2019):

- Significant pain

- Formation of a fistula

- Edema (two or three weeks after the intervention)

- Abscess

- Fever

- Loss of bone graft material

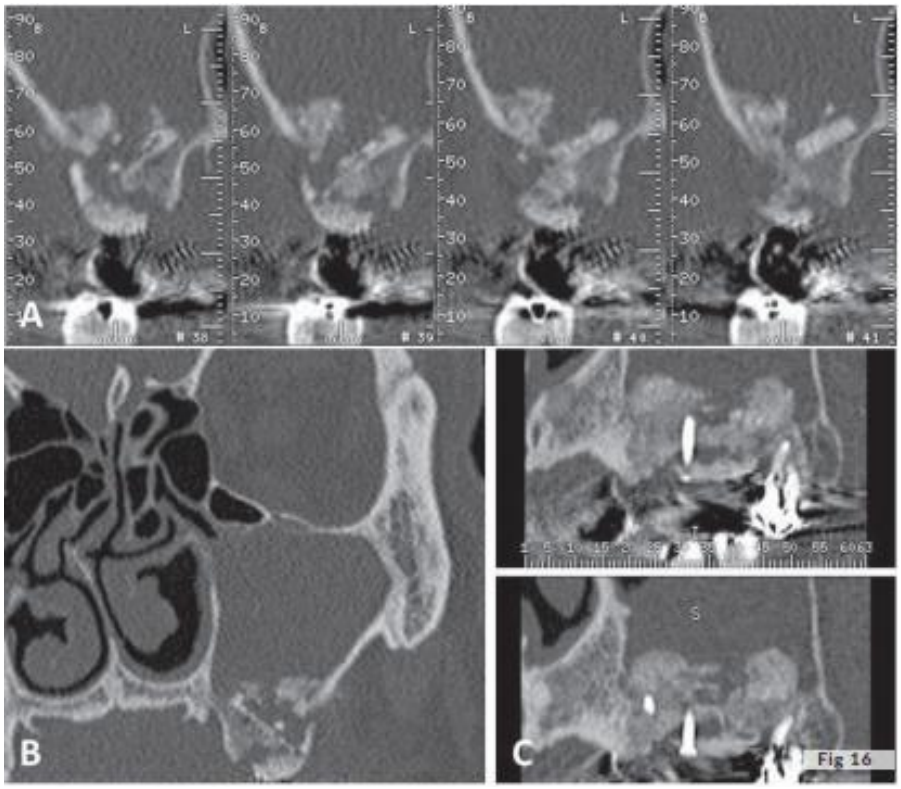

Figure 28 Left maxillary sinusitis on osteitis with graft necrosis; Dentascanner oblique coronal reconstructions (A), panoramic views (C) and coronal CT section (B): heterogeneous graft appearance reflecting graft osteitis complicated by left maxillary sinusitis . Adapted from (Tarragano Hervé et al., 2019)

4.2 Management and Treatment

The diagnosis of sub-sinus bone graft infection necessitates both surgical intervention and curative antibiotic therapy.

Surgical intervention for bone graft infection initially involves a meatalotomy to help control suppuration and preserve the graft.

Subsequently, treatment entails removing infected portions of the graft: the surgical approach is revisited, and the infected sections of the graft are excised (appearing grayish and easily detachable, often with particles floating in purulent exudate) until a healthy-looking graft is achieved. However, since the decision to remove the infected graft is at the discretion of the practitioner and complete removal of all infected portions cannot be

ensured, local antibiotic therapy is adjunctive to this procedure: application of a mixture of 100-200 mg of Doxycycline powder and 0.1-0.2 mL of saline solution to the remaining graft, left in place for 2 minutes then rinsed with saline solution. Additionally, rinsing with povidone iodine (Betadine®) mouthwash is performed. (Urban et al., 2012)

The site is then re-curetted to induce bleeding at the operative area to promote clot formation. The flap is subsequently sutured.

Curative systemic antibiotic therapy is combined with this treatment (noting that antibiotic therapy alone would be inadequate and unable to treat the graft infection, which would continue to spread): prescription of Amoxicillin + Clavulanic Acid 2g per day for 7 days.

It should be noted that a nasal decongestant may also be associated with this antibiotic therapy: prescription of Nasonex (one spray twice a day for 21 days).

Typically, the sinus can be regrafted after the infection has been eradicated. An antibiotic and nasal decongestant regimen is initiated before sinus grafting and continued throughout the healing process. (Katranji et al., 2008)

4.3 Dissemination of graft material within the sinus

4.3.1 Diagnosis

When there is a breach in the sinus membrane, and if not managed properly, the escape of biomaterial can lead to sinus infections. These particles may migrate towards the ostium or into the middle meatus, impeding sinus drainage and potentially causing sinusitis (Figure 29).

Moreover, operating on seemingly healthy mucosa can induce reactive swelling, resulting in functional issues.

Patients typically present with intense post-operative discomfort, persistent swelling in the oral and facial regions, alongside moderate fever that does not respond well to antibiotics. An intraoral fistula with the discharge of pus may also be observed. (Katranji et al., 2008)

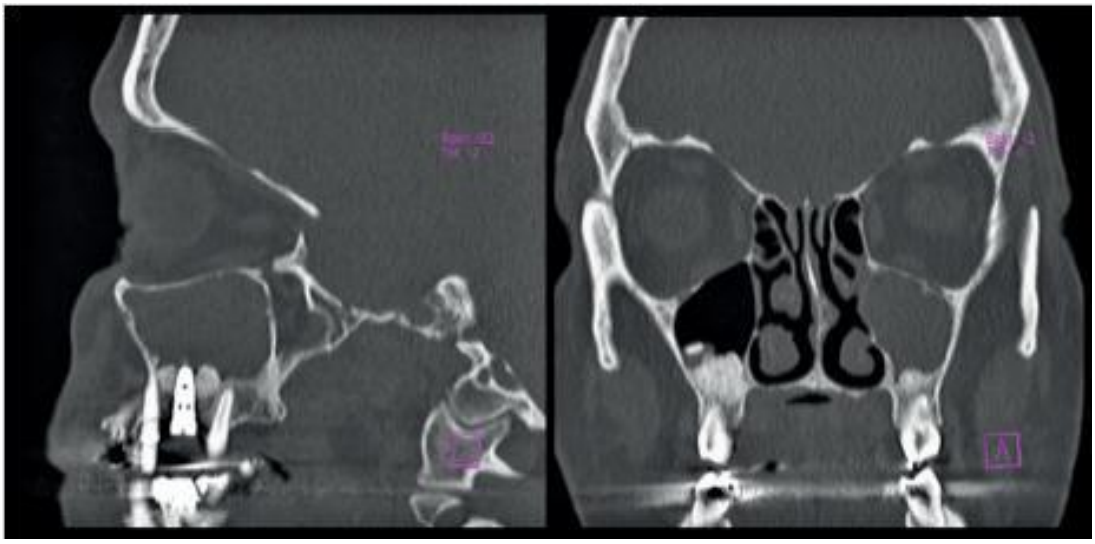

Figure 29 Purulent left maxillary sinusitis with classic symptomatology in a 63-year-old woman. The right and left sinus lifts had been performed on the same day, as well as the placement of dental implants. An undetected tear may have led to biomaterial projectin into the sinus cavity. Adapted from (Katranji et al., 2008)

4.3.2 Management and Treatment

Addressing infection of the surgical site and the grafted biomaterial entails surgical intervention for graft removal. This process typically involves a middle meatal antrostomy performed under endoscopic guidance by otorhinolaryngologists, followed by the initiation of antibiotic therapy. (Katranji et al., 2008)

4.4 Obstruction of the Middle Nasal Meatus

4.4.1 Diagnosis

Obstruction of the middle nasal meatus can result from the unintended migration of bone substitute material through a perforation in the sinus membrane or from edema or hematoma. This obstruction triggers sinus inflammation, which may quickly progress to infection (Figure 30).

Clinically, patients present with nasal congestion, facial pain, often accompanied by fever. (Nolan et al., 2014)

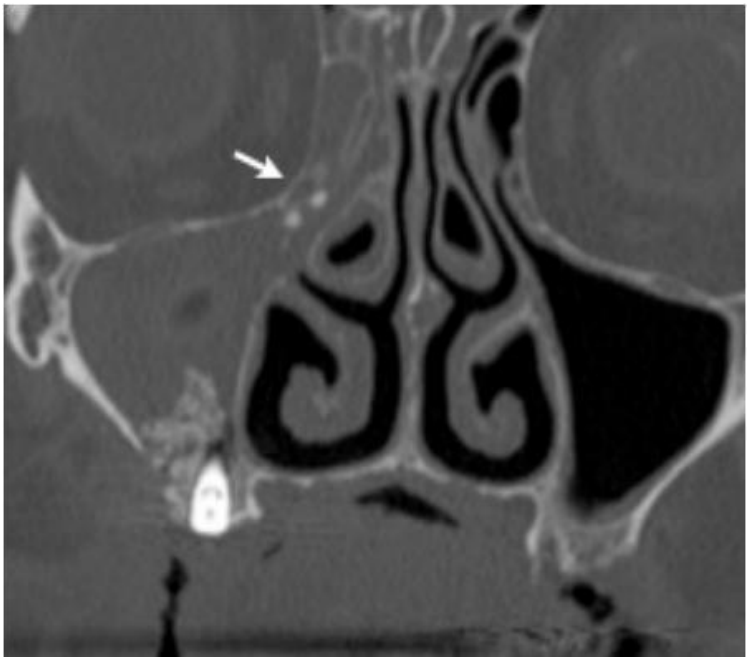

Figure 30 : Graft residue trapped in the meatus (left arrow) causing acute sinusitis. Adapted from (Valentini et al., 2013)

4.4.2 Management and Treatment

Resolution of the obstruction in the middle nasal meatus necessitates surgical intervention under endoscopic guidance to remove the obstructing material. This procedure is typically performed by an otorhinolaryngologist. (Hunter et al., 2009)

4.5 Maxillary Sinusitis

4.5.1 Definition

According to the World Health Organization, sinusitis refers to inflammation of the mucous membrane lining the sinuses (Figure 31) and may manifest as either acute or chronic. When sinus drainage is impeded, allowing for fluid accumulation, bacterial growth can occur, leading to symptoms such as headaches and yellowish nasal discharge. Maxillary sinusitis specifically involves symptomatic inflammation of the maxillary sinuses, primarily originating from nasal sources, although anatomical proximity to the teeth can occasionally lead to secondary odontogenic involvement (Kretzschmar & Kretzschmar, 2003). Sinusitis is further classified based on duration and symptom frequency, with distinct diagnostic criteria applied to acute and chronic forms. Each of these entities has specific diagnostic criteria. (Broome et al., 2008)

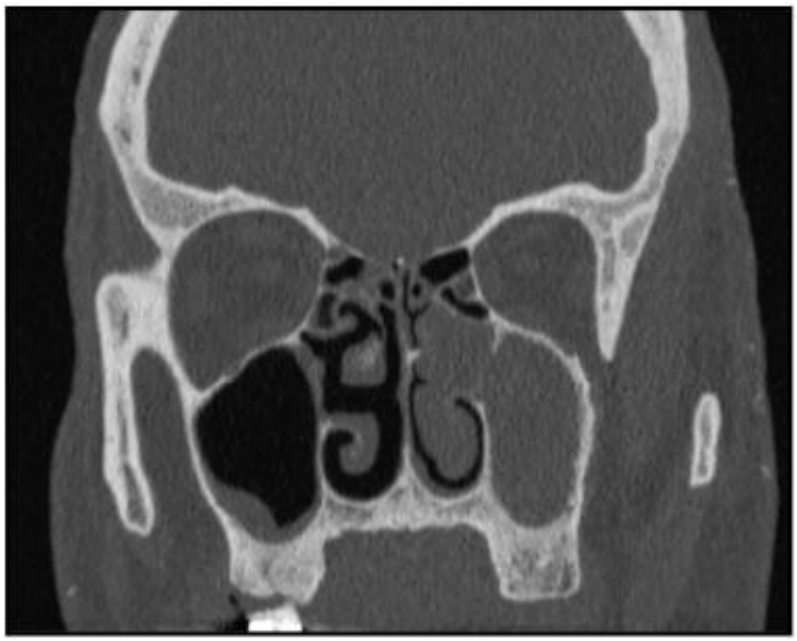

Figure 31 X-ray showing maxillary sinusitis. Adapted from (Maddy-Hélène Delattre, 2020)

4.6 Acute Maxillary Sinusitis

4.6.1 Diagnosis

Studies by Dr. Nolan's team in 2014 have demonstrated a link between membrane perforation and post-operative acute maxillary sinusitis, reporting an incidence of 11.3% when perforation is present versus 1.4% when absent. Additionally, TIMMENGA and others have noted that the risk of acute maxillary sinusitis following sinus membrane perforation correlates with the size of the perforation, the larger the diameter, the bigger is the risk of sinusitis. (Galli et al., 2001)

Contrarily, research led by Dr. Moreno Vasquez suggests that intraoperative perforation of the sinus membrane does not significantly increase the risk of acute maxillary sinusitis, while a history of sinusitis predisposes patients to higher risk (Galli et al., 2001). Patients with a history of maxillary sinusitis should thus be informed of the elevated risk of sinus inflammation post-operatively and, if actively symptomatic, should receive treatment before surgery to mitigate complications.

Furthermore, sinusitis has been identified as a potential complication of sinus lift procedures involving antral bone augmentation (Galli et al., 2001). This technique involves creating a subperiosteal pocket in the maxillary sinus floor to accommodate graft material comprising autogenous, allogeneic, or alloplastic components. However,

obstruction of the sinus outflow tract by mucosal edema and graft particles can lead to sinusitis. (Galli et al., 2001)

Symptoms of acute maxillary sinusitis include progressive, pulsatile, unilateral suborbital pain exacerbated by exertion and head movement, nasal congestion, purulent rhinorrhea often tinged with blood, low-grade fever, and possible genian and palpebral edema, with or without vestibular tenderness.

Clinical diagnosis involves endoscopic examination revealing pus in the middle meatus. Bacterial cultures may be obtained to guide antibiotic therapy, although their utility is limited due to preoperative antibiotic prophylaxis. Radiographic imaging confirms the diagnosis, demonstrating significant thickening of sinus mucosa and potential graft material migration, which informs subsequent management.

4.6.2 Management and Treatment

While initial antibiotic therapy may provide some relief, it often fails to resolve acute maxillary sinusitis. However, it remains the first-line treatment option. Antibiotic choices include (Table V):

- Amoxicillin-clavulanate combination (7 to 10 days),

- Cefpodoxime proxetil (5 days),

- Cefotiam hexetil (5 days),

- Cefuroxime axetil (5 days)

- Pristinamycin* (4 days),

- Telithromycin* (5 days)

Table 5 Antibiotic treatment modalities according to clinical situation

Clinical situations	Proposed antibiotic therapy and dosage	Duration
Maxillary sinusitis	Amoxicillin-clavulanic acid: 2 to 3 g/day in 2 or 3 doses	(7 to 10 days)
	Cefpodoxime proxetil: 200 mg every 12 hours	5 days
	Cefotiam hexétil: 200 mg every 12 hours	5 days
	Céfuroxime axétil: 250 mg every 12 hours	5 days
	Pristinamycine: 1 g every 12 hours	4 days
	Telithromycin: 800 mg every 24 hours	5 days
Maxillary sinusitis in failure, after radiological documentation and/or bacteriological	Levofloxacin: 500 mg every 24 hours	(7 to 10 days)
	Moxifloxacine: 400 mg every 24 hours	(7 to 10 days)

(Afssaps recommendations, October 2005)

In cases where antibiotic therapy proves ineffective, local interventions are warranted. This involves drainage of the sinus via middle meatal antrostomy, and if graft infection is present, revision of the vestibular approach and removal of infected graft material and granulation tissue.

4.7 Chronic Maxillary Sinusitis

4.7.1 Diagnosis

Chronic maxillary sinusitis is defined by the French College of Otolaryngology as sinus inflammation persisting for over three months, marked by enduring or intermittent rhinosinusitis symptoms (Timmenga et al., 2001). It is characterized by at least two subjective criteria, including purulent rhinorrhea, nasal blockage, sinus discomfort, or reduced sense of smell, alongside the presence of nasal polyps or sinus mucosal inflammation. These symptoms must endure for more than twelve weeks . (Broome et al., 2008)

4.7.2 Management and Treatment

Timmenga suggests several preventive measures against chronic maxillary sinusitis secondary to sinus floor elevation:

- A preoperative assessment to evaluate sinus clearance and identify risk factors, such as prior sinusitis.

- Postoperative administration of nasal decongestants and topical corticosteroids to prevent ostium blockage post-surgery.

- Prophylactic antibiotic therapy starting one hour before surgery and continuing for 48 hours afterward. (Timmenga et al., 2001)

Similarly, Timmenga recommends the following treatment approach for chronic maxillary sinusitis secondary to sinus floor elevation (Timmenga et al., 2001):

- Use of decongestants and antibiotics.

- Performing a CT scan along with localized intervention through endoscopic surgery.

4.8 Hemosinus

4.8.1 Diagnosis

Hemorrhagic complications occasionally occur post-surgery following sinus floor elevation. Sinus membrane perforation risk can lead to hemosinus, sometimes accompanied by epistaxis. Despite being minor, these hemorrhagic issues typically do not compromise the surgical outcome. (Hamon J et al., 2020)

4.8.2 Management and Treatment

The primary concern with hemosinus is superinfection, which can be prevented with antibiotic prophylaxis. (Hamon J et al., 2020)

Epistaxis associated with hemosinus requires:

- Thorough cleaning of the nasal cavity/cavities to remove clots perpetuating bleeding via local fibrinolysis, either by blowing the nose or through aspiration.

- Extended bidigital compression (using thumb and index finger) for ten minutes.

Epistaxis is usually of minimal volume and resolves within ten to fifteen days . (Pope & Hobbs, 2005)

5 Management of Sinus Membrane Perforation During Surgery

A considerable number of studies (Y.-K. Kim et al., 2013; Schwartz-Arad et al., 2004) have highlighted a notable occurrence of perforations during sinus floor elevation procedures. These perforations can arise from rotary instruments used to define the osseous window for accessing the sinus cavity or from manual curettes employed during sinus membrane detachment. Various factors, such as significant bleeding, intra-sinus septa presence, osseous dehiscences of the sinus floor, oroantral communications, or exceedingly delicate pellucid sinus membranes, contribute to their occurrence. While some experts argue that piezosurgery may reduce perforation rates, this assertion remains contentious. Notably, perforations may be observable during surgery but can also escape detection (Aimetti et al., 2001) when graft material is being placed into the sinus cavity.

Regardless, it is essential to continue detaching the sinus membrane away from the torn area to minimize tension on the membrane and allow for potential spontaneous closure. Detecting a sinus membrane lesion when perforation goes unnoticed poses significant challenges, if not impossibilities. However, managing this perioperative complication is crucial, as it can lead to graft failure (Ammar F, 2022). The risk associated with perforating Schneider's membrane is the potential leakage of the bone substitute biomaterial beyond the grafting site, which could lead to infection, ostium obstruction, or inadequate sinus filling for implantation.

Numerous techniques have been described for repairing sinus membrane perforations, including the use of:

- Sutures (Clementini, 2013),

- Resorbable collagen membranes (Proussaefs et al., 2004a)

- Stabilized collagen membranes

- Platelet-rich fibrin (PRF)

- Fat from the cheek.

- Covering with a bone lamella from the lateral access window.

However, a review of the literature by (Viña-Almunia et al., 2009) concluded that in cases of large membrane perforations, most authors opted to abandon the grafting procedure. According to Schwartz-Arad et al, a classification based on the size of the sinus

membrane perforation has been proposed to guide practitioners in selecting the appropriate management approach (Table 6). (Hernández-Alfaro et al., 2008)

This classification categorizes perforations into three groups based on size:

- < 5 mm

- 5-10 mm

- 10 mm

Table 6 Summary of treatment options for sinus membrane perforation, according to extent,

Perforation study (mm)	Surgical treatment of sinus membrane perforations
<5	Suture Resorbable collagen membrane
5-10	Lamellar bone + Resorbable collagen membrane
<10	Lamellar bone Lamellar bone + buccal fat pad Bone block graft

(Hernández-Alfaro et al., 2008)

5.1 Abstention from Therapeutic Intervention on the Membrane

5.1.1 Indications

When a tear occurs in the membrane during pre-implant surgery, and if the perforation measures less than 2mm and extends towards the upper edge of the osteotomy (classified as Class 1 according to Fugazzato's classification), therapeutic abstention might be advised. The procedure involves only detaching the membrane to facilitate sealing at the edges, achieved by folding the membrane over itself . (Fugazzotto & Vlassis, 2003)

5.1.2 Surgical Technique

In cases where the perforation of the membrane is under 2mm, the approach involves cautiously continuing the detachment process, and therapeutic abstention may be considered without delaying bone grafting. Detaching the membrane often results in it folding, which typically suffices to close the perforation (Chen L, 2011). Subsequently, the grafting material is delicately inserted and compacted to fill the newly created sub-sinus space.

Some experts, such as Antoun, suggest postponing bone grafting if a perforation is identified during site preparation due to the challenges of intraoperative management and their inherent imprecision. Follow-up nasal endoscopy typically reveals membrane healing after six weeks, especially in cases of small perforations, as evidenced by the findings of Dr. Bowman's team in 1999. (Antoun et al., 2020)

5.2 Direct Membrane Suturing

5.2.1 Indications

When a membrane tear occurs during pre-implant surgery and the perforation measures under 5mm in diameter, suturing with absorbable thread can be considered to prevent any risk of graft material dissemination into the sinus cavity.

5.2.2 Surgical Technique

The procedure begins by detaching the sinus membrane around the perforation to minimize stress on it. If the perforation is near the upper edge of the lateral access window, the membrane can be sutured to the bone using 6/0 absorbable thread. Subsequently, the cortical bone is perforated at the upper edge of the lateral access window using a carbide bur. O-sutures are then performed using 6/0 absorbable thread, an atraumatic round needle, and a Castroviejo surgical needle holder. The first suture is placed approximately 4-5mm from the caudal edge of the membrane perforation to ensure initial cranio-caudal approximation of the perforation edges without tension. Subsequent sutures are made every 4-5mm in the mesio-distal direction towards the cranial direction. The final suture passes through the perforation made near the access window, ensuring sinus membrane attachment to the maxillary bone. Depending on the orientation of the perforation, this technique can be adapted, such as making multiple transcortical perforations for several

suspension points in cases of mesio-distal perforation orientation (Figure 32). (Hernández-Alfaro et al., 2008)

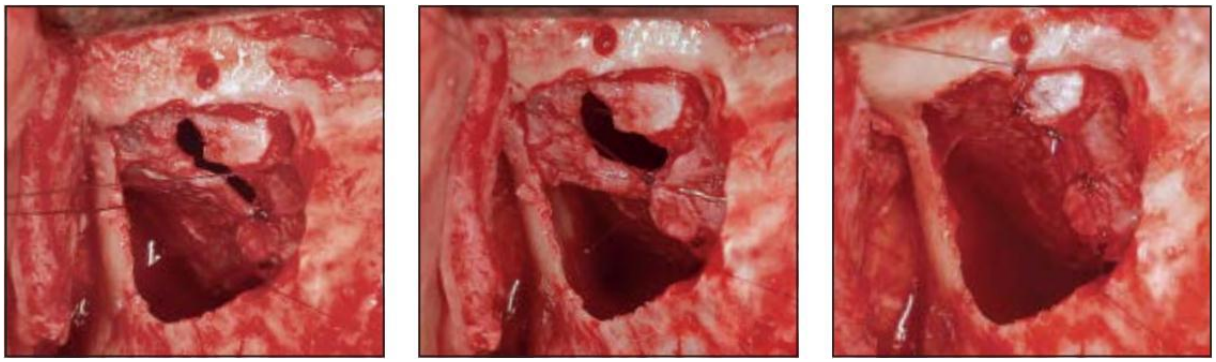

Figure 32 Suturing the perforated sinus membrane to the bone wall. Adapted from (Massei et al., 2015)

5.3 Resorbable Collagen Membrane

5.3.1 Indications

In cases of perforation, this approach involves the application of a resorbable collagen membrane, extending beyond the perforation. (Proussaefs et al., 2004b)

Several scenarios can arise:

- Perforation of the sinus membrane less than 5mm in diameter: the perforation is covered using a collagen membrane.

- Perforation of the sinus membrane between 5 and 10mm: the perforation can be covered with a collagen membrane, coupled with the application of the bone lamella from the lateral access window against this membrane . (Schlegel et al., 1997)

5.3.2 Surgical Technique

- The sinus membrane is initially detached around the perforation to minimize stress on it. A collagen membrane is then tailored to dimensions notably larger than those of the perforation and placed into the sub-sinus space thus created. It is then applied against the sinus membrane at the site of perforation. Subsequently, the substitute biomaterial is gently inserted, followed by either immediate or delayed implantation. Finally, the flap is sutured conventionally (Figure 33).

Figure 33 Perforation of the sinus membrane during floor elevation surgery. A. The perforation (arrow) is marked. B. It is repaired by placing a collagenous membrane in contact with it. C. Bone biomaterial is then packed under the repaired sinus mucosa. D. Dental implants are then inserted. Adapted from (Hamon J et al., 2020)

5.4 Stabilized Collagen Membrane

5.4.1 Indications

The use of stabilized collagen membrane technique is indicated for treating perforations of the sinus membrane with a diameter exceeding 10mm. (Testori et al., 2008)

5.4.2 Surgical Technique

For perforations with a diameter exceeding 10mm, the procedure becomes more intricate: a "Loma Linda Pocket" is thus formed (Figure 34). (Proussaefs & Lozada, 2003) This entails the use of a large collagen membrane inserted into the perforated sinus to enclose all the filling material within the central pocket. Subsequently, the membrane is secured with pins arranged in a frame surrounding the sinus osteotomy window.

Figure 34 Loma Linda pocket technique. Adapted from (Proussaefs & Lozada, 2003)

5.5 Platelet-Rich Fibrin (PRF)

5.5.1 Indications

PRF membrane finds application in cases of sinus membrane perforation during pre-implant surgeries, specifically for perforations of small extent, less than 5mm in diameter .(Sanghani et al., 2014)

5.5.2 Surgical Technique

Preparation of PRF is carried out extemporaneously during the intervention, with blood drawn from the patient for PRF preparation. (Baykul & Fındık, 2014)

Upon identification of the perforation, the sinus membrane is initially detached around it to minimize stress. The PRF membrane, obtained through centrifugation, is then applied at the perforation site (Figure 35).

Once positioned and secured with sutures, it mechanically restores integrity (visibly observing sinus membrane swelling during breathing) and enables continuation of the surgery. Membrane regeneration subsequently occurs naturally. (Rakotoarison et al., 2013)

5.6 Cheek Adipose Tissue

5.6.1 Indications

- This approach is suitable for addressing sinus membrane perforations ranging from 5 mm to 10 mm (R. Breheret, 2013), or for any perforations exceeding 5 mm . (Toledo-Arenas R & Descroix V, 2010)

- It offers a relatively straightforward technique, is resilient against infections, does not necessitate vascular anastomosis, and ensures patient comfort.

5.7 Surgical Procedure

The surgical sequence commences with a continued detachment of the sinus membrane to minimize tension. An incision is made horizontally at the vestibule's base, adjacent to the second molar, facilitating access to the cheek's adipose tissue. Through dissection of the buccinator muscle, the cheek's adipose tissue protrudes into the oral cavity. Subsequently, the main bulk of the cheek's adipose tissue, along with its buccal extensions, is gently mobilized to provide traction up to the membrane perforation. Following this, a palatal initial suture secures and positions the cheek's adipose tissue in place. Once the perforation is sealed, the substitute bone material is introduced, and the flap is sutured conventionally (Figure 35). It's noteworthy that the physiological anatomy of the vestibular sulcus bottom is restored approximately after 2 months . (Liversedge & Wong, 2002)

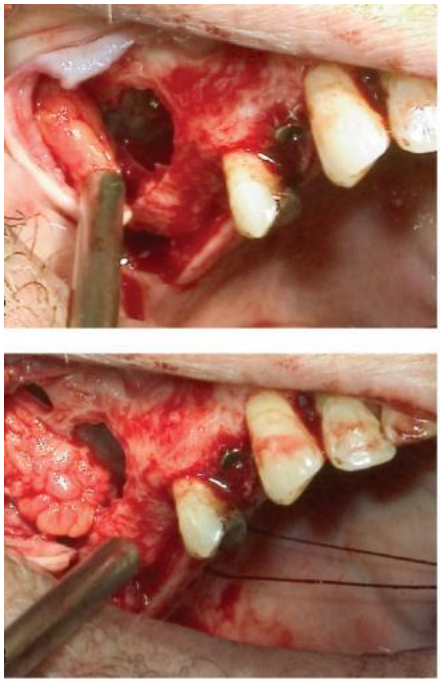

Figure 35 : Traction of the fat body from the cheek to the level of the lateral access window. Adapted from (Hassani et al., 2008)

5.8 Coverage with Bone Lamella from the Lateral Access Window

5.8.1 Indications

- Utilized for perforations exceeding 5 mm in the sinus membrane, this technique can be applied independently or in conjunction with a resorbable collagen membrane.

- In cases of perforations exceeding 10 mm, this technique is combined with cheek adipose tissue traction. (Hernández-Alfaro et al., 2008)

5.8.2 Surgical Technique

The surgical protocol starts with continued detachment of the sinus membrane to minimize tension and allow for membrane folding. For perforations ranging from 5 to 10 mm:

- The bone lamella is rotated within the sinus to cover the perforation, or alternatively, a resorbable collagen membrane larger than the perforation is applied against it. The bone lamella is then rotated inside the sinus to cover the collagen membrane (Nathalie PERROS, 2016).

- In cases where perforations exceed 10 mm, the bone lamella is rotated within the sinus to cover the perforation, and subsequent traction of cheek adipose tissue optimally closes the perforation. (Hernández-Alfaro et al., 2008)

6 Preventing Sinus Membrane Perforation Complication

Sinus floor elevation surgery is a valuable technique for increasing jawbone volume to accommodate dental implants. However, one potential complication involves the sinus membrane, a thin lining separating the sinus cavity from the underlying bone. Accidental tearing or perforation of this membrane during surgery can lead to chronic sinusitis, delayed implant placement, and the need for additional procedures.

This section will explore various strategies to minimize the risk of sinus membrane perforation. We'll delve into techniques and considerations employed by dentists to ensure a smooth and successful procedure.

6.1 Preoperative Diagnosis

The preoperative assessment involves several steps:

- Understanding the patient's desires and requirements

- Conducting a thorough health evaluation, including identifying any harmful habits

- Performing a comprehensive intraoral and extraoral clinical examination

- Considering the necessity of additional diagnostic tests

- Developing a treatment plan and providing a cost estimate

- Informing the patient about the surgical procedure and potential complications

- Obtaining the patient's informed consent:

This document, signed and dated by the patient, ensures they disclose all relevant information, allowing the practitioner to demonstrate adherence to their professional obligations in case of any complications.

It's also essential to identify medications requiring special precautions during treatment (e.g., antiplatelet and anticoagulant drugs with bleeding risks) and medical conditions necessitating special precautions (e.g., uncontrolled diabetes, risk of endocarditis).

Moreover, the medical history should highlight any local or regional pathologies or past conditions that could affect the success of sinus bone grafting. For example, chronic periodontitis requires comprehensive treatment before sinus lift surgery due to its high risk factor for procedure success (though success rates remain limited even after treatment, compared to a healthy population, which should be communicated to the patient). Acute sinusitis, particularly of dental origin (occurring in 10-12% of cases) (Brook, 2006) , and associated periapical lesions or maxillary dental cysts should also be investigated. Sinusitis and its cause must be addressed before sinus lift surgery, requiring both sinus and dental treatments. If communication exists between a dental root and the sinus, a healing period after tooth extraction should precede sinus lift surgery to facilitate optimal healing and minimize the risk of sinus membrane perforation. A history of Caldwell-Luc sinus surgery (a procedure used in cases of unresolved chronic sinusitis not responsive to endonasal surgery) should also be noted, as it represents a contraindication to sinus lift surgery.

6.2 Alternative Approaches to Access Window Creation

In lateral sinus lift surgery, the access window is typically created using either a standard round bur or piezoelectric instruments with a diameter not exceeding 1 cm, balancing good visibility with bone tissue preservation.

6.2.1 Rotary Instruments vs. Piezoelectric Instruments

The use of piezoelectric instruments for creating the lateral access window and sinus membrane elevation carries a membrane perforation risk of approximately 5%, whereas traditional rotary instruments pose a perforation risk of 20 to 25% . (Vercellotti et al., 2001)

Piezoelectric instruments operate at ultrasonic frequencies ranging from 22 to 30 kHz, allowing selective cutting: effective on hard (mineralized) tissues without damaging soft tissues like the Schneiderian membrane (Vercellotti et al., 2001). Thus, even if the insert is positioned incorrectly, it causes minimal to no damage to soft tissues. These instruments come in various inserts for osteotomy and therefore the creation of the access window,and membrane elevation, making them suitable for the entire sinus lift procedure. Complete kits are available for performing this surgery with a set of inserts chosen for each step. Overall, numerous studies have concluded that piezosurgery significantly reduces membrane perforation compared to traditional techniques, making it a safer option . (Stübinger et al., 2005)

6.3 Alternative Systems for Sinus Membrane Elevation

6.3.1 Sinus Balloon Elevation Technique

The sinus balloon elevation technique, also known as the Minimally Invasive Antral Membrane Balloon Elevation (MIAMBE) method, represents a modification of the Summers technique aimed at elevating the sinus membrane via a crestal approach utilizing balloon inflation force.

This approach employs a specialized device featuring a steel tube with dual ends (Figure 36):

- A plastic tubing connected to an inflation syringe, further linked to a pressure gauge at one end.

- The opposite end incorporates an internal screw mechanism designed to secure the device at the osteotomy site, housing a single-use balloon within the cylinder.

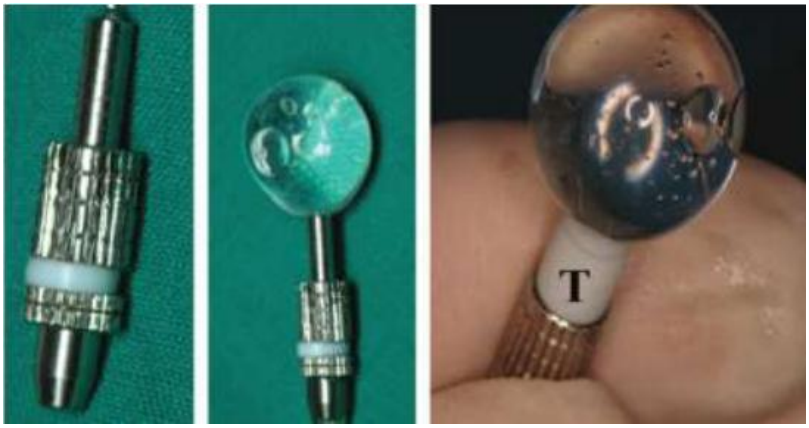

Figure 36 Sinus elevation balloon (MIAMBE). Adapted from (Kfir et al., 2009)

Implementation of the MIAMBE system begins with site preparation using the Summers technique and osteotomes. Once the initial approach is completed, sinus membrane integrity is confirmed via the Valsalva maneuver. Subsequently, the MIAMBE system is utilized to elevate the sinus membrane:

- The tip containing the balloon is cautiously inserted into the osteotome-created approach, maintaining a distance of up to 1mm from the sinus floor.

- Gradual inflation of the balloon with air, monitored by the pressure gauge, achieves a pressure of 2 atm.

- Upon inflation beneath the sinus membrane, pressure is reduced to 0.5 atm, and the balloon is slowly filled with a radiopaque contrast agent, as confirmed by a periapical radiography.

- Following the attainment of desired elevation, the balloon is left in situ for 5 minutes to minimize membrane repositioning.

- Subsequently, the balloon and MIAMBE device are removed, with membrane integrity confirmed by direct observation, synchronizing with the patient's respiration.

- The grafting procedure ensues, utilizing a syringe for bone substitute injection into the submembranous space created.

This technique offers the advantage of achieving greater bone height augmentation compared to the Summers technique, while being less invasive and enhancing patient comfort . (Kfir et al., 2009; Muronoi et al., 2003)

6.3.2 Sinus Membrane Elevation Using Hydraulic System

The method of lifting the sinus membrane with a hydraulic system enables a controlled detachment of the membrane. It is applied subsequent to creating the lateral access window, immediately following the use of osteotomes. This approach relies on hydraulic force to delicately detach and raise the sinus membrane in a precise and gentle manner.

In 2012, this technique underwent further refinement with the introduction of the Water Lift System by Kim and Itoh (D. Y. Kim et al., 2012) . This system employs hydraulic pressure to lift the membrane uniformly, effectively eliminating potential pressure points that could lead to membrane tears.

Consisting of atraumatic burs designed for the sinus membrane and a hydraulic mechanism for membrane detachment, from lateral approach, the procedure begins with the establishment of an access pathway. Isotonic saline solution is then injected to facilitate the detachment of the sinus membrane. After achieving sufficient detachment, the access window is created, allowing for graft placement (Figure 37).

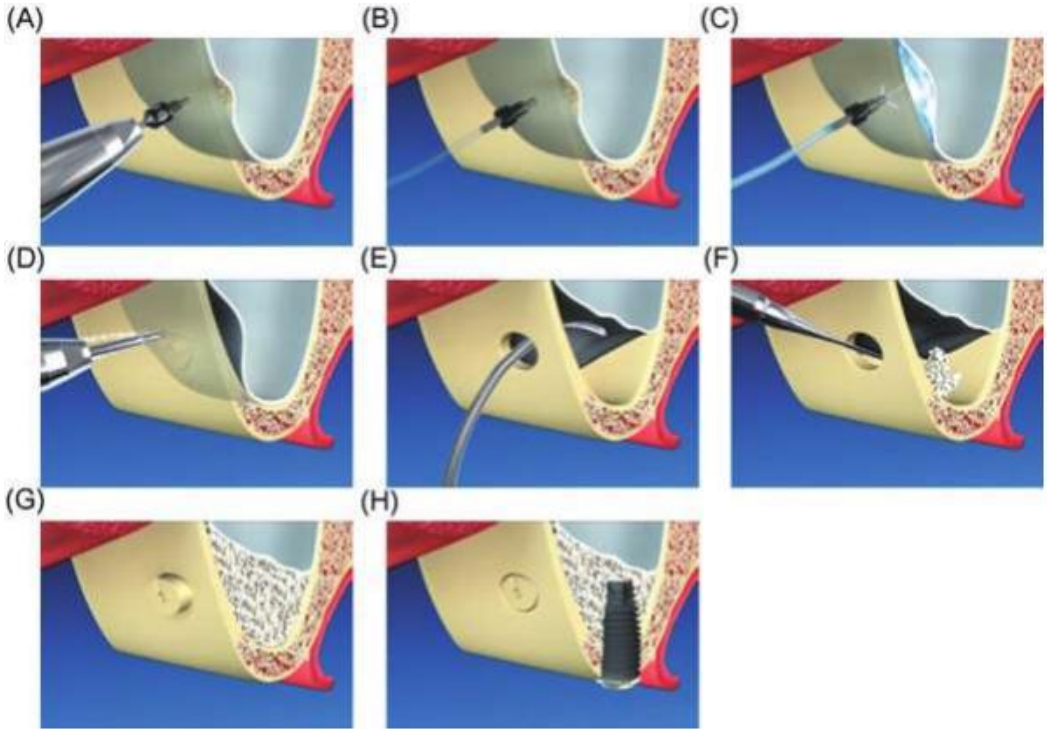

Figure 37 Using the Water Lift System® for a lateral approach. Adapted from (Kao & DeHaven, 2011)

Utilizing the Water Lift System® for sinus membrane elevation reduces the risk of membrane perforation to 2.9%, significantly lower than traditional methods. (Kao & DeHaven, 2011)

6.4 Surgical Guide for Access Window Localization

The technique of using a surgical guide for localizing the lateral access window in sinus lift procedures was pioneered by Dr. Mandelaris's team in 2008. This guide is created through the process of stereolithography, a rapid prototyping technique used to produce solid objects from digital models. By utilizing an implant planning system, the optimal positioning of the access window is determined based on sinus anatomy and the presence of any anatomical risk factors. The resulting digital file allows for the production of a study model and two surgical guides. One guide defines the mesial, distal, and inferior boundaries of the window, while the other delineates the superior boundary (Figure 38). (D. Y. Kim et al., 2012)

This surgical guide technique helps minimize the risk of Schneiderian membrane perforation by ensuring precise positioning of the access window while respecting anatomical constraints and optimizing instrument access. (Zaniol et al., 2018)

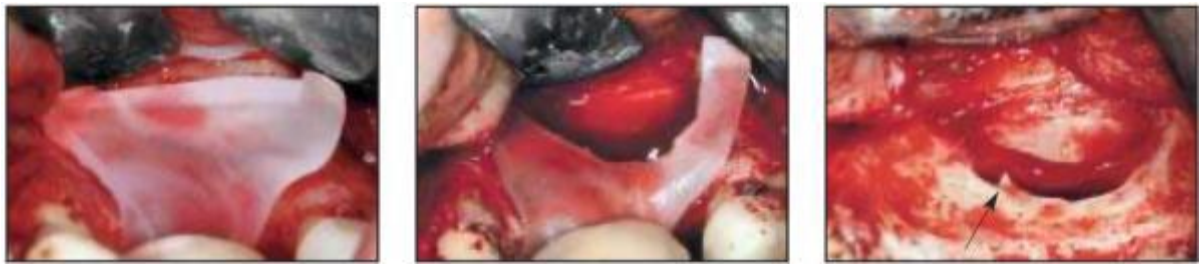

Figure 38 Using a surgical guide to create the access window. Adapted from (Mandelaris & Rosenfeld, 2008)

III Conclusion

Sinus lift surgery, aimed at increasing maxillary bone height in the sub-sinus region, is a complex procedure often required to address vertical bone defects prior to implant surgery. However, the risk of sinus membrane perforation poses a significant challenge during this operation. Given the delicate nature of the membrane, any perforation can lead to serious complications like infection and delayed healing. Therefore, meticulous preoperative planning and precise execution of the sinus lift procedure are crucial. Comprehensive evaluation of clinical and radiological data is necessary to assess the feasibility of the procedure and effectively plan the surgery.

Recent advancements in dental technology have introduced new tools and techniques for managing sinus membrane perforation during sinus lift procedures. Digital workflows, for instance, offer enhanced precision and predictability in both planning and executing the procedure. Utilizing digital surgical guides allows for precise localization of the membrane, thus helping to prevent intraoperative complications. Cone-beam computed tomography (CBCT) enables 3D visualization of the surgical site, facilitating accurate planning and execution of the sinus lift procedure. Integrating clinical and radiological data into the planning and fabrication of surgical guides ensures maximum accuracy.

By leveraging digital surgical guides, surgeons can minimize unnecessary incisions, reduce the risk of complications, and promote faster recovery. Moreover, digital technology enables simulation of the procedure before actual implementation, enabling surgeons to refine their skills in pre-implantation bone augmentation surgery.

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ANNEX

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Autorisation utilisation figures

1 message

Mootaz MLOUKA <drmloukamootaz@hotmail.com> 13 juin 2024 à 22:47
À : "elmatri53@gmail.com" <elmatri53@gmail.com>

Je présente, Dr Mootaz Mlouka assistant hospitalo Universitaire à la faculté de médecine dentaire de Monastir.
Faisant suite à sa demande, j'autorise par le présent mail, monsieur Rami Matri étudiant à l'université Egas moniz au Portugal, à utiliser les figures publiées dans mon article, dans sa thèse.
Cordialement.

Dr Mootaz MLOUKA
Assistant Professor in Dental Surgery
Monastir - Tunisia