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GRADUATION PROJECT

Degree in Dentistry

TRANSCRESTAL SINUS LIFT TECHNIQUES : UPDATE AND NEW PROTOCOLS

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To my parents, to my brothers, your support, your carrier, and your courage constitute such a strength, which represents for me a source of daily admiration which has pushed me to give the best of myself for years in order to realize my dream, I hope to make you proud.

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ABSTRACT

Introduction : Maxillary posterior edentulism implies several complications such as physiological bone resorption, making implants prosthesis impossible as sufficient bone volume is missing to ensure implant stability. Sinus lift through crestal approach is a major advance in bone regeneration allowing the increase of alveolar bone height to receive future implant rehabilitation.

Objectives : The major purpose of this literature review was to investigate the available procedures to achieve sinus floor elevation by transcrestal approach. Secondary aims were to determine advantages and complications of this crestal technique to finally evaluate alveolar bone gain necessary for later implants.

Methodology : A research was conducted to look for relevant clinical studies on transcrestal techniques to increase maxillary sinus floor. The literature review was conducted through electronic databases such as PubMed/Medline and Scopus combining precise filters and keywords. The investigation was restricted to in vivo studies published within the last ten years, between 2013 and 2023.

Results : A total of 188 results were obtained according to our inclusion and exclusion criteria. Finally, the 17 most relevant studies were included in the review as a way to compare these different techniques of crestal approach sinus lift.

Conclusions : Maxillary sinus augmentation via transcrestal access can be realized using several processes such as hydraulic pressure, special drilling sequences, balloon technique and magnetic system. This new approach is a safe and predictable alternative to the lateral window, specially to avoid the more prevalent complication during sinus lift surgery which is the perforation of the Schneider membrane.

Key words : Dentistry, Maxillary sinus lift, Crestal approach, Bone grafts, Complications.

RESUMEN

Introducción : El edentulismo maxilar posterior implica varias complicaciones, como la reabsorción ósea fisiológica, lo que imposibilita la colocación de prótesis sobre implantes, porque falta bastante volumen óseo para garantizar la solidez del tratamiento. La elevación del suelo del seno a través del abordaje crestal es un gran avance en la regeneración ósea que permite aumentar la altura del hueso alveolar para recibir futuras rehabilitaciones con implantes.

Objetivos : El motivo principal de esta revisión de la literatura fue investigar los procedimientos disponibles para lograr la elevación del piso del seno mediante un abordaje transcrestal. Los objetivos secundarios fueron determinar las ventajas y complicaciones de esta técnica crestal para finalmente evaluar la ganancia ósea alveolar necesaria para implantes posteriores.

Metodología : Se realizó una búsqueda para encontrar estudios clínicos relevantes sobre técnicas crestales para aumentar el piso del seno maxilar. La revisión de la literatura se realizó mediante referencias electrónicas como PubMed/Medline y Scopus, combinando filtros y palabras clave precisos. La búsqueda se limitó a estudios in vivo publicados en los últimos diez años, entre 2013 y 2023.

Resultados : Se obtuvieron un total de 188 resultados según nuestros criterios de inclusión y exclusión. Finalmente, se incluyeron en la revisión los 17 estudios más relevantes para comparar estas diferentes técnicas.

Conclusiones : El aumento del seno maxilar a través del acceso transcrestal se puede realizar utilizando varios procesos, como presión hidráulica, secuencias especiales de perforación, técnica de balón y sistema magnético. Este nuevo abordaje es una alternativa segura y predecible a la ventana lateral, especialmente para evitar la complicación más frecuente durante la cirugía de elevación de seno que es la perforación de la membrana de Schneider.

Palabras clave : Odontología, Elevación de seno maxilar, Abordaje crestal, Injertos óseos, Complicaciones.

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INTRODUCTION

1. General anatomy

1.1 Maxillary bone

1.1.1. Sinus

The maxillary bone is the most voluminous facial bone, presenting a pyramid shape. It consists of 4 faces and a large triangular opening called the maxillary hiatus.

Most of the volume of the bone is occupied by a pneumatic cavity, called maxillary sinus. It is indirectly connected to orbital and oral cavities but directly related to the nasal cavity. (1)

Maxillary sinuses evolve over time and widen as the patient grows (Figure 1). Moreover, different functions are associated with the sinuses such as :

- interchange of carbon dioxide and oxygen between nose and lungs providing a moderate airflow during the respiration
- resonance to achieve phonation
- shock resistance in case of traumatic injuries (2)

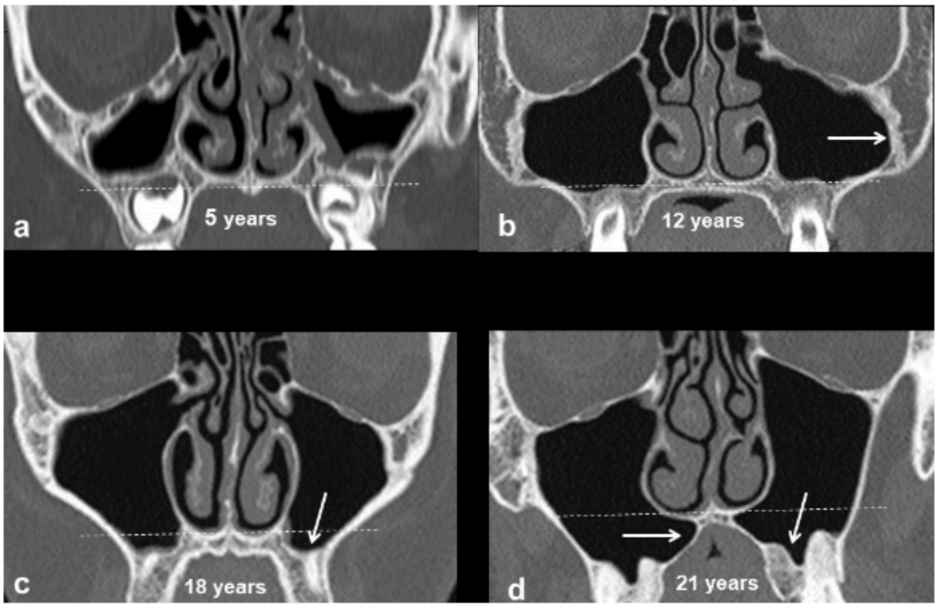

Figure 1. Cone Beam Computed Tomography (CBCT) of the maxillary sinus enlargement during human growth (2)

There are four pairs of paranasal sinuses :

- ethmoidal : made of air cells between the eyes and the nose, with a small volume about 2 to 3 milliliters (mL).

- frontal : found in frontal bone, superior to the orbit, with a volume of 5-7 mL.

- sphenoidal : found in the sphenoid bone with a volume between 0,5 and 8 mL.

- maxillary : the largest sinus with six walls and a volume capacity varying between 5 and 22 mL. (3) The mesial wall isolates the sinus from nasal fossa, and reveals an ovoid orifice named ostium. The floor that extends from the premolar region to maxillary tuberosity is adjacent to posterior teeth roots named antral teeth (Figure 2). We also observe the orbit floor on the superior wall, where infraorbital nerve and artery pass. Finally, lateral wall is contiguous with the vestibular bone, and through which a type of sinus lift procedure can be achieved. (4,5)

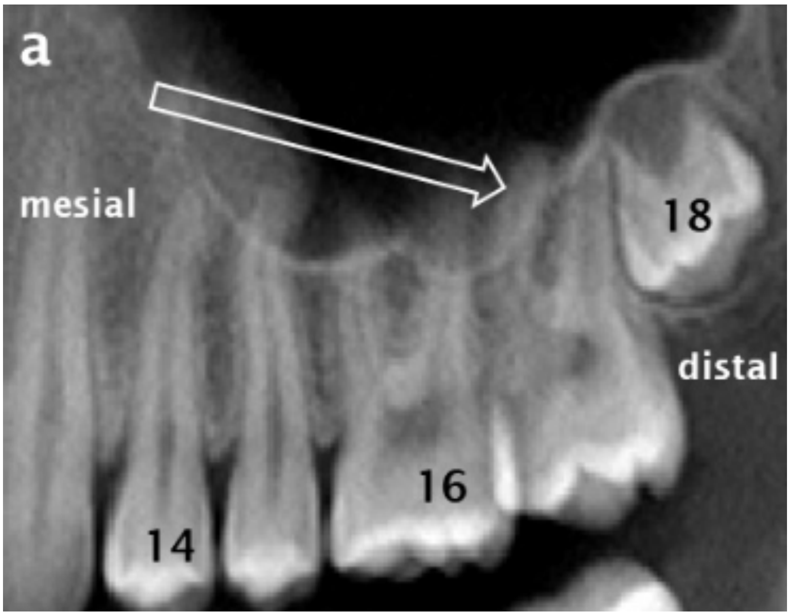

Figure 2. Radiography of the proximity of antral teeth with the maxillary sinus (2)

1.1.2. Membrane

The sinus membrane, also called Schneider's membrane, lines the inner wall of the sinus and is composed of different layers (Figure 3) :

- a ciliated pseudostratified columnar epithelial lining on the inner side,
- a lamina propria (layer of connective tissue) and
- a periosteum on the bony side containing the osteoprogenitor cells. (2,6)

The membrane is really thin, usually inferior to 0.5 millimeters (mm) and plays a major role in bone remodeling. The presence of blood vessels and osteoprogenitor cells would promote bone formation, constituting a stable environment for the maturation of the filling material. (7)

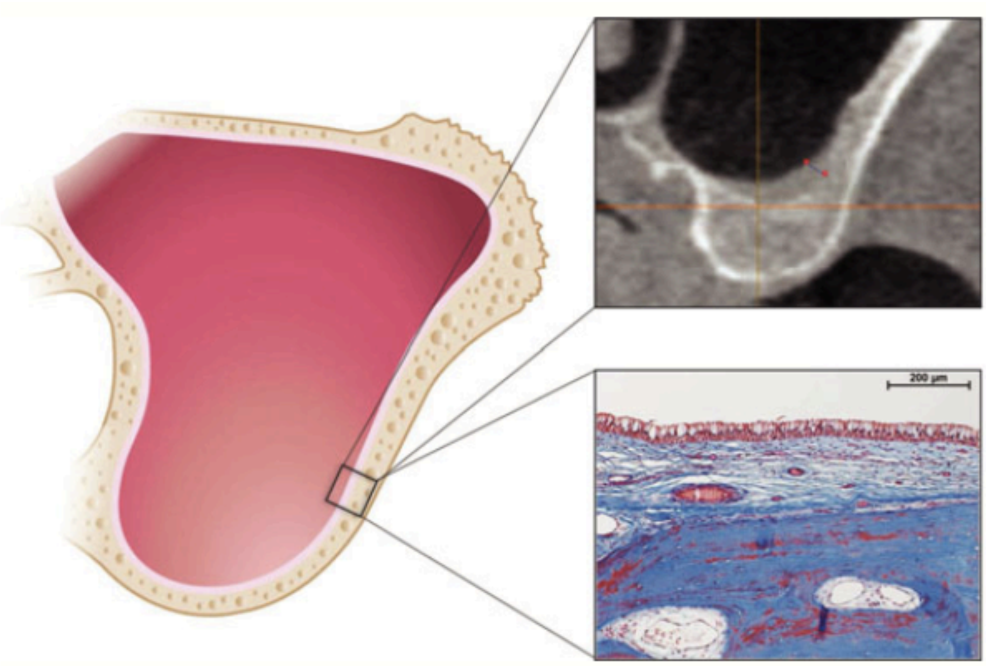

Figure 3. Schneider membrane under histological and radiological views (7)

1.1.3. Septa

They are anatomical formations of thin cortical bone that can expand from one sinus wall to the other one. The size of a bony septum can vary from a patient to another one, but in voluminous septum, division of the sinus can be partial or complete (Figure 4).

The sinus mucosa is often thinner when septa are present. The existence of a bony septa can cause perforation of the sinus membrane or constitute an obstacle during a sinus lift surgery. (4)

Two types of septa can be distinguished :

- primary septa or developmental : mainly present in dentate patient, they are commonly located between 2nd premolar and 1st molar roots, or between the roots of the 1st and 2nd molars or even in distal area of the 3rd molar.

- secondary septa or acquired : related to pneumatization of the maxillary sinus following extractions, commonly found in edentulous ridges and therefore present in partially dentate patients. (6)

Septa are really frequent, in around 50% of the cases. As they increase the probability of mucosal perforation, a good diagnostic imaging before any procedure is important in order to prevent any complications. (3)

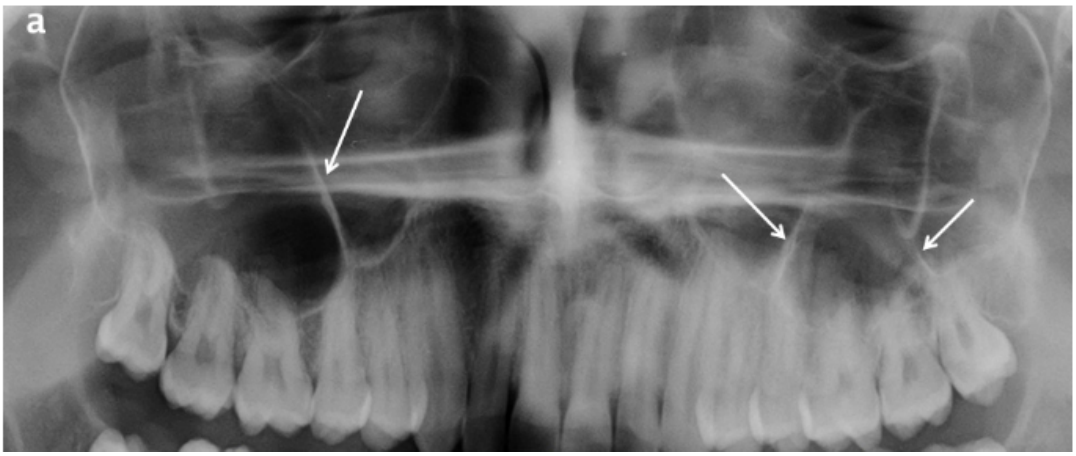

Figure 4. Panoramic radiography of sinus septa (2)

1.2 Vascularization and innervation

- Vascularization

It is crucial to know presence and location of the arterial blood supply using radiographic images, to prevent lesions or bleedings during surgery. The main advantage of this huge vascularization is that it will provide an important territory for graft consolidation (1).

The sinus is vascularized by the branches of the maxillary artery (which is a terminal branch of the external carotid artery) including (Figure 5) :

- posterior superior alveolar artery
- descending palatine artery
- sphenopalatine artery and its terminal branch and posterolateral nasal artery
- infra-orbital artery. (8,9)

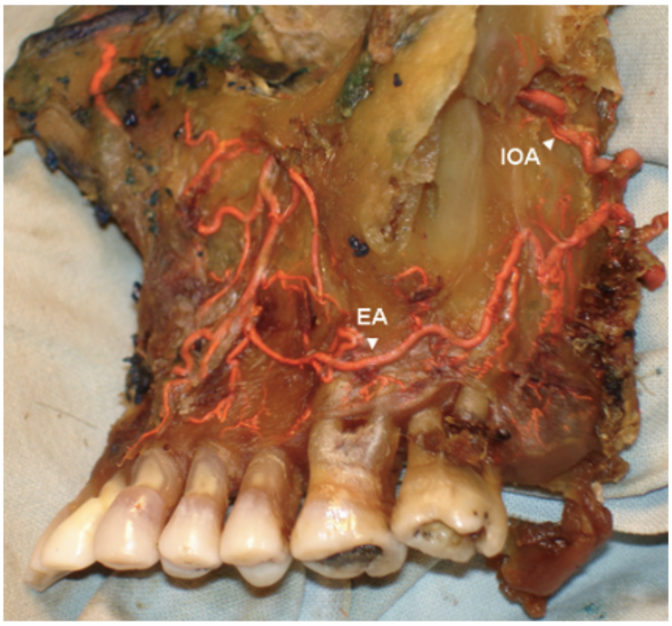

Figure 5. Maxillary sinus blood supply (8)

EA, Extraosseous anastomosis; IOA, Infraorbital artery

The venous return is done in 2 different ways, on the one hand with the sphenopalatine vein which will join the internal maxillary vein. On the other hand, it can be done via 3 venous plexuses : anterior and posterior pterygoid plexuses and alveolar plexus, which converge on one hand towards the facial vein and on the other hand towards the maxillary vein. (6)

- Innervation

The sensory information of the sinus is dependent on maxillary nerve V2, (branch of the trigeminal nerve V), and its branches : superior alveolar nerve, infra-orbital nerve and greater palatine nerve. (1)

The superior alveolar nerve divides itself into 3 collateral nerves for different parts of the sinus :

- sinus anterior wall, incisors, canines: supplied by anterior superior alveolar nerve
- posterior wall, premolars, molars : by middle and posterior superior alveolar nerves
- medial wall and sinus roof : by infraorbital nerve
- sinus floor and ostium : supplied by greater palatine nerve (3,10)

The parasympathetic innervation responsible for the secretions of the sinus mucosa is provided by greater petrosal nerve (branch of the facial nerve VII). (1)

1.3 Pneumatization

The maxillary sinus begins at birth, appearing as an initial groove extending on both sides of the nasal cavities. The growth develops little by little until adulthood obtaining its final volume, it is called pneumatization. (11).

Its average volume in adulthood is 15 cm3 (cubic centimeter). It varies according to the maxillary bone volume and dimensions of the other face bones (Figure 6). Different processes can influence the phenomenon of pneumatization, such as inflammation of the sinus mucosa, periodontal disease or avulsion of maxillary teeth. (12)

These factors can produce bone remodeling, resulting in a descending enlargement of the sinus which can diminish the convenient crest height for later implant placement. Knowing the sinus volume and the bone walls makes it possible to estimate the possibility of membrane tear and volume of filling material to be added. (13)

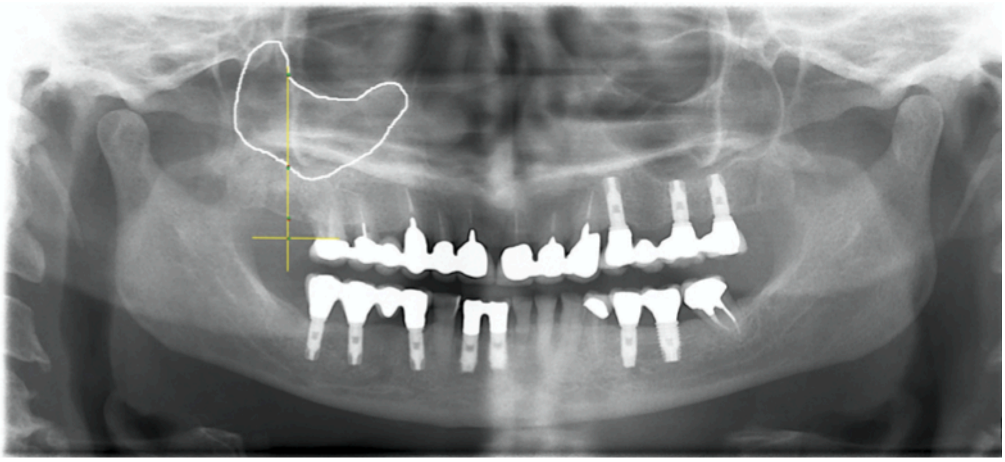

Figure 6. Panoramic radiography highlighting sinus volume (14)

2. Sinus elevation procedures

Dental implantology has been a total revolution as oral rehabilitation after several posterior maxillary tooth extractions. Indeed, alveolar ridges suffer various changes after extractions which must be solved before the implant placement. Posterior edentulism of the maxilla produces a bone height reduction due to sinus pneumatization and alveolar crest resorption. (14)

A pre-prosthetic surgery is necessary to increase bone in these areas. The sinus augmentation is a successful technique used to vertically heighten alveolar ridge in maxilla until reaching the dimensions needed for the dental implant placement. (15) Schneider membrane elevation is realized to prevent perforation when placing the implants (Figure 7). This created empty space between sinus floor and membrane will later be supplied with bone grafts. (10,16)

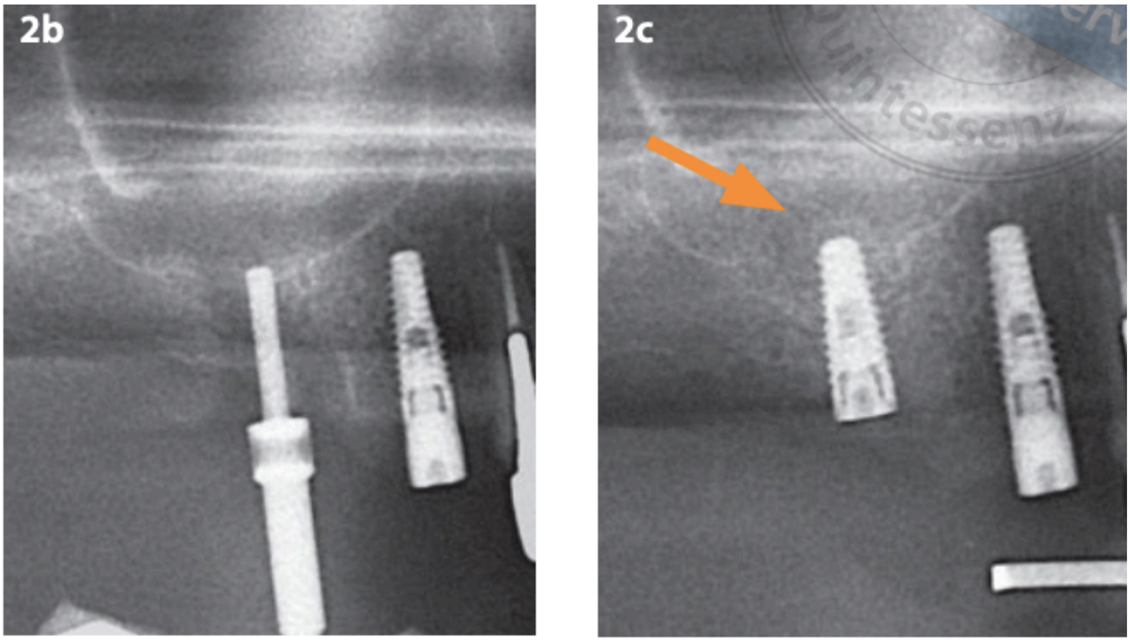

Figure 7. Radiological comparison before/after sinus lift with grafting (6)

2b, before; 2c, after surgery

CBCT imaging is essential to assess the thickness of the wall and its position, the alveolar-antral artery and any septa. These intermediate septa are excellent osteogenic sources and are preserved if possible. Otherwise, two windows are made on either side of the septum. (2,17)

The two most frequent approaches for sinus lift surgery are :

- Direct technique/ Lateral window
- Indirect technique/ Transcrestal approach. (18)

The sequences are carried out with precaution allowing to preserve the entirety of the membrane. In both techniques, the objective being to increase the bone height, the use of a filling material and a membrane would favor this process.

The maxillary bone being of a low bone density after extractions (type III or IV according to Lekholm & Zarb), generally the type of procedure is selected according to the height of residual bone. (19,20)

2.1 Direct technique / Lateral window

When the maxillary sinus is widely extended and the sinus floor is no more than a thin bone blade, usually < 5 mm, it is often necessary to lift the sinus membrane via a lateral approach allowing direct visual access. Using this invasive technique, more recurrent and important complications have been reported, it will therefore be preferentially used for multiple implantations. (18)

Lateral window procedure is habitually suggested with a postponed implant surgery. Significant average bone gain ≥ 10 mm is observed using this technique. (20)

Protocol (Figure 8) **:**

- Anesthesia and incision
- Flap
- Osteotomy and access window : high speed/ handpiece and burs, ultrasounds
- Detachment of the membrane
- Sinus filling (or not) : Bone graft is gently inserted in the area created under the Schneider membrane, avoiding creation of gaps. Packing down the graft material allow the formation of a blood clot and optimal osteogenesis.
- Placement of the membrane and sutures : Membrane is therefore not essential, but better ossification has been observed when it is applied. It prevents connective tissue infiltration through the access window
- Implant placement : instantaneously or after complete bone healing. (21)

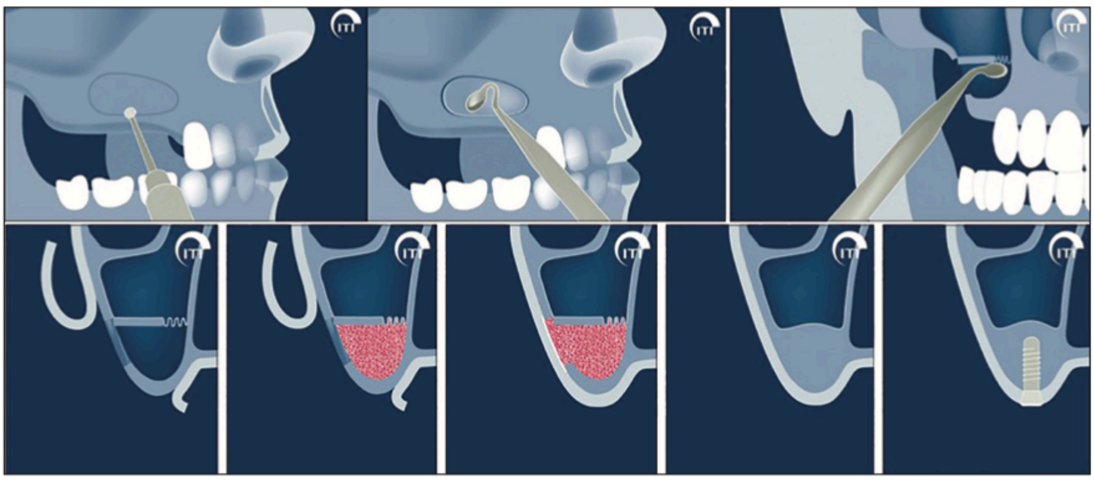

Figure 8. Lateral sinus lift surgery protocol (15)

2.2 Indirect technique / Transcrestal approach

The procedure consists in achieving an indirect sinus access through the alveolar crest, consequently it is named as transcrestal sinus lift. The most known is the Summers osteotomy, also called osteotome technique. This technique consists in increasing the vertical bone density thanks to various osteotomes by compression of the bone tissue. Therefore, the possibility of immediate placement of an implant is defined by the initial bone height to ensure good stability. (18,19)

This approach often used for cases of single tooth loss because it is less invasive and therefore induces fewer complications. Crestal approach is usually indicated for residual bone height > 4-5 mm. It can be performed with or without bone filling material and the average bone gain of this technique is between 3 and 5 mm. (20)

Protocol (Figure 9) **:**

- Determination of the osteotomy sequence : based on diagnostic imaging
- Anesthesia and incision
- Flap
- Osteotomy : increasing diameter of osteotomes
- Elevation of the membrane
- Sinus filling (or not), membrane placement and sutures
- Implant placement : instantaneously or after complete bone healing. (21)

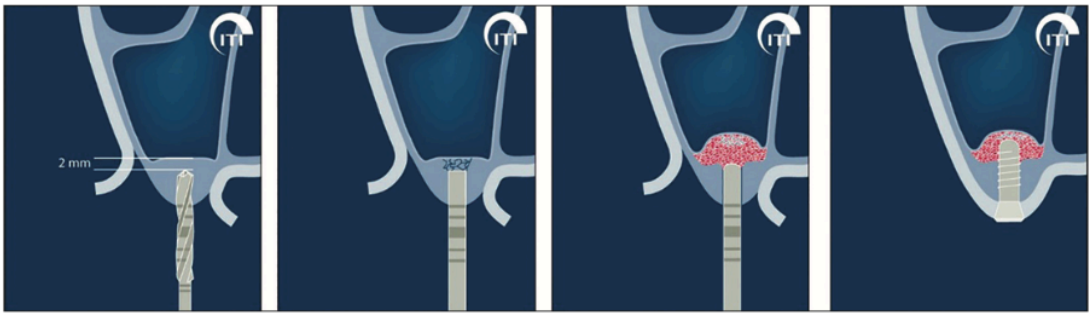

Figure 9. Crestal sinus lift surgery protocol (15)

Recently, new different crestal methods are emerging to raise the Schneider membrane, this is what we will discuss in the next part.

3. Transcrestal sinus lift evolution

Sinus elevation surgery can be achieved by 2 main approaches : the lateral and the crestal one (Figure 10). The choice will be made according to several factors, among which we mainly find the residual bone volume as mentioned above. (22)

In 1976, Tatum firstly described the lateral approach, using bone graft to increase the alveolar height of the posterior maxilla. Boyne and James published this new procedure in 1980. Later, in 1994, Summers described another method by crestal approach with the use of osteotomes of different diameters allowing a simpler procedure with the simultaneous placement of the implant. (23)
Throughout the ages, these procedures evolved a lot into different alternative options.

3.1 Hydraulic pressure

Different methods using hydraulic pressure have been developed to increase the sinus bone height. (24) These techniques are very varied :

- **Irrigation emitted by the surgical handpiece** (Figure 10) : This atraumatic technique was described in 2005 by Chen and Cha. The water pressure must be at its maximum, to avoid any embolism linked to the air emitted by the handpiece. (25, 26)

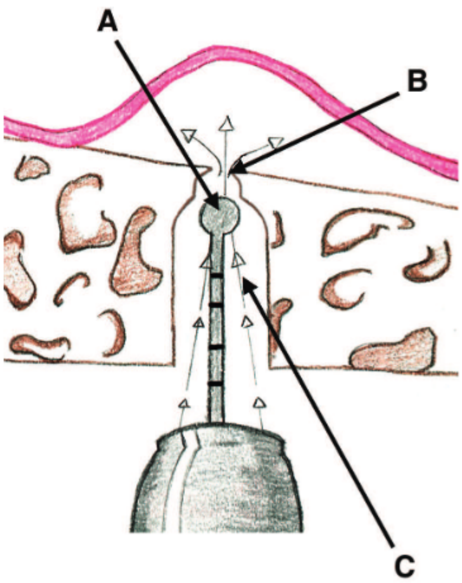

Figure 10. Irrigation through handpiece (25)
A, bur; B, membrane elevation; C, irrigation

- **Hydraulic pressure generator** (Figure 11) : Emerged in 2013, the Jeder system is a modification of the initial technique which uses high hydraulic pressure and vibrations with a frequency of 50 Hertz to elevate the Schneider membrane. (26) The procedure is constantly controlled by the pressure and the volume of saline solution injected. The generator also includes a safety system that limits the injection volume to 0.2 mL with each pedal stroke. (27) Despite high pressure, perforation of the membrane is thus limited by the supply of small fluid quantity.

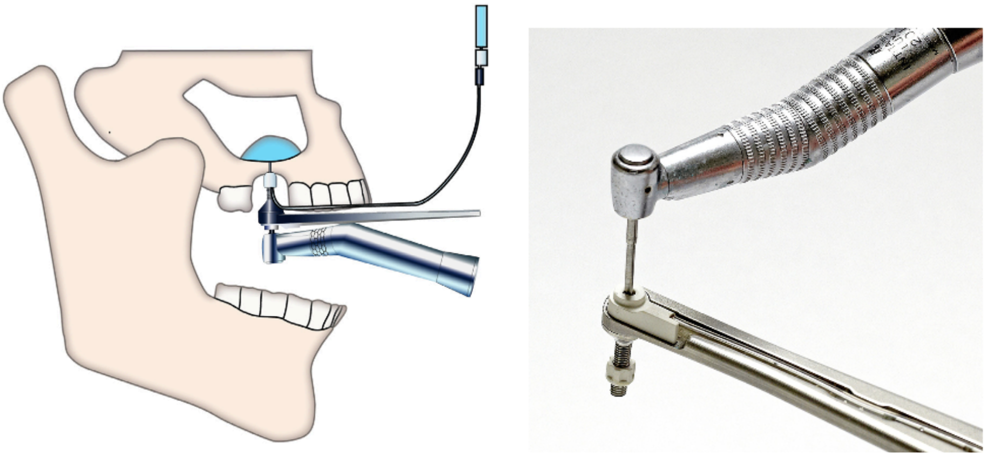

Figure 11. Jeder system (27)

- **Hydrogel injection via the implant** (Figure 12) : Consists of using an irrigation system directly through the implant which has openings allowing passage of saline solution and bone graft. (26) The iRaise system appeared in 2016, and allows the membrane elevation by pressure, the insertion of gel filling material and the implant placement in a single step. On the same principle, DIVA system is also described using flowable bone graft. With these systems, the elevation of the sinus membrane is therefore completely hermetic. (28)

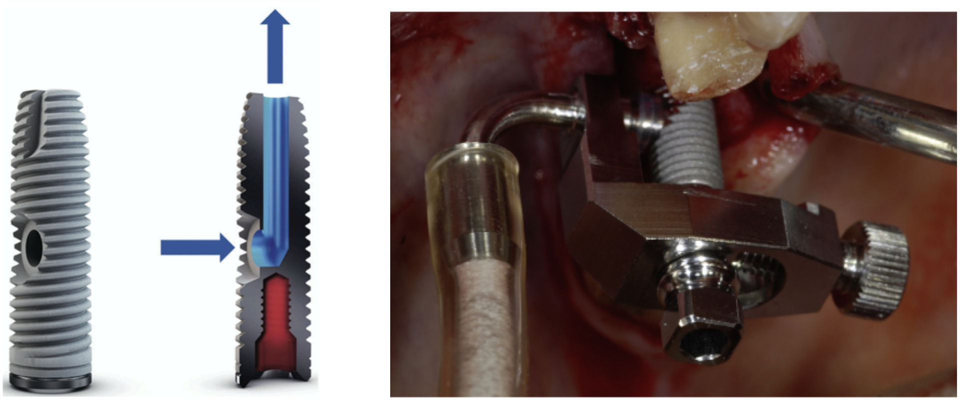

Figure 12. Iraise system (28)

- **Use of viscous filling material** (Figures 13,14) : This technique published in 2014 consists of the injection of putty bone graft, called Novabone, composed of calcium phosphosilicate. (29) It comes in the form of a cartridge to be used with an applicator gun. It allows the membrane to be elevated at the same time as the biomaterial is added. (26)

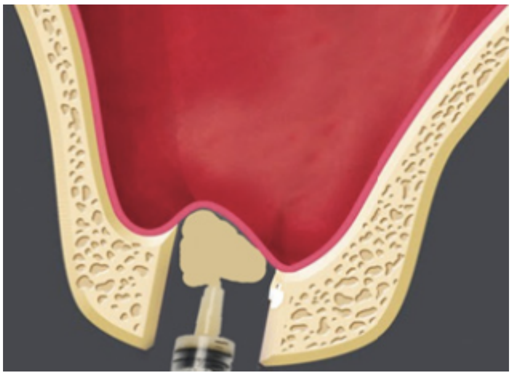

Figure 13. Viscous material injection (26) **Figure 14.** Novabone gun (29)

3.2 Balloon technique

Called MIAMBE, for Minimally Invasive Antral Balloon Elevation, this technique was introduced in 2005 by Soltan and Smiler. (30) The elevation of the membrane is carried out under the effect of the hydraulic pressure exerted by the inflation of a latex balloon or silicone. Initially for the lateral approach, the method was then adapted for sinus lifts via the crestal approach. (24,26)

In this protocol, after the osteotomy, a first introduction of bone substitute is performed, because the biomaterial serves here as a primary shock absorber. Then, the balloon connected to a metal syringe, is introduced 1mm beyond the sinus floor. (31)

It is gradually inflated under a pressure of 2 atmospheres (atm), specially until it emerges from the syringe, then the pressure is reduced to 0.5 atm (Figures 15,16). The balloon will then be filled with a contrast solution to perform a control radio. (32)

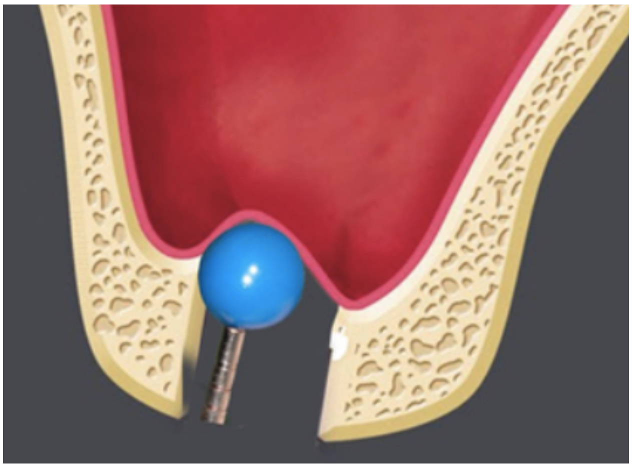

Figure 15. MIAMBE technique (26)

Figure 16. Balloon inflation (32)

This operation is very fast and generally lasts 10 minutes, which is why the withdrawal of the balloon must be done gradually with deflation in 5 minutes to simultaneously avoid the recoil of the Schneiderian membrane. At the end of the surgery, a new supply of biomaterial is made to complete the first transplant. (33)

3.3 Drilling sequences

Irrigation of rotary instruments associated with drilling debris, can prevent good visibility and thus increase the depth of action by increasing the risk of perforation.

These special drilling kits are not so different from those used during the conventional technique of Summers, they include: drill bits, drills and osteotomes but on which are placed stops, constituting a physical barrier to limit the drilling depth. (24, 26)

The preliminary study of radiographic and three-dimensional images makes possible to evaluate the height and thickness of the alveolar bone in the edentulous area and therefore place the stop adequately and accurately on the instruments. This method thus controls all movements throughout the intervention. (17)

These sequences include :

- **Smart Lift system** (Figure 17) : which involves osteotomes, drills and trephines of different diameters on which stops are positioned. (34)

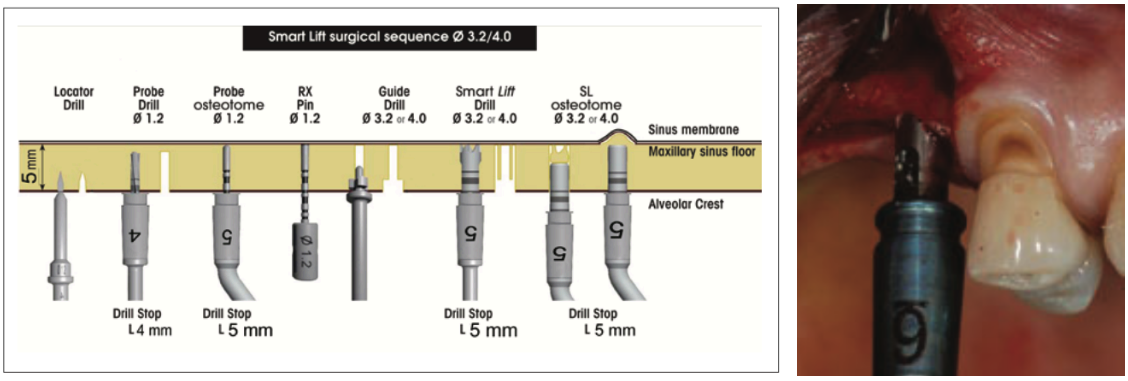

Figure 17. Smart Lift drills system (34)

- **SCA Kit** (Figure 18) : In 2017, the team of Xian Zhou published results of their studies with this system, which consists of drills, osteotomes with stops, supports for biomaterials and condensers. (35)

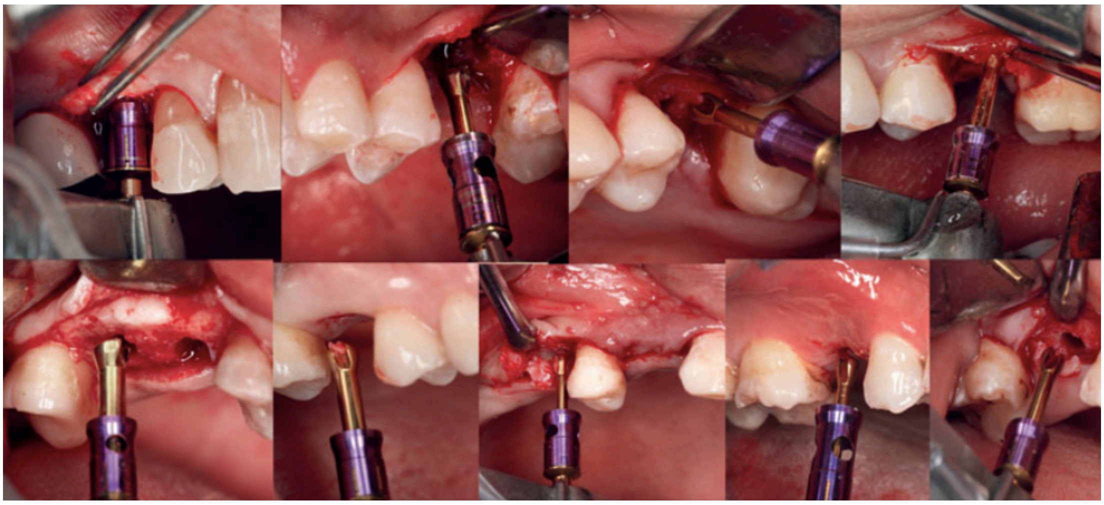

Figure 18. Intraoral photographs with S-reamer drills from SKA Kit (35)

- **Densah system** (Figure 19) : On the same principle, it contains osseodensification burs in order to help the professional to lift the membrane thanks to a ready-made kit. (36)

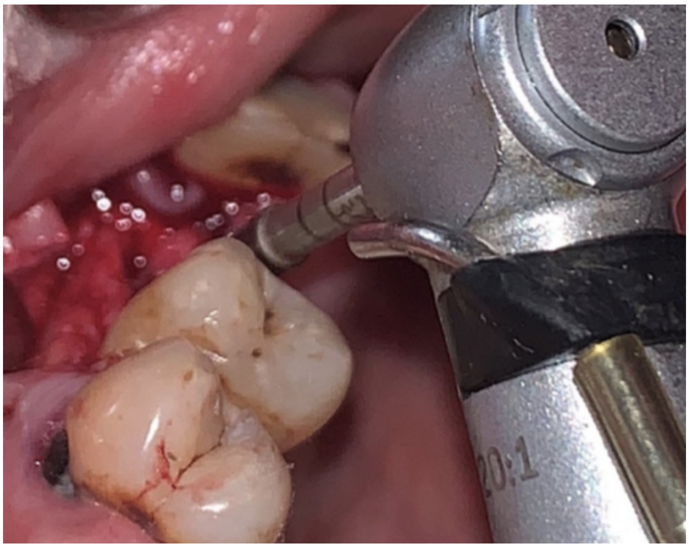

Figure 19. Intraoral photograph of Densah burs system (36)

In parallel, to facilitate the dentists' work, the guided surgery makes possible to perform sinus lifts with instantaneous placement of implants using a digitally created template (Figure 20). The goal is to "guide" the dental surgeon during drilling to preserve the anatomical structures and place the implant precisely in the available bone, with the axis of the future prosthesis. The use of the guide allows reproducible flapless surgery, which reduces operative time and complications as carried out by Pozzi and Moy in 2014. (37)

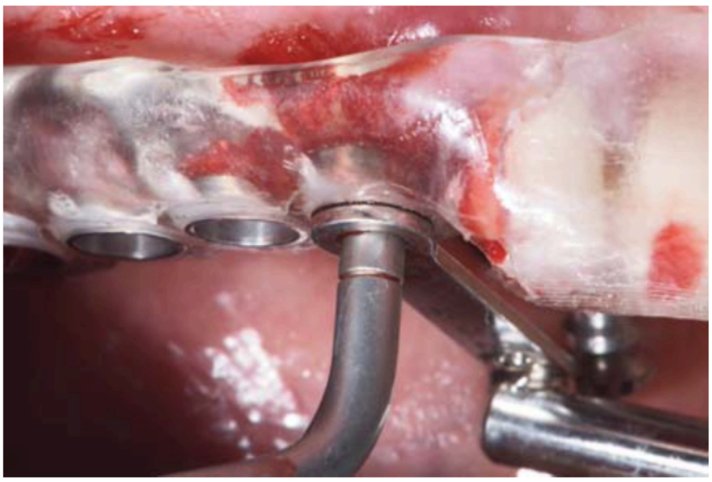

Figure 20. Intraoral photograph of the surgical guide (37)

3.4 Magnetic system

The magnetic mallet system was first established in 1873 by Bonwill in general dentistry. Later, in 2012, Crespi exploited this device in implantology.
This procedure can be applicated in multiple fields such as : implantology, extractions, alveolar crest expansion and crestal sinus elevation (Figure 21).
It uses magneto-dynamics and appears to be a real improvement of the traditional hand mallet technique. (38) Different kits are available according to the type of surgery with osteotomes, cutters, chisels and expanders for example Sweden & Martina system for sinus lift surgery. (39)

The unit contains a handpiece and several exchangeable end inserts to generate a discharge wave (Figure 22). The impulsion time is about 80-100 µs which is really fast, and there are 4 force modes on the unit. Shock waves produce small movements of osteotome insert to create controlled bone displacement and sinus elevation. (40)

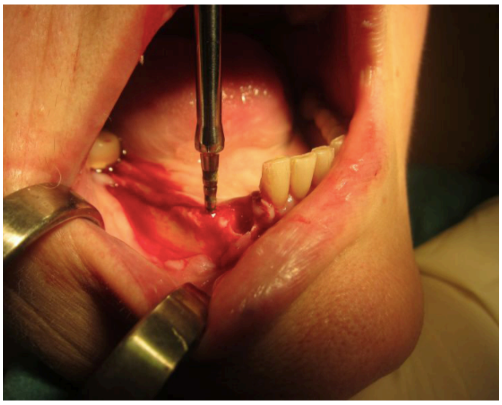

Figure 21. Intraoral photograph (40)

Figure 22. Magnetic mallet system (39)

4. Graft materials

4.1 Bone graft

During the sinus elevation surgery, bone grafts are deposited underneath the Schneider membrane to increase alveolar height allowing an adequate future implant's stability.(41)

Bone transplant is an active procedure which implies various properties including :

- Osteoconduction : bone growth on the graft's surface
- Osteogenesis : formation of bone tissue starting from living cells coming from the graft
- Osteoinduction : mesenchymal cells are transformed into osteoforming cells allowing bone formation (stimulus provided by growth factors). (42)

These filling materials must respect these 3 properties and be : biocompatible, harmless, accessible, non-cancerous, easy to handle and stabilize. Depending on their origin, biomaterials are classified into four main categories (Figure 23) :

- Autogenic/ autograft/ autologous : graft is taken directly from the recipient itself
- Allogenic/ allograft/ homologous : graft from an individual of the same species as the recipient, such as FDBA (Freeze-dried bone allograft) or DFDBA (demineralized FDBA)
- Xenogenic/ xenograft/ heterologous : the graft comes from an individual belonging to a different species from that of the recipient, mainly bovine, porcine and equine
- Alloplastic : the graft is of synthetic origin. Such as bioceramics (hydroxyapatite and beta-tri-calcium phosphate (ß-TCP)), polymers and bioactive glass. (22,43)

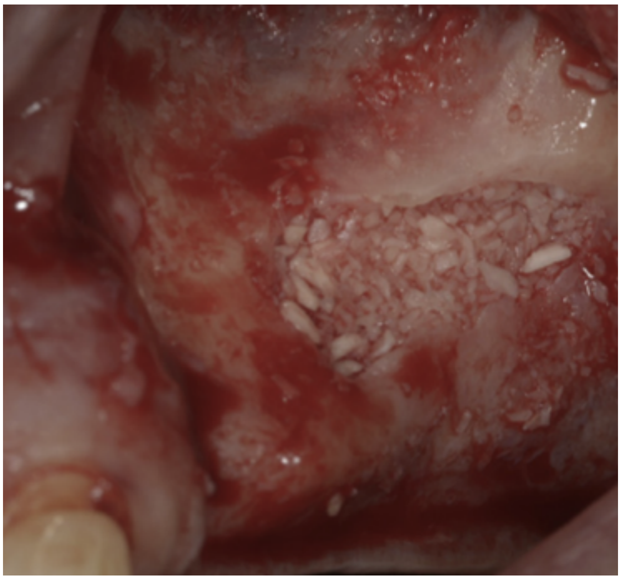

Figure 23. Placement of bone graft during sinus lift (4)

Autograft is the gold standard in regenerative surgery thanks to its compatibility, as well as its osteogenic, osteoinductive and osteoconductive properties. However, it has certain drawbacks due to the sampling and its postoperative complications. The sample can be intraoral (maxillary tuberosity, mandibular ramus or symphysis) or extraoral (iliac crest, tibia bone). (23) Moreover, it presents a rapid and unpredictable resorption that does not allow the desired bone volume to be maintained, and the long-term implant survival rate is low. (41)
As a result, bone substitutes are going to replace it, as they are less invasive for the patient and more readily available. Xenografts and alloplastic grafts are the most widely used nowadays as they are considered reliable for sinus elevation. The resorption is slow, bone formation and implant survival are remarkable. (44)

4.2 Membranes

They can be added to these filling materials, allowing their stabilization and limiting invasion by soft tissues, which will promote the formation of bone tissue. (22)
In regenerative surgery, various types of membranes exist (Figure 24) :

- Resorbable membranes : made of collagen (porcine, bovine) or polymers (synthetic). They avoid a second surgery and have ideal biological properties.

- Non-resorbable membranes/ mesh : synthetic origin such as PTFE (polytetrafluoroethylene), titanium-reinforced PTFE and titanium membranes. They require a second surgery for their removal and mainly used for lateral and vertical ridge increases. (45)

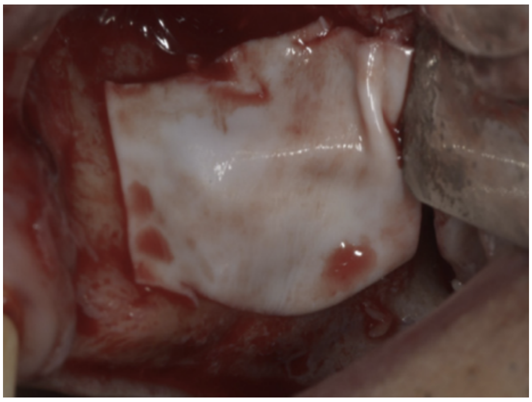

Figure 24. Collagen membrane placement during surgery (4)

4.3 Tissue engineering

It is gaining an important place in regenerative medicine nowadays, especially in sinus augmentations. Two main strategies have been developed in order to avoid the harvesting of autologous bone and to limit surgical interventions and their complications. (46)

4.3.1 Growth factors

Factors from the recombinant human Bone Morphogenetic Protein (rhBMPs) family are the most commonly used and are extracted from demineralized bone matrix (alloplastic graft). RhBMPs are involved in the phases of osteoinduction and it is on this principle that bone remodeling and healing are based. As a result, the integration of the graft is improved thanks to bone apposition and neovascularization, promoting bone regeneration. Bone gain and the quality of the tissue obtained are favorable for implant placement (47).

They are available in the initial form of impregnated collagen sponges, which are used alone or with another material. The sponge alone does not allow a satisfactory maintenance of the volume created by the sinus lift, which is why the association with other solid biomaterials constitutes a better support favorable to bone formation. (48)

4.3.2 Stem cells

Recently, the contribution of stem cells in implant surgery is developing. These are Bone Marrow-Mesenchymal Stem Cells (BM-MSCs) in autologous cell therapy for the reconstruction of the bone crest before implantology phase. Samples of MSCs from bone marrow is taken from the patient’s iliac crest in order to culture them and obtain autologous bone tissue, called TEB (tissue-engineered bone) and usable during sinus surgery. (49)

The use of stem cells seems to be a real alternative to autogenous bone in terms of sinus filling materials. They avoid the sampling of autogenous bone, but however the procedures undertaken are invasive as they require two surgeries, including one for the removal of MSCs by puncture. Nowadays, other sources of MSCs of oral origin can be taken, in particular gingival and pulpal, which would limit the invasiveness of the technique. (50)

All these alternatives are available to preserve the space by keeping the Schneider membrane at the required position and height. Today, a lot of authors publish studies on a potential graft-less approach, but better ossification has been observed when it is applied. (51)

Therefore, the decision whether or not to use a bone graft or the type of materials can be generally adapted on patient's case and dentist's predilections but it́ s established that any grafting material can conduct to effective results. (52) During the weeks following the surgery, careful postoperative follow-up by the professional should be done in order to control the graft evolution and stability (Figure 25). (53)

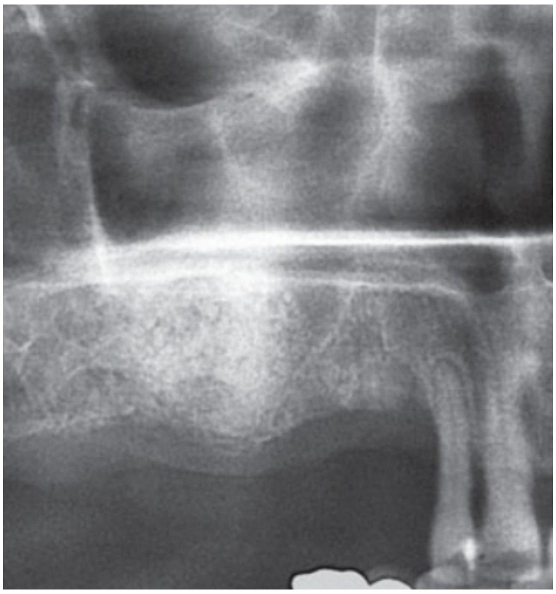

Figure 25. Postoperative radiograph control of bone grafting (6)

5. Complications of crestal technique

Complications are quite rare and can be the cause of implant failure. They can take place intraoperatively or postoperatively. It will be necessary to carry out a precise anterior radiographic analysis in order to better understand the risks of complications. (4,6)

5.1 Intraoperative

They correspond to the complications occurring during the surgery.

- **Tear of Schneider sinus membrane**

One of the most frequent complications is the perforation of the sinus membrane (Figure 26). When the perforation is small and localized, it can be closed with an absorbable membrane. If the perforation is too large, the graft will have to be postponed. (54) That's why, the Valsalva maneuver is a crucial step during the surgery to check the membrane integrity, by balancing internal and external pressures. (35) The probability of perforating the membrane is higher when the approach is done laterally, rather than in the crestal approach. (54)

Figure 26. Intraoral photograph of membrane perforation (54)

- **Fracture of vestibular bone**

The vestibular bone is weakened during drilling and preparation of the recipient site. Implant placement can cause a vertical fracture of this bone wall. It is then necessary to postpone the implant positioning with biomaterials in order to allow the healing of the site. (55)

- **Absence of primary stability**

Excessive drilling of the implant site can cause poor primary stability and lead to the absence of osseointegration. Implant placement should therefore be postponed.
During a crestal approach, the use of osteotomes increases bone density by lateral compaction and thus improves the primary stability of the implant. (56)

- **Projections in the sinus**

- implant : Often occurs in the case of implant placement simultaneously with the sinus lift. This complication may be due to the absence of primary stability, insufficient residual bone height or poor orientation of the implant axis.

- filling materials : It may be linked to an unidentified Schneiderian membrane perforation during the procedure, or due to excessive forces when placing the material. This could impede sinus drainage by the interposition of particles of material at the level of the middle meatus. Late complications can therefore appear as we will discuss in the next section. (55)

5.2 Postoperative

They correspond to the complications that occur after the operation.

- **Bleeding**

Post-operative hemorrhage may occur in the event of injury to an intraosseous artery or perforation of the Schneiderian membrane. Drainage is done nasally in the form of nosebleed, also called epistaxis, which can last a few days. As the bleeding is not abundant, an intervention by the nasal route is not necessary (except in the case of obstruction of the meatus). (57)

- **Migration of the graft**

This is a common complication that can occur in two possible directions :

- intra-oral direction : when the muco-periosteal flap is not properly pressed against the graft, if the sutures are not airtight, then bone granules may end up in the patient's mouth. To prevent this leakage, a membrane against the graft is placed.

- intra-sinus direction : if the membrane has been teared, there is a risk of sinusitis. The patient can also find bone granules while sneezing, it will then be necessary to consult the Oto-Rhino-Laryngologist. (58)

- **Inflammation of the sinus mucosa**

The elevation of the Schneiderian membrane causes trauma that can manifest itself in the development of a temporary inflammatory process. This inflammation can also be associated with the secondary reaction due to the filling materials installed during surgery. (59)

- **Infection of the grafted sinus**

Acute sinusitis can appear a week after surgery, with usually rapid resolution when the physiology of the maxillary sinus is not impeded. (58) It is often linked to intraoperative bacterial contamination, superinfection, or deficient antibiotic coverage (Figure 27).
Sinusitis can also appear later on, around 3 to 4 weeks post-operatively. Often due to obstruction of the drainage holes by the filling material, an elevation of a polyp of the sinus floor, or following a complication of a pre-existing chronic sinusitis.
Treatment for maxillary sinusitis includes antibiotic therapy for 7 days. A meatotomy may be considered to restore proper drainage or remove interfering filling material. (60)

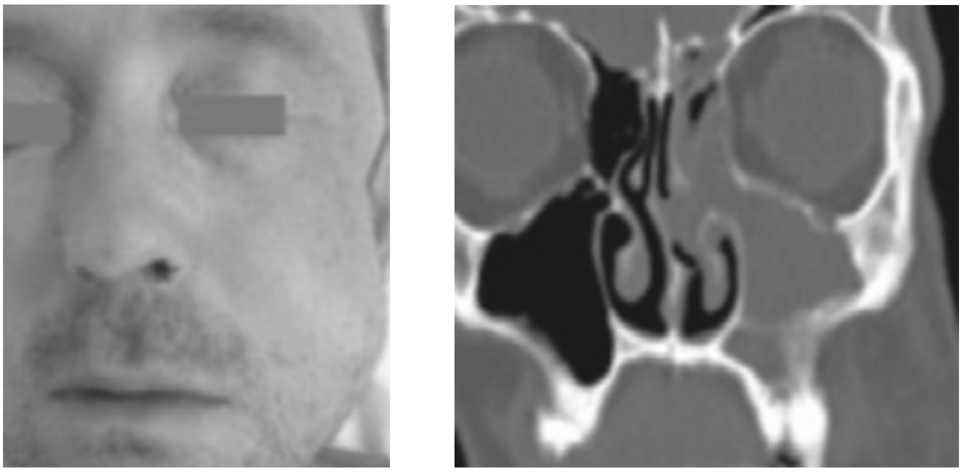

Figure 27. Bacterial sinusitis with pus filled sinus on CBCT view (58)

6. Justification

Since last years, implant rehabilitations became the most desired treatment in dental surgery, but posterior atrophic maxilla after teeth extractions can be complicated and doubtful for the success of the future fixed prosthesis. Complex surgical procedures like sinus floor elevation using graft materials require extensive training and knowledge of the sequence. (61)

One of the frequent surgeries is the crestal sinus lift that elevates vertically sinus floor within the posterior maxillary area when the membrane closeness and the residual crest height do not permit implant placement at a first sight. (62)

What are the new techniques to restore maxillary posterior edentulous areas using transcrestal sinus lift procedure ?

The main purpose of this final work is to explore and differentiate the most updated crestal procedures and protocols.

OBJECTIVES

We are going to carry out a literature review in order to analyze the different crestal techniques of sinus lifts. For this, we will center on three goals when analyzing and working on diverse articles.

Principal objective : To investigate recent protocols of transcrestal sinus elevation.

Additional objectives :

To determine crestal techniques' advantages and their surgical complications.

To evaluate the efficacy of crestal bone augmentation to place future implants.

MATERIALS AND METHODS

Information sources

The research was conducted to focus on relevant clinical studies about transcrestal techniques to increase maxillary sinus floor in order to place future implants. An electronic investigation was performed mainly on Pubmed database (Medline) and Scopus library.
The publications selected are recent articles or books, in full text, published in English, Spanish or French. A time restriction limited to 10 years is applied, specifically a search interval between 2013 and 2023.

Search strategy

Key words used for this research were : Dentistry, Maxillary sinus lift, Sinus floor augmentation, Crestal approach, New modifications, Bone grafts, Biomaterials, Complications, Implant placement.

Using PubMed database, the search equation was : (((((((maxillary sinus elevation) OR (sinus lift)) OR (sinus floor elevation)) OR (sinus graft)) AND ((((crestal approach) OR (indirect procedure)) OR (transcrestal sinus surgery)) OR (new methods))) AND (((graft materials) OR (bone graft)) OR (biomaterials))) AND ((implantology) OR (implant placement))) NOT ((lateral) OR (direct)).

Using Scopus library, the search equation was : (TITLE-ABS-KEY (maxillary AND sinus) OR TITLE-ABS-KEY (sinus AND floor AND augmentation) OR TITLE-ABS-KEY (sinus AND elevation) OR TITLE-ABS-KEY (sinus AND lift) AND TITLE-ABS-KEY (indirect) OR TITLE-ABS-KEY (crestal AND technique) OR TITLE-ABS-KEY (balloon) OR TITLE-ABS-KEY (magnetic AND mallet) OR TITLE-ABS-KEY (hydraulic AND pressure) OR TITLE-ABS-KEY (drilling AND burs) AND TITLE-ABS-KEY (complications) OR TITLE-ABS-KEY (membrane AND perforation) OR TITLE-ABS-KEY (implant AND failure) AND NOT TITLE-ABS-KEY (lateral AND technique) OR TITLE-ABS-KEY (direct AND approach)).

Eligibility criteria

The inclusion and exclusion criteria are presented below (Table 1).

Inclusion criteria	Exclusion criteria
• Maxillary sinus studies	• Mandibular studies
• Transcrestal surgery only	• Lateral surgery
• Any type of study, except systematic reviews and meta-analysis	• Systematic reviews and meta-analysis
• Any type of population studied	• Studies on cadavers or animals
• Publications between 2013 and 2023	
• Full text publications	

Table 1. Inclusion and exclusion criteria

RESULTS

The bibliographic research initially suggested 624 articles in total, of which 322 from PubMed and 302 from Scopus online databases. Then, 275 articles were excluded because the titles and abstracts did not suit to our criteria. Applying many filters, about 193 results appeared from which 17 interesting articles were chosen according to our criteria. The research strategy as well as the selected articles are represented through the PRISMA flow chart below (Figure 28).

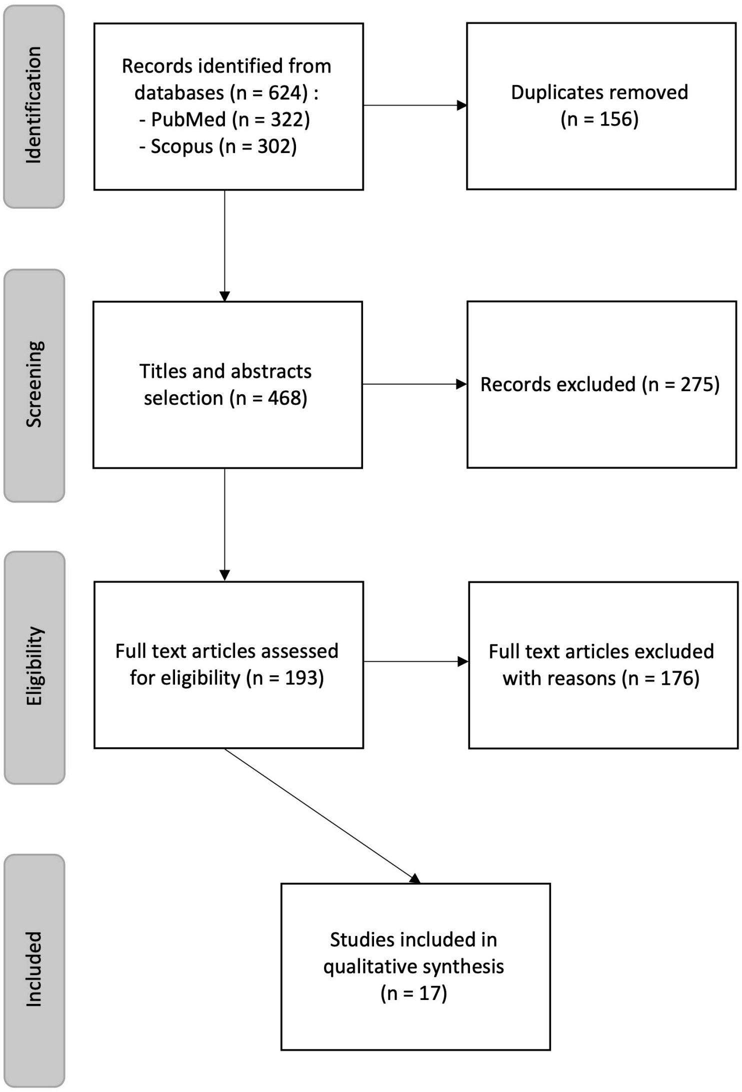

Figure 28. PRISMA flow diagram

Our search strategy made it possible to retain the most relevant articles concerning new crestal sinus lifting techniques. The 17 selected articles allow us to present the protocols and to compare the results obtained, particularly the biomaterials used, bone gain and membrane perforation rate.

The ten variables analyzed in this literature review are detailed below :

- **Authors** : Names of article writers
- **Date** : Date of article publication
- **Type** : Type of study
- **Population** : People studied in the article
    - Number of patients
    - Sex
    - Groups formed
    - Age : intervals or mean age
- **Technique** : Type of crestal surgery used
    - Hydraulic pressure
    - Drilling sequence
    - Balloon technique
    - Magnetic system
- **Residual bone height** : Initial crestal height before the surgery (in millimeters)
- **Biomaterials** : Graft materials used to increase bone height
    - Autograft
    - Allograft
    - Xenograft
    - Alloplastic graft
- **Implants placement** : Number of implants placed
- **Sinus floor augmentation** : Bone gain after the surgery (in millimeters)
- **Follow up/ complications** :
    - Supervision period (in months)
    - Types of surgical complications
  - Membrane perforation
  - Implant failure
  - No major complications : all other minor complications

These methods are varied and presented below (Table 2).

AUTHORS	DATE	TYPE	POPULATION	TECHNIQUE	RESIDUAL BONE HEIGHT	BIOMATERIALS	IMPLANTS PLACEMENT	SINUS FLOOR AUGMENTATION	FOLLOW UP/ COMPLICATIONS
Zhou et al. (35)	2017	Case series	11 patients : 5 women/ 6 men	SCA Kit, Drilling sequence	Mean = 6.4 mm	Xenograft (Bio-Oss collagen bovine origin)	12	Mean = 4.8 mm	Mean = 49.4 months. No major complications.
Trombelli L. et al. (63)	2013	Randomized clinical trial	38 patients : Divided in two groups of 19	Smart Lift system, Drilling sequence	> 4 mm	Xenograft (Deproteinized bovine mineral) + Alloplastic graft (β-tricalcium phosphate)	Yes, number not specified	Mean = 6 mm	6 months. 5 membrane perforations.
Kim YK. et al. (64)	2017	Retrospective clinical study	19 patients : 9 women/ 10 men, 23-69 years old	SCA Kit, Drilling sequence	< 8 mm	Autograft (oral cavity) + Allograft + Xenograft + Alloplastic graft	21	Mean = 5.81 mm	6 months. No major complications.

Chaushu L. et al. (65)	2020	Retrospective cohort study	50 patients : 28 women/ 22 men. Divided in two groups of 25, 45-70 years old	IRaise system, Hydraulic pressure technique	Mean= 5.4 mm	Alloplastic graft (MBCP gel : biphasic calcium phosphate)	25	Study group : mean = 8 mm. Control group : mean = 9.3 mm.	Mean = 17.5 months. No major complications.
Kher U. et al. (66)	2014	Case series	21 patients : 9 women/ 12 men, mean age = 48.5 years old	Hydraulic pressure via putty material	< 6 mm	Alloplastic graft (calcium phosphosilicate putty)	28	Mean = 10.31 mm	6-18 months. No major complications.
Tallarico M. et al. (28)	2016	Retrospective clinical study	62 patients : 35 women/ 29 men, mean age = 53.1 years old	IRaise system, Hydraulic pressure technique	Mean = 5.2 mm	Alloplastic graft (MBCP gel : biphasic calcium phosphate)	79	Mean = 10.9 mm	Mean = 23 months. No major complications.
Kotsakis GA. et al. (29)	2015	Case report	1 woman patient, 56 years old	Hydraulic pressure via putty material (Novabone)	5 mm	Alloplastic graft (calcium phosphosilicate putty)	2	Mean = 8 mm	18 months. No major complications.

Mijiritsky E. et al. (67)	2016	Clinical observational study	37 patients, mean age = 51.2 years old	IRaise system, Hydraulic pressure technique	Mean = 5.24 mm	Alloplastic graft (MBCP gel : biphasic calcium phosphate)	37	/	Mean = 24.81 months. No major complications.
Martinez Saez R. et al. (68)	2014	Retrospective clinical study	14 patients	Balloon technique (MIAMBE)	Mean = 5.2 mm	Xenograft (bovine)	14	Mean = 8.5 mm	12 months. 4 membrane perforations.
Arroyo R. et al. (69)	2013	Case report	3 patients : 2 women/ 1 man, 38-63 years old	Balloon technique (MIAMBE)	Mean = 3 mm	Autograft + Xenograft	9	Mean = 10 mm	6 months. No major complications.
Rostom D. et al. (70)	2021	Randomized clinical trial	10 patients : 8 women/ 2 men. Divided in 2 groups of 5, 25-55 years old	Summers technique (osteotomes) + Densah drilling sequence	Osteotomes mean = 6.9 mm Densah mean = 8 mm	Autograft	Yes, number not specified	Osteotomes mean = 1.4 mm Densah mean = 1.8mm	6 months. No major complications.
Asmael HM. et al. (71)	2016	Retrospective clinical study	13 patients : 9 women/ 4 men, 28-55 years old	Balloon technique (MIAMBE)	Mean = 5.56 mm	Alloplastic graft (β- tricalcium phosphate)	23	Mean = 6.70 mm	12 months. 2 implants failure.

Rodda A. et al. (36)	2022	Case report	1 woman patient : 60 years old	Densah, Drilling sequence	5 mm	Allograft (DFDBA : demineralized freeze-dried)	1	4-5 mm	3 months. No major complications
Ismaeil AM. et al. (72)	2023	Randomized clinical trial	14 patients : 7 women/ 7 men. Divided in 2 groups of 7, 29-69 years old	DIVA system, Hydraulic pressure + Balloon technique (MIAMBE)	DIVA mean = 5.8 mm Balloon mean = 6.8 mm	Alloplastic graft (β- tricalcium phosphate gel)	11 DIVA 11 MIAMBE = 22	DIVA mean = 6.9 mm Balloon mean = 4 mm	6 months. 1 membrane perforation (MIAMBE) and 2 implants failure (DIVA +MIAMBE)
Rajkumar B. et al. (73)	2016	Case report	1 woman patient, 57 years old	Sweden and Martina, Magnetic mallet	5 mm	Alloplastic graft (Biograft Nano hydroxyapatite)	2	3 mm	No major complications.
Dhandapani RB. et al. (74)	2016	Case series	9 patients, 25-60 years old	Balloon technique (MIAMBE)	Mean = 6.16 mm	Allograft (cancellous bone)	Yes, number not specified	Mean = 4.34 mm	6 months. No major complications
Bruschi GB. et al. (75)	2021	Retrospective non-randomized study	52 patients	Sweden and Martina, Magnetic mallet	Mean = 5.06 mm	/	71	Mean = 7 mm	Mean = 29.8 months. No major complications.

Table 2. Results organization of the selected articles

This table was an organization of all the collected results from the selected articles, however in order to analyze and compare them some diagrams and graphs are designed below. Indeed, conducted studies were all different but retrospective clinical studies and case reports were the most prevalent types reported in this review (Figure 29).

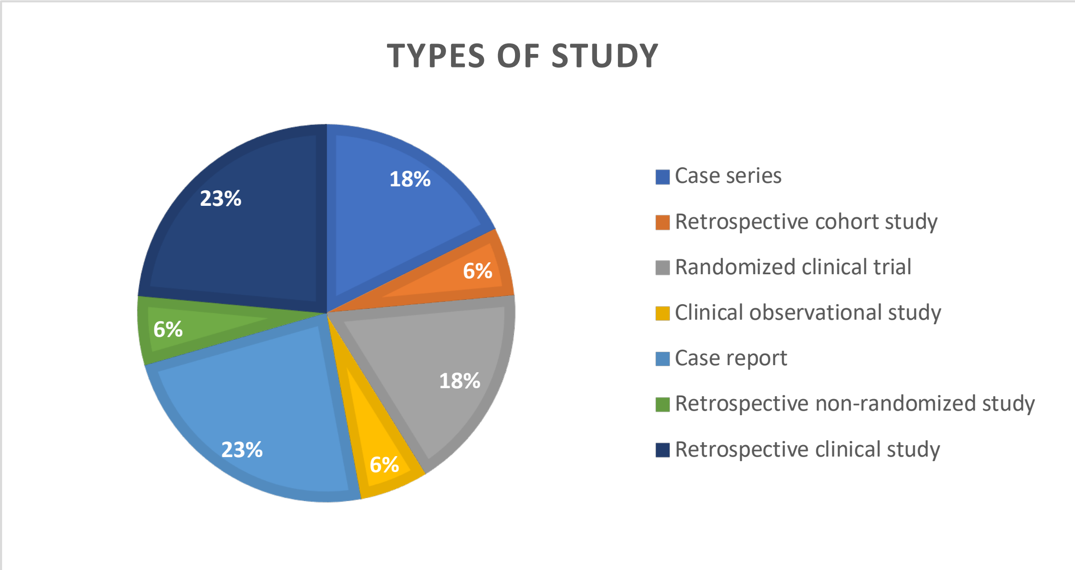

Figure 29. Pie chart of the different types of study represented in percentages

Size samples in these studies varied a lot but the mean number of patients was established to 20.9 people as you can observe with the dotted line below (Figure 30).

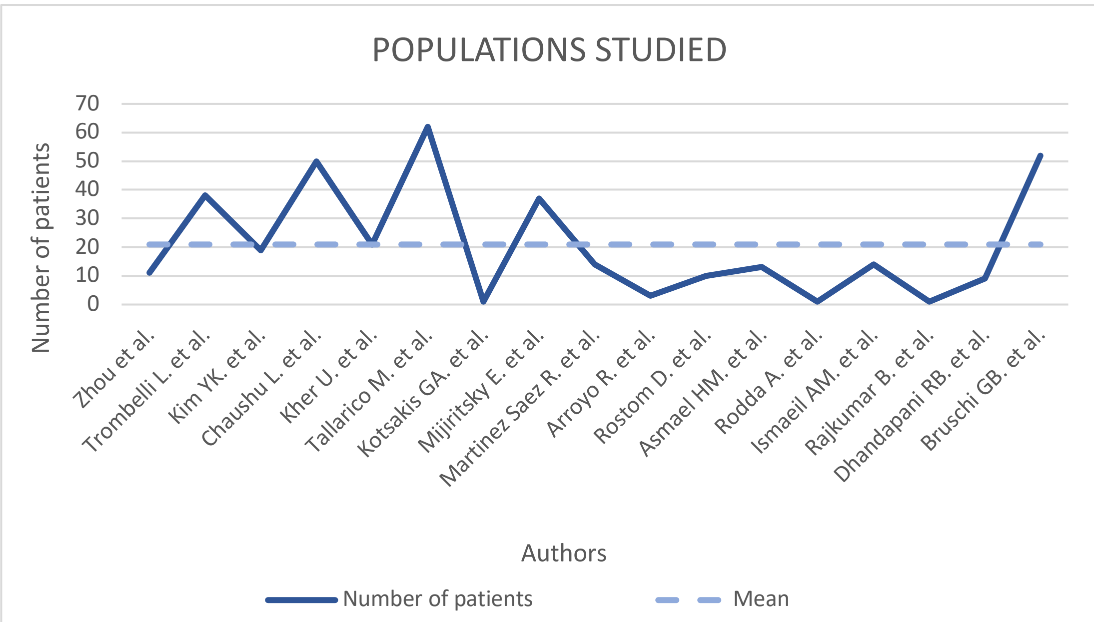

Figure 30. Line chart of patients' number in each study and the associated mean

Numbers of each crestal sinus lift techniques are roughly balanced, but the most used in the 17 selected articles was the hydraulic pressure compared to magnetic mallet system which was scarce (Figure 31).

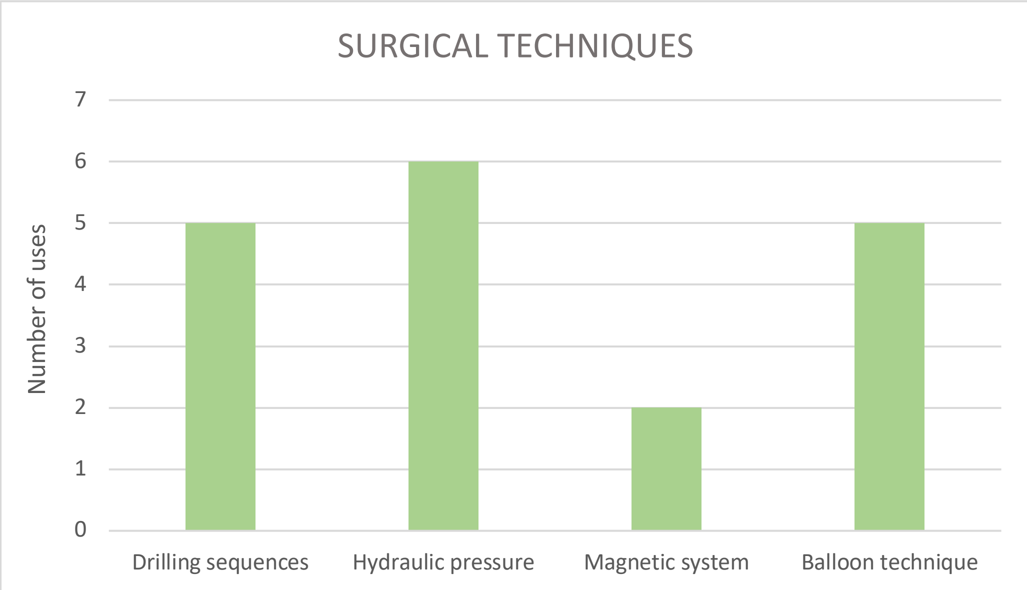

Figure 31. Bar chart of the number of uses of each surgical technique

As seen below, the majority of the residual bone heights was between 5 and 6 mm (Figure 32).

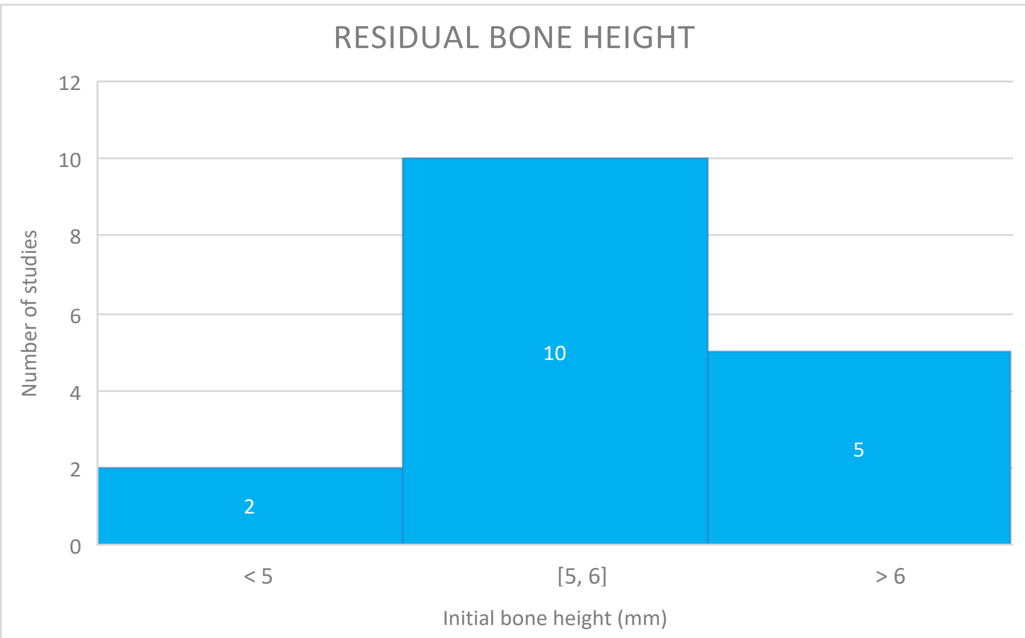

Figure 32. Histogram of initial alveolar crest heights represented in intervals

Four types of bone grafts are used in sinus lift surgery, but in this review the most used was alloplastic graft according to the following diagram (Figure 33).

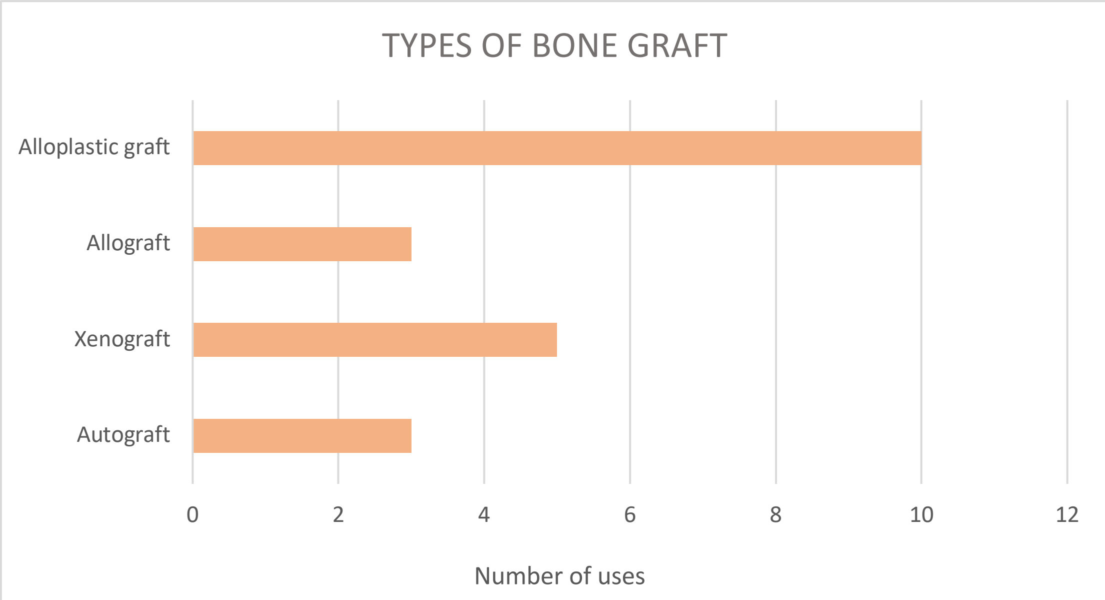

Figure 33. Bar chart of the number of uses of each bone graft

The main goal of sinus lift surgery is to increase the vertical height of the alveolar crest, for that reason we collected all values of crestal augmentation to determine the mean established to 6.6 mm (Figure 34).

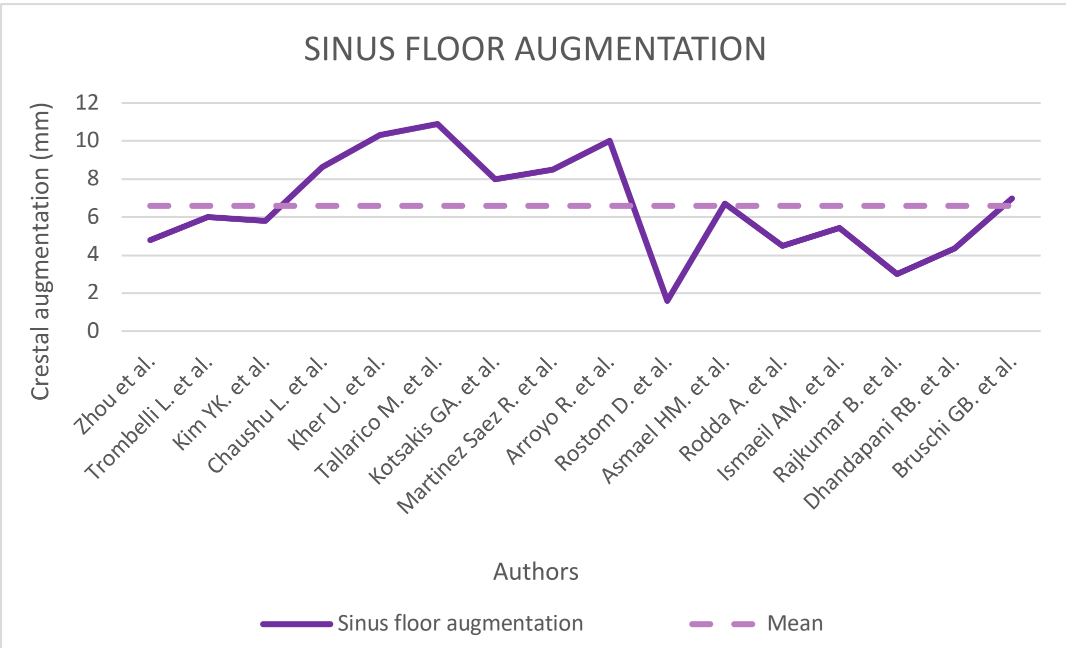

Figure 34. Line chart of crestal augmentations in each study and the associated mean

The hydraulic pressure procedure represented the best average bone gain with 8.9mm (Table 3).

TECHNIQUES	INTERVALS (mm)	MEAN (mm)
Hydraulic pressure	[6.9 - 10.9]	8.9
Drilling sequences	[1.8 - 6]	4.6
Balloon technique	[4 - 10]	6.7
Magnetic system	[3 - 7]	5

Table 3. Comparison of bone gain according to each technique

All 17 studies reported implant placement after crestal surgery, but only 14 articles specified a precise number, for a total of 346 placed implants.

Follow-up period was realized in all results, with an amplitude between 3 and 49.4 months. Most of the studies have not revealed major complications but the most prevalent issue reported was the perforation of the Schneider membrane as represented below (Figure 35).

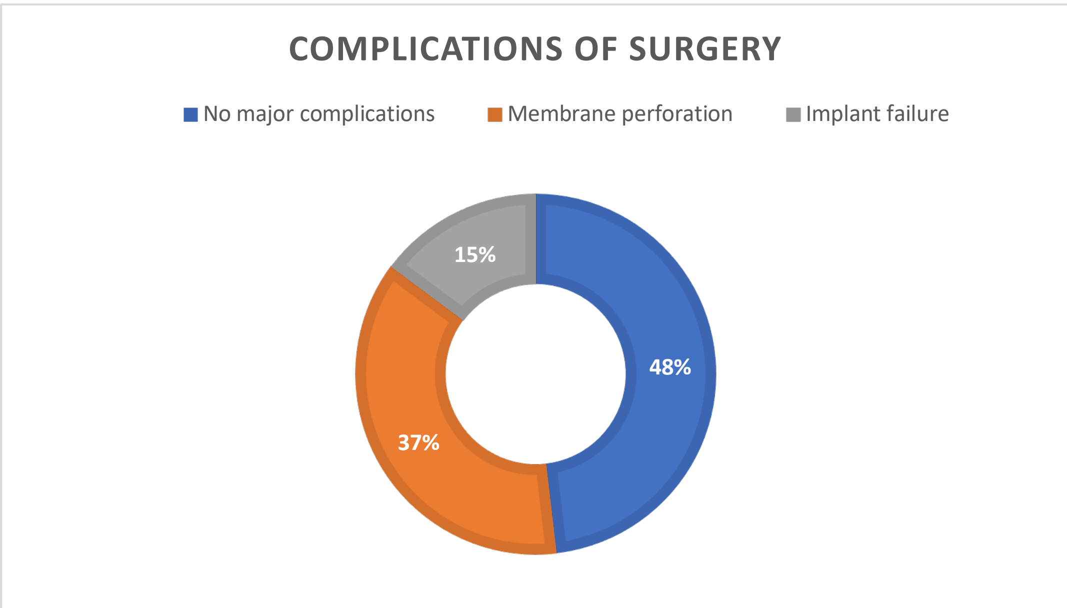

Figure 35. Donut pie chart of the surgical complications represented in percentages

Balloon technique presented the greatest number of complications, 8 in total as seen in the following comparative table (Table 4).

TECHNIQUES	MEMBRANE PERFORATION	IMPLANT FAILURE
Hydraulic pressure	0	1
Drilling sequences	5	0
Balloon technique	5	3
Magnetic system	0	0

Table 4. Comparison of postoperative complications according to each technique

A final comparative table of all methods is set out below (Table 5).

TECHNIQUES	ADVANTAGES	DISADVANTAGES
Drilling sequences	Action depth limited by stoppers	Specific surgical tray
Hydraulic pressure	- Avoid anatomical obstacles (septa) - Membrane detachment by lateral forces - Small tray for putty materials	- Specific surgical tray - Wide mouth opening
MIAMBE	- Limited mouth opening - Useful in posterior region - Rapid procedure	- Single tooth loss - Increased risk of perforation (rapid inflation or explosion) - Specific surgical tray - Practical training
Magnetic mallet	- Better control (strength, time) - Rapid and comfortable - Several uses in oral surgery - One hand technique	- Specific surgical tray - Practical training

Table 5. Comparison of ridge elevation techniques

DISCUSSION

The transcrestal sinus lift seems now considered as a secure and foreseeable surgical approach with lower morbidity rates according to our 17 analyzed studies. Although, this surgery did not present a null risk, that could lead to longer operating times and additional interventions, according to Tallarico M. et al. (28) New methods have been developed over the past twenty years, where only pre- and post-operative radiographies allowed control of sinus augmentation (Figure 31).

The invasiveness seemed to vary according to procedures, bone regeneration strategy and biological phenomena involved. These innovative approaches were designed to limit the risk of complications, however the reduced visibility makes it difficult to manage these issues, as described in the retrospective study of Ismaeil AM. et al. (72)

The balloon technique and the use of hydraulic pressure detached the membrane in three spatial directions, and not unidirectionally as an osteotome would do, which appeared to reduce the stress exerted on the membrane. However, pressure control depends on the practitioner's experience, which does not exclude the risk of Schneider membrane perforation, as it was reported with Martinez Saez R. et al. (68)
Since the drilling sequences are calibrated and armed with stops, they would offer a mechanical barrier to the depth of cut, according to Zhou et al. (35), Trombelli L. et al.(63), Kim YK. et al. (64), Rostom D. et al. (70) and Rodda A. et al. (36)

Indeed, the acquisition of a specific tray, such as the Jeder generator or IRaise system (hydraulic pressure), calibrated osteotome kits (SCA Kit, etc.), or the balloon system, would involve another financial cost for the surgeon regardless of the technique used (Table 5).

Transcrestal techniques are diverse but they were equitably distributed according to the studies, except those on the magnetic mallet which were less numerous with a total of 2 studies, especially Rajkumar B. et al. and Bruschi GB. et al. (73,75)
Regarding residual bone heights, 10 studies out of 17 had values between 5 and 6 mm, which corresponds to the criteria for choosing the crestal technique that we discussed in the introduction, specially an initial ridge height > 4-5mm (Figure 32).

In addition, it is accepted in many studies that the conventional Summers technique allows bone gain of 3 to 5 mm. In our results, according to Tallarico M. et al. (28), Rostom D. et al. (70), Mijiritsky E. et al. (67), Chaushu L. et al. (65) and all others, the mean of sinus floor augmentation was established to 6.6 mm, that is superior to initial theoretical previsions (Figure 34).
Hydraulic pressure studies presented the highest mean of bone gain, corresponding to 8.9 mm, with intervals ranging from 6.9 mm to 10.9 mm (Table 3).
Sinus lift by balloon technique has revealed intermediate results, with an average gain established to 6.7 mm. Effectively, the values were rather comparable, varying from 4 mm to 8.5 mm, only Arroyo R. et al.'s study reported a greater bone gain equal to 10 millimeters. (69)
Drilling sequences and magnetic systems, presented lower average gain, but both had similar results around 4-5 mm (Table 3).

These values are therefore higher than the Summers technique, but remain lower than those by hydraulic pressure for example which presented the best results. The acquisition of theoretical and practical knowledge is necessary to promote the speed and safety of surgery (Table 5).
On the other hand, to better compare these techniques, several crestal procedures would have had to be performed on the same patient, to keep same surgical conditions. The samples being small and the number of studies limited, cautions must be made concerning the results, although they are favorable.

Indeed, even if the majority of studies have not revealed major complications (48%), membrane perforation and implant failure are the most frequent ones. According to Trombelli L. et al. (63), Martinez Saez R. et al. (68), Asmael HM. et al. (71) and Ismaeil AM. et al. (72) they represent 37 % and 15% respectively (Figure 35).

All studies using hydraulic pressure and magnetic mallet did not show perforations while drilling and balloon techniques revealed 5 ruptures each. The use of drilling sequences showed membrane perforation rates really close to the conventional crestal method of Summers. This seems coherent, since only the presence of abutment on the instruments differs from the use of osteotomes alone (Table 4).

Conversely, drilling sequences and magnetic mallet did not report implant failure. Nevertheless, the balloon method showed 3 failures out of 57 implants placed, that is to say the highest failure rate of this review. According to Ismaeil AM. et al.' study in 2023, it is the only one using hydraulic pressure which has revealed implant failure with the DIVA system over the 6 studies applying this method in our results. (72)

Diverse bone grafts were available to fill the maxillary sinus, the two most used were alloplastic grafts and xenografts. This review does not correlate the bone gains obtained according to the biomaterials used, the values cannot therefore be extrapolated, although they are on the whole acceptable. Autologous bone is assumed to be the "gold standard", however xenografts and alloplastic grafts would achieve equivalent results in long term (Figure 33).

Indeed, whatever the method studied or the system used, the implant survival rates are similar to conventional methods, a total of 4 implant failures over 346 placed are reported, that is to say an osseointegration much more than satisfactory (Figure 35, Table 4).

Actually, these results are promising and encourage their use in everyday practice by the practitioner in oral implantology. These methods seem really interesting in terms of bone gain, reduction in the rate of perforations and implant survival rate. However, residual bone height is a crucial variable for the technique choice and the determination of the prognosis.

The decision-making criteria stem from a precise analysis of the clinical situation and radiological examinations, taking into account the residual bone height, the anatomical criteria related to the maxillary sinus and the extent of the tooth loss. New technological advances will allow these protocols to be refined and improved over the years.

However, additional studies, with larger and different samples, over a longer term, with other health patient conditions are necessary to obtain sufficient clinical experience to compare more these emerging methods.

CONCLUSION

The crestal approach to sinus lifts is a real alternative to conventional lateral techniques. Protocols have impressively progressed and several techniques are now available : special drills sequences, hydraulic pressure, antral balloon and magnetic system. All the procedures are well structured and efficient to elevate the sinus floor in posterior maxillary edentulous areas.

Common goals of these techniques being safe, easy, rapid, the less invasive, by modifying the conventional technique and the instruments to gain time and avoid long protocols related errors. These new methods present lower complication rates than in lateral approaches, and specifically a reduction in the perforation of the sinus membrane. The main limitation of the crestal surgery is a low initial alveolar height, in this case traditional techniques are recommended.

An immense diversity of graft materials is available to realize a methodical and efficient elevation of bone height. All the biomaterials and crestal techniques used have revealed increased bone gain in order to place future implants. Implant survival rates appeared to be satisfying and equivalent for all surgeries by crestal approach. The variety of methods and biomaterials therefore allows the dentist to select the most suitable sinus lift surgery for each patient.

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ANNEXES