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CORSO DI LAUREA IN ODONTOIATRIA E PROTESI DENTARIA

"Up to Ten-Year Bone Resorption Following Lateral Sinus Floor Elevation: A Retrospective Comparative Study of Deproteinized Bovine Bone Mineral and Synthetic Hydroxyapatite"

Relatore:

Nicola de Angelis

Candidata:

Sabrina Musso

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INTRODUCTION

BONE BIOLOGY

Bone tissue has mesenchymal origin and has a supporting function.

It consists of:

- extracellular matrix: in turn divided into an organic fraction (collagen fibers, proteoglycans, GAGs, glycoproteins) and inorganic fraction, the most predominant part, containing minerals including hydroxyapatite crystals.
- Cellular component: different cells including osteoblasts, osteoclasts and osteocytes

The organic component of the matrix represents 35% of the dry weight of the bone and is mostly made up of type I collagen fibers, organized in a lamellar structure that gives the bone resistance to tensile and torsional stresses. The remaining part is composed of the fundamental substance, a complex of proteins such as osteocalcin, osteopontin, sialoproteins and proteoglycans, which play a crucial role in regulating bone mineralization.

The inorganic component represents 65% of the dry weight of the bone and is made up of calcium salts, especially calcium phosphates to which smaller quantities of calcium carbonate and traces of other salts, such as calcium fluoride and magnesium phosphate, must be added.

Calcium phosphate is present in the form of hydroxyapatite crystals $Ca10(PO4)6(OH)2$, which bind to collagen fibers; their arrangement will therefore influence the structure of the bone itself.

The presence of mineral salts gives the bone the characteristics of hardness that distinguish it, and which allow it to withstand loads, protect the organs from external forces and constitute a reserve of minerals that contributes to body homeostasis.

Focusing on the cellular component of bone tissue, we can distinguish them into 4 varieties:

- osteoprogenitor cells
- osteoblasts
- osteoclasts
- osteocytes

We can define osteoprogenitor cells, osteoblasts and osteocytes as belonging to the same cell type, but in a different differentiation phase: as the cell differentiates, its proliferative capacity decreases.
Osteoprogenitor cells originate from the mesenchyme and have a high proliferative capacity during body growth and in general during adult life; When they take the route of differentiation, osteoprogenitor cells become osteoblasts.

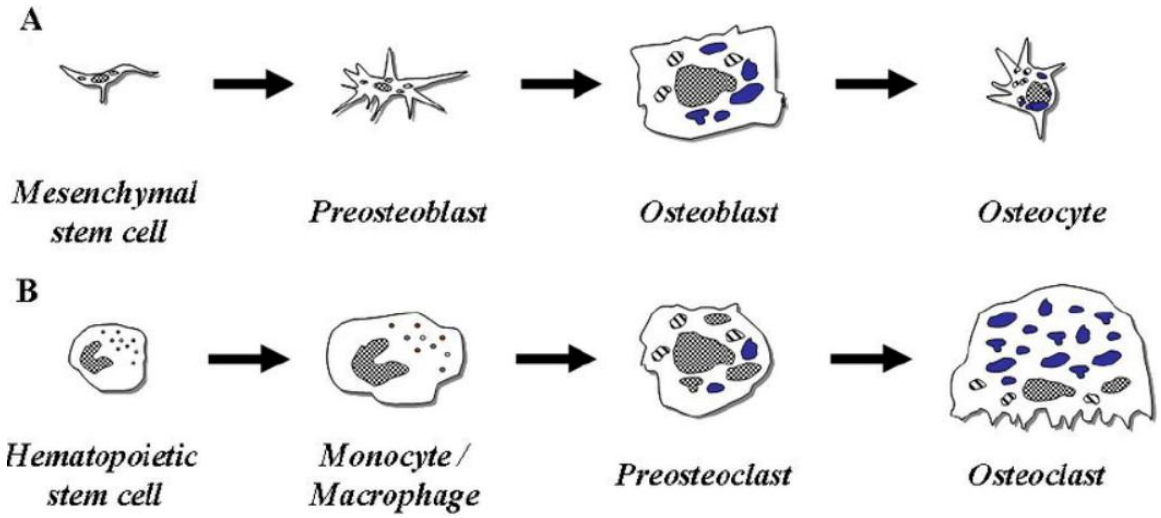
Osteoblasts are cells responsible not only for the deposition of new bone matrix (osteoid), but also for its mineralization.
The production of bone matrix takes place according to a very precise orientation: first bone is deposited on the side facing the surface already present, and then it is deposited on each side around it, so as to distance each cell from the surrounding ones due to the interposition of intercellular substance.
Osteoblasts also play a crucial role in bone remodeling, in particular in the deposition of bone matrix in order to allow bone adaptations, under the influence of the individual's needs such as weight, activity and posture.
When the osteoblasts are completely surrounded by osteoid, the ossification process begins, and when the osteoid is completely mineralized, the osteoblasts will slow down their metabolic activity and become osteocytes.

Osteocytes are mature cells that have lost both their proliferative capacity and their ability to synthesize. As a result of their differentiation process, osteoblasts that have now become osteocytes remain trapped inside niches dug into the bone tissue, which are called bone gaps.
The extensions of the cell dig bone canaliculi through the tissue and communicate with each other, forming a network of osteocytes.
Through the gaps and canaliculi, water and dissolved substances are able to reach all osteocytes.

Osteoclasts, on the other hand, are not native cells of bone tissue, but derive from precursors from the blood, preosteoclasts, which are transported by the bloodstream until they reach the site of bone resorption processes.
They are cells whose function is bone resorption, as they are capable of removing the mineral component of bone and digesting its organic component.

When the osteoclast is activated, it is usually located inside a dimple in the matrix, which is called the Howship lacuna, which is formed by the action of the erosion of the cell on the bone. A sealed area is created, delimited by tight joints, and substances are released first that remove the mineral component of the bone (hydroxyapatite crystals), through the acidification of the environment, and then hydrolytic enzymes that digest the various organic components.

Osteoclastic function is regulated by hormonal and local factors.



(Image credit: "Bone cells-biomaterials interactions" by Marquis et al., published in Frontiers in Bioscience 14, 1023-1067, 2009)

TYPES OF BONE TISSUE

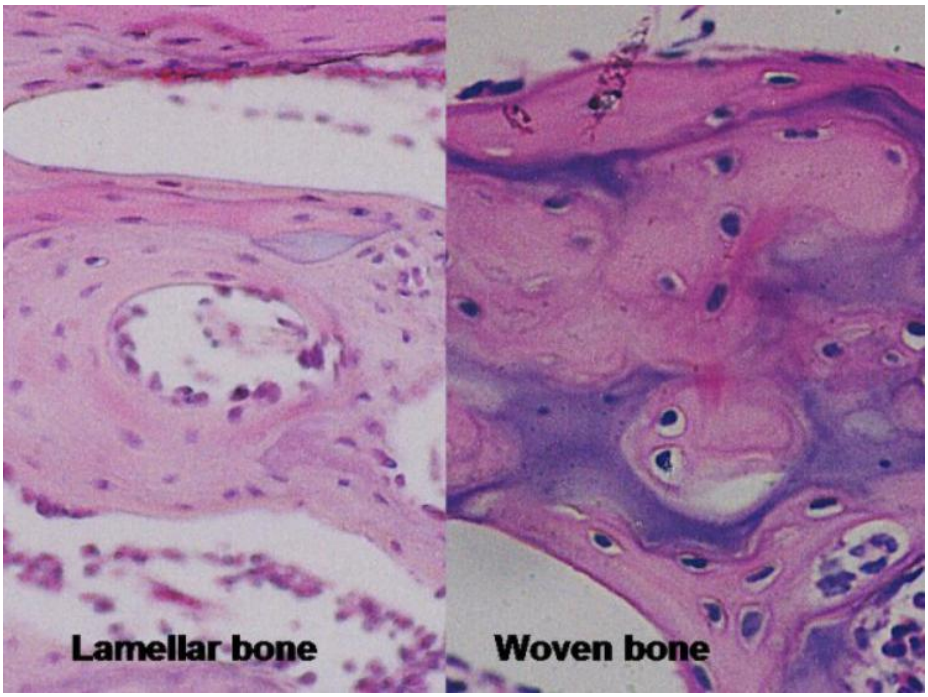
Bone tissue is initially deposited by the action of osteoblasts that deposit the osteoid. Subsequently, the osteocytes will remain trapped here and the mineralization phase of the tissue will begin, in which there will be an enrichment of mineral salts, in order to acquire the characteristics of hardness and resistance typical of mature tissue.

Depending on whether or not the extracellular matrix organizes itself to form a lamellar structure, we can distinguish different types of bone:

- Non-lamellar or woven bone: the cells, collagen fibers and hydroxyapatite crystals are arranged in a random, disordered manner around the vascular structures.

  It is defined as primary bone, it is the precursor of lamellar bone; it will later be degraded and rebuilt.

- Parallel fibre bone: poorly represented in humans, exclusively in portions subjected to traction, such as tendon insertions
- Lamellar bone: the extracellular matrix is organized into bone lamellae, derives from the remodeling of the non-lamellar bone and represents the mature bone, typical in adults. The collagen fibers are all oriented in the same direction with respect to the bone layer, but in different directions with respect to the adjacent lamellae



(Image credit: "Histomorphometric evaluation of bone healing in rabbit fibular osteotomy model without fixation" by Matos et al., published in Journal of Orthopaedic Surgery and Research, 2008)

Based on the arrangement of the bone lamellae, we can make a further macroscopic distinction of bone tissue into:

1. Spongy bone tissue: represents 20% of the skeleton
2. Compact bone tissue: represents 80% of the skeleton

Spongy bone tissue is composed of a low-density extracellular matrix and we find structures called bone trabeculae, which delimit the medullary spaces, the medullary cavities, which in turn are occupied by bone marrow. The bone trabeculae are generally arranged according to the stress trajectories that are created as a result of the load due to muscle action and body weight. (1) (2)

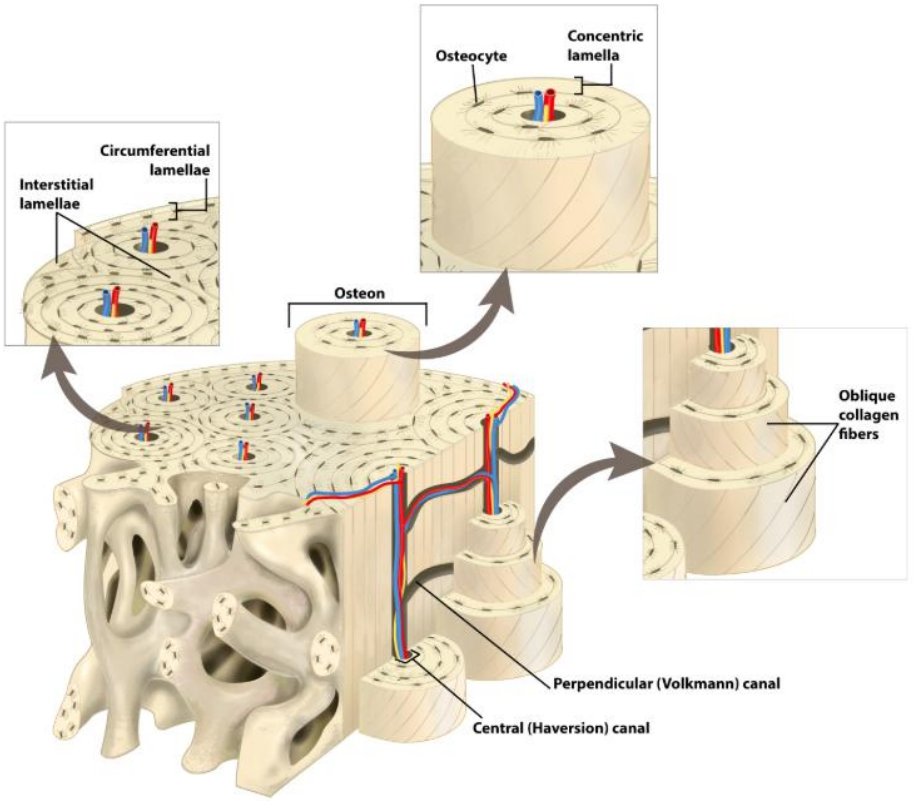
Thanks to its particular structure, it confers to bone the characteristic of resistance to tensile and mechanical stresses, as well as good resistance to compression.
The fundamental difference between spongy bone and compact bone is the absence in the former of Haversian canals and the lack of blood vessels and lymphatic ducts.
This type of bone is found in the epiphyses of long bones and in the plates of compact bone in flat bones.

Compact bone, on the other hand, is composed of a particularly dense extracellular matrix; it has a condensed, whitish appearance and is apparently devoid of cavities.
Compact bone is organized into a functional unit, the osteon, which has a cylindrical shape and is composed of a series of concentric lamellae around which osteocytes are located. The lamellae are arranged around Haversian canals, which contain blood capillaries; the Haversian canal is responsible for the nourishment of the bone.

The various canals communicate with each other through other canals arranged perpendicularly, known as Volkmann's canals, which also contain blood capillaries; these canals not only provide nourishment but also allow communication between the Haversian canals and the periosteum. Adequate blood supply is essential for the cells responsible for bone metabolism: at the level of the periosteum, multiple blood vessels penetrate the bone through Volkmann's canals and connect to the Haversian canals; simultaneously, additional blood supply comes from the bone marrow.

Spaces are formed between the osteons containing fragments of lamellar bone, which may vary in shape and size, and are called interstitial systems.
Between the osteon and the interstitial system lies the cement line.
The bone surface in contact with the periosteum and endosteum is also formed by lamellae arranged parallel to the free bone surface, known as circumferential lamellae.

This type of bone is found in flat bones, particularly in the outer layer, and at the diaphysis, the central part of long bones, thus delimiting the medullary cavity.



(Image credit: "Enlargements of Long Bone Diaphysis" by Mark Schaeffer and Jennifer Lange is licensed under CC BY-NC-SA 4.0, a derivative from the original work of "Slagter - Drawing Bone matrix - no labels" by Ron Slagter.)

BONE DENSITY

Bone density is determined by the macroscopic combination and spatial distribution of compact and trabecular bone; in the maxillofacial region, these components are respectively identified as cortical bone and medullary bone.

Focusing on the maxillofacial region, the maxilla is characterized by a predominance of spongy bone and a wide trabecular network, especially in the posterior sectors. In contrast, the mandible presents a denser structure, with a thick cortical layer and a reduced trabecular component, particularly in the anterior symphyseal region.

In 1970, Linkow classified bone density into three categories:

1. Class I : ideal bone type with homogeneously spaced trabeculae with small spongy spaces
2. Class II : bone that has slightly larger reticulated spaces, with less uniformity of the bone pattern
3. Class III : between the bony trabeculae we see large spaces filled with marrow

Successively Lekholm and Zarb in 1985 (3) proposed a new classification that takes into account the relationship between cortical bone and cancellous bone:

1. Type 1 bone: compact bone almost exclusively formed by cortical bone
2. Type 2 bone: bone with thick compact cortical and dense internal trabecular meshwork
3. Type 3 bone: bone with less thick cortical and less dense cancellous
4. Type 4 bone: bone with thin cortical and rarefied trabecular meshwork

Carl Mish in the 1987 (4) finally defined the relationship between the compact and spongy components, according to a classification based on the macroscopic resistance encountered by the clinician during the surgical phase.

The five classes are as follows:

- Class D1 : Dense cortical bone.
  Typically found in the mandibular symphyseal region, and absent in the maxilla.
  This type of bone presents critical challenges for implant placement and for the stabilization of any bone grafts; its limited vascularization reduces regenerative capacity. Furthermore, its high density makes site preparation complex: the friction generated by the drills requires high torque, increasing the risk of local overheating and consequent tissue necrosis.

- Class D2 : Thick cortical bone with dense trabecular network.
  This is the most commonly encountered bone type in both the maxilla and mandible and represents optimal bone quality. It can be found in the mandibular body and in the anterior maxillary region.

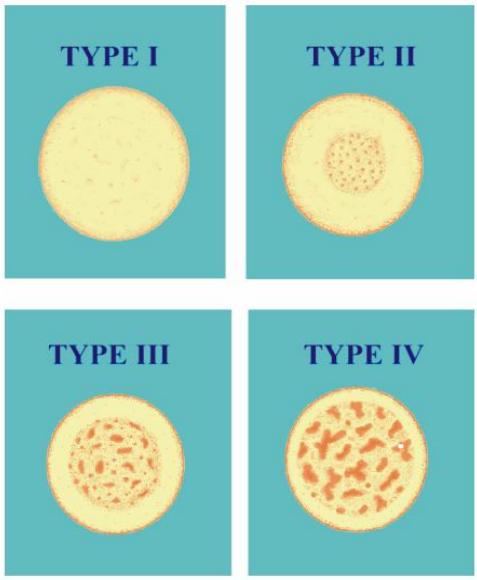
The cortical layer is sufficiently thick to ensure primary stability for potential implants or fixation devices for bone grafts.

- Class D3: Thin cortical bone with dense trabecular network
  Very common in the anterolateral region of the maxilla and the lateral region of the mandible.
  It has generally favorable characteristics, although the trabecular bone is less vascularized than in D2 bone.

- Class D4: Thin cortical bone with sparse trabecular network
  Typically found in the maxilla, it represents the least favorable bone for implant purposes, as the cortical layer does not provide sufficient primary stability and the trabecular bone is poorly vascularized.

- Class D5: Immature bone

This type of bone is not suitable for surgical or implant procedures.



(Image credit: Aspects of oral morohology as decision factors in mini-implant supported overdenture" by Preotesa et al, Romanian Journal of Morphology and Embryology, 2010, 51(2): 309-314.)

BONE REMODELING

Bone tissue is metabolically very active, and bone remodeling consists of a finely balanced process between the deposition and resorption of bone matrix (5). The primary purpose is to replace primary, non-lamellar bone with lamellar-structured bone, but bone remodeling is also involved in the morphological and dimensional modifications of bone during growth phases.

This aspect is described by Wolff's Law, according to which external mechanical stresses directly influence remodeling. (1)
In particular, bone tissue responds to increased load with an increase in mineral density, whereas the lack of mechanical stimuli, as occurs in the edentulous alveolar process, induces disuse atrophy, which often precedes the need for regenerative interventions.

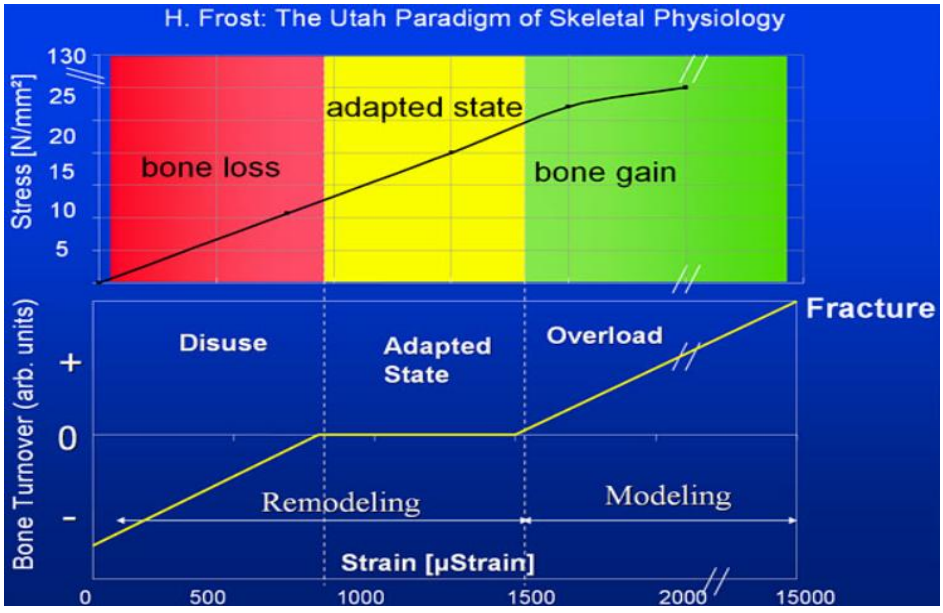
Wolff's Law has found a modern evolution thanks to the studies of Harold Frost, who formulated the mechanostat model: he introduced a biomechanical model that describes how bone responds not to a generic load, but to specific ranges of elastic deformation, expressed in μstrain, which function as precise biological commands. (6)
The functioning of this model is based on two key postulates.
According to the first postulate, bone possesses a kind of "internal sensor" composed of mechanoreceptors (primarily osteocytes). These cells are capable of detecting when the tissue is deformed by weight or an external force; once the stimulus is perceived, they send signals to activate the formation of new bone or the removal of old bone, thus adapting the structure to the body's needs.

The second postulate clarifies that these "sensors" do not operate in isolation: their sensitivity to physical stimuli is modulated by chemical factors, such as hormones (e.g., parathyroid hormone or estrogens) and cytokines, which can make the sensors more or less responsive to mechanical loads.

From the interaction between these sensors and the intensity of the applied force, the predominance of anabolic or catabolic remodeling processes is determined, which respond to well-defined mechanical load thresholds, identifiable in the following load zones:

- Physiological load zone (200 µstrain – 2500 µstrain): the deformations are in equilibrium with the strength of the existing structures, no modifications of bone mass are observed, and the turnover is normal.

- Critical load zone (50 µstrain – 200 µstrain): the mechanical stresses are of low magnitude, and therefore maintaining a skeletal structure oversized relative to the minimal mechanical stimuli is metabolically costly. A process of targeted bone resorption is initiated to reduce bone density until the ratio between the load magnitude and the tissue strength is restored. This mechanism continues until the elastic deformation falls back within the physiological load zone, thus ensuring maximum metabolic efficiency.
- Overload zone (2500 µstrain – 4000 µstrain): the mechanical stresses are of high magnitude, and therefore the increased degree of deformation acts as an anabolic stimulus, inducing the bone to increase its mass and mineral density to adapt structural strength to the new biomechanical loads. These forces lead to the recruitment of new osteogenic cells, which form lamellar bone through appositional modeling, without the normal resorptive processes that characterize the physiological remodeling process
- Pathological overload zone (above 4000 µstrain): the mechanical stresses are of such magnitude that they induce bone fracture



(Image credit: by Wikipedia commons, 2006)

ANATOMY OF THE MAXILLARY SINUS

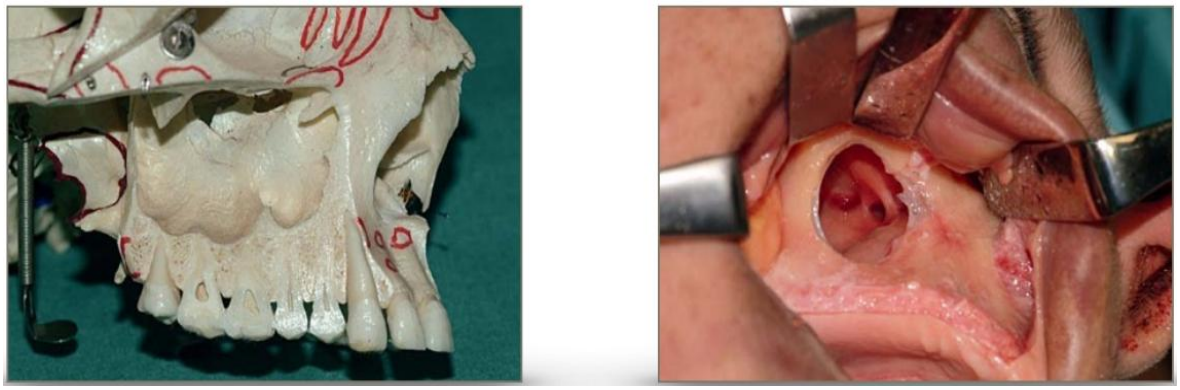
The paranasal sinuses consist of a series of air-filled spaces strategically located around the nasal cavities and the orbits. Their mucosal lining ensures the proper level of humidity in the inhaled air, while their anatomical configuration serves two essential functions: to lighten the bony structure of the skull and to act as natural resonators for phonation (7) (8).

There are four pairs of paranasal sinuses:

- frontal
- maxillary
- ethmoidal
- sphenoidal

The maxillary sinus, also called the antro of Highmore, is located within the maxillary bone and, in addition to being the largest, it is also the first of the paranasal sinuses to develop.
It is configured as a large pneumatic cavity, situated in the body of the maxilla and in close communication with the nasal fossae. It has the shape of a quadrangular pyramid, with its apex directed toward the zygomatic process.
The sinus space is bounded by six distinct walls: anterior, superior (or orbital), posterior, inferior (or alveolar), lateral, and medial.

The identification of the maxillary sinuses was first carried out by Leonardo da Vinci in the late 15th century (1489), but it was not until 1651 that the anatomist Nathaniel Highmore provided a detailed documentation (9).



(Image credit: "Manuale di Chirurgia Orale" by Barone A, Bianchi A.E, 2015)

EMBRYOLOGY

According to Lawson et al. (2008), the maxillary sinus is the first nasal cavity to appear during fetal development, already by the 2nd–3rd month of intrauterine life. However, its subsequent postnatal development is not an isolated process but is closely connected to the maturation of the alveolo-dental apparatus.

Indeed, after birth and during the following three months of life, its growth is strongly influenced by intraorbital pressure on the orbital floor, tension from the muscles on the maxillary bone, and the developing dentition.

The sinus grows in a cranio-caudal direction along a growth vector such that the floor of the sinus is positioned, at birth, more cranially relative to the nasal fossae, at the same level by twelve years of age, and more caudally after eruption is complete.

By the eleventh week of intrauterine life, a single oval cavity forms as a result of the fusion of multiple mucosal invaginations of the ethmoidal infundibulum into the surrounding mesenchyme. This structure represents the primordial stage of the maxillary sinus, initially manifesting as an antro with smooth walls lacking irregularities (10).

During the first three years of life, expansion and the consequent bone resorption proceed laterally until reaching the infraorbital canal. Subsequently, between the ages of 6 and 12 years, the cavity extends toward the zygomatic recess, reaching the level of the hard palate by the ninth year. The final growth phase coincides with the pneumatization of the alveolar process; at this stage, the eruption of permanent premolars and molars induces a lowering of the sinus floor, which is positioned approximately 4–5 mm below the level of the nasal cavity. (11) (12).

The main development occurs with the eruption of the permanent dentition, around 12–13 years of age, and is completed with the eruption of the third molar, between 16 and 18 years of age. (13).

It is interesting to note a distinction between the developmental dynamics of the maxillary sinus and its behavior in adulthood. While primordial and postnatal growth is closely linked to the maturation of the alveolo-dental apparatus, completing, as noted by Lang, only with the eruption of the third molar between 16 and 18 years of age, recent literature highlights a different phenomenon following the loss of dental elements.

Although the extraction of a molar or premolar often causes a localized expansion of the sinus floor toward the alveolar ridge (post-extraction pneumatization), this does not appear to translate into an increase in the overall sinus volume. On the contrary, many studies indicate that the total volumetric capacity of the sinus remains almost unchanged relative to the dentate state, showing instead a tendency to contract with advancing age. (12)

STRUCTURE

The maxillary sinus represents the largest cavity of the paranasal system, with an average capacity of approximately 15 ml.
Its shape resembles a quadrangular pyramid, oriented with the base toward the lateral wall of the nasal fossae and the apex directed toward the zygomatic process of the maxilla.
In an individual with complete skeletal development, the cavity extends in an antero-posterior direction from the region of the first premolars to the maxillary tuberosity, covering a length ranging from 38 to 45 mm.
The vertical dimensions (height) range between 36 and 45 mm, while the transverse width is approximately 25 to 35 mm.
A clinically relevant detail is the position of the sinus floor, which, at the end of growth, is usually located about 1 cm below the plane of the nasal fossae.
The structure is bounded by six distinct **anatomical walls**:

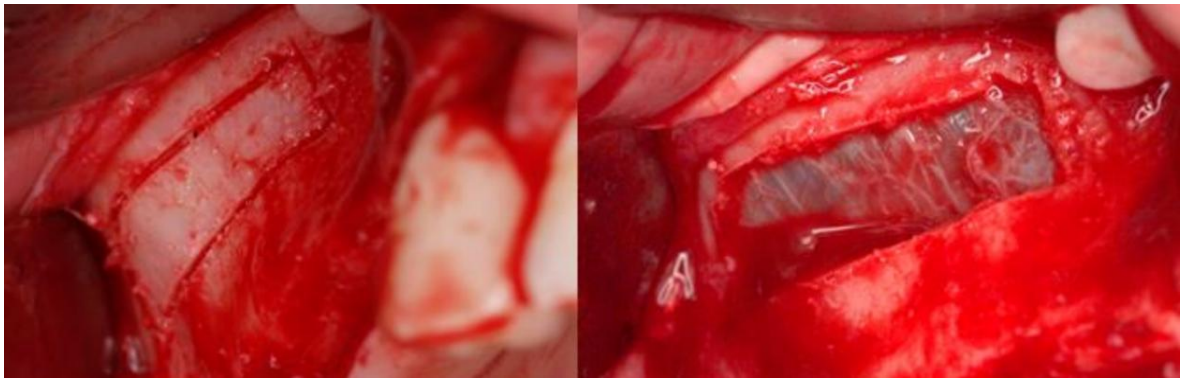
- Anterior Wall: Composed of thin compact bone, it extends from the infraorbital margin to the region above the apex of the canine tooth. It is traversed by critical structures such as the anterior superior alveolar artery and branches of the infraorbital nerve.

- Superior (Orbital) Wall: Corresponds to the floor of the orbit, mediating topographical relationships with the eyeball and the ethmoidal air cells
- Posterior Wall: Borders the pterygomaxillary region. In this area, the sinus is related to the pterygoid venous plexus, the internal maxillary artery, and the posterior superior alveolar nerve.
- Medial (Nasal) Wall: Represents the boundary with the nasal cavities. In its superior portion, it houses the maxillary sinus ostium, a fundamental opening through which physiological drainage of secretions into the middle meatus occurs.

- Lateral Wall: Includes the posterior surface of the maxilla and the zygomatic process. The thickness of this wall is strongly influenced by the state of dentition: it can measure several millimeters in dentate subjects, while it often reduces drastically (frequently below 1 mm) in edentulous patients due to bone resorption processes.

- Inferior (Floor) Wall: Constitutes the base of the sinus and is in direct relationship with the apices of premolars and molars. The interface between these structures is mediated exclusively by a thin layer of alveolar bone and the mucous membrane (Schneiderian membrane).(14) (15)

SCHNEIDER MEMBRANE



(Image credit: "Long-Term Clinical Study of Implants Placed in Maxillary Sinus Floor Augmentation Using Beta-Tricalcium Phosphate" by Velasco-Ortega E et al, 2021)

The entire internal surface of the maxillary sinus is covered by the Schneiderian membrane, a specialized mucosa with a physiological thickness ranging from 0.13 to 0.5 mm. (15). This lining, which appears macroscopically smooth and pale pink in color, is continuous with the mucosa of the nasal cavities and the entire paranasal system through the communication ostia.

From a histological perspective, the membrane presents a three-layered structure composed of an epithelial layer, a connective layer, and a periosteal layer.

The most superficial portion consists of a ciliated pseudostratified columnar epithelium, where ciliated cells and mucous goblet cells can be distinguished; the latter are responsible for the production of the protective fluid film.

Each ciliated cell possesses approximately 150–200 cilia, operating with a coordinated vibratory frequency of 10–20 Hz. This kinetic activity is fundamental for mucociliary

transport, that is, the movement of mucus toward the sinus ostium for physiological drainage into the nasal cavities.
The epithelium rests on a basement membrane, which serves as an interface with the underlying connective compartment.

The connective layer is itself divided into two portions: a superficial layer of loose connective tissue, particularly susceptible to edematous phenomena during inflammatory processes, and a deeper, denser layer that houses simple tubuloalveolar seromucous glands, whose concentration increases significantly near the ostium.
Finally, the deepest layer is the periosteal layer, a dense fibrous membrane that, while in close continuity with the overlying connective tissue, adheres firmly to the bony tissue of the antral walls.

Understanding the extreme fragility of the Schneiderian membrane, together with its complex glandular and vascular architecture, is crucial for the surgeon during elevation and detachment maneuvers in sinus lift procedures.
An intact membrane not only ensures the correct physiology of the paranasal sinuses, but also serves as an essential biological barrier for the containment and stabilization of grafting biomaterials, directly influencing the success of bone regeneration.

VASCULARIZATION

The vascularization of the maxillary sinus is provided by branches of the internal maxillary artery, which is itself a branch of the external carotid artery, namely:

- Infraorbital artery
- Greater palatine artery
- Posterior superior alveolar artery (16)

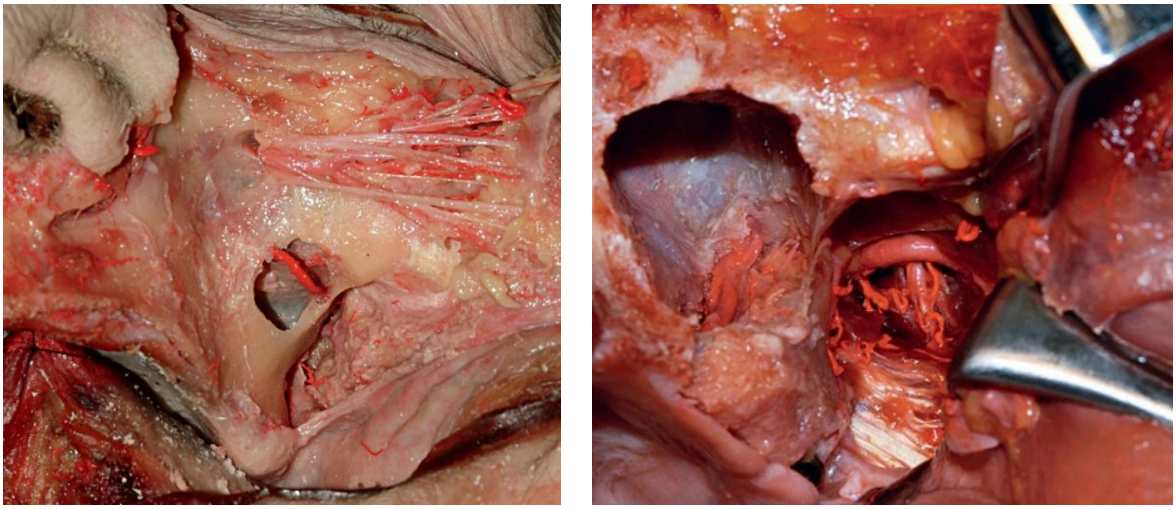


Fig 1 : Alveolar-antral artery, which forms an anastomosis with the infraorbital artery and the posterior superior alveolar artery.;

Fig 2 : Internal maxillary artery: while it passes through the pterygopalatine fossa, the descending palatine artery can also be identified, one of the branches of the internal maxillary artery, which courses through the palatine canal and emerges at the level of the palatine foramen as the greater palatine artery

(Image credit: "Manuale di chirurgia orale" by Barone A, Bianchi A.E, 2015")

The posterior superior alveolar artery often forms anastomoses with the infraorbital artery, supplying the membrane and periosteal tissues. (17).

It is therefore essential to map the course of these vessels using CT imaging (CBCT) during the diagnostic phase; this precaution allows for the prevention of intraoperative hemorrhagic complications during the creation of the lateral bone window for maxillary sinus floor elevation.

Specifically, the posterior superior alveolar artery may run along the medial wall of the sinus, while the infraorbital artery travels along its corresponding groove and canal beneath the orbit, eventually emerging through the infraorbital foramen on the facial surface of the maxilla. Another essential component is the posterolateral nasal artery, a branch of the

sphenopalatine artery: it enters the nasal cavity through the sphenopalatine foramen and, continuing anteriorly along the medial wall, supplies blood to the posterior and medial regions of the sinus.

All these vessels converge into a dense anastomotic network, ensuring capillary perfusion to all sinus walls, even in the presence of extremely thin bone.
Of particular relevance for implant surgery is the anastomosis between the infraorbital artery and the superior alveolar artery, which can be intraosseous or extraosseous. This connection gives rise to the alveolo-antral artery, a vascular structure that must be carefully assessed during diagnostics: its course (which can be intraosseous or submucosal) renders it vulnerable to potential injury during the delineation of the bone window in extensive sinus floor elevation procedures.

Although the transection of small arterial branches can occur, clinically significant bleeding during sinus elevation is rare, as the main trunks are usually located outside the surgical field; in most cases, mechanical compression with gauze is sufficient to achieve effective hemostasis.

The venous compartment follows a parallel course, with drainage ensured by the facial vein, sphenopalatine vein, and pterygoid plexus. It is important to note that this venous system can act as a pathway for the spread of infections originating in the sinus to adjacent anatomical areas.

Finally, the vascularization of the posterior maxilla is strongly affected by physiological aging and edentulism.
The loss of teeth and the atrophy of the alveolar processes are associated with a progressive reduction of intraosseous blood supply, characterized by a decrease in vessel number and caliber, which also tend to follow a more tortuous course.

INNERVATION

The innervation of the maxillary sinus is provided directly by the maxillary nerve, the second branch of the fifth cranial nerve, the trigeminal nerve.

The nerve distribution follows a complex network of branches that not only provides sensation to the antral cavity but also coordinates the innervation of the posterior teeth. Specifically, the innervation of the posterior region of the oral floor and the molars and premolars is supplied by the posterior and middle superior alveolar branches. These branches converge on the lateral wall of the sinus to form, along with the anterior branch, the superior dental plexus.

The anterior superior alveolar branch runs beneath the Schneiderian membrane and innervates the anterior wall. It is important to highlight that the Schneiderian membrane contains rich afferent innervation, responding to mechanical and pressure stimuli.

The medial wall is innervated by branches derived from the infraorbital nerve, which separate before exiting the infraorbital foramen.

NON-IATROGENIC PATHOLOGY OF THE MAXILLARY SINUS

The pathological conditions that most frequently affect the sinus district are essentially represented by the frameworks of rhinosinusitis, which can manifest clinically according to an acute, subacute, or chronic course. Alongside these, with significant relevance, are sinonasal polyposis, characterized by hyperplastic mucosal outgrowths, and odontogenic sinusitis.

It should also be noted that there is also a very rare malformative skeletal pathology involving the paranasal sinuses.

RHINOSINUSITIS

Rhinosinusitis is defined as an inflammatory process that simultaneously involves the mucosa of the nasal cavities and the paranasal sinuses. These pneumatic cavities, responsible among other functions for lightening the weight of the facial mass, can undergo inflammatory phenomena that determine mucosal edema and the consequent narrowing of the drainage channels (ostia) that connect the nasal cavities with the paranasal ones, with the consequent accumulation of mucus which makes breathing very difficult and creates an optimal terrain for bacterial development.

The rhinosinusitis can be of viral origin, the common cold (viral rhinosinusitis) lasting a few days, or of bacterial origin which can present in acute, subacute, recurrent acute, chronic, or exacerbated chronic form. It is a pathology not to be underestimated and to be treated adequately. Viral rhinosinusitis is the common cold. It is characterized by the presence of congestion of the nasal fossae, which limits nasal breathing, leads to the production of thick and viscous mucous exudate, and increases lacrimation and the sense of pressure at the level of the paranasal sinuses. In some cases, a true form of headache can occur.

The symptoms include:

- Nasal respiratory obstruction with nasal congestion
- Cough
- Rhinorrhea
- Decreased ability to perceive all, or part of, odors (hyposmia)
- Reduction of taste (dysgeusia)
- Headache
- Bad breath (halitosis)
- Aural fullness
- Fever (sometimes)

Rhinosinusitis is nothing more than the inflammation of the paranasal sinuses, namely those pneumatic cavities of the facial mass that serve to lighten the weight of the skull, which can occur for congenital reasons, such as the conformation of the skull bones, the presence of allergies to pollen, mites, and animal hair, or for traumatic causes affecting the nasal septum or the skull.
It is therefore not an exclusive phenomenon of the winter season, but a disorder that, as a whole, affects about 15% of the population throughout the year.

In the event that the inflammation is not attributable to a viral rhinitis, but becomes chronic, a specialist visit to an otolaryngologist allows for a differential diagnosis and to trace the causes of the pathology. To do this, a diagnostic assessment is often also required, such as a CBCT (Cone Beam Computed Tomography) of the facial mass (a radiological technique that uses a conical beam of X-rays and is characterized by a reduced radiation intake) and nasal

fibroscopy (an outpatient examination performed via a thin tube equipped with a camera that is inserted into the nasal cavity).
With these two investigations, the anatomical characteristics of the nose can be defined and the most indicated therapeutic approach is determined which, in a first phase, in most cases involves antibiotic therapy and aerosol therapy, using micronized douches based on cortisone which acts as a local anti-inflammatory, favoring the reduction of the swelling of the nasal mucosa. With the latter, in particular, it is possible to act effectively directly on the nasal cavities, concentrating the action of the inhaled drug on the nasal and paranasal cavities and avoiding its spread to the lungs.

When medical therapies fail to definitively resolve the inflammatory state, then it is appropriate to evaluate the option of surgery. Today the solution for chronic sinusitis, whether associated with nasal polyps or not, is functional endoscopic sinus surgery, called FESS (Functional Endoscopic Sinus Surgery).
This minimally invasive surgical technique uses endoscopic optics, video cameras, and dedicated instruments with which it is possible to intervene with great precision in even very small spaces and surfaces. In detail, it allows for the removal of secretions accumulated in the cavities, the bony lamellae that can obstruct the normal flow of air, and also any polyps. In this way, the spaces between the nose and paranasal cavities are enlarged and a correct flow of air is restored which will allow the healing of the sinusitis.
After this intervention the benefit is immediate and the patient feels the sensation of having a "free nose" already from the first week.

SINONASAL POLYPOSIS

This is a chronic inflammatory pathology of the mucosa characterized by the formation of edematous, benign but hyperplastic outgrowths, called precisely polyps. Polyps usually originate from the mucosa of the ethmoidal labyrinth or the recesses of the maxillary sinus. Theoretically, they are the result of chronic inflammation (often of an eosinophilic nature) that causes an accumulation of interstitial fluid in the submucosal space; this leads to the formation of pedunculated projections that tend to prolapse into the nasal cavities by gravity. The main problem of polyposis in the dental surgical field is mechanical obstruction.

Polyps tend to be localized in correspondence with the Osteomeatal Complex, thus preventing the passage of air and the outflow of secretions, with a consequent risk of accumulation of infected secretions inside the sinus.

ODONTOGENIC SINUSITIS

Odontogenic Maxillary Sinusitis represents a specific variant of chronic rhinosinusitis that originates from pathological processes involving the dental elements or the supporting tissues. Although historically it has been the subject of fragmented scientific literature, recent evidence has re-evaluated its incidence, estimating that it may constitute between 25% and 40% of all forms of chronic maxillary sinusitis.

Under the diagnostic profile, the integration of advanced radiological examinations (CBCT) has revealed that over 45% of unilateral opacifications of the maxillary sinus recognize a cause of an odontogenic nature, making a multidisciplinary approach between dentists, maxillofacial surgeons, and otolaryngologists indispensable.

The link between the sinus cavity and the dental apparatus is dictated by the close anatomical proximity. Although the sinus floor is normally composed of a thick bony layer, as age progresses the maxillary alveolar bone can progressively reduce, leaving only a thin mucoperiosteal layer between the sinus and the dental roots, the Schneiderian membrane. This anatomical contiguity means that the dental apices can project into the sinus, creating protrusions and elevation of parts of the Schneiderian membrane.

In this context, non-iatrogenic factors play a crucial role. The pathway of infection spread is facilitated by the communication between the arterial and lymphatic vessels that are in communication between the sinus and the dental roots; therefore, an inflammatory process can extend to the sinus even in the presence of the bony structures that divide the sinus and the roots of the teeth. Once involved, the Schneiderian mucosa undergoes processes of hypertrophy, inflammation, edema, up to processes of fibrosis and granulation that compromise the physiological ventilation of the sinus.

Excluding surgical maneuvers, the main causes of ODS are attributable to spontaneous infectious processes. Periodontal and endodontic pathologies constitute the most relevant share of these factors:

- Apical periodontitis and Granulomas: Following pulp necrosis, the bacterial infection expands beyond the root apex, determining periapical lesions (cysts, granulomas, or abscesses) that serve as an infectious reservoir for the sinus mucosa
- Severe periodontitis: The resorption of the tooth's supporting tissues can create a microbiological communication pathway towards the floor of the sinus
- Third molar anomalies and odontogenic cysts: Impacted teeth or cystic formations of dental origin can occupy sinus volume, altering its homeostasis.

Under the topographic profile, the teeth most frequently involved are the first and second molar (over half of the cases), followed in decreasing order by the premolars.
This distribution is justified not only by the anatomical proximity, but also by the eruption chronology: the first molar, being the first permanent tooth to appear, is exposed for a longer time to the risk of caries and endodontic complications, statistically becoming the main responsible for reflex sinusitis phenomena.

OBSTRUCTIVE ANATOMICAL FACTORS

The study of anatomical and obstructive factors plays a crucial role.
These conditions, although they are not pathologies in the strict sense of the term, represent "non-iatrogenic" structural variants that can profoundly alter sinus homeostasis, compromising ventilation and drainage and predisposing the patient to post-operative infectious complications.

The key element of this district is the Osteomeatal Complex, a functional unit that includes the natural ostium of the maxillary sinus, the infundibulum, and the middle meatus. The patency of this passage is the only guarantee for the maintenance of negative air pressure and for mucociliary clearance. Any anatomical alteration that reduces its lumen transforms an asymptomatic sinus into a high-risk surgical site.

Among the main obstructive anatomical variants we see:

- Nasal Septal Deviation: A pronounced curvature of the osteo-cartilaginous lamina of the septum can determine a mechanical compression of the turbinates towards the lateral wall of the nose. This displacement can physically obstruct the outlet of the maxillary sinus, hindering the outflow of mucus and favoring a "silent" chronic rhinosinusitis that would be drastically exacerbated by a sinus lift intervention
- Concha Bullosa: This is an anatomical variant in which the middle turbinate presents an internal pneumatization (an air bubble). If of significant size, the concha bullosa occupies an excessive space in the middle meatus, acting as a mechanical plug that presses against the ethmoidal infundibulum, blocking the drainage of the ipsilateral maxillary sinus
- Turbinate Hypertrophy: A chronic volumetric increase of the mucosa of the turbinates (often associated with allergic or vasomotor rhinitis) reduces the nasal airspace. This not only limits the patient's breathing but creates an environment of stagnation of secretions that can easily contaminate the maxillary sinus, especially after surgical stress.

A separate mention is deserved for Underwood’s septa, transverse bony walls that originate from the floor or the lateral walls of the sinus. Although they do not directly influence nasal drainage, they represent the main "non-iatrogenic" anatomical obstacle during the surgical act. These septa divide the sinus into recesses (anterior, middle, and posterior), making the Schneiderian membrane extremely tense and adherent to the bony ridges. Their presence drastically increases the technical difficulty in the detachment of the membrane, raising the probability of intraoperative perforations from 10% up to over 40%.

NEED FOR MAXILLARY SINUS AUGMENTATION FOR IMPLANT PLACEMENT

Following the extraction of teeth, whether due to destructive periodontal disease, endodontic failures, trauma, or simply aging, the alveolar bone undergoes a physiological remodeling process, often clinically significant, known as atrophy.
This phenomenon is not merely a volumetric reduction but a dynamic process that causes centripetal contraction of the maxilla, often exacerbated by the concomitant pneumatization of the maxillary sinus (i.e., positive pressure generated during respiration). (18).
The extent and shape of such pneumatization are highly variable, both among individuals and between the contralateral sinuses of the same subject (19).

Such remodeling can reach levels so pronounced that it drastically alters the original bone architecture, making implant rehabilitation a complex challenge (20).
In these circumstances, the available bone may be insufficient not only in quantitative terms but also in quality, compromising the placement of implants that are both biomechanically stable and prosthetically appropriate. Therefore, a rigorous classification of the degree of atrophy, according to classical systems such as Cawood and Howell(21), is essential to determine whether the residual anatomy allows for a direct implant approach or, conversely, necessitates bone augmentation procedures or alternative solutions.

CAWOOD AND HOWELL CLASSIFICATION

The Cawood and Howell classification represents the main reference in the literature for describing maxillary atrophy.
It is based on a study of post-extraction resorption patterns and demonstrates how bone loss follows predictable schemes, influenced by factors such as age, sex, and skeletal morphology. Specifically:

- Age: elderly individuals are more susceptible
- Sex: females are more susceptible
- Skeletal morphology: patients with reduced vertical dimensions due to deep bite are more sensitive (21)

Evidence from the studies by Cawood and Howell highlights a clear distinction between basal bone and alveolar bone: while the former tends to maintain its structural integrity unless subjected to external mechanical insults such as incongruent occlusal loads or pressures from improperly adjusted removable prostheses, the alveolar process undergoes a profound and inevitable transformation post-extraction.
The resorption pattern shows specific topographic characteristics depending on the area involved:

- Maxillary sectors and the interforaminal mandibular region: here, bone loss occurs predominantly on the horizontal plane, with a higher incidence on the buccal wall.

- Posterior mandibular sectors: in this area, the atrophic process develops primarily in the vertical dimension.

This progressive atrophy significantly alters intermaxillary relationships across the three planes of space.

Longitudinally, a reduction in arch length is observed; transversely, there is a morphological divergence: the maxilla tends to narrow, while the mandible undergoes a relative widening.

From a biomechanical perspective, this is described as centripetal contraction for the maxilla and centrifugal expansion for the mandible.

A clinically relevant point concerns the speed of these processes: the mandible shows a rate of vertical resorption approximately four times higher than that of the maxilla (22).
This difference is attributable to the absence of the palatal vault in the lower jaw, which in the maxilla serves as a structural support and protective element.
In addition to the bony components, atrophy affects the entire soft tissue complex and facial aesthetics:

- Vertical Dimension and Interarch Relationships: Although bone resorption leads to an increased distance between the alveolar ridges, this is often masked by a compensatory mandibular rotation. This movement, typically occurring in an upward and forward direction, ensues as an attempt to establish a functional contact to make up for the loss of occlusal height. Consequently, this rotation reduces the vertical dimension of the lower third of the face and may obscure the true extent of bone atrophy, complicating the clinical assessment of the space required for prosthetic rehabilitation.. occurs

- Soft Tissues and Gingiva: there is a marked reduction of the attached gingiva and progressive superficialization of the muscular insertions of the oral floor and perioral area.

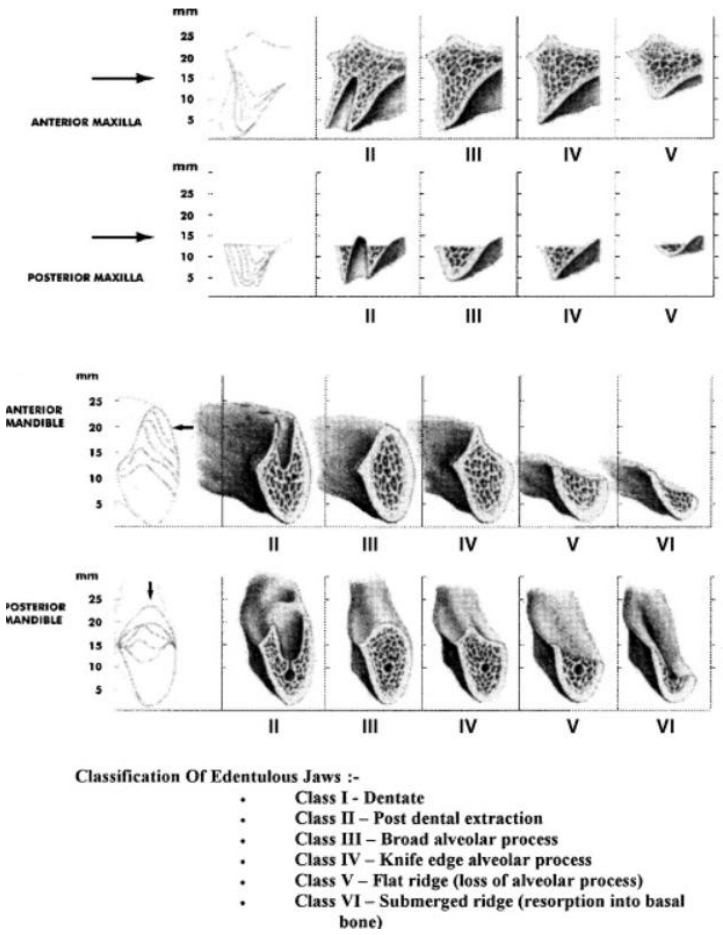
- Facial Aesthetics: the patient's aesthetic profile undergoes characteristic changes, directly reflecting the degree of bony base involution and the consequent collapse of supporting soft tissues.

Six progressive stages are distinguished (the sixth class is specific to the mandible)

- Class I: Dentition present.
- Class II: Immediately post-extraction alveolar ridge.
- Class III: Edentulous ridge with adequate height and width.
- Class IV: "Knife-edge" ridge (sufficient height, insufficient width).
- Class V: Total loss of the alveolar process (insufficient height and width).

In Classes I, II, and III, it is possible to place endosseous implants without resorting to surgical bone augmentation techniques; in Classes IV, V, and VI, however, correction of the bone volume becomes necessary (23).

The Mandibular Class VI represents the greatest clinical challenge. The superficialization of the alveolar nerve and the loss of vestibular and lingual fornices require complex procedures such as vestibular plastic surgery or extensive bone grafting, since even the stability of removable prostheses is compromised.



(Image credit: "Changes in facial form relative to progressive atrophy of the edentulous jaws" by Sutton D.N, et al, 2004)

MISCH AND JUDY CLASSIFICATION

An additional contribution to the classification of atrophies comes from Carl E. Misch and K. Judy. The authors developed a classification scheme based on different bone morphologies that faithfully reflect the temporal stages of resorption. The core concept of this classification is available bone, defined as the quantity of bone measured in terms of height and width (24).

To define the amount of available bone, Misch identifies two biometric parameters:

- Height: measured vertically from the crest of the edentulous ridge to an anatomically immutable boundary, such as the floor of the maxillary sinus in the upper jaw or the mandibular canal in the lower arch.

- Width (or breadth): represented by the transverse distance between the two bony plates (buccal and lingual/palatal), measured at the crest of the potential implant site

For each bone category or "division," the authors associate three clinical parameters that vary depending on bone characteristics:

- Alveolar process width: the mesio-distal space measured between teeth or adjacent implants in the atrophic area.
- Implant insertion angulation: refers to the need for the implant axis to align as closely as possible with the vector of occlusal forces. This parameter is influenced by ridge width: the more bone available, the greater the flexibility in angulation.

- Crown-to-implant (C/I) ratio : a fundamental biomechanical value. Crown height is measured from the occlusal (or incisal) plane to the bone crest, while implant length is measured from the crest apex to the implant apex. An increased ratio implies greater stress on the bone-implant interface, raising the risk of mechanical complications.

Based on these criteria, Misch and Judy identify four clinical scenarios (25):

- Division A: abundant available bone, almost intact alveolar ridge. Here, available bone is generous in all dimensions. Height exceeds 12 mm and width exceeds 5 mm. These volumes allow surgical flexibility, supporting implant angulation up to 30° relative to the occlusal load vector and ensuring an ideal C/I ratio, usually below 1. Optimal implant rehabilitation can be achieved
- Division B: mild atrophy, with limited bucco-lingual resorption of the ridge. As atrophy progresses, bone width initially decreases, primarily affecting the buccal plate, following a centripetal resorption pattern.
  The ridge is narrower than in Division A but retains sufficient bone for implant placement. Values indicate a height of at least 10 mm and a width between 2.5 and 5 mm.
  In this case, reduced width requires a mesio-distal space of 15 mm to ensure proper interface.
  Maximum angulation tolerance drops to 20°, and the C/I ratio should remain below 1.
  A subcategory, Bw (Width), identifies cases where width is critical, between 2.5 and 3.5 mm, making the bone inadequate for implants

- Division C: moderate-to-advanced atrophy. Resorption continues first affecting width, then height. Available bone is insufficient in one or more dimensions: width may be less than 2.5 mm and height below 8 mm.
  Two subcategories exist:

    - Cw (Width): the ridge is primarily deficient in width. In these cases, a knife-edge ridge must be reshaped into a Ch class.

    - Ch (Height): when vertical deficiency is also present, indicating more pronounced resorption.

- Division D: severe atrophy. This stage represents total loss of the alveolar process combined with basal bone atrophy. Fixed rehabilitation is possible only with autologous bone grafts or bone bank material.

CHIAPASCO CLASSIFICATION OF BONE RESORPTION

While the classifications by Cawood and Howell and by Misch and Judy provide a morphological and biomechanical framework for the edentulous site, Chiapasco's classification (26) translates this information into a decision-making workflow. It correlates the residual bone height (RBH) with the most appropriate surgical technique, defining the limits between conventional implant placement and the need for regenerative procedures, such as maxillary sinus floor elevation.

The identified classes are

- Class A: the residual alveolar ridge presents a height between 4 and 8 mm and a width up to 5 mm, with interarch distance within normal limits. In these anatomical conditions, the most indicated surgical options include sinus floor elevation performed either via a lateral window approach or through a transalveolar technique

- Class B: in this category, the residual ridge height is also between 4 and 8 mm, while the width is less than 5 mm; interarch distance remains normal. The recommended surgical treatment involves lateral sinus floor elevation combined with crestal width augmentation through onlay bone grafts or guided bone regeneration (GBR) procedures.

- Class C: the residual alveolar ridge shows a height less than 4 mm, with a width equal to or greater than 5 mm, maintaining a physiological interarch distance. In these situations, the surgical protocol of choice is sinus floor elevation via a lateral approach

- Class D: this class is characterized by a residual alveolar ridge height below 4 mm and width less than 5 mm, with a normal interarch distance. The recommended

treatment includes sinus floor elevation, often combined with extensive regenerative procedures to allow subsequent implant placement.

- Class E: the bone conditions are similar to those described for Class A, but are accompanied by an increased interarch distance. In these cases, the suggested surgical protocols include the use of vertical onlay bone grafts or guided bone regeneration (GBR) procedures, aimed at restoring a proper interarch relationship.

- Class F: presents characteristics similar to Class B, with ridge height between 4 and 8 mm and reduced width, but with an increased interarch distance. The indicated surgical treatment consists of maxillary sinus elevation via a lateral approach, if deemed appropriate, combined with both vertical and horizontal reconstruction of the residual ridge using vestibular and vertical onlay bone grafts or GBR, to be carefully evaluated on a case-by-case basis..

- Class G: in this category, bone characteristics correspond to those of Class C, with residual ridge height below 4 mm and adequate width, but associated with an increased interarch distance. The recommended surgical protocol involves lateral sinus floor elevation combined with the use of autologous vertical onlay bone grafts.

- Class H: this class mirrors the conditions of Class D, with reduced height and width of the residual alveolar ridge, but with an increased interarch distance. The recommended surgical treatment includes lateral sinus elevation, combined with autologous onlay bone grafts both vertically and horizontally; in these cases, the use of guided bone regeneration is generally not indicated.

BONE REGENERATION: MAXILLARY SINUS AUGMENTATION

In edentulous patients, especially when this condition persists for a long period, the alveolar ridge undergoes progressive thinning, which can lead to extremely reduced thicknesses, sometimes less than 1 mm. (21)
Functional loads applied during mastication on the alveolar processes play a critical role in maintaining the stability and integrity of the bone structures.
Teeth are capable of transmitting continuous biomechanical stimuli to the alveolar bone, which are essential for the preservation of its structure and density.
The loss of these stimuli, following tooth extraction, leads to a disruption of bone homeostasis.

The period of greatest bone loss occurs immediately after tooth extraction, when an intense remodeling process is activated.
It is well established that, within the first three months after tooth loss, there is a 30% reduction in alveolar bone width, and after one year, 50% of the total width is lost, particularly affecting the buccal wall (27).
Subsequently, vertical bone loss tends to stabilize, with an average estimated loss of approximately 0.1 mm per year.
However, significant individual variations are possible, sometimes of considerable magnitude.
Bone resorption may be further accelerated by systemic factors, including hormonal imbalances, metabolic disorders, inflammatory processes, as well as the patient's age and sex.
The severity of resorption, and therefore the degree of alveolar ridge atrophy, is closely related to the duration of edentulism.
Patients edentulous for a long time often lack sufficient residual bone to allow for the placement of dental implants, especially in the posterior maxillary regions.
In these cases, the primary limiting factor for implant placement is not so much the ridge width, but rather the residual ridge height, that is, the space between the crest margin and the floor of the maxillary sinus.

The vertical deficit observed in such cases results from two concomitant phenomena: the progressive resorption of the alveolar ridge and the pneumatization of the maxillary sinus, a process that appears to play a critical role in the development of atrophy.

In the presence of this vertical deficiency, it is often necessary to perform maxillary sinus floor elevation procedures, frequently combined with bone regeneration techniques, to create anatomical conditions suitable for proper implant rehabilitation.

The surgical technique for augmenting the maxillary sinus floor, known as the sinus lift, originated in the late 1960s and 1970s with Boyne and James, who began the first attempts to increase bone volume in atrophic maxillae to allow for implant rehabilitation (28).

Surgeon Oscar Hilt Tatum Jr. described in 1986 a modified procedure based on the Caldwell–Luc technique, namely the lateral window approach for maxillary sinus floor elevation (29), and presented its fundamental concepts in specialist conferences as early as 1976.
Subsequently, Boyne and James formally published the lateral approach technique in 1980, describing the use of autologous bone grafts to increase the available bone in the posterior maxillary sinus before implant placement (30).

Summers (31) described a crestal approach protocol for sinus floor elevation, based on the use of osteotomes. In this procedure, controlled percussion with a surgical mallet is used to indirectly displace the Schneiderian membrane.
Through the osteotomy thus created, the maxillary sinus is subsequently filled with graft material.

This method allows for simultaneous implant placement in cases where the residual vertical bone height at the sinus floor is between 5 and 6 mm.
If, instead, the residual bone height is below these values, implant placement is postponed to a second surgical stage, following the healing and maturation of the graft.

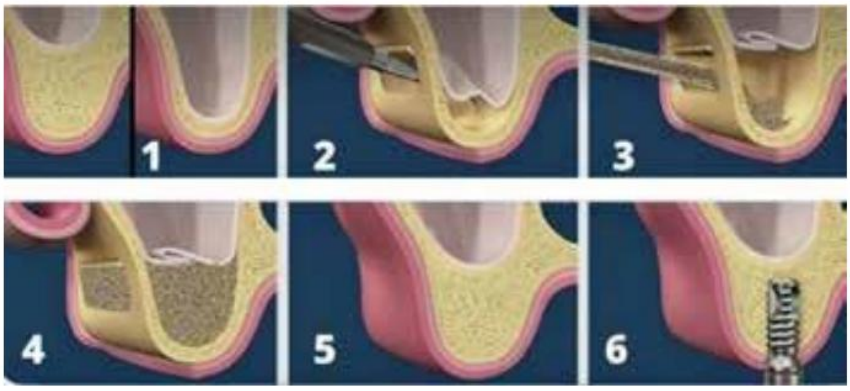
SURGICAL TECHNIQUE

The clinical and scientific literature identifies two main approaches for increasing bone volume in the posterior maxilla of atrophic sites: the lateral window technique (open approach) and the transalveolar technique (closed approach with osteotomes) (32).

The choice between these methods primarily depends on the preoperative residual bone height (RBH) and the volumetric objectives of the implant rehabilitation.

1. Lateral Window Approach (Open Technique)

Originally described by Tatum in the 1970s, the lateral window represents the approach of choice in cases of severe bone atrophy, especially when the residual alveolar crest height is less than 5 mm (33).



(Image credit: "Maxillary Sinus Lift Surgery: Description and Comparison of the Different Techniques. Int J Dent Med." ByMacías Lloret A, Parra Rogel C, 2024)

Surgical Protocol:

A crestal incision with mesial and distal release is performed, raising a full-thickness flap to expose the buccal bone wall of the sinus.

A "trapdoor" osteotomy is then created on the lateral wall, allowing access to the Schneiderian membrane. The membrane is carefully elevated in an apical direction, creating a protected space for the graft (34).

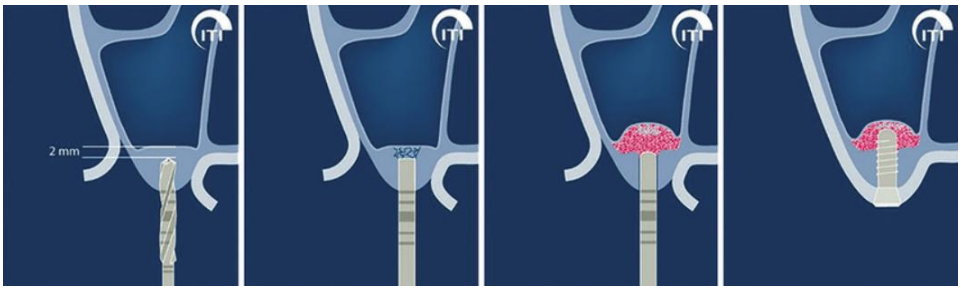
This method allows for significant vertical gains, exceeding 9 mm, making it ideal for substantial volumetric deficits.

Technological Advancements:

The introduction of piezoelectric surgery has made this procedure safer, reducing the risk of accidental perforations due to its selective action on mineralized tissues.

2. Trans-Alveolar Osteotome Approach (Closed Technique)

Introduced by Summers in 1994, the trans-alveolar approach is less invasive than the lateral window technique and is indicated when the residual bone height is equal to or greater than 5–6 mm.



(Image credit: "Minimally Invasive Transalveolar Sinus Augmentation: An Answer to Sinus Conundrum" Dentistry and Medical Research, by Saumiya Gopal et al. , 2020)

Surgical Protocol:

Site preparation does not differ from that of a standard implant in the posterior regions. Following a crestal incision, a full-thickness flap is elevated to expose the alveolar ridge, limiting flap elevation to the minimum necessary to avoid compromising the vascularization of the sinus membrane supplied by the supraperiosteal vessels along the buccal wall (35).

Sinus floor elevation can be performed according to three modalities:

- Elevation with biomaterials and simultaneous implant placement: indicated for ridges with a residual height of at least 5 mm below the sinus floor (31).

- Elevation without biomaterials with immediate implant placement: indicated for minor vertical gains (1–2 mm).

- Elevation with biomaterials without immediate implant placement: recommended when the residual height is less than 5 mm, postponing implant insertion to approximately 6 months after graft healing.

Protocol with Osteotomes:

The crest is marked using a round bur; subsequently, a pilot drill is used to perform a perforation up to 1 mm from the sinus floor, defining the working length. The first osteotome (2.2 mm diameter) is introduced and advanced using delicate percussion, followed by osteotomes of increasing diameter up to the predetermined working length. This process generates bone chips (particulate bone) at the apical portion of the site, which is beneficial for osseointegration. If planned, the biomaterial is introduced and compacted using the final osteotome employed, thereby increasing the hydraulic pressure beneath the Schneiderian membrane and facilitating its elevation. Subsequent increments of biomaterial are compacted until the desired volume is achieved.

An intraoral periapical radiograph, potentially with the osteotome in situ, allows for the verification of the degree of sinus floor elevation achieved.

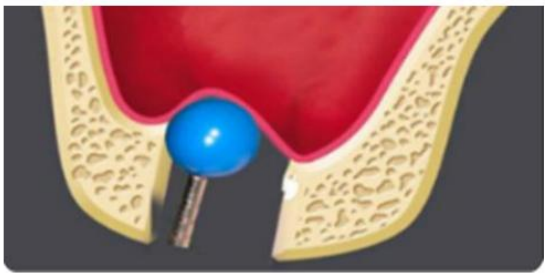
Any residual granules of biomaterial are removed from the walls of the osteotomy canal to maximize direct contact between the native bone and the implant surface.

Finally, the implant, featuring a diameter slightly larger than the osteotomy site, is placed, thereby completing the membrane elevation and the compaction of the underlying grafting material.

3. Emerging Minimally Invasive Methodologies

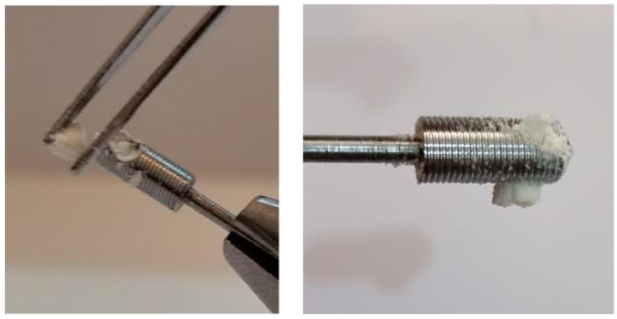
The pursuit of increasingly less traumatic protocols has led to the development of innovative approaches:

- Antral Membrane Balloon Elevation: the Schneiderian membrane is gradually elevated through controlled pressure exerted by a latex balloon, reducing the risk of perforations and post-operative discomfort (36). However, a critical constraint is the lack of direct visualization. This "blind" approach poses a significant risk when anatomical irregularities, such as Underwood's septa, are present, as small or occult perforations may go undetected, potentially leading to secondary iatrogenic sinusitis (1)



(Image credit: "Maxillary sinus lifting procedures" Int J Dent Med Sci Res., by Amudalapalli M. et al. , 2008)

- Bioactive screw systems: novel implants that combine osteotomy, autologous grafting, and implant stabilization in a single surgical phase; however, long-term efficacy still requires confirmation through longitudinal studies (37). Nonetheless, their clinical reliability is limited in cases of extreme vertical atrophy (residual bone height < 4mm), where achieving adequate primary stability remains a challenge. Furthermore, the biological quality of the bone-to-implant interface generated by these rapid protocols requires further validation compared to traditional staged grafting techniques (2)



(Image credit: "Maxillary sinus lifting procedures" Int J Dent Med Sci Res., by Amudalapalli M. et al. , 2008)

4. Timing of Implant Placement

The placement of implants can follow two protocols:

- One-stage (simultaneous): insertion performed concurrently with the sinus lift, indicated only when there is sufficient residual bone height (>4-5 mm) to guarantee primary stability (38).

- Two-stage (delayed): the implant is placed only after the healing and maturation of the graft, typically 6 months after the elevation with biomaterials.

The landscape of maxillary sinus elevation techniques has significantly evolved since the initial protocols of Tatum and Summers, shifting the focus not only to the quantity of bone gained but also to the reduction of operative morbidity and the precision of surgical maneuvers.

Although the lateral window technique remains the "gold standard" for cases of severe atrophy, the introduction of piezoelectric surgery has marked a fundamental turning point. Unlike traditional rotary instruments, piezoelectric inserts utilize ultrasonic micro-vibrations that act selectively on mineralized tissues.

As highlighted in the literature and supported by clinical studies (including those analyzing flap safety, such as Tanner), this technology allows for the performance of the lateral wall osteotomy with a drastically reduced risk of Schneiderian membrane perforation.

The "soft-tissue saving" nature of ultrasound ensures that, in the event of accidental contact with the membrane, it remains undamaged, significantly improving the prognosis of the procedure.

DESCRIPTION OF COMMONLY USED MATERIALS

Maxillary sinus elevation represents a fundamental procedure in the implant rehabilitation of the posterior maxillary sectors, especially in cases of severe bone atrophy.

One of the key elements for the biological and clinical success of the intervention is the choice of grafting material.

This material must ensure bone neoformation, long-term volumetric stability, and the capability to correctly integrate the implants.

The decision depends on various factors, including the residual bone height, the amount of bone required, the biological and mechanical characteristics of the material, and the specific needs of the patient.

The scientific literature has identified several categories of materials, each with specific advantages and limitations, which we will analyze in detail.

AUTOLOGOUS BONE

Autologous bone (or autograft) has represented the gold standard for maxillary sinus elevation for decades due to its complete biological properties: it is osteogenic, osteoconductive, and osteoinductive.

Osteoconductivity refers to the ability of a graft to function as a scaffold for the formation of new bone tissue: the graft is progressively colonized by blood vessels that transport osteoprogenitor cells from both the circulation and surrounding tissues, allowing for the gradual replacement of the graft itself with neoformed bone that develops from the periphery toward the center. All the previously mentioned materials possess osteoconductive properties.

Osteoinduction, on the other hand, indicates the ability of a tissue to stimulate the differentiation of pluripotent mesenchymal cells, originating from both the recipient site and the blood, into osteoblasts, promoting bone formation both within the graft and in the surrounding tissue. This function is mediated by the release of biochemical signals from the graft that induce bone differentiation, including the so-called Bone Morphogenetic Proteins (BMPs). Osteoinductive properties are typical of autologous and allogenic bone.

It is evident how autologous bone, by integrating osteoconductive, osteoinductive, and osteogenic capacities, is unanimously recognized as the gold standard in peri-implant bone

reconstruction procedures. The primary objective of utilizing this material is to maximize the formation of "Vital Bone." As defined in the pivotal studies by Wallace and Froum, this term refers to the percentage of newly formed, mineralized, and vascularized bone tissue produced by the patient's own metabolism, which is histologically distinguishable from residual graft particles still undergoing the resorption process.

It is harvested from intraoral sites, such as the symphysis, mandibular ramus, tuber maxillae, edentulous ridges, zygomatic process, nasal spine, or exostoses; alternatively, it can be harvested from extraoral sites, such as the iliac crest, cranial vault, or tibia, always obtained from the same recipient individual.

The ability to promote bone neoformation directly derived from the progenitor cells contained within the harvested tissue guarantees rapid osseointegration and predictable long-term results.

Furthermore, there are no immunological compatibility issues, as the organism recognizes the graft as "self"; additionally, it can be obtained at a low cost since its harvesting requires only standard surgical and therapeutic materials.

Several studies and systematic reviews confirm that the use of autologous bone alone yields a high percentage of neoformed bone tissue and high implant success rates.

However, the use of autologous bone is limited by material availability and donor site morbidity: the harvesting procedure may not be applicable in elderly patients, pediatric patients, or in cases of neoplastic diseases.

From a clinical perspective, as highlighted by the systematic review of Wallace and Froum (3), a significant limitation of autologous bone is its high rate of early volumetric resorption. If used as the sole grafting material, the rapid degradation of the volume may compromise the structural support required for implants over the long term.

Moreover, the procedure may involve pain, edema, and risks associated with the secondary surgical site. (39)

ALLOGRAFT

Homologous bone (allograft) constitutes a valid alternative to autologous bone, as it is harvested from donors belonging to the same species as the recipient. Transplantation can be performed using bone tissue from either living donors, such as femoral heads removed during hip arthroplasty, or cadaveric donors. In both cases, the material must undergo specific processing protocols and subsequently be stored in authorized bone banks to ensure biological safety and clinical suitability.

From a biological perspective, the allograft possesses primarily osteoconductive properties and may manifest limited osteoinductive capacity if, depending on the processing methods, certain growth factors remain present (40).

According to the systematic evidence provided by Wallace and Froum, allografts demonstrate implant survival rates comparable to autologous bone, although they exhibit a distinct bone remodeling rate that requires careful clinical monitoring. (3)

However, the sterilization procedures required to reduce the risk of infection can compromise the mechanical characteristics of the material and lead to the inactivation of the bioactive proteins normally contained within vital bone.

In the past, the use of allografts raised concerns regarding the possible transmission of infectious agents; today, however, the evolution of harvesting, treatment, and preservation techniques has significantly reduced these risks, making their clinical use considerably safer.

The main limitations associated with this type of graft include high costs related to complex collection and processing procedures, lower mechanical resistance compared to autologous bone, reduced osteoinductive capacity, and a residual, albeit minimal, risk of infection.

XENOGRAFTS

To reduce the risks associated with autologous harvesting and minimize post-operative morbidity, xenogenic materials have been developed.

These consist of heterologous bone from species other than the recipient, which can be of bovine, equine, or porcine origin.

Among these, deproteinized bovine bone mineral (DBBM) is one of the most widely used.

These materials offer high osteoconductive properties, a porous structure similar to human bone, and slow resorption, ensuring long-term volumetric stability.

The crucial advantage of xenografts, as emphasized by Wallace and Froum, lies in their excellent volumetric stability. By acting as a slow-resorbing "scaffold," they prevent the collapse of the Schneiderian membrane and maintain the space necessary for regeneration.

Conversely, the main disadvantage is their purely osteoconductive nature: the material does not provide living cells, and the process of replacement with Vital Bone is extremely slow, often leading to the persistence of non-resorbed granules even several years after the procedure.

Heterologous grafts offer advantages over autologous bone, such as high material availability, making them suitable even for large defects, and reduced invasiveness for the patient, who does not need to undergo a second surgical procedure for bone harvesting, resulting in shorter healing times and no residual disability (41).

Bioglasses are silicate-based biomaterials characterized by high biocompatibility and marked osteoconductive properties.

They establish a physicochemical bond with the surrounding bone tissue through the superficial formation of a calcium phosphate (Ca-P) layer.

These materials are considered non-resorbable, as osteoclasts are unable to degrade silicate-based structures; consequently, the bioglass persists over time as an extremely resistant glassy matrix.

Due to these characteristics, it is clinically indicated in cases requiring high structural stability combined with good integration with the recipient site.

Although it is used both in Guided Bone Regeneration (GBR) procedures and in maxillary sinus lift interventions, its granular and non-porous structure limits the capacity for revascularization and volumetric filling compared to other grafting materials.

The literature highlights that the physicochemical characteristics of the material, such as porosity, particle size, and crystallinity, significantly influence bone neoformation and integration with the native bone tissue.

Xenografts are often used in combination with autologous bone to maximize volumetric gain and long-term stability, allowing for vertical augmentation even in cases of severe atrophy. (41)

However, among the disadvantages of using this type of material, we observe the risk of infection at the implant site, the possibility of pathogen transmission, and host sensitization to donor proteins.

SYNTHETIC MATERIALS

Synthetic bone substitutes, such as beta-tricalcium phosphate (β-TCP), porous hydroxyapatite (HA), and bioglasses, represent a completely artificial alternative, free from immunological risk or pathogen transmission. They do not present risks of immune or foreign-body reactions, guarantee short recovery periods, are free of systemic or local toxicity, and are easily sterilized and commercially available (41).

These materials offer high biocompatibility and osteoconductivity, allowing for bone ingrowth along the material surface and providing a stable scaffold for the neoformed tissue. However, Wallace and Froum observe that the percentage of Vital Bone formed within the sinus is generally lower than that achieved with natural grafts, as artificial materials provide a biological potential limited primarily to surface conduction.

Although the quantity of neoformed bone is generally lower than that of autologous bone, synthetic substitutes show comparable clinical results in terms of implant success rates, with the added advantage of reducing morbidity and surgical time (43).

Hydroxyapatite is recognized as an osteoconductive and substantially non-resorbable material, whereas tricalcium phosphate also possesses osteoconductive properties but is rapidly resorbed by the body. To simultaneously exploit the advantages of both materials, biphasic calcium phosphates (BCP) have been developed—combinations of hydroxyapatite and tricalcium phosphate—which allow for the integration of the volume-maintenance capacity of hydroxyapatite with the natural resorbability of tricalcium phosphate (44).

COMPOSITE MATERIALS

In recent years, the use of composite materials, which combine autologous bone with xenografts or synthetic substitutes, has become increasingly widespread.

This combination is strategic for optimizing the histomorphometry of the regenerated site: the autologous bone provides the cellular component necessary for Vital Bone formation, while the xenograft ensures the volumetric stability required to prevent graft resorption. (3)

These materials merge the biological properties of autologous bone, specifically its osteogenic capacity, with the volumetric stability of substitutes, ensuring predictable bone augmentation even in the most complex cases. Furthermore, the systematic evidence (3)confirms that long-term success is significantly influenced by the use of textured (rough) implant surfaces and the placement of a barrier membrane over the lateral window, ensuring survival rates comparable to those found in non-augmented bone.

This combination proves particularly effective in significant vertical augmentations, where compressive strength and volume persistence are fundamental.

Clinical studies have highlighted that composite materials maintain volume over time better than autologous bone alone, thereby offering greater predictability of clinical outcomes. (45)

INNOVATIVE MATERIALS AND ALTERNATIVE SOURCES

Recently, new sources of biomaterials have been introduced, including autologous tooth graft material (ATGM), biological membranes, and bioactive materials.

ATGM, for example, exploits a chemical composition similar to human bone and represents an interesting alternative for reducing morbidity and healing times.

Membranes and platelet concentrates, such as PRF (platelet-rich fibrin), can be used in combination with other materials to promote bone regeneration, stimulate neoangiogenesis, and improve graft stability.

Although promising, these innovative approaches require further clinical trials and long-term follow-up to confirm their efficacy (46).

The choice of grafting material must be carefully evaluated in relation to the patient's clinical situation. In general:

- Autologous bone remains the reference for osseointegration and bone neoformation, especially when available in sufficient quantities.
- Allografts represent a valid alternative to avoid autologous harvesting, offering good osteoconductive properties and limited osteoinduction, albeit with lower mechanical resistance and a residual risk of infection.

- Xenografts and synthetic substitutes are indicated when the objective is to reduce morbidity or in cases where patients have limited autologous bone availability.

- Composite materials represent an effective strategy to combine the biological properties of different materials and enhance volumetric stability.

- New sources and bioactive materials offer innovative possibilities, particularly for selected patients or within minimally invasive protocols.

Ultimately, the choice of biomaterial must be carefully weighed based on the type of atrophy, the required bone volume, the surgical technique employed, and the biological characteristics of the materials.
Current scientific evidence supports both the use of single materials and strategic combinations, aimed at ensuring effective and stable bone regeneration over time, an indispensable prerequisite for the long-term success of maxillary sinus elevations and implant rehabilitation.

DESCRIPTION OF COMPLICATIONS

Although maxillary sinus elevation is a predictable and widely utilized procedure in the implant rehabilitation of the atrophic upper maxilla, the use of bone regeneration materials is not exempt from clinical and biological complications.

It is crucial for the clinician to be aware of the potential issues related to both the surgical technique and the use of biomaterials, as these can negatively influence the graft outcome and the patient's health.

The incidence and nature of these complications are strictly related to the chosen surgical approach. Literature indicates that the lateral window technique, while allowing for greater visibility and higher volume gain, is associated with a higher overall complication rate, ranging from 15% to 25%, with Schneiderian membrane perforation being the most frequent occurrence. (4)

Conversely, trans-crestal techniques offer a less invasive profile and lower post-operative morbidity; however, they carry a "blind" procedural risk, where micro-perforations may go undetected due to lack of direct visualization. (5)

Furthermore, according to Anavi's findings, post-operative complications such as acute sinusitis or graft infection can occur in a small but significant percentage of cases, often necessitating prompt pharmacological or surgical intervention to prevent graft failure. (6)

PERFORATION OF THE SCHNEIDERIAN MEMBRANE

One of the most common complications associated with maxillary sinus lift surgery is the perforation of the Schneiderian membrane, which can occur during the creation of the lateral window or during the elevation of the sinus floor.

This lesion can facilitate the leakage or extrusion of the grafting material into the sinus cavity, increasing the risk of infection, delayed healing, and compromised graft stability.

Perforations are reported in the literature with a frequency ranging from 10% to over 40% and represent a risk factor for postoperative inflammatory complications(47).

ACUTE AND CHRONIC SINUSITIS

The presence of grafting materials or inflammatory cells within the maxillary sinus cavity can predispose to the development of acute or chronic sinusitis.

These infections manifest with symptoms such as facial pain, nasal congestion, mucopurulent discharge, and fever; they may require antibiotic therapy or, in more severe cases, otorhinolaryngological intervention for the drainage and removal of the displaced grafting material.

The incidence of sinusitis following the sinus lift procedure varies significantly in the literature but can reach 10-20% of cases, particularly in the presence of membrane perforations or pre-existing sinus pathologies (48).

MIGRATION OR EXTRUSION OF THE GRAFTING MATERIAL

The migration of the grafting material outside the intended site is another possible complication. In some instances, the biomaterial may displace into the maxillary sinus or adjacent soft tissues, leading to facial cellulitis or the formation of granulomas, consequently necessitating surgical removal and debridement.

These events are relatively rare but documented in the literature as possible adverse outcomes, especially when there is poor primary stability of the graft or a compromised Schneiderian membrane (48).

GRAFT INFECTION AND LACK OF OSSEOINTEGRATION

The risk of microbial infection of the graft is present, although rare, in sinus augmentation procedures.

This can occur due to either intraoperative contamination or postoperative bacterial colonization, potentially leading to sinusitis or local infections that hinder bone neoformation. Graft infections can cause wound dehiscence, loss of the regenerative material, and failure of the implant site, necessitating graft removal and a re-evaluation of the treatment plan (49).

ISSUES RELATED TO IMPLANT STABILITY

A grafting material that does not integrate correctly can negatively influence both the primary and secondary stability of the dental implant.

In some cases, allowing the grafted tissue to remain too mobile or unconsolidated can lead to the migration or dislocation of the implant into the maxillary sinus, especially in the presence of insufficient residual bone or inadequate bone neoformation (50).

OTHER INTRA- AND POST-OPERATIVE COMPLICATIONS

In addition to complications directly related to regenerative materials, the sinus lift procedure may involve other adverse events that often occur in combination with the use of grafts:

- Intraoperative or postoperative hemorrhages, especially in cases of complex vascular anatomy or in subjects with bleeding disorders.

  These represent a potential complication, particularly in lateral window sinus lift procedures. Bleeding may result from injury to the branches of the posterior superior alveolar artery or the infraorbital artery, especially in the presence of anatomical variants or an extensive lateral window. Although hemorrhage is controllable intraoperatively in most cases, inadequately managed bleeding can compromise surgical field visibility, increase the risk of membrane perforation, and promote the formation of postoperative hematomas, potentially delaying healing processes.

- Wound dehiscence with graft exposure.

  This constitutes a significant postoperative complication.

  It can be precipitated by excessive flap tension, poor soft tissue quality, or excessive graft volume.

  Graft exposure increases the risk of bacterial contamination, local infection, and partial or total loss of the regenerative material, sometimes necessitating graft removal and a re-evaluation of the treatment plan.

- Extensive inflammatory reactions, with edema and thickening of the sinus mucosa that can compromise natural drainage.

  The use of bone regeneration materials in maxillary sinus elevation can be associated with the development of local inflammatory reactions, the extent of which is influenced by the biomaterial's characteristics, its resorption rate, and the patient's individual biological response.

  Specifically, materials with slow or no resorption may persist over time within the sinus cavity, inducing low-grade chronic inflammation or a foreign-body response.

  Clinically, such reactions can manifest as persistent edema, localized pain, and mucosal thickening, interfering with the revascularization and remodeling processes of the graft and potentially compromising the quality of the neoformed bone.

- Blockage of the sinus ostium due to swelling or impaired mucociliary clearance, with an additional risk of sinusitis.

  The ostium represents a fundamental structure for the drainage and ventilation of the maxillary sinus.

  Mucosal edema, sinus membrane thickening, or the migration of biomaterial particles can hinder mucociliary clearance, promoting secretion stagnation and increasing the risk of acute or chronic sinusitis.

  This condition is more frequent in patients with pre-existing rhinosinusitis pathologies and may require, in persistent cases, targeted pharmacological treatment or a multidisciplinary approach involving an Otolaryngologist.

The prevention of complications associated with regenerative materials in the maxillary sinus relies on a thorough preoperative assessment, which includes a comprehensive patient history, three-dimensional radiographic examinations (CBCT), and, if necessary, collaboration with an otolaryngologist to identify any pre-existing sinus pathologies. Careful planning, combined with the use of advanced surgical techniques (e.g., piezoelectric devices), can significantly reduce the incidence of membrane perforations and other adverse events.

When complications occur, management ranges from conservative procedures (clinical monitoring and antibiotic therapy for mild sinusitis) to corrective surgical interventions (repair of the Schneiderian membrane, removal of displaced material, or debridement). The literature suggests that timely interventions and regular follow-up improve long-term outcomes and reduce the risk of graft or implant failure.

MATERIALS AND METHODS

STUDY DESIGN AND SIMPLE SIZE CALCULATION

The present study was designed as a retrospective comparative investigation aimed at evaluating long-term marginal bone loss (MBL) following lateral sinus floor elevation (LSFE) procedures, comparing deproteinized bovine bone matrix to synthetic graft materials.

Given the retrospective nature of this clinical investigation, the sample size was primarily determined by case availability within the institutional database, reflecting real-world clinical follow-up over an extended period.

To justify the statistical validity of the available cohort, a post-hoc power analysis was performed for descriptive and exploratory purposes.

Statistical power was computed assuming a two-sided independent samples t-test (Welch's adaptation for unequal variances) with a significance level set at $\alpha = 0.05$. The statistical unit of analysis was defined as the single surgical intervention.

Due to the long-term, multi-centric, and retrospective design of the study, a progressive and physiological attrition of the sample size was observed across the designated follow-up intervals:

- 1-Year Follow-up: n = 21 total interventions (13 deproteinized material; 8 synthetic material).
- 5-Year Follow-up: n = 17 total interventions (8 deproteinized material; 9 synthetic material).
- 10-Year Follow-up: n = 12 total interventions (3 deproteinized material; 9 synthetic material).

Considering the sample size available at the final 10-year recall, the analysis was focused not only on strict hypothesis testing but also on the rigorous estimation of effect sizes (Cohen's d) and corresponding 95% confidence intervals to ensure clinical relevance. When multiple interventions were performed within the same patient, mixed-effects models were planned to mathematically account for intra-subject correlation.

PATIENT SELECTION: INCLUSION AND EXCLUSION CRITERIA

A meticulous screening of medical records and radiographic databases was conducted to select patients who underwent lateral sinus floor elevation. To be enrolled in the study, patients had to fulfill specific selection criteria.

INCLUSION CRITERIA

Patients were considered eligible for inclusion if they met all of the following requirements:

- Age ≥18 years at the time of the surgical intervention.
- Received a lateral sinus floor elevation procedure with either simultaneous or staged implant placement.
- Use of a resorbable barrier membrane (either collagen-based or pericardium-based) to protect the antrostomy.
- Availability of complete, high-quality, and standardizable radiographic documentation at baseline (immediately post-surgery/loading), 1 year, 5 years, and up to 10 years after functional loading.
- Sufficient residual alveolar bone quality and quantity to safely allow implant placement according to standard clinical protocols.
- Provision of a signed informed consent form for both the surgical treatment and the use of their clinical data for follow-up investigations.

EXCLUSION CRITERIA

Patients were excluded from the study if they presented any of the following conditions:

- Systemic medical conditions or disorders known to significantly affect bone metabolism or impair wound healing (e.g., uncontrolled diabetes mellitus, severe osteoporosis, metabolic bone diseases, or prolonged corticosteroid therapy).
- History of head and neck radiotherapy or recent chemotherapy.
- Active localized sinus pathology, acute or chronic sinusitis, or oro-antral communications present at the time of surgery.
- Heavy smoking habits, defined as smoking more than 10 cigarettes per day.
- Pregnancy or lactation at the time of the surgical procedure.
- Previous bone augmentation or reconstructive procedures performed in the same maxillary sinus.

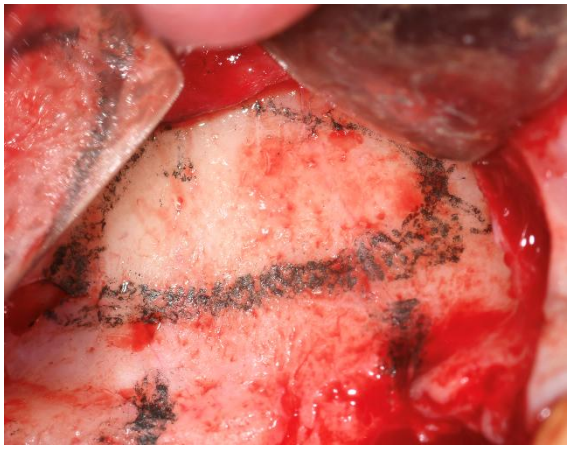
- Incomplete or unstandardizable radiographic or clinical follow-up data at any of the mandatory recall intervals

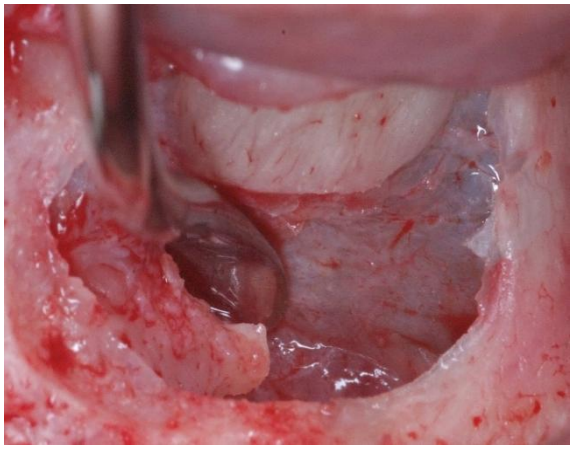
SURGICAL PROCEDURE

The lateral sinus lift procedures were all performed using a standardized lateral window approach under local anesthesia in an outpatient setting.

SURGICAL ACCESS AND ANTROSTOMY

Following local anesthesia with articaine 4% with epinephrine 1:100,000, a mid-crestal incision with one or two small vertical releasing incisions was made to expose the lateral wall of the maxilla in the edentulous posterior area. A full-thickness mucoperiosteal flap was elevated to obtain adequate access and visibility of the lateral sinus wall. A lateral antrostomy was then prepared using rotary instruments under copious sterile saline irrigation, creating a bony window of sufficient size to allow sinus membrane elevation and graft placement while preserving the integrity of the Schneiderian membrane.

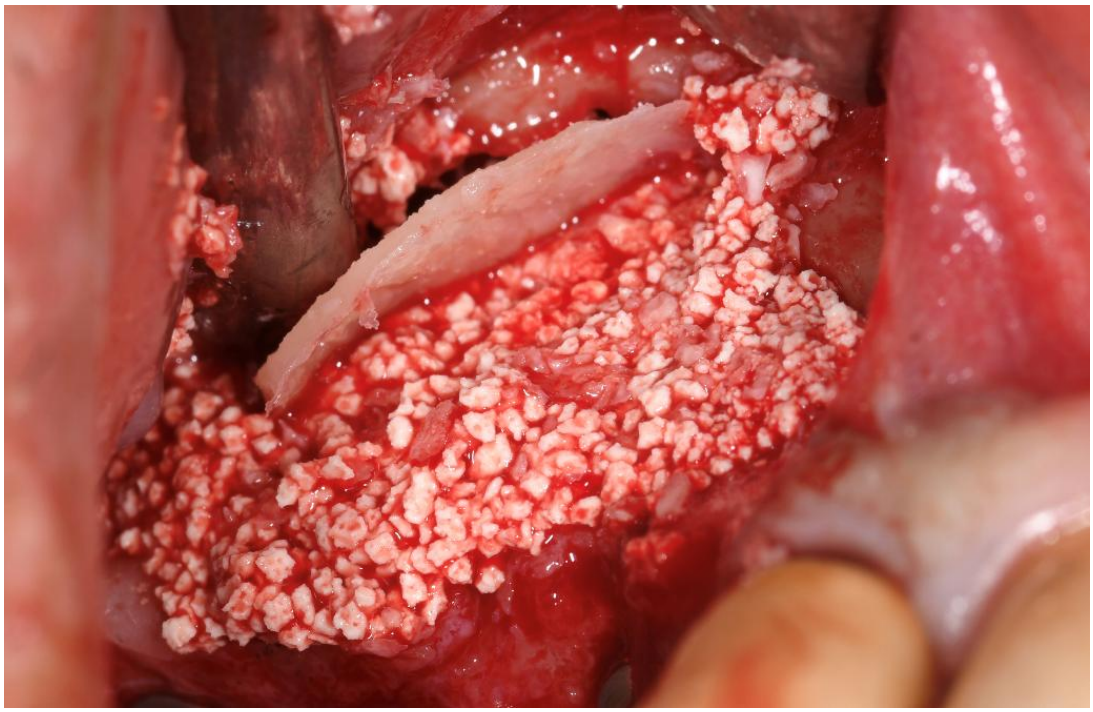




The bony window was either infractured and hinged or carefully removed, and the sinus membrane was elevated from the sinus floor and surrounding bony walls with dedicated sinus curettes to create a compartment for the graft material. Care was taken to avoid perforations of the sinus membrane; in the event of minor perforation, elevation was continued cautiously after ensuring membrane integrity was functionally restored according to standard practice.

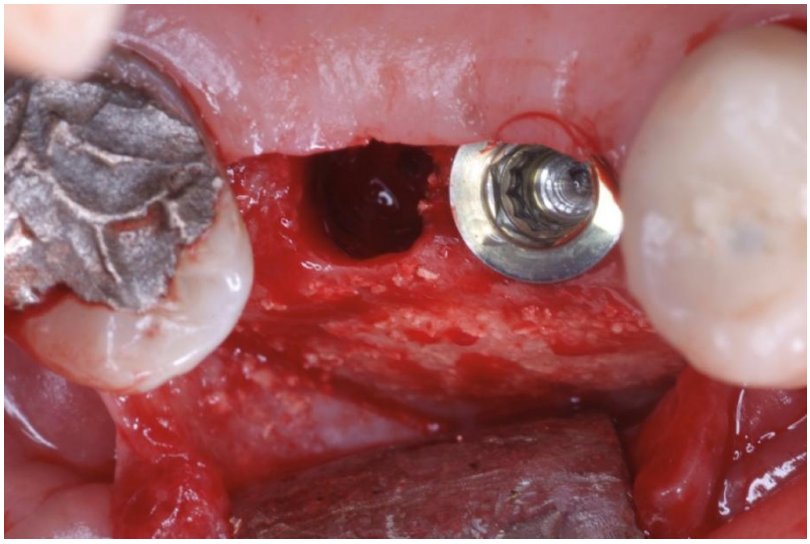
GRAFTING MATERIAL SELECTION AND SINUS FILLING

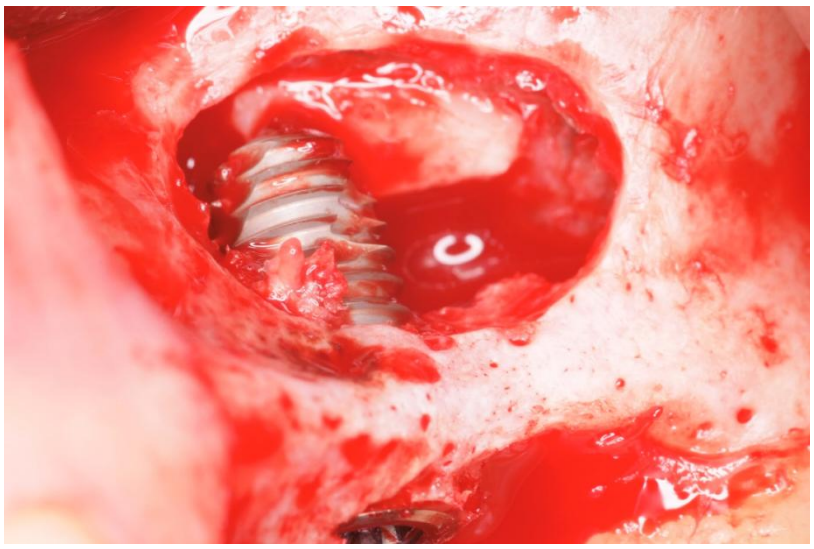
After complete elevation of the sinus membrane in the planned region, the subantral space was grafted using a particulate bone substitute. The graft material was selected intraoperatively at the discretion of the surgeon between deproteinized bovine bone mineral and a synthetic hydroxyapatite, and this choice was made independently for each case based on clinical and radiographic considerations. Once the material had been selected, all sinuses were filled following the same protocol, placing the particulate graft in small increments through the lateral window and gently compacting it to obtain a homogeneous fill without excessive pressure on the membrane. The graft was extended to achieve the planned vertical augmentation required for future or simultaneous implant placement, maintaining at least 1–2 mm of space between the most coronal portion of the graft and the elevated membrane to reduce the risk of tension and perforation.



IMPLANT PLACEMENT TIMING AND LOADING

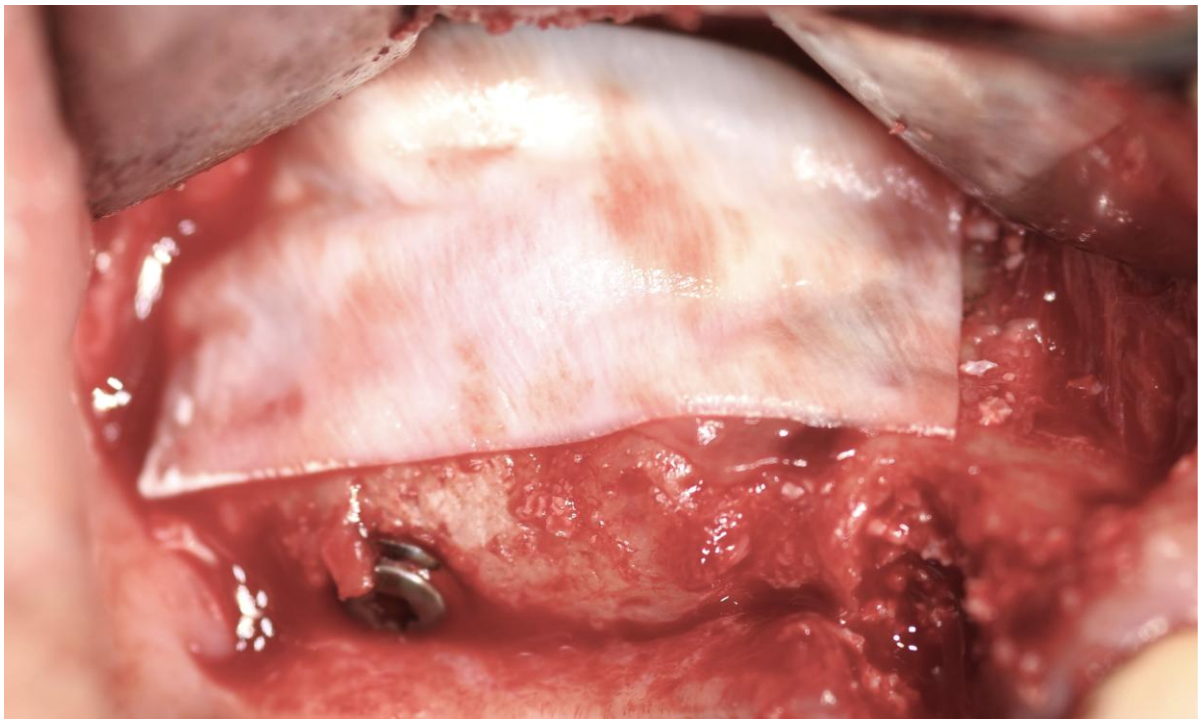
The decision for immediate or delayed implant placement was based on the residual alveolar bone height measured on preoperative radiographs and CBCT scans. In sites with a minimum of 4–5 mm of residual alveolar bone, implants were placed simultaneously with the sinus augmentation through the crestal aspect using a one-stage lateral antrostomy approach, provided that adequate primary stability could be achieved. When the residual bone height was less than 4–5 mm, only the sinus augmentation was performed, and implant placement was planned as a second-stage procedure after a healing period of 6–8 months to allow sufficient graft consolidation. For both immediately placed and delayed implants, the prosthetic loading was postponed, and all implants were restored after a total healing period of approximately 9–10 months from the time of sinus augmentation to ensure adequate osseointegration in the augmented area.





CLOSURE AND POSTOPERATIVE MANAGEMENT

After graft placement and, when indicated, implant installation, the lateral window was covered with a resorbable barrier membrane either in native collagen or derived from pericardium to protect the graft and stabilize the blood clot during the initial healing phase.



The mucoperiosteal flap was repositioned and sutured with interrupted or mattress sutures to obtain primary closure without tension, and patients were instructed to avoid wearing removable prostheses that could interfere with the surgical site during early healing. Postoperatively, all patients received systemic antibiotic therapy with co-amoxiclav 1 g every 8 hours for 6 days, starting on the day of surgery, in accordance with commonly used prophylactic regimens for sinus augmentation procedures. In addition, dexamethasone 2 mg once daily was prescribed for 3 days to reduce postoperative edema and discomfort, together with non-steroidal or other analgesics taken as needed according to individual pain levels. Patients were instructed to perform mouth rinses with 0.20% chlorhexidine gluconate three times daily for local plaque control and to support soft tissue healing around the surgical site. They were also given specific postoperative sinus precautions, including strict avoidance of nose blowing for 10 days and refraining from sneezing with a closed mouth, in order to minimize the risk of sinus membrane displacement, bleeding, or graft migration.

OUTCOME MEASURES

The clinical and radiographic success of the lateral sinus floor elevation (LSFE) procedures was evaluated based on pre-established primary and secondary outcome measures.

The primary outcome measure was defined as the long-term marginal bone loss (MBL) measured longitudinally around the stable dental implants, evaluated to compare the clinical behavior of two different graft materials: deproteinized bovine bone mineral and synthetic hydroxyapatite. MBL was measured at the 1-year, 5-year, and 10-year follow-up intervals relative to the baseline (T_0).

The secondary outcome measures included:

- Implant failure and survival rates: defined as the definitive loss of the fixture requiring removal due to biological or mechanical complications, evaluated out of the total pool of 50 initially placed implants.
- Clinical complications: recorded in absolute values and analyzed in direct relation to the specific bone graft materials employed (synthetic material versus deproteinized bovine bone matrix)

RADIOGRAPHIC EVALUATION

Longitudinal changes in marginal bone loss (MBL) were assessed through digital intraoral periapical radiographs.

All radiographic assessments and linear measurements were carried out by a single investigator utilizing digital imaging software (MicroDicom® DICOM Viewer, MicroDicom, Sofia, Bulgaria).

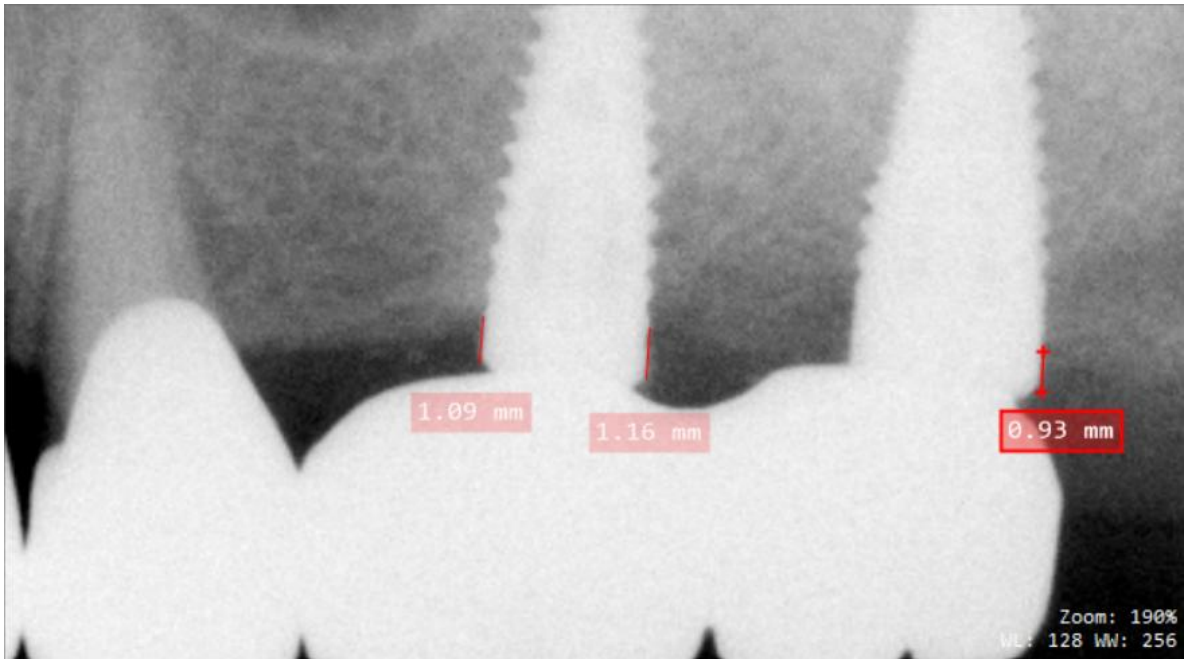
To correct for any geometric distortion or magnification errors inherent to individual radiographic exposures, radiographic calibration was standardized across timepoints using the actual implant length

Linear bone measurements were recorded at both the mesial and distal aspects of each stable implant. The reference landmarks for measurement were defined as follows:

- The Implant-Abutment Junction (Implant Head): Utilized as the primary baseline coronal reference point 0 mm.

- The Alveolar Bone Crest: Defined as the highest point where the bone-to-implant contact was radiographically visible.

Initially, the vertical distance from the implant head to the bone crest was recorded at baseline, immediately following prosthetic loading (T0). During the subsequent longitudinal recall intervals (1 year, 5 years, and 10 years), subsequent periapical radiographs were analyzed. Mesial and distal bone level values were measured independently for each single implant to calculate a mean bone level representing the total bone loss at that specific chronological point.



The definitive Marginal Bone Loss (MBL) for each chronological check-point was mathematically calculated according to the following formula:

$$MBL = T_0 - Mean\ Total\ Bone\ Loss\ _{Time\ X}$$

According to this mathematical convention, the subtraction yielded the final effective bone remodeling value over time.

In addition to radiographic MBL, implant survival rates were tracked as a complementary clinical parameter. Implant failure was defined as the definitive loss of a fixture requiring removal.

Within the evaluated database of 50 initially placed implants, 2 fixtures failed in 2 separate patients. Since each of these patients retained a secondary, fully stable and functioning

implant within the augmented sinus cavity, the underlying surgical interventions were not excluded from the study.
Longitudinal MBL tracking was successfully continued by focusing exclusively on the remaining stable fixtures.

DATA MANAGEMENT AND STATISTICAL ANALYSIS

The gathered clinical and radiographic dataset was sorted and systematically tabulated utilizing digital spreadsheet software (Microsoft Excel). Patients were rigorously stratified into distinct digital databases according to the specific graft material utilized during the lateral sinus floor elevation surgery (namely, synthetic material or deproteinized bovine bone matrix) and further subdivided based on the longitudinal recall intervals (1 year, 5 years, and 10 years).

Descriptive statistics, including the group means and corresponding standard deviations (SD) of the MBL, were computed within the spreadsheet framework.
Inferential statistical analyses and high-resolution graphical visualizations were executed utilizing Python Programming Language (Version 3.10) through advanced scientific computing libraries, specifically Pandas for data manipulation, SciPy (Stats module) for computation, and Seaborn/Matplotlib for plot rendering.

Continuous radiographic variables were checked for normal distribution. Comparative hypotheses regarding the marginal bone loss (MBL) between the deproteinized graft group and the synthetic graft group across the three designated follow-up periods (1, 5, and 10 years) were evaluated using the Independent Samples t-test (incorporating Welch's correction for unequal variances) to compare group means and standard deviations (SD), under the following statistical framework:

- Null Hypothesis (H_0): The means of marginal bone loss (MBL) in the two grafting groups are equal across the longitudinal timelines.
- Alternative Hypothesis (H_1): The means of marginal bone loss (MBL) in the two grafting groups are not equal across the longitudinal timelines.

The threshold for statistical significance across all executed inferential tests was set *a priori* at $p < 0.05$.

RESULTS

1-YEAR FOLLOW-UP OUTCOMES

At the 1-year evaluation interval, 21 stable fixtures were radiographically monitored, involving 13 implants in the deproteinized bovine bone matrix group and 8 implants in the synthetic material group.

The descriptive analysis for marginal bone loss (MBL) revealed an initial mean vertical bone loss of 0.38 ± 0.33 mm for the deproteinized cohort and 1.03 ± 0.90 mm for the synthetic cohort .

The Independent Samples t-test with Welch's correction showed that this initial clinical difference did not cross the threshold for statistical significance(t = - 1.9783, df ≈8.2, p = 0.0824).

Patient	Sex	Type of Material	T 0	Mesial	Distal	Mean	MBL 1 year
P1	M	deprotenized	0	-0,25	-0,26	-0,26	0,26
P2	F	deprotenized	0	-0,24	0	-0,12	0,12
P3	M	deprotenized	-0,52	-0,57	-2,54	-1,56	1,04
P4	M	deprotenized	-0,4	-1,1	-1,2	-1,15	0,75
P5	F	deprotenized	-0,72	-0,26	-1,35	-0,81	0,09
P6	F	deprotenized	0	-0,27	-0,64	-0,46	0,46
P7	F	deprotenized	0	0	0	0,00	0,00
P8	F	deprotenized	0	-0,29	-1,1	-0,70	0,70
P9	F	deprotenized	0	-0,47	-0,48	-0,48	0,48
P10	M	deprotenized	0	-0,38	-0,29	-0,34	0,34
P11	M	deprotenized	0	0	-0,14	-0,07	0,07
P12	M	deprotenized	0	-0,52	-0,78	-0,65	0,65
P13	F	deprotenized	0	0	0	0,00	0,00

Table 1: Radiographic marginal bone loss (MBL) parameters at the 1-year longitudinal follow-up interval according to the utilized graft material: Deproteinized Bovine Bone Mineral

Patient	Sex	Type of Material	T 0	Mesial	Distal	Mean	MBL 1 year
P16	M	synthetic	-0,28	-0,78	-1	-0,89	0,61
P17	M	synthetic	0	-0,4	-0,87	-0,64	0,64
P18	F	synthetic	0	-0,41	-0,44	-0,43	0,43
P19	F	synthetic	1,99	-1,35	-1	-1,18	3,17
P20	F	synthetic	0	-0,47	-0,66	-0,57	0,57
P21	M	synthetic	0	-1,16	-0,75	-0,96	0,96
P22	M	synthetic	0	-0,95	-0,46	-0,71	0,71
P23	F	synthetic	0	-0,79	-1,58	-1,19	1,19

Table 2: Radiographic marginal bone loss (MBL) parameters at the 1-year longitudinal follow-up interval according to the utilized graft material: Synthetic Hydroxyapatite

Type of Material	n	Mean MBL	SD(mm)
deprotenized	13	0.38	0.33
synthetic	8	1.03	0.90

Table 3: Radiographic MBL parameters and distribution according to graft material (1 years post-loading)

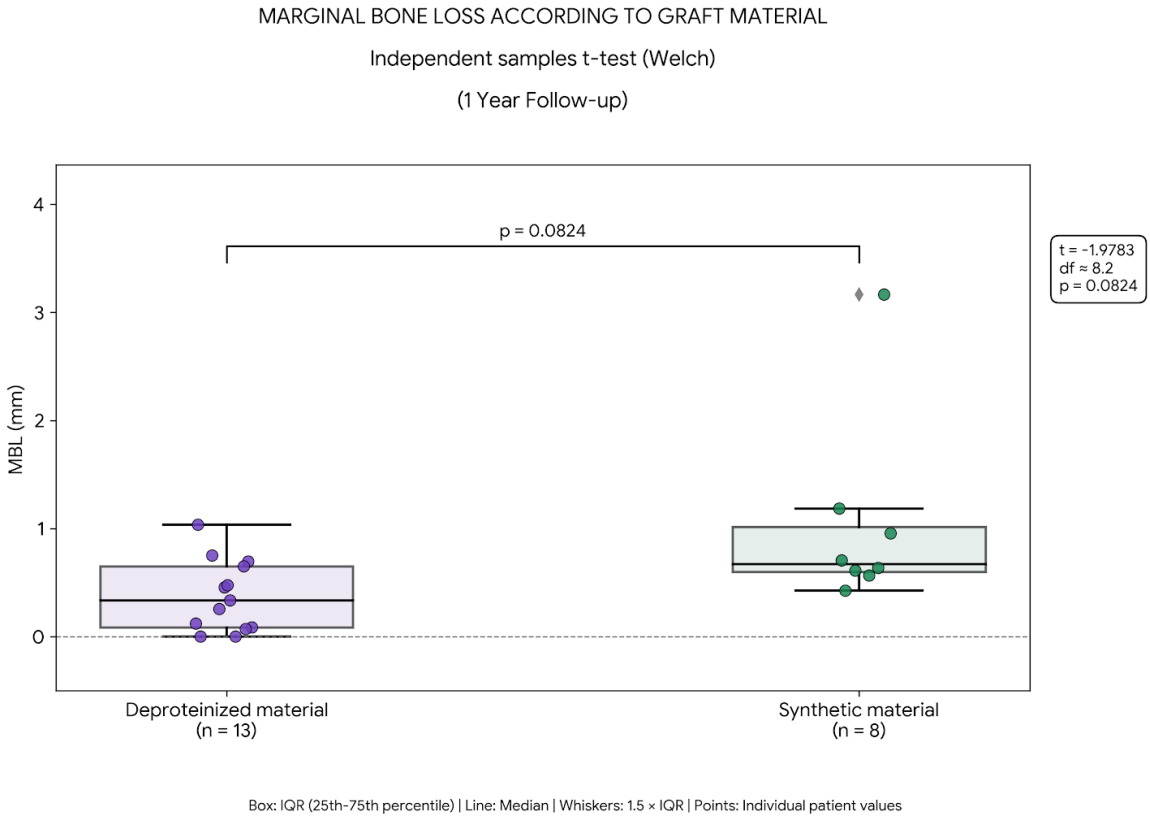


Table 4: Boxplot and individual patient values for 1-year marginal bone loss (MBL) comparing deproteinized and synthetic graft materials.

5-YEAR FOLLOW-UP OUTCOMES

At the 5-year longitudinal follow-up, data from 17 implants were available for comparison (8 in the deproteinized group and 9 in the synthetic group).

The descriptive analysis indicated a mean MBL of 0.70 ± 0.54 mm for the deproteinized group, whereas the synthetic material group displayed a higher bone loss of 1.57 ± 1.07 mm. Welch's t-test demonstrated that the difference between the groups approached the classic limit of statistical significance ($t = -2.1394$, $df \approx 12.1$, $p = 0.0535$).

Patient	Sex	Type of Material	T 0	Mesial	Distal	Mean	MBL 5 years
P1	M	deprotenized	0	-0,54	-0,34	-0,44	0,44
P2	F	deprotenized	0	-1,22	-1,74	-1,48	1,48
P3	M	deprotenized	-0,52	-0,73	-2,41	-1,57	1,05
P5	F	deprotenized	-0,72	-0,78	-0,97	-0,875	0,155
P6	F	deprotenized	0	-0,51	-0,82	-0,67	0,665
P7	F	deprotenized	0	0	0	0,00	0
P14	M	deprotenized	0	-0,48	-0,5	-0,49	0,49
P15	F	deprotenized	-1,3	-2,3	-2,96	-2,63	1,33

Table 5: Radiographic marginal bone loss (MBL) parameters at the 5-year longitudinal follow-up interval according to the utilized graft material: Deproteinized Bovine Bone Mineral

Patient	Sex	Type of Material	T 0	Mesial	Distal	Mean	MBL 5 years
P16	M	synthetic	-0,28	-0,9	-1,2	-1,05	0,77
P17	M	synthetic	0	-1,21	-1,13	-1,17	1,17
P18	F	synthetic	0	-0,55	-1,1	-0,83	0,83
P19	F	synthetic	+1,99	-1,4	-2,33	-1,87	3,86
P20	F	synthetic	0	-1,3	-1,98	-1,64	1,64
P21	M	synthetic	0	-2,23	-2,2	-2,22	2,22
P24	M	synthetic	0	-2,51	-2,07	-2,29	2,29
P25	F	synthetic	0	-0,35	-1,09	-0,72	0,72
P26	F	synthetic	0	-0,42	-0,8	-0,61	0,61

Table 6: Radiographic marginal bone loss (MBL) parameters at the 5-year longitudinal follow-up interval according to the utilized graft material: Synthetic Hydroxyapatite

Type of Material	n	Mean MB	SD(mm)
deprotenized	8	0.70	0.54
synthetic	9	1.57	1.07

Table 7: Radiographic MBL parameters and distribution according to graft material (5 years post-loading)

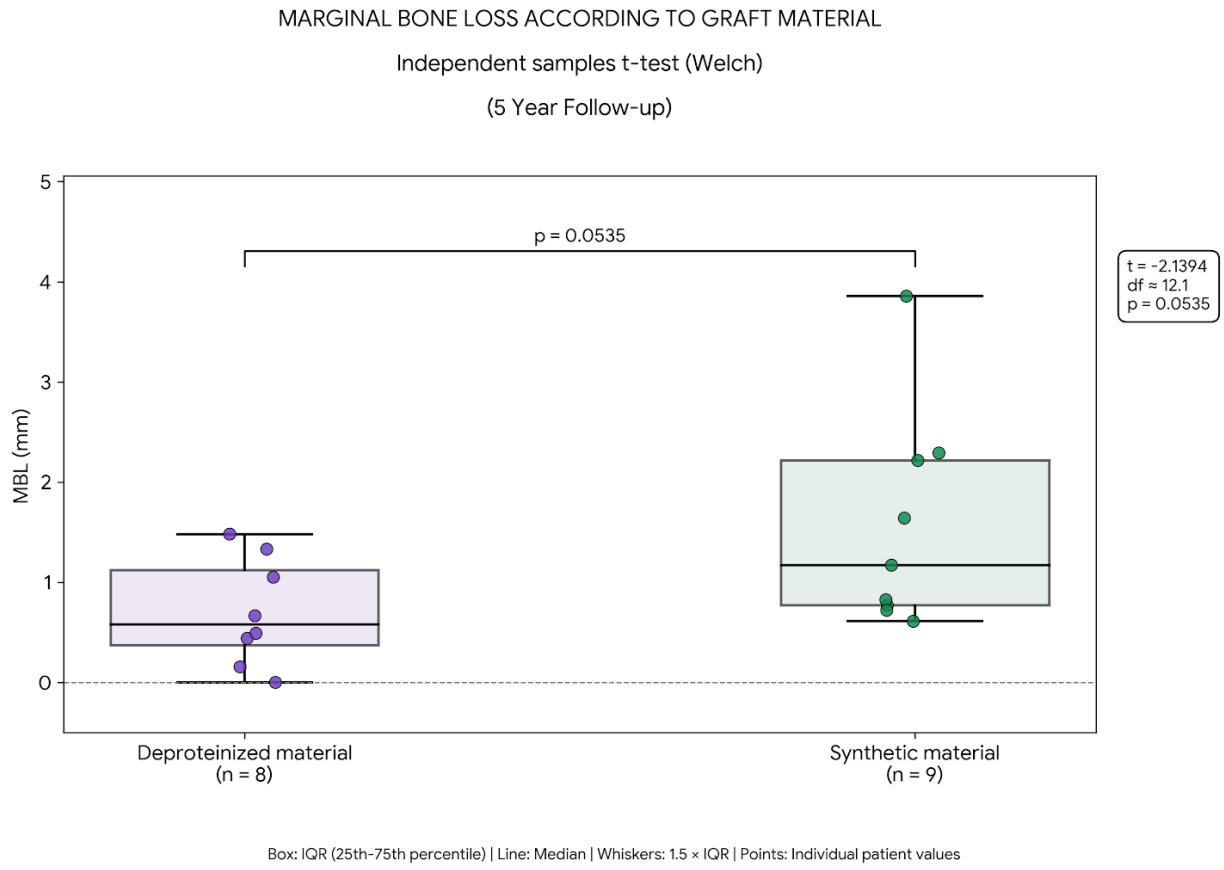


Table 8: Boxplot and individual patient values for 5-year marginal bone loss (MBL) comparing deproteinized and synthetic graft materials.

10-YEAR FOLLOW-UP OUTCOMES

At the maximum longitudinal milestone of 10 years, a total of 12 implants were successfully followed up (3 in the deproteinized matrix cohort and 9 in the synthetic material cohort).

The descriptive tracking showed a mean cumulative MBL of 1.14 ± 0.90 mm for the deproteinized patients and 1.89 ± 0.86 mm for the synthetic material patients.

Inferential statistical testing confirmed that the long-term difference was not significant due to the limited sample size in the deproteinized database at this extreme interval ($t = -1.2745$, $df \approx 3.3$, $p = 0.2843$).

Patient	Sex	Type of Material	T 0	Mesial	Distal	Mean	MBL 10 years
P1	M	deprotenized	0	-0,4	-0,3	-0,35	0,35
P3	M	deprotenized	-0,52	-2,49	-2,79	-2,64	2,12
P14	M	deprotenized	0	-0,89	-0,99	-0,94	0,94

Table 9: Radiographic marginal bone loss (MBL) parameters at the 10-year longitudinal follow-up interval according to the utilized graft material: Deproteinized Bovine Bone Mineral

Patient	Sex	Type of Material	T 0	Mesial	Distal	Mean	MBL 10 years
P16	M	synthetic	-0,28	-1,27	-1,3	-1,29	1,01
P17	M	synthetic	0	-2,11	-1,41	-1,76	1,76
P19	F	synthetic	+1,99	-1,41	-2,2	-1,81	3,80
P20	F	synthetic	0	-1,23	-2,19	-1,71	1,71
P21	M	synthetic	0	-2,29	-2,58	-2,44	2,44
P24	M	synthetic	0	-1,84	-2,79	-2,32	2,32
P25	F	synthetic	0	-0,72	-1,5	-1,11	1,11
P26	F	synthetic	0	-1,47	-1,43	-1,45	1,45
P27	F	synthetic	0	-1,51	-1,42	-1,47	1,47

Table 10: Radiographic marginal bone loss (MBL) parameters at the 10-year longitudinal follow-up interval according to the utilized graft material: Synthetic Hydroxyapatite

Type of Material	n	Mean MBL	SD(mm)
deprotenized	3	1.14	0.90
synthetic	9	1.89	0.86

Table 11: Radiographic MBL parameters and distribution according to graft material (10 years post-loading)

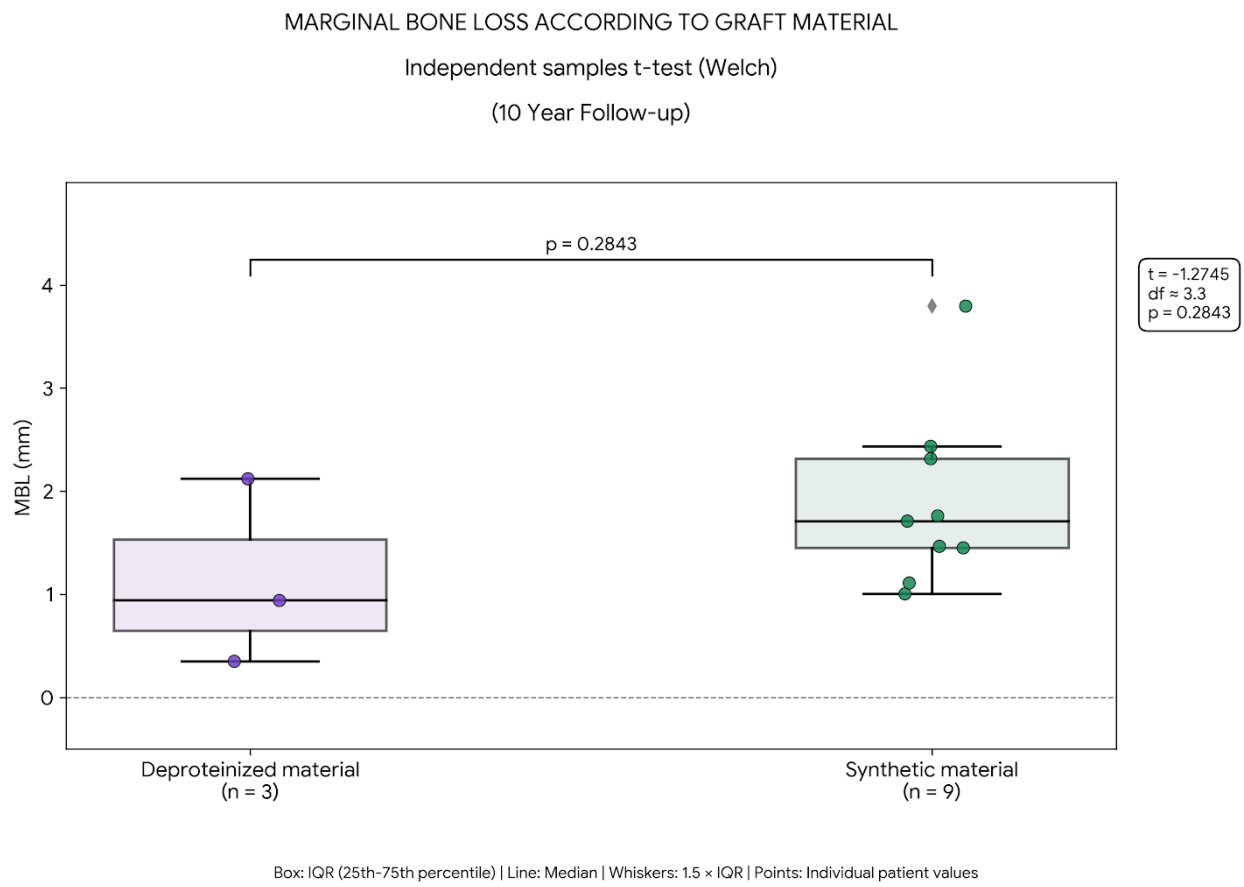


Table 12: Boxplot and individual patient values for 10-year marginal bone loss (MBL) comparing deproteinized and synthetic graft materials.

DISCUSSION

The present retrospective study aimed to evaluate the long-term radiographic outcomes of implants placed in sites previously augmented through lateral sinus floor elevation using either deproteinized bovine bone mineral (DBBM) or synthetic hydroxyapatite (HA). Clinical performance was assessed by measuring marginal bone loss (MBL) at 1, 5, and 10 year follow-up intervals, with the objective of determining whether the grafting material could influence peri-implant bone stability over time.

The results demonstrated that both biomaterials provided favorable long-term outcomes, with limited marginal bone loss and high implant survival throughout the observation period. In both groups, a gradual increase in MBL was observed over time, reflecting the physiological bone remodeling that typically occurs around dental implants placed in augmented maxillary sinuses. Nevertheless, implants associated with DBBM consistently exhibited lower MBL values compared with those grafted with synthetic hydroxyapatite at all follow-up intervals. Although these differences did not reach statistical significance, a clear numerical trend in favor of DBBM was evident throughout the entire follow-up period.

These findings suggest that both grafting materials represent clinically valid options for sinus floor augmentation procedures. However, the reduced marginal bone loss observed in the DBBM group may indicate a more stable long-term peri-implant bone response. This trend could be related to the biological characteristics of DBBM, which has been widely reported to exhibit slow resorption kinetics, prolonged scaffold persistence, and excellent volumetric stability. Such properties may contribute to maintaining a more favorable peri-implant environment and reducing the extent of marginal bone remodeling over time.

On the other hand, synthetic hydroxyapatite also demonstrated satisfactory clinical performance, supporting previous evidence that synthetic biomaterials can effectively promote bone regeneration while eliminating the potential biological concerns associated with xenogeneic grafts. Despite the slightly higher MBL values recorded in this group, implant survival remained favorable, suggesting that the observed differences may have limited impact on overall treatment success.

Taken together, these results indicate that LSFE is a predictable and effective procedure regardless of the grafting material employed. Nevertheless, the tendency toward lower marginal bone loss observed with DBBM warrants further investigation, particularly considering the potential clinical relevance of peri-implant bone preservation in the long term.

Although no statistically significant differences were detected between the two groups, it is essential to interpret these findings within the broader context of the existing scientific literature. Comparing the present results with those reported in previous clinical studies and systematic reviews may help clarify whether the observed trends reflect consistent biological differences between xenogeneic and synthetic grafting materials or are influenced by methodological factors such as sample size and follow-up duration.

In the following sections, the findings of the present study will be critically discussed in relation to the most relevant evidence available in the literature, with particular attention to marginal bone loss, implant survival, graft stability, biological behavior of the biomaterials, and their implications for long-term clinical outcomes.

MARGINAL BONE LOSS AND PERI-IMPLANT STABILITY AFTER SINUS FLOOR ELEVATION: COMPARISON WITH THE LITERATURE

The results obtained in the present study are substantially consistent with the evidence available in the literature regarding the use of deproteinized bovine bone mineral (DBBM) in maxillary sinus floor elevation procedures. Numerous studies have documented that this biomaterial represents a reliable and predictable solution for the treatment of posterior maxillary atrophy, allowing the achievement of adequate bone volumes for subsequent implant placement and ensuring high implant survival rates over the long term.
Among these, the study by Valentini and Abensur (53) reported particularly favorable outcomes, demonstrating that deproteinized bovine bone mineral graft is capable of effectively supporting new bone formation and maintaining graft stability over time.

The histological analyses reported by the authors revealed the presence of newly formed bone in direct contact with the residual particles of the biomaterial, confirming the high

osteoconductive potential of DBBM. Furthermore, the persistence of deproteinized bovine bone mineral particles several months after surgery, combined with the absence of evident resorption phenomena, suggests a remarkable ability of the material to preserve graft volume over time. These observations are particularly relevant when considered in light of the findings of the present study, in which the DBBM group exhibited consistently lower marginal bone loss values than the synthetic hydroxyapatite group at all follow-up intervals.

An additional point of interest emerges from studies that have directly compared xenogeneic and synthetic biomaterials in sinus floor elevation procedures. Trombelli and colleagues (54) reported that both DBBM and synthetic hydroxyapatite are capable of providing favorable clinical outcomes, with no evident differences in terms of implant success and long-term clinical stability. The authors further emphasized that previous comparative studies had demonstrated similarly positive outcomes for both materials, suggesting that xenogeneic and synthetic biomaterials may both represent valid therapeutic options for maxillary sinus bone regeneration.

These observations are consistent with the findings of the present study. Although the mean marginal bone loss values were lower in the DBBM group (0.38 mm at 1 year, 0.70 mm at 5 years, and 1.14 mm at 10 years) compared with the HA group (1.03 mm, 1.57 mm, and 1.89 mm, respectively), statistical analysis did not reveal any significant differences between the two biomaterials. This finding suggests that both materials are capable of ensuring long-term implant maintenance and further confirms the predictability of maxillary sinus floor elevation procedures regardless of the grafting material employed.

Nevertheless, the consistent trend observed in favor of DBBM deserves further consideration. Several authors have attributed to this biomaterial a particular ability to maintain graft volume over time due to its slow resorption kinetics and the persistence of residual particles within the regenerated tissue. The structural characteristics of deproteinized bovine bone mineral, whose porosity and architecture closely resemble those of human bone, promote colonization by osteogenic cells and the formation of new bone tissue while simultaneously maintaining a long-term mechanical support function.

Therefore, although the results obtained do not allow the assertion of a statistically significant superiority of DBBM over synthetic hydroxyapatite, they appear to support the hypothesis that the biological and physicochemical properties of this xenogeneic biomaterial may contribute to greater long-term peri-implant bone stability. This interpretation is consistent with the histological and clinical evidence reported in the literature and may represent a possible explanation for the lower marginal bone loss observed in the DBBM group throughout the follow-up period.
Despite the trend observed in favor of DBBM in terms of marginal bone loss, the interpretation of these findings requires a broader evaluation of the biological characteristics and remodeling behavior of synthetic hydroxyapatite-based biomaterials. Although DBBM is well known for its high dimensional stability and slow resorption kinetics, these properties should not necessarily be regarded as the sole indicators of regenerative success. Conversely, the ability of a biomaterial to be progressively replaced by vital bone may represent a relevant biological advantage, particularly with regard to tissue integration and the physiological renewal of the regenerated bone compartment.

In this context, several studies have confirmed the clinical and biological validity of hydroxyapatite-based synthetic biomaterials for maxillary sinus floor augmentation procedures. Scarano et al. (55), through a histological and histomorphometric analysis in humans, demonstrated that hydroxyapatite particles become closely integrated with newly formed bone, without evidence of inflammatory reactions or signs of biological incompatibility. The authors observed an intimate association between the graft material and newly formed bone, confirming the osteoconductive properties of hydroxyapatite and its ability to effectively support regenerative processes within the augmented maxillary sinus.

Similar findings were reported by Schmitt et al. (56) in a randomized clinical trial comparing different biomaterials for sinus floor augmentation, including Bio-Oss® and a biphasic synthetic graft composed of hydroxyapatite and β-tricalcium phosphate (BoneCeramic®). The authors observed a greater percentage of newly formed bone in the synthetic biomaterial group compared with the DBBM group, together with a lower amount of residual graft material after the healing period. These findings suggest a more dynamic remodeling process of synthetic bone substitutes and a progressive replacement of the graft by vital bone tissue. However, the authors also emphasized that it remains unclear whether a greater amount of

newly formed bone and a more rapid reduction of residual graft particles necessarily represent a clinical advantage compared with the greater volumetric persistence typically associated with DBBM.

An additional aspect that should be considered is the intrinsic heterogeneity of biomaterials classified as hydroxyapatite. Lambert et al.(57) demonstrated that materials sharing a similar chemical composition may exhibit substantially different biological performances depending on their microstructure, porosity, and surface topography. The observed differences in osteoconductivity and bone formation suggest that clinical performance is influenced not only by the nature of the biomaterial itself but also by its specific physicochemical characteristics and manufacturing processes.

In light of these considerations, the slightly greater marginal bone loss observed in the HA group of the present study should be interpreted with caution. Although DBBM consistently exhibited lower MBL values throughout the follow-up period, the absence of statistically significant differences and the available histological evidence reported in the literature indicate that hydroxyapatite-based synthetic biomaterials remain a valid option for bone regeneration in the posterior maxilla. Therefore, it is possible that the differences observed in the present study reflect distinct patterns of remodeling and maturation of the regenerated tissue rather than a true biological superiority of one material over the other.

CLINICAL SIGNIFICANCE OF THE FINDINGS

Although biological and histological differences between xenogeneic and synthetic grafting materials have been widely reported in the literature, the actual clinical relevance of these differences remains a matter of debate. The results of the present study suggest that both grafting materials are capable of providing favorable long-term outcomes following lateral sinus floor elevation, allowing implant maintenance and substantial peri-implant tissue stability throughout the follow-up period. Although the DBBM group consistently exhibited lower marginal bone loss values compared with the synthetic hydroxyapatite group, these differences did not reach statistical significance and were not associated with evident differences in implant survival or overall clinical success. This finding suggests that the radiographic variations observed between the two groups may not necessarily translate into clinically meaningful differences for the patient.

It is also important to consider that the long-term maintenance of osseointegrated implants is a multifactorial process influenced not only by the biological characteristics of the grafting material but also by numerous surgical, prosthetic, and patient-related variables. Factors such as the surgical technique employed, primary implant stability, occlusal load distribution, plaque control, long-term peri-implant tissue health, and the patient's systemic conditions may all contribute significantly to treatment outcomes, sometimes exerting a greater influence than the grafting material itself. From this perspective, the graft material should be regarded as one of several factors involved in the success of regenerative procedures rather than the sole determinant of the final outcome.

From a practical clinical standpoint, the findings of the present study support the use of both DBBM and synthetic hydroxyapatite as reliable treatment options for bone regeneration in the atrophic posterior maxilla. While DBBM appears to provide greater dimensional stability over time due to its slow resorption kinetics and prolonged persistence within the regenerated tissue, synthetic biomaterials offer several noteworthy advantages, including the absence of animal-derived components, unlimited availability, standardized manufacturing processes, and the potential for progressive replacement by vital bone during tissue remodeling. In light of these considerations, the choice of grafting material should not be based exclusively on its intrinsic biological properties but should also take into account the specific clinical

circumstances of each case, the clinician's experience and preferences, and the long-term therapeutic objectives of treatment.

STRENGTHS OF THE STUDY

The present study presents several strengths that contribute to its scientific relevance and clinical applicability. One of the most important strengths is the long-term follow-up period, with radiographic evaluations extending up to ten years after implant placement. Long-term evidence regarding maxillary sinus floor elevation procedures remains relatively limited in the current literature, as many studies report outcomes after one to five years of follow-up. Consequently, the availability of data collected over a decade provides valuable information regarding the long-term stability of peri-implant bone levels and the behavior of regenerated tissues over time. This extended observation period allows a more comprehensive assessment of treatment outcomes and offers clinically meaningful evidence regarding the durability of implant-supported rehabilitations performed in grafted posterior maxillary sites.

Another significant strength of the study is the direct comparison between deproteinized bovine bone mineral (DBBM) and synthetic hydroxyapatite (HA), two biomaterials that are widely used in clinical practice for sinus augmentation procedures. Although both materials have been extensively investigated individually, relatively few studies have directly compared their long-term performance under similar clinical conditions. Therefore, the present investigation contributes additional evidence to a topic that remains only partially clarified in the existing literature. By evaluating marginal bone loss over an extended follow-up period, the study provides useful information regarding the potential influence of grafting material selection on peri-implant bone stability.

Furthermore, the study reflects a realistic clinical scenario commonly encountered in implant dentistry. The rehabilitation of the atrophic posterior maxilla following sinus floor elevation continues to represent one of the most frequent indications for bone augmentation procedures. For this reason, the results obtained may be considered highly relevant to everyday clinical practice. Unlike highly controlled experimental settings, retrospective clinical investigations provide insight into the performance of treatment protocols under

routine conditions, thereby increasing the external validity and practical applicability of the findings.

An additional strength lies in the use of marginal bone loss as the primary outcome measure. Marginal bone stability is widely recognized as one of the most important indicators of long-term implant success and remains a frequently adopted parameter in implant research. The longitudinal assessment of peri-implant bone levels allowed a direct evaluation of tissue stability surrounding the implants and provided objective information regarding the long-term maintenance of the regenerated sites.

Moreover, all patients included in the study underwent treatment according to established surgical protocols and were followed using a consistent radiographic methodology. This methodological consistency contributed to reducing variability in data collection and facilitated reliable comparisons between the two study groups. Although retrospective by nature, the study maintained a structured approach to data analysis, allowing meaningful interpretation of the observed clinical and radiographic outcomes.

Finally, the study contributes to the growing body of evidence investigating the relationship between graft remodeling and long-term implant performance. While many investigations focus primarily on short-term bone formation or implant survival, the present study provides additional information regarding the long-term behavior of regenerated peri-implant tissues. This aspect is particularly relevant given the increasing life expectancy of patients and the growing demand for implant rehabilitations capable of maintaining stability and function over extended periods of time.

LIMITATIONS OF THE STUDY

Despite the encouraging findings observed in the present investigation, several limitations should be considered when interpreting the results. As with all retrospective studies, the study design itself represents an inherent limitation. Retrospective analyses rely on previously collected clinical and radiographic records and therefore do not allow complete control over all variables that may influence treatment outcomes. Although this methodology provides valuable information regarding the performance of therapeutic approaches in routine clinical practice, it is inevitably associated with a greater risk of bias when compared with prospective randomized clinical trials.

Another important limitation concerns the sample size and the progressive reduction in the number of patients available during follow-up. While the extended observation period represents one of the main strengths of the present study, maintaining patient compliance over a period of up to ten years is inherently challenging. As a consequence, the number of available radiographic evaluations gradually decreased over time, particularly at the longest follow-up intervals. This reduction may have affected the statistical power of the analyses and limited the ability to detect subtle differences between the two biomaterials. Interestingly, although the DBBM group consistently exhibited lower marginal bone loss values throughout the observation period, these differences did not reach statistical significance. Therefore, it cannot be excluded that a larger sample size may have revealed statistically significant differences between the groups.

A further limitation relates to the radiographic assessment methodology. Marginal bone loss was evaluated using standardized periapical radiographs, which remain one of the most widely accepted tools for monitoring peri-implant bone levels. Nevertheless, periapical radiographs provide only a two-dimensional representation of a highly complex biological process. While they allow accurate assessment of crestal bone changes around implants, they do not provide information regarding the three-dimensional architecture of the augmented sinus, volumetric graft stability, or the distribution of regenerated bone within the grafted area. Consequently, important aspects of graft remodeling may not have been fully captured by the radiographic analysis performed in this study.

In addition, the present investigation focused primarily on clinical and radiographic outcomes and did not include histological or histomorphometric evaluations. As a result, it was not possible to directly investigate the biological mechanisms underlying the observed radiographic findings. Parameters such as the percentage of newly formed bone, the persistence of residual graft particles, the degree of biomaterial substitution, and the quality of regenerated tissue could not be assessed. For this reason, the biological explanations proposed throughout the discussion remain speculative and are primarily based on evidence derived from previous histological studies available in the literature.

Another aspect that deserves consideration is the potential influence of patient-related and treatment-related factors that could not be completely standardized. Variables such as smoking habits, oral hygiene levels, systemic health conditions, periodontal history, prosthetic design, occlusal loading patterns, and individual healing capacity may all contribute to peri-implant bone remodeling over time. Although these factors reflect the complexity of everyday clinical practice and increase the external validity of the study, their influence cannot be completely excluded and may have contributed to the variability observed within the study population.

Finally, it should be emphasized that marginal bone loss, although widely recognized as a reliable indicator of peri-implant tissue stability, represents only one aspect of treatment success. Implant survival, prosthetic function, patient satisfaction, and the long-term maintenance of peri-implant health are equally important outcomes when evaluating the effectiveness of sinus augmentation procedures. Therefore, the interpretation of the present findings should be integrated within a broader clinical perspective rather than being limited exclusively to radiographic measurements.

Despite these limitations, the study provides clinically relevant information regarding the long-term behavior of DBBM and synthetic hydroxyapatite following lateral sinus floor elevation. The combination of a direct comparison between two widely used grafting materials and a follow-up period extending up to ten years represents a valuable contribution to the existing literature and offers useful insights into the long-term stability of implant-supported rehabilitations in grafted posterior maxillary sites.

FUTURE PERSPECTIVES

The findings of the present study provide valuable information regarding the long-term behavior of deproteinized bovine bone mineral (DBBM) and synthetic hydroxyapatite (HA) following lateral sinus floor elevation. However, they also highlight several areas that deserve further investigation in order to better understand the biological and clinical implications of graft material selection in maxillary sinus augmentation procedures.

One of the most important future objectives should be the development of prospective studies with larger sample sizes and standardized follow-up protocols. Although the present investigation demonstrated a consistent trend toward lower marginal bone loss values in the DBBM group, the absence of statistically significant differences prevents definitive conclusions regarding the superiority of one biomaterial over the other. Future studies involving larger patient cohorts may help clarify whether the trends observed in the present study represent true biological differences or simply reflect the variability associated with limited sample sizes.

Another promising area of research concerns the use of advanced imaging techniques for the evaluation of graft remodeling. While marginal bone loss remains one of the most widely accepted indicators of peri-implant tissue stability, it provides only partial information regarding the behavior of the grafted area. The incorporation of serial cone-beam computed tomography (CBCT) examinations could allow a more comprehensive assessment of volumetric changes, graft resorption patterns, and long-term dimensional stability. Combining peri-implant bone level measurements with three-dimensional volumetric analyses may provide a more complete understanding of the relationship between graft remodeling and implant outcomes.

Future investigations should also focus on the biological mechanisms underlying the different remodeling patterns observed among grafting materials. Histological and histomorphometric studies could help clarify the relationship between newly formed bone, residual graft particles, tissue maturation, and peri-implant bone stability. In particular, further research may help determine whether the greater dimensional stability typically associated with DBBM or the potentially more dynamic remodeling observed in synthetic

hydroxyapatite-based biomaterials translates into clinically relevant advantages over extended periods of time.

Another interesting perspective involves the growing development of synthetic biomaterials. Advances in material engineering are leading to the introduction of increasingly sophisticated calcium phosphate substitutes characterized by optimized porosity, improved microarchitecture, and enhanced osteoconductive properties. These innovations may contribute to improving the biological performance of synthetic grafts and potentially reduce the differences currently observed between xenogeneic and alloplastic materials. Consequently, future comparisons should not only evaluate traditional hydroxyapatite formulations but also investigate the performance of next-generation synthetic biomaterials specifically designed to mimic the structure and remodeling behavior of natural bone.

Finally, future research should adopt a broader and more patient-centered approach to treatment evaluation. In addition to radiographic outcomes and implant survival rates, increasing attention should be devoted to patient-reported outcome measures, quality of life, treatment acceptance, and long-term functional outcomes. Modern implant dentistry increasingly recognizes that successful treatment is not defined exclusively by bone stability or implant survival, but also by the patient's perception of function, comfort, and overall satisfaction. Integrating these parameters into future clinical studies may provide a more comprehensive assessment of treatment effectiveness and help clinicians make more informed decisions regarding graft material selection.

As implant dentistry continues to evolve, a deeper understanding of the long-term biological behavior of grafting materials will be essential for optimizing treatment outcomes. Future multidisciplinary investigations combining clinical, radiographic, histological, and patient-centered data may contribute to the development of increasingly predictable and personalized regenerative protocols for the rehabilitation of the atrophic posterior maxilla.

CONCLUSION

Maxillary sinus floor elevation has become one of the most predictable and widely adopted procedures for the rehabilitation of the atrophic posterior maxilla, allowing implant placement in clinical situations that would otherwise be unsuitable for implant-supported restorations. Over the years, the continuous development of grafting materials has expanded the therapeutic possibilities available to clinicians, offering different biological and mechanical approaches to bone regeneration.

The present retrospective study compared the long-term performance of deproteinized bovine bone mineral (DBBM) and synthetic hydroxyapatite (HA) following lateral sinus floor elevation by evaluating marginal bone loss around implants over an observation period extending up to ten years. Both biomaterials demonstrated favorable clinical outcomes and were associated with satisfactory long-term peri-implant bone stability. Although the DBBM group consistently exhibited lower marginal bone loss values throughout the follow-up period, no statistically significant differences were observed between the two groups.

Beyond the numerical results, the findings of this study suggest that both biomaterials are capable of providing predictable support for implant rehabilitation in grafted posterior maxillary sites. The greater dimensional stability commonly associated with DBBM and the potentially more dynamic remodeling behavior of hydroxyapatite-based grafts appear to represent different biological pathways leading to similarly favorable clinical outcomes. This observation reinforces the concept that successful bone regeneration depends not only on the intrinsic characteristics of the grafting material but also on the complex interaction between biomaterial properties, surgical technique, implant placement, prosthetic rehabilitation, and patient-related factors.

The comparison between DBBM and synthetic hydroxyapatite also highlights an important aspect of contemporary regenerative dentistry: the absence of a universally superior biomaterial. Rather than identifying a single ideal grafting material, current evidence increasingly suggests that different biomaterials may achieve comparable clinical results through distinct biological mechanisms. Consequently, graft selection should be guided by

the specific clinical situation, the characteristics of the defect, the clinician's experience, and the therapeutic objectives of each individual case.

From a broader perspective, this study contributes to the growing body of evidence supporting the long-term predictability of sinus augmentation procedures. The availability of follow-up data extending up to ten years provides valuable insight into the stability of regenerated peri-implant tissues and confirms that both xenogeneic and synthetic grafting materials can be successfully employed in the rehabilitation of the atrophic posterior maxilla.

Ultimately, the findings of the present investigation emphasize that long-term treatment success should not be evaluated exclusively through radiographic measurements, but through a comprehensive assessment of biological stability, implant function, and patient benefit. As regenerative technologies continue to evolve and new biomaterials become available, future research will further refine our understanding of graft remodeling and help clinicians develop increasingly personalized and evidence-based treatment strategies for maxillary sinus augmentation.

Bibliografia

1. *Das gesetz der transformation der Knochen. Berlin : Hirschwald.* J., Wolff. 1892.

2. *Gesammelte Abhandlungen uber Entwicklungsmechanik der Organismen. Leipzig: Engelmann.* Roux, W. 1895.

3. *Tissue integrated prostheses Chicago, Classifications and treatment options of the completely edentulous arch in implant dentistry.* Zarb G.A., Lekholm U. s.l. : Quintessence, 1985.

4. *Bone classification, training keys to implant success. Dent Today.* CE:, Misch. 1989.

5. *Il rimodellamento osseo periprotesico.* G. Maccauro, C. Conti, E. Pola, F. Larosa, L. Aulisa. 2005.

6. *Bone "Mass" and the "Mechanostat" : A proposal. Anat Rec.* HM., Frost. 1987.

7. *A 10-year prospective study of ITI dental implants placed in the posterior region. II: Influence of the crown-to-implant ratio and different prosthetic treatment modalities on crestal bone loss .* Blanes RJ, Bernard JP, Blanes ZM, Belser UC. s.l. : Clin Oral Imlants Res, 2007.

8. *The effect of increased crown-to-implant ratio on single-tooth locking-taper implants.* Urdaneta RA, Rodriguez S, McNeil DC, Weed M, Chuang SK. s.l. : Int J Oral Maxillofac Implants, 2010.

9. *The maxillary sinus: phusiology, development and imaging anatomy.* White A., Boeddinghaus R. s.l. : DentoMaxilloFacial Radiology, 2019.

10. *Clinical anatomy of the maxillary sinus: application to sinus floor augmentation.* Iwanaga J., Wilson C. , Lachkar S. , Tomaszewski K. , Walocha J. , Tubbs R. s.l. : Anatomy & Cell Biology Journal, 2019.

11. *Pneumatization of the paranasal sinuses: normal features of importance to the accurate interpretation of CT scans and MR images.* Scuderi AJ, Harnsberger HR, Boyer RS. s.l. : American Journal of Roentgenology, 1993.

12. *Three-Dimensional CAD/CAM imaging of the maxillary sinus in ageing process. .* Lovasova K, Kachlik D, Rozpravkova M, Matusevska M, Ferkova J, Kluchova D. 2018.

13. *Clinical Anatomy of the Nose, Nasal Cavity and Paranasal Sinuses.* J., Lang. 1989.

14. *Anatomical aspects of sinus floor elevations.* Van den Bergh JP, ten Bruggenkate CM, Disch FJ, Tuinzing DB. s.l. : Clin Oral Implants Res, 2000.

15. *The maxillary sinus and its dental implications.* Mc Gowan DA, Baxter PW, James J. 1993.

16. *Maxillary sinus: anatomy, physiology, surgery, and bone grafting related to implantology--eleven years of surgical experience.* M., Chanavaz. 1990.

17. *Blood supply to the maxillary sinus relevant to sinus floor elevation procedures.* Solar P, Geyerhofer U, Traxler H, Windisch A, Ulm C, Watzek G. s.l. : Clin Oral Implants Res, 1999.

18. *Which hard tissue augmentation techniques are the most successful in furnishing bony support for implant placement?* Aghaloo, T.L. & Moy, P.K. s.l. : The International Journal of Oral & Maxillofacial Implants, 2007.

19. *Maxillary sinus pneumatization following extractions: a radiographic study.* Sharan A, Madjar D. s.l. : Int J Oral Maxillofac Implants, 2008.

20. *Impact of Membrane Thickening and Perforation on Graft Remodeling After Osteotome Sinus Elevation: A Retrospective Study.* Hsuan-Hung Chen, Yu-Ming Kuo, Yi Chun Lin, Ya-Chi Chen, Guo-Hao Lin, Yu-Lin Lai. s.l. : Clin Implant Dent Relat Res, 2025.

21. *A classification of the edentulous jaws.* Cawood J, Howell R. s.l. : International Journal of Oral and Maxillofacial Surgery, 1988.

22. *Changes in height of the alveolar process in edentulous segments. A longitudinal clinical and radiographic study of full upper denture cases with residual lower anteriors.* Carlsson GE, Ragnarson N, Astrand P. s.l. : Odontol Tidskr, 1967.

23. *Manuale di chirurgia orale.* Barone A, Bianchi A.E. 2015.

24. *Classification of partially edentulous arches for implant dentistry. International Journal of Oral Implantology.* Misch, C. E., & Judy, K. W. 1987.

25. *Clinical and radiological classification of the jawbone anatomy in endosseous dental implant treatment.* Juodzbalys G, Kubilius M. s.l. : J Oral Maxillofacial Research, 2013.

26. *l rialzo del seno mascellare a scopo implantologico: classificazione del deficit osseo, tecniche di trattamento e biomateriali impiegabili.* Rossi A, Chiapasco M. s.l. : Implantologia Orale, 2004.

27. *Radiographic and histomorphologic evaluation of the Maxillary bone after Crestal Mini Sinus lift using Absorbable collagen-retrospective evaluation. .* Cosola S, Di Dino B, Traini T, Kim YS, Park YM, Marconcini S, Covani U, Vinci R. s.l. : Dent J (Basel), 2022.

28. *Correlation between Schneiderian membrane perforation and sinus lift graft outcome: a retrospective evaluation of 359 augmented sinuses.* Nolan PJ, Freeman K, Kraut RA. s.l. : J Oral Maxillofac Surg. , 2014.

29. *Maxillary and sinus implant reconstructions.* H, Tatum. s.l. : Dent Clin North Am., 1986.

30. *Maxillary Sinus Augmentation Using Autologous Platelet Concentrates (Platelet-Rich Plasma, Platelet-Rich Fibrin, and Concentrated Growth Factor) Combined with Bone Graft: A Systematic Review.* al, Malcangi G. et. 2023.

31. *The osteotome technique: Part 3-Less invasive methods of elevating the sinus floor.* RB, Sumers. s.l. : Compend Contin Educ Dent, 1994.

32. *A comprehensive clinical review of maxillary sinus floor elevation: anatomy, techniques, biomaterials and complications.* danesh-Sani SA, Loomer PM, Wallace SS. s.l. : Br J Oral Maxillofac Surg, 2016.

33. *Implant survival rates after osteotome technique for implant placement in fresh molar sockets.* Del Fabbro M, Corbella S, Weistein T, Ceresoli V, Taschieri S. s.l. : Clin Implant Dent Relat Res, 2013.

34. *Maxillary Sinus Lift Procedures: An Overview of Current Techniques, Presurgical Evaluation, and Complication.* Abdulrahmaz M. Alshamrani, Mazen Mubarki , Abdulelah S. Alsager , Hussam K. Alsharif , Saud A., AlHumaidan , Ahmad Al-Omar. 2023.

35. *A new concept in maxillary implant surgery: the osteotome technique .* RB, Summers. s.l. : Compendium, 1994.

36. *Antral balloon sinus elevation and grafting prior to dental implant placement: review of 34 cases.* Rao GS, Reddy SK. s.l. : Int J Oral Maxillofac Implants, 2014.

37. *Is antral membrane balloon elevation truly minimally invasive technique in sinus floor elevation surgery? A systematic review.* HM, Asmael. s.l. : Int J Implant Dent, 2018.

38. *Structural analysis of the new bioactive kinetic screw in titanium alloy vs. commercially pure titanium. .* Andreucci CA, Fonseca EMM, Natal Jorge RM. s.l. : J Computat Artific Intellig Mech Biomechan, 2022.

39. *Maxillary Sinus Floor Augmentation with Autogenous Bone Graft Alone Compared with Alternate Grafting Materials: a Systematic Review and Meta-Analysis Focusing on Histomorphometric Outcome.* Thomas Starch-Jensen, Daniel Deluiz , Niels Henrik Bruun , Eduardo Muniz Barretto Tinoco. s.l. : J Oral Maxillofac Res, 2020.

40. *Bone substitutes in orthopaedic surgery : from basic science to clinical practice.* al, V. Campana et. 2014.

41. *Proposta di valutazione microtomografica di alcuni sostituti ossei.* R. Bedini, R. Pecci, P. Ioppolo, D. Meleo, A. Bianco, and P. Casti. 2009.

42. *Comparison of Two Xenograft Materials Used in Sinus Lift Procedures: Material Characterization and In Vivo Behavior.* María Piedad Ramírez Fernández, Patricia Mazón, Sergio A Gehrke, Jose Luis Calvo-Guirado, Piedad N De Aza. 2017.

43. *Maxillary Sinus Floor Augmentation With Synthetic Bone Substitutes Compared With Other Grafting Materials: A Systematic Review and Meta-analysis.* Thomas Starch-Jensen, Arne Mordenfeld, Jonas Peter Becktor, Simon Storgård Jensen. s.l. : Implant Dent, 2018.

44. *Materiali da innesto, pp. 49–71.* Acocella, A.

45. *Maxillary Sinus Floor Augmentation with Autogenous Bone Graft Compared with a Composite Grafting Material or Bone Substitute Alone: a Systematic Review and Meta-Analysis Assessing Volumetric Stability of the Grafting Material.* Thomas Starch-Jensen, Daniel Deluiz, Julie Vitenson, Niels Henrik Bruun, Eduardo Muniz Barretto Tinoco. s.l. : J Oral Maxillofac Res, 2021.

46. *Maxillary Sinus Augmentation with Autogenous Tooth Grafting Material: A Systematic Review.* Diba Ghodsian, Sofía D'Jesús, Luis Sánchez-Labrador, Carlos Manuel Cobo-Vázquez , Jorge Cortés-Bretón Brinkmann, José María Martínez-González , Cristina Meniz-García. 2024.

47. *A review of complications of maxillary sinus augmentation and available treatment methods.* Joongmin Kim, Hyonseok Jang. s.l. : J Korean Assoc Oral Maxillofac Surg, 2019.

48. *Sinonasal Complications Following the Sinus Lift Procedure.* Jakob L Fischer, Charles A Riley, Ashutosh Kacker. s.l. : Ochsner J., 2023.

49. *Lateral Window Sinus Augmentation Complications and Outcomes of 101 Consecutive Procedures.* Guerrero, Jaime Santiago DDS. s.l. : Implant Dentistry, 2015.

50. *Displacement of implant into the maxillary sinus: case report and literature review.* Borgonovo A.E, Re D. s.l. : Dental Cadmos, 2015.

51. *Clinical outcomes of sinus floor augmentation for implant placement using autogenous bone or bone substitutes: a systematic review.* Nkenke E, Stelzle F. s.l. : Clin Oral Implants Res, 2009.

52. *Tabassum A, Walboomers XF, Wolke JG, et al.Bone particles and the undersized surgical.*

53. Valentini P, Abensur D. Maxillary sinus floor elevation for implant placement with demineralized freeze-dried bone and bovine bone (Bio-Oss): a clinical study of 20 patients. Int J Periodontics Restorative Dent. 1997

54. Trombelli L, Franceschetti G, Rizzi A, Minenna P, Minenna L, Farina R. TMinimally invasive transcrestal sinus floor elevation with graft biomaterials. A randomized clinical trial. Clin. Oral Impl. Res., 2011

55. Scarano A, Degidi M, Iezzi G, Pecora G, Piattelli M, Orsini G, Caputi S, Perrotti V, Mangano C, Piattelli A. Maxillary sinus augmentation with different biomaterials: a comparative histologic and histomorphometric study in man. Implant Dent. 2006

56. To cite this article: Schmitt CM, Doering H, Schmidt T, Lutz R, Neukam F, Schlegel KA. Histological results after maxillary sinus augmentation with Straumann® BoneCeramic, Bio-Oss®, Puros®, and autologous bone. A randomized controlled clinical trial. Clin. Oral Impl. Res., 2012

57. Lambert F, Bacevic M, Layrolle P, Schüpbach P, Drion P, Rompen E. Impact of biomaterial microtopography on bone regeneration: comparison of three hydroxyapatites. Clin Oral Implants Res. 2017

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