MAXILLARY SINUS FLOOR ELEVATION PROCEDURE, A NARRATIVE REVIEW OF SINUS ANATOMY AND DIFFERENT ELEVATION APPROACHES

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Abstract

Aim: The aim of this study is to review different maxillary sinus elevation technique and its relevant to the surrounding structure. **Material and Methods:** A comprehensive literature search was conducted in PubMed, Scopus, Web of Science, and the Cochrane Library using keywords related to sinus augmentation and dental implants. Studies published in the last 20 years were included to ensure relevance and up-to-date findings. **Result:** Implant placement in the posterior maxilla has changed due to sinus elevation techniques; the approach chosen depends on patient-specific characteristics, bone quality, and residual bone height (RBH). When the maxilla is significantly atrophic (RBH < 4 mm), the lateral window approach is the best option because it provides great access but has a higher risk of complications. While balloon-assisted sinus lift , Versha burs and piezoelectric surgery offer less invasive and more accurate options, the trans-crestal method is best suited for moderate RBH 5mm < and has lower morbidity. While sequential treatments are advised for lower RBH, simultaneous implant insertion works well for adequate RBH (>5 mm) and primary stability. Minimizing problems and attaining long-term success need careful patient selection and adherence to technique-specific procedures. **Conclusion:** With the development and improvement of sinus elevation procedures, clinicians now have more alternatives to maximize therapy results. To reduce difficulties and guarantee long-term success in implant rehabilitation, a comprehensive preoperative evaluation, customized treatment planning, and adherence to technique-specific guidelines are essential.

Keywords: Maxillary sinus elevation, Sinus anatomy, Implant dentistry and Implant in maxillary sinus.

Introduction:

During the last 40 years, osseo-integrated dental implants have become one of the most used biomaterials to replace missing or lost teeth, and the treatment has been characterized by a highly successful outcome of complete, partial or single edentulism (1). The development of bone-augmentation techniques, such as guided bone regeneration and sinus floor elevation, to correct local bone defects at potential implant sites has increased the indications for implant therapy. Implant placement in the posterior region of the maxilla is usually impaired or difficult because of alveolar process atrophy, low bone quality, and maxillary sinus pneumatization. Several surgical approaches have been proposed to achieve the necessary vertical height of the alveolar process for the installation of implants of sufficient length, including maxillary sinus floor augmentation with the lateral window technique, osteotome-mediated sinus floor elevation, and sinus membrane elevation without the use of a graft material. (2).

Methodology:

A thorough literature review was performed utilizing four primary databases: PubMed, Scopus, Web of Science, and the Cochrane Library. The search utilized a combination of keywords, such as "sinus

DOI : 10.62610/RJOR.2025.2.17.42

elevation," "sinus lift," "maxillary sinus augmentation," "bone grafting," "dental implants," "minimally invasive sinus lift," and "sinus anatomy." The selected keywords encompass a comprehensive yet targeted spectrum of research pertaining to sinus augmentation treatments and their consequences in dental implantology.

Only studies published in the last 20 years were deemed relevant for review to guarantee the incorporation of the most recent research.

Maxillary sinus anatomy:

The maxillary sinus is a pyramid in form and is the biggest among the paranasal sinuses. The front wall of the maxillary sinus is created by the facial side of the maxilla and contains the canalis sinuosus, where the anterior superior alveolar nerve and vessels are located. The front side has three main features: the slight hollow canine fossa; the infraorbital foramen situated in the middle upper region; and the infraorbital groove. The infratemporal surface of the maxilla forms the back wall. It creates the front edge of the pterygo-palatine fossa. The delicate triangular orbit floor forms the superior wall, with the infraorbital groove passing through it. The thickness of the sinus roof increases as it reaches the orbital margin, measuring 0.4 mm on the medial side of the infraorbital canal and 0.5 mm on the lateral side (3, 4).

The wall in the medial of the maxillary sinus divides the sinus from the nasal cavity, smooth on the sinus side and supports the inferior nasal conchae on the nasal side. The medial wall is a rectangular shape and has a slight deficiency at the maxillary hiatus. In an articulated skull, the opening is partly blocked by parts of the inferior turbinate, the ethmoid bone's uncinate process, the palatine bone's perpendicular plate, the lacrimal bone, and the covering mucosa to create the ostium, along with frontal and posterior fontanelles (4, 5).

The osteum located at the superior aspect of the medial sinus wall with an average diameter of 2.4 mm. Drainage of the sinus depends on the movement of the cilia because of the location, it drains into the ethmoidal infundebillum and then into the middle meatus. The distance from the floor of the sinus to the ostium is about 28.5mm with a schneiderian membrane thickness of 0.91 mm. Thickness of the membrane increases in different situation such as chronic sinusitis, periodontitis and smoking (6).

Sinus relation to the adjacent structures:

The side tip of the maxillary sinus stretches into the zygomatic process of the maxilla and can extend to the zygomatic bone, creating the zygomatic recess. The bottom of the sinus is created by the alveolar and palatine processes of the maxilla, situated beneath the nasal cavity, typically spanning from the first premolar to the third molar, with the lowest point at the first and second molars. A thin layer of compact bone separates the molar dentition from the floor of the sinus. The roots of the maxillary back teeth are near the sinus floor, with the molars' root tips closer to the sinus floor than the premolars . Cone beam CT (CBCT) scans have shown that, on average, the distance between the back teeth in the

DOI : 10.62610/RJOR.2025.2.17.42

upper jaw and the sinus floor is 1.97 mm (3).

CBCT scans have also demonstrated a close connection between the roots of the first and second molars and the sinus floor in 40% of cases, with perforations occurring in 2.2% and 2.0% of cases, respectively (7).

Several CBCT studies have been done on how common septa are in the maxillary sinus, with reported rates ranging from 16% to 58% (8, 9). Full division of the maxillary sinus is not common, with prevalence rates ranging from 1.0% to 2.5% in reported cases (4, 10).

Maxillary sinus septa	
Incidence	Occurs in a percentage of individuals.
	May divide the sinus into compartments (complete or incomplete).
	Important consideration in sinus lift procedures.
Morphology	Primary Septa: Formed during maxillary growth.
	Secondary Septa: Related to tooth loss or sinus pneumatization.
	Orientation: Commonly anterior-posterior or transverse.
Clinical Implications	Risk: Increased risk of sinus membrane perforation during sinus lift surgery.
	Surgical Challenges: May require modified techniques or instruments for safe access.
	Imaging Importance: preoperative CBCT imaging is crucial for identifying septa.

Two distinct kinds of septa have been recognized, primary septa form at birth due to maxillary growth and are located superior to the teeth and secondary septa form due to irregular pneumatization of the sinus floor following the loss of a tooth (table 1) (11). Above a ridge without teeth, both primary and secondary septa can be observed. The occurrence of septa in the front area (above the premolar teeth) varies from 17.5% to 70% (12-14), located in the middle area (above the first and second molar teeth) varies between 41% and 65% according to different studies. The occurrence of septa in the back part (far end of the second molar) is reported to be around 22.5% to 22.7% (14-16), and height of septa varies between 2.5 mm and 6.0 mm (17). Studies using CBCT have shown that the presence of septa is higher in cases of edentulism (27.7%) than in cases of having teeth (14.0% to 19.3%), but clinical and anatomical research have demonstrated that septa are taller in cases with teeth compared to cases without teeth. In dentate cases, the average septa height is 12.2 mm, while edentulous cases (total and partial) have a mean septa height of 8.06 mm (12, 15).

DOI : 10.62610/RJOR.2025.2.17.42

Table 1 a summary of maxillary sinus septa incidence, morphology and clinical implications.

The mucosal lining of the maxillary sinus does not have periosteum and is only covered with mucus-producing ciliated pseudostratified columnar epithelium, with more cilia concentrated near the ostium (4). Since the ostium is typically situated higher up on the medial side of the sinus, mucous drainage depends mostly on the mucociliary escalator, where the sinus cilia move towards the ostium (18).

Blood supply:

The maxillary sinus is primarily supplied by three main arteries: the posterior superior alveolar artery, infraorbital artery, and posterior lateral nasal. The maxillary artery's third portion (pterygopalatine) gives rise to the posterior superior and infraorbital branches, both of which are direct, and originates from the external carotid artery. The lateral nasal posterior is a branch of the artery that comes off the maxillary artery called the sphenopalatine artery. The consequences of these blood vessels create a system found within and beneath the mucous membrane covering the nasal cavity and sinuses, and can also travel within the bones (19).

Venous drainage:

The maxillary sinus's venous drainage mainly occurs via veins that eventually empty into the head's larger venous systems after following the artery supply. The principal venous pathways implicated are: the facial vein receives its blood flow from the maxillary sinus veins, which in turn empty into the internal jugular vein through minor tributaries. Pterygoid venous plexus: The pterygoid venous plexus, a network of veins situated in the infratemporal fossa, is another important pathway for venous drainage. There are possible channels for the spread of infection because of the communication between this plexus and the cavernous sinus. The infraorbital vein empties into the facial vein or the pterygoid venous plexus after draining the anterior region of the maxillary sinus. Superior ophthalmic vein: The superior ophthalmic vein has a minor drainage pathway that joins the cavernous sinus. These venous channels are important because infections in the maxillary sinus can potentially spread to adjacent structures, including the brain, through these connections (e.g., to the cavernous sinus) (19).

Lymph nodes:

There are two main categories of lymph nodes involved in the lymphatic drainage of the maxillary sinus: Submandibular lymph nodes: Beneath the jaw, the submandibular lymph nodes receive the majority of the lymph that drains from the maxillary sinus. These lymph nodes, which drain lymph from the cheeks, sinuses, and lateral portion of the nose, are a component of the face's superficial lymphatic drainage system. Deep cervical lymph nodes: The jugulodigastric and other deep cervical lymph nodes can receive direct lymphatic drainage from the maxillary sinus, especially from deeper areas. These nodes are a component of the head and neck's deep lymphatic system and are situated along the internal jugular vein. This lymphatic drainage system aids in the removal of pathogens and foreign objects

DOI : 10.62610/RJOR.2025.2.17.42

from the maxillary sinus area and stops infections from spreading. (4, 20)

Sensory innervation:

The sensory pathways of the maxillary sinus are mainly provided by the trigeminal nerve (cranial nerve V), particularly the maxillary nerve (V2), which belongs to the second division of the trigeminal nerve. The key nerves involved include: Infraorbital nerve: a segment of the maxillary nerve that runs through the infraorbital foramen, delivering sensory signals to the front part of the maxillary sinus, as well as the upper lip, cheek, and lower eyelid. Posterior superior alveolar nerves: these nerves supply sensory feedback to the back side of the maxillary sinus and also cover the upper molar teeth. Middle superior alveolar nerve: this nerve provides sensory input to the side and middle parts of the maxillary sinus, as well as the teeth in the premolar area. Anterior superior alveolar nerve: It supplies sensory information to the front of the maxillary sinus and the teeth at the front. These nerves transmit sensory signals from the maxillary sinus to the brain, enabling the experience of pain, pressure, and other sensory inputs in this area (6).

Different approaches for maxillary sinus elevation:

The type of sinus floor elevation procedure used is mostly determined by residual vertical bone height, marginal bone width, local intra-sinus anatomy, and the number of teeth to be replaced, while other criteria (such as surgical training and experience) may play a role. The lateral wall technique of Boyne and James used a large round carbide bur to obliterate the wall to make a window access for the placement of an autogenous bone graft (21). Over the years, numerous modifications to this technique have been published. Wood and Moore, who first published the hinge osteotomy technique in 1988, and smiler, who reviewed multiple technique variations in 1997, modified the original rotary techniques.(22) (23).

In 2001, Vercellotti introduced the Piezoelectric technique in the United States, and in 2011, Lozada et al. published the Dentium Advanced Sinus Kit (DASK) technique. Multiple publications have demonstrated transcranial approaches to the sinus using osteotomes, special safe-cutting drills, diamonds, hydraulic pressure, piezoelectric surgery, and balloon elevation techniques. (24) (25).

The continuous introduction of new techniques for lateral window entry are, in reality, surgical modifications designed to increase the predictability of the procedure while reducing the occurrence of the 2 main intraoperative complications: profuse bleeding and sinus membrane perforation. These complications can affect the procedural outcome by resulting in the abandonment of the procedure (26). They can also affect procedural success by creating postoperative complications and, ultimately, they can affect implant survival by resulting in a deficient quantity and/or poor quality of bone (27).

For single tooth space with sufficient bone width for implant placement and a residual bone height of 5-8 mm, a trans-crestal sinus floor elevation approach is recommended. When < 5 mm of bone is available and multiple teeth need to be replaced, lateral sinus floor elevation with or without grafting materials is indicated. In terms of implant placement time, a one-stage

DOI : 10.62610/RJOR.2025.2.17.42

operation is favored as long as high primary stability is guaranteed. (28).

Sinus membrane perforations occurred in up to 44% of the procedures (29), however the piezoelectric scalpel does not cut through non mineralized tissue solving the issue of perforation. The average thickness of the cut was approximately 1 mm when preparing the window, so that significantly reduction in perforation rate to 5% with piezoelectric technique (figure 1) (24).

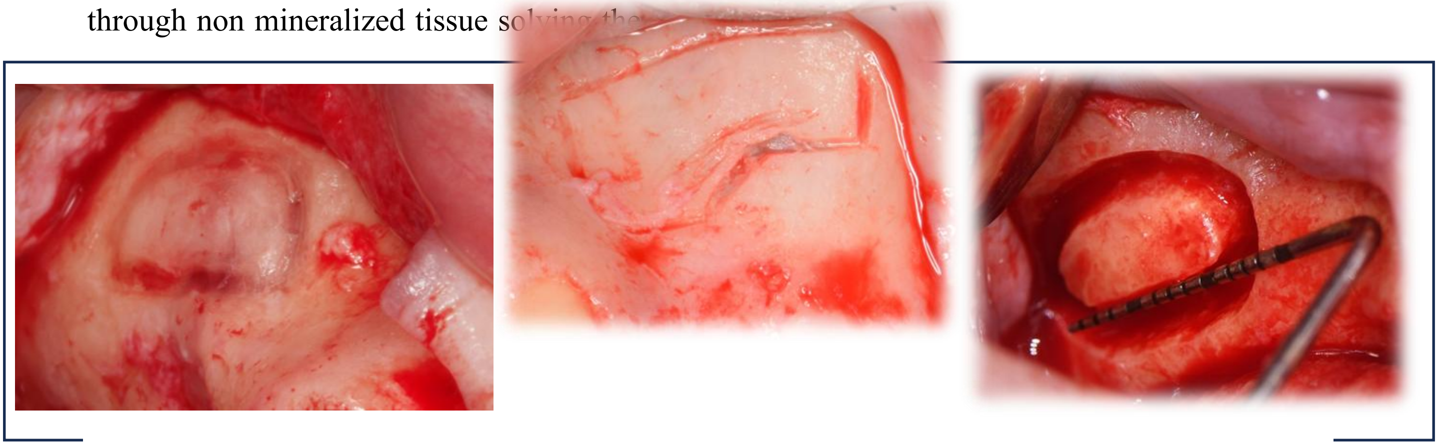

Figure 1: various techniques of lateral window preparation for sinus grafting procedure using diamond round bur or piezoelectric tip.

Trans-alveolar Osteotome approach:

Summers in 1994 introduced the Trans-alveolar Osteotome approach. The osteotome technique involves the use of a surgical mallet to compact the alveolar bone with an osteotome

A: the implant site is prepared to a depth 1mm below the sinus floor.

B: graft material is added to the osteotomy before braking the sinus floor

C: Infracture the sinus floor cortical bone with light malleting.

D: the instrument can then progress about 2mm deeper than the depth of the infracture at each time. The amount of bone needed is 1 cc for 6 mm, it is recommended that 2–3mm of bone graft material around the apex of the implant may add the implant primary stability (figure 2) (30).

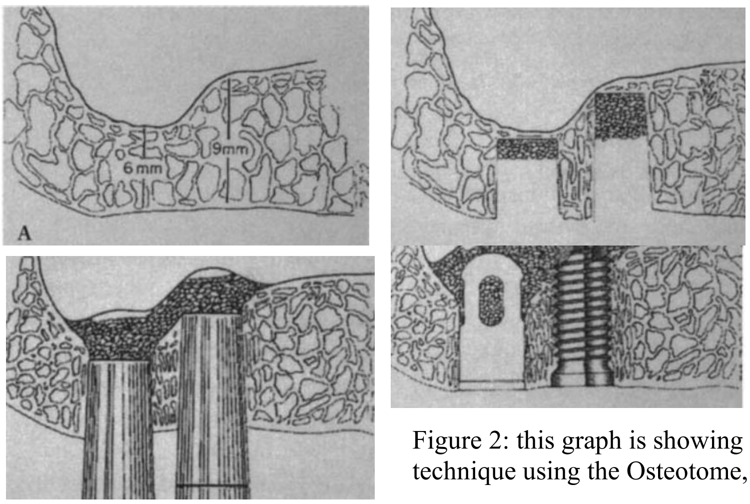

Figure 2: this graph is showing the vertical sinus elevation technique using the Osteotome, Summer 1994 method.

The trans-crestal hydrodynamic ultrasonic cavitational sinus lift:

Piezoelectrical surgery has continually gained ground over standard bone surgery.

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Which lead to the introduction of insert kits designed to raise the sinus floor by the crestal approach. The Intra-lift is thus a technique for raising the sinus floor via the crestal approach, using ultrasonic tips to first pierce an access hole to the sinus floor and then to hydrodynamically push back the Schneider membrane (figure 3). **The first step** is the access to the sinus floor using the TKW1 diamond tip, this tip cannot cut through soft tissue, but if pressure was put on the tip it will pierce the sinus membrane. If the crestal bone hight is more than 3 mm osteotomy is started with 2mm pilot drill 2 mm shallow of the sinus floor. **The second step** is the gradual enlargement of the drilling hole and entails successive use of tips TKW2 (2.1 mm), TKW3 (2.35 mm), and TKW4 (2.8 mm). These diamond-coated tips require full power and substantial irrigation to counteract any rise in temperature caused by friction. **The third step** is the raising of the sinus membrane using tip TKW5 to be inserted within 2mm of the Schneider membrane and then activated. It should be used 5-second bursts with an irrigation set initially at 40 mL/min and increased progressively to 50 mL/min and then to 60 mL/min . Membrane should be checked with large diameter probe with round end. **Final step** is adding the bone graft, a resorbable membrane or a collagen plug can be placed prior to introducing the bone graft to act as a buffer between the membrane and the bone graft (figure 4) (31).

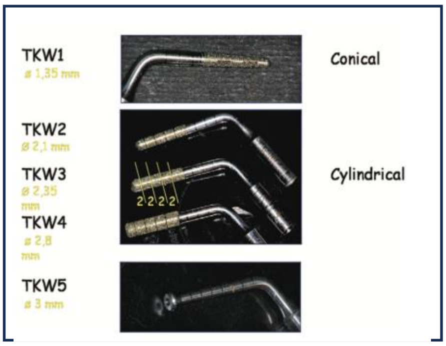

Figure 3: different tips which is using in trans-crestal hydrodynamic ultrasonic cavitational sinus lift .

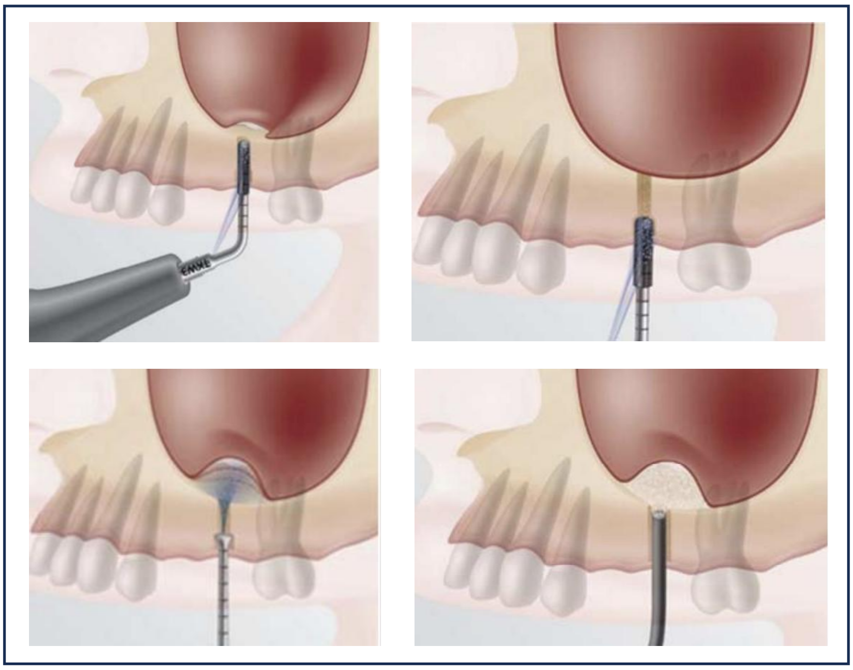

Figure 4: steps of trans-crestal hydrodynamic ultrasonic cavitational sinus lift.

Utilizing a method that enhances bone density and allows for trans-crestal sinus augmentation through compaction grafting:

DOI : 10.62610/RJOR.2025.2.17.42

This technique offers biomechanical osteotomy preparation that preserves bone through a non-excavating drilling process utilizing specially designed burs with a tapered geometry and specially designed flutes to progressively expand the osteotomy while compacting bone into its walls and apex. Advantages of bone densification method enhances implant primary stability,
irrigation solution and autogenous bone chips perform a hydraulic detachment of the sinus membrane and subsequent elevation (figure 5) (32).

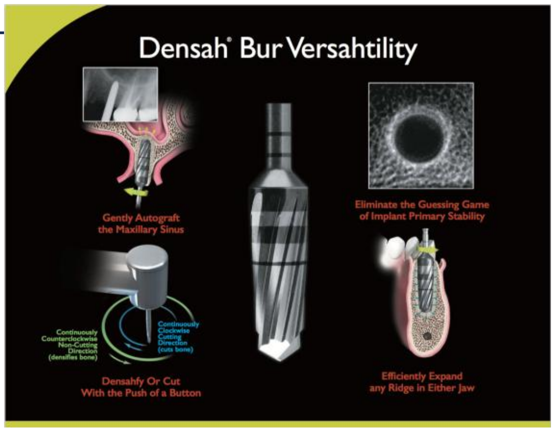

Figure 5: trans-crestal sinus augmentation through bone densification or compaction

Treatment decision:
Fugazzotto, et al 2003 (33) represents a decision tree for different sinus lift procedures, which incorporates the need for bucco-palatal ridge augmentation and evaluates preoperative bone height. Here is a succinct overview of the pathways:

1. Bucco-Palatal Ridge Augmentation Required:

- At least 4 mm of bone surrounding the implant: Perform a lateral approach with simultaneous implant placement.
- Less than 4 mm of bone surrounding the implant: Perform a lateral approach with second-stage implant placement.

2. No Bucco-Palatal Ridge Augmentation Required:

- Less than 4 mm of bone radiographically: Perform a lateral approach with second-stage implant placement.
- Bone sufficient for implant length (2× bone coronal to the sinus floor): If 4×–6× the bone length is sufficient: Use trephine and osteotome therapy with simultaneous implant placement. But If 2× bone coronal to sinus floor is insufficient: Use trephine and osteotome therapy, followed by simultaneous implant placement.
- Bone insufficient for implant length: Use the lateral approach with second-stage implant placement.

Notes: **x** = amount of preoperative bone coronal to the sinus floor.

DOI : 10.62610/RJOR.2025.2.17.42

This decision tree is a visual representation of clinical choices based on ridge dimensions and bone availability, aligning with sinus lift and implant placement strategies.

Grafting materials:

Retrospective data collected from 1007 sinus graft with 2997 implant placement over 10 year. Various form of bone graft materials used. Two different approaches of implant placement, delayed and simultaneous with the sinus graft procedure. Because success rate is almost similar for implants in different graft materials, it's impossible to state that one material is clearly better than the other. Autografts and alloplasts performed consistently well either alone or in combination with other materials. Allografts used alone did less well and when used in combination with other materials were not as successful as the other materials used alone. All materials compared in both simultaneous and delayed approach demonstrated no clear difference based on type of graft material except for autograft did well with the delayed approach (34).

Maxillary sinus lift surgery, with or without graft:

A systematic review compared the use or not of graft material in maxillary sinus lift surgery.

It showed that maxillary sinus lift surgery is a safe technique with a low complication rate and predictable outcomes. Although the effective use of graft materials has been documented in the literature, this treatment is also possible without graft material, and the results are fairly similar with and without graft material. The implant survival rate was 96% for procedures without grafting, and 99.6% for surgeries with grafting (35).

Classification of sinus lift complication:

This table divides the risk factors and possible complications of sinus lift surgeries into four major categories:

1. Systemic Disease and Medications Related

- Medical conditions: Uncontrolled diabetes or osteoporosis.
- Medications: Bisphosphonate medication.
- Lifestyle factors: Immunocompromised patients or smoking.

2. Anatomy and Surgical Procedure Related

- Perforation of the Schneiderian membrane.
- Sinus septa.
- Bleeding.
- Implant displacement into the sinus cavity.
- Obliteration of the sinus cavity.

3. Sinus Pathology Related

- Pseudocysts, retention cysts, or mucoceles.
- Existing sinus issues that may impact outcomes.

4. Infection Related

- General infections (swelling, pus, purulence, hematoma).
- Nose or sinus bleeding.
- Incision line opening or wound dehiscence.
- Bone sequestrum or fragments.
- Sinusitis (nasal congestion, purulent discharge, headaches).
- Oroantral fistula

5. Prosthetic Related

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- Issues with postoperative temporary prostheses.
- Improper implant length or diameter. (33)

Perforation of Schneiderian Membrane:
The most common complication arising during sinus augmentation is the perforation of the Schneiderian membrane. large tears are considered to be upwards of 2 to 3 cm in diameter with smaller tears more commonly of 2 to 5 mm in diameter (36).

Risk Factor of perforation:
The primary risk factors for an increase in sinus membrane perforation rates are the presence of sinus septa and residual bone height of less than 3.5 mm. Despite surgical closure with resorbable membranes (Bio-Guide), sinusitis was more common in situations of membrane perforation (31.4%). In general, smokers were more likely to experience difficulties. (29).

Bleeding:
The average height from the alveolar ridge of these vessels is 18.9 to 19.6 mm.
Treatment of a injured vessel could be by firm pressure, direct ligation, placement of particulate bone graft, bone wax, burnish with burs, and electrocautery (36).

Discussion:
The research examined the factors that influence sinus augmentation and their clinical implications. The predictability of the sinus augmentation and implant placement procedure is largely dependent on the inherent host factors and not solely on the biomaterials. The checklist provides guidelines for treatment planning in enhancing the atrophic maxilla to minimize intraoperative complications.
It is generally recommended to have at least 5 mm of residual bone height (RBH) for simultaneous procedures to ensure proper implant stabilization and alignment (figure 6). However, when the RBH is less than 4 mm, delayed implant placement is typically advised (37). Placing implants simultaneously with insufficient RBH may raise the risk of implant migration into the sinus cavity after initial bone remodeling. However, Peleg M et al. found no statistically significant difference in implant survival rates for simultaneous placement at varying RBH levels, as long as primary stability was achieved (38).
Primary stability can be enhanced by under-drilling, using internal anatomical structures when possible, or angling the implant to engage a greater amount of native bone, provided that the prosthetic design allows for it. Furthermore, the residual bone height often varies along the anterior-posterior axis, which allows primary stability to be achieved by utilizing these uneven areas (39).
Sinus elevation procedures have become a reliable and effective technique for enhancing the posterior maxilla, allowing implant placement in areas of reduced bone height. To address particular clinical situations, a range of strategies are available, such as trans-crestal, lateral window, and minimally invasive procedures. Improvements in imaging technologies and graft materials have led to better results and fewer problems.

Conclusion:
Notwithstanding the general success, several challenges still exist, such as the

DOI : 10.62610/RJOR.2025.2.17.42

need to optimize graft integration, minimize complications, and manage anatomical variances properly (figure 7). Future studies should focus on improving methods, creating biomaterials with improved osteogenic qualities, and compiling long-term implant survival data. To guarantee consistent and useful results, clinicians should thoroughly evaluate each patient's needs before selecting the best sinus elevation technique.

Source of funding:
The research was self-funded.

Acknowledgment:
Thanks to Dr. Hassan Abed for his valuable help in paper submission.

Credit contribution:
The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Ethics statement:
Ethical approval number ZACJ060125 has been granted from Institutional Research Ethics Board (IRB) at Umm Al-Qura University.

Conflict of interest:
no conflicts of interest to disclose.

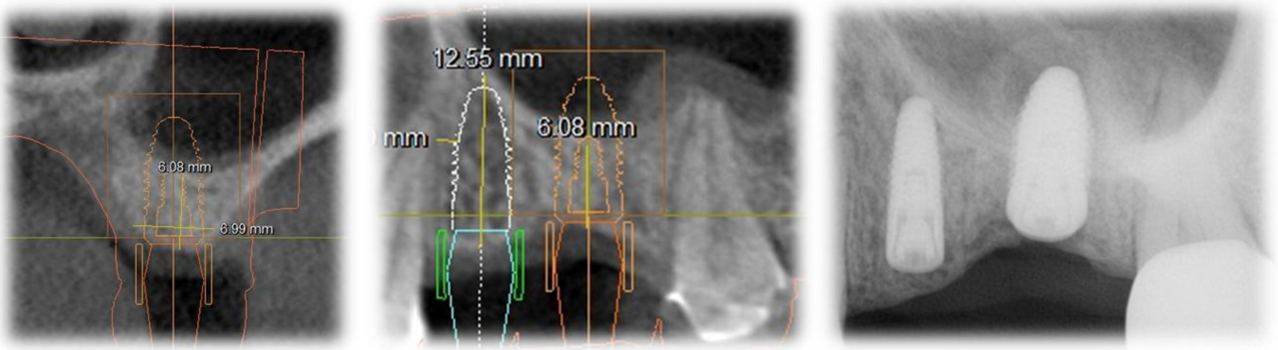
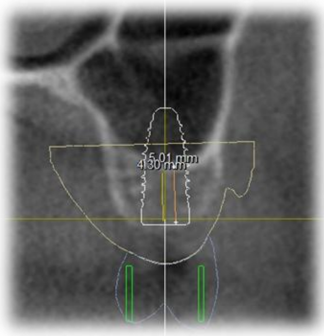
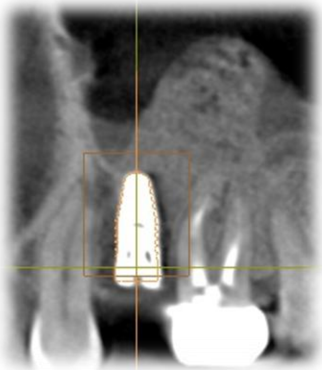


Figure 6: Implant placement in #26 with residual ridge height 6mm and sinus pneumatization. Internal sinus elevation procedure done using Versa drills with xenograft bone material in site.





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