

# Maxillary Sinus Augmentation Techniques in Prosthodontics: A Narrative Review

## Abstract:

Maxillary sinus augmentation is an essential procedure for implant rehabilitation in the atrophic posterior maxilla. Advancements in imaging, surgical instrumentation, and biomaterials have significantly improved the safety, predictability, and minimally invasive nature of sinus lift procedures. Accurate anatomical assessment and proper technique selection remain central to predictable implant outcomes. The objective of this article is to provide a concise, evidence-based review of contemporary maxillary sinus augmentation techniques, highlighting anatomical considerations, diagnostic workflows, surgical approaches, grafting strategies, and emerging technologies.

**Key-words:** Maxillary sinus augmentation; lateral window technique; transcrestal sinus lift; piezosurgery; osseodensification; implant dentistry

## Introduction:

Rehabilitation of the atrophic posterior maxilla with implant-supported prostheses presents unique anatomical and surgical challenges. Progressive maxillary sinus pneumatization combined with alveolar ridge resorption frequently results in insufficient vertical bone height, making implant placement unpredictable without prior augmentation. Since Tatum first introduced the sinus lift concept in 1976 and Boyne and James formalized the lateral window technique in 1980, maxillary sinus augmentation has evolved substantially.[1,2]

The development of contemporary sinus elevation techniques has been driven by improved understanding of maxillary sinus anatomy, advances in imaging such as Cone-Beam Computed Tomography (CBCT), and technological innovations including piezoelectric surgery, hydraulic elevation, and osseodensification.[3–5] More recently, minimally invasive and graftless philosophies have emerged, aiming to reduce morbidity and harness the osteogenic potential of the Schneiderian membrane while maintaining predictable implant outcomes.[6]

This narrative review synthesizes the current evidence and provides a concise, clinically oriented appraisal of

contemporary maxillary sinus augmentation modalities, anatomical considerations, diagnostic workflows, grafting strategies, and future directions.

## Anatomical considerations for sinus augmentation:

The maxillary sinus is the largest of the paranasal sinuses, with an average volume ranging from 12.5 to 24.5 cm<sup>3</sup> in dentate individuals. Following tooth loss, progressive sinus pneumatization and alveolar ridge resorption significantly reduce the residual bone height, often by as much as 10–15 mm, thereby compromising implant placement without augmentation.[7–9]

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The sinus is lined by the Schneiderian membrane, a pseudostratified ciliated epithelium with goblet cells. Membrane thickness varies between 0.3 and 2.1 mm and is an important determinant of technique selection and perforation risk during membrane elevation.[10,11] Thicker or inflamed membranes are more prone to tearing, whereas thinner membranes may require highly controlled techniques such as piezoelectric or hydraulic elevation.

The vascular anatomy also plays a crucial role in planning sinus augmentation. The posterior superior alveolar artery (PSAA)—often coursing within a bony canal—is typically located 15–17 mm superior to the alveolar crest and may anastomose with the infraorbital artery. Preoperative identification of this vessel using CBCT is critical for minimizing bleeding during lateral window preparation.[12,13]

Another clinically relevant anatomical variation is the presence of Underwood's septa. (Figure 1) These bony partitions occur in approximately 25–30% of individuals, especially in the premolar–molar region, and average around 4 mm in height. Their presence can complicate membrane elevation and may require modifications in the design or position of the lateral window.[14–16]

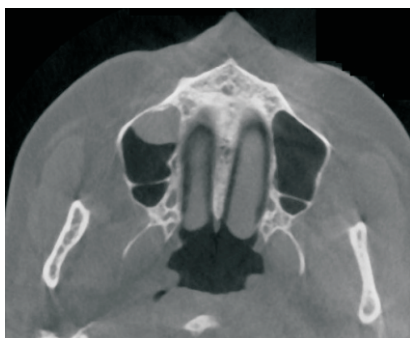


Figure 1. Axial CBCT section of the maxillary sinus demonstrating the presence of Underwood's septa along the sinus floor

A thorough understanding of these anatomical parameters—augmented by CBCT imaging—is essential for predicting surgical complexity, reducing complications, and achieving optimal outcomes in sinus augmentation procedures.

**Diagnostic workflow in sinus augmentation:**

A comprehensive diagnostic workflow is essential for ensuring predictable outcomes in maxillary sinus augmentation and prosthetically driven implant rehabilitation. The assessment begins with a detailed clinical evaluation that includes inspection of the edentulous ridge

morphology, evaluation of keratinized tissue, occlusal analysis, and consideration of patient-specific anatomical and systemic factors that may influence healing or sinus physiology.[17]

Radiographic imaging forms the cornerstone of diagnosis. Cone-Beam Computed Tomography (CBCT) provides superior three-dimensional visualization of the maxillary sinus compared with conventional radiographs, enabling precise evaluation of key parameters such as sinus septa, Schneiderian membrane thickness, residual bone height, sinus ostium patency, and proximity to vital structures including the posterior superior alveolar artery.[18,19]

CBCT measurements directly inform the choice between lateral window and transcrestal approaches, the feasibility of simultaneous implant placement, and the expected extent of augmentation. Integration of CBCT with intraoral scans further supports prosthetically driven implant planning and allows the design of accurate surgical guides.

Overall, meticulous diagnostic evaluation supported by CBCT imaging not only minimizes intraoperative complications but also enhances surgical precision and long-term implant success.

**Surgical techniques for sinus elevation:**

**1. Lateral Window Technique:**

The lateral window (direct) sinus augmentation approach remains the most predictable method for managing cases with severe posterior maxillary atrophy, particularly when the residual bone height is <4 mm. The procedure begins with the elevation of a full-thickness mucoperiosteal flap to expose the lateral maxillary sinus wall. A bony window—typically 10 × 15 mm—is created using rotary or piezoelectric instruments, followed by careful reflection of the Schneiderian membrane using specialized curettes.[20–22] (Figure 2)

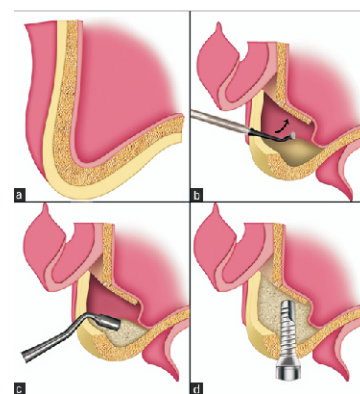


Figure 2. Direct (lateral window) sinus lift with simultaneous implant placement: (A) Atrophic posterior maxilla with

inadequate residual bone height, (B) Lateral sinus wall osteotomy with elevation of the Schneiderian membrane, (C) Placement and condensation of graft material into the elevated sinus cavity, and (D) Augmented maxillary sinus with implant positioned

Once the membrane is elevated, graft materials such as autogenous bone, allograft, xenograft, or composite grafts are placed to create a stable subantral space. Simultaneous implant placement may be considered when sufficient primary stability can be achieved; otherwise, a staged approach is recommended.

Modern refinements aim to minimize morbidity through techniques such as reduced window size, hinged (partial-thickness) windows that preserve vascularity, and the use of piezoelectric devices to reduce heat generation and soft tissue trauma.[23–25] These modifications have improved patient comfort, reduced perforation rates, and enhanced overall predictability.

## **2. Osteotome-Mediated Sinus Floor Elevation (Summers Technique):**

The osteotome-mediated sinus lift, introduced by Summers in 1994, revolutionized minimally invasive sinus augmentation by providing a predictable approach for cases with moderate residual bone height (5–8 mm).[26] Originating from Tatum's earlier transcrestal concept,[27] this technique enables controlled sinus membrane elevation through the alveolar crest without creating a lateral window.

Following crestal incision and flap elevation, osteotomy preparation begins with a pilot drill that stops approximately 2 mm short of the sinus floor. In low-density bone or when residual bone height is  $\leq 5$  mm, the pilot drill may be omitted to minimize perforation risk. Sequential osteotomes of increasing diameter are then advanced using controlled malleting, creating apical and lateral bone compaction. This densification supports gradual tenting of the Schneiderian membrane while enhancing bone density within the osteotomy site.[28,29]

The accumulation of bone debris and physiologic fluids during osteotome use generates a natural hydraulic effect, assisting in membrane elevation. Hydrated graft material is placed incrementally before the final osteotome, and a characteristic pitch change during tapping indicates sinus floor fracture and membrane elevation.[30]

Implant placement is performed immediately, with the implant acting as a tenting mechanism for the elevated membrane. Reported survival rates range from 92–96% at 5 years, confirming the predictability of this method when applied appropriately.[31,32] However, the technique is operator-dependent and generally limited to cases requiring  $\leq 3$ –4 mm of additional bone height.

## **3. Piezoelectric Sinus Lift:**

Piezoelectric surgery has significantly enhanced the safety and precision of lateral window sinus augmentation. Operating at selective ultrasonic frequencies (25–30 kHz), piezoelectric units cut mineralized tissues while preserving soft tissue integrity, thereby minimizing Schneiderian membrane perforation and reducing thermal damage.[33]

The procedure involves outlining and removing the lateral bony window with piezoelectric inserts (e.g., OT7S), followed by membrane exposure and elevation using atraumatic tips (e.g., OP3). This technique provides a blood-free surgical field, improved visibility, and reduced risk of soft tissue injury. Perforation rates as low as 5–8% have been reported, compared with 20–30% using conventional rotary instruments.[34,35]

Owing to its precision and tissue-sparing properties, piezosurgery is particularly advantageous in cases with thin membranes, anatomical complexities, or close proximity to the posterior superior alveolar artery.

## **4. Balloon-Assisted Sinus Elevation (MIAMBE):**

Balloon-assisted sinus elevation (MIAMBE) introduces a minimally invasive method for controlled membrane elevation using a saline-inflated balloon catheter.[36] Once the osteotomy is prepared, a deflated balloon is inserted and gradually inflated (0.5–1.5 ml), gently separating the membrane from the sinus floor.

This approach reduces the risk of mechanical trauma and is ideal for anatomically restricted sites. Clinical studies report mean vertical gains of approximately 7 mm and reduced perforation rates compared with osteotome techniques.[37–39] Limitations include higher equipment costs and reduced efficacy in sinuses with septa.

## **5. Hydraulic Sinus Condensing (Chen Technique):**

The hydraulic sinus condensing technique uses controlled saline pressure to detach the Schneiderian membrane

atraumatically. After forming a conical osteotomy 1 mm short of the sinus floor, sterile saline is delivered at a slow rate ( $\approx 0.1$  ml/sec) to elevate the membrane hydraulically.[40]

This technique minimizes perforation risk and reduces surgical trauma, allowing simultaneous implant placement. Chen et al. Reported mean vertical gains of 5–6 mm and 97% implant survival at 5 years, demonstrating its predictability.

### **6. Osseodensification Technique:**

Osseodensification, introduced by Huwais, employs Densah burs in reverse (counterclockwise) rotation to compact rather than remove bone, increasing density and enhancing primary implant stability.[41,42] When used for transcrestal sinus elevation, a graft slurry is introduced into the osteotomy, and the final bur compacts the material apically, gently elevating the Schneiderian membrane.

Benefits include higher bone-to-implant contact, improved insertion torque, low perforation rates ( $\approx 2-7\%$ ), and reduced morbidity. This technique is well suited for cases requiring 2–4 mm of additional bone height.

### **7. Other Minimally Invasive Techniques (Concise Overview):**

#### **A. Gel Pressure Sinus Elevation:**

This method uses a radiopaque viscoelastic gel injected under controlled pressure to elevate the Schneiderian membrane gently, reducing perforation risk and enabling enhanced radiographic visualization during elevation.[43]

#### **B. Reamer-Mediated Elevation:**

Ahn et al. Introduced a flat-ended reamer that prepares the osteotomy and simultaneously applies controlled apical pressure to elevate the membrane safely at low rotational speeds.[44]

#### **C. DASK Technique:**

The Dentium Advanced Sinus Kit uses dome-shaped drills to thin the sinus floor safely, followed by membrane elevation with atraumatic curettes and graft placement.[45]

#### **D. NovabonePutty Hydraulic Technique:**

A highly viscous calcium phosphosilicate putty is injected into the osteotomy, applying hydraulic pressure that gently elevates the membrane while minimizing perforation risk.[46]

### **8. Guided Sinus Lift Techniques:**

Digital integration has enhanced the accuracy and safety of sinus augmentation. CBCT data combined with intraoral scans enable prosthetically driven virtual planning and fabrication of 3D-printed surgical guides.[47]

Guided lateral window techniques improve localization, window design, and instrument angulation, reducing membrane perforation risk and surgical time. Dynamic navigation systems further enhance accuracy by providing real-time feedback during osteotomy preparation, achieving positional deviations as low as 0.3 mm.[48]

Digital workflows are especially beneficial in anatomically complex sinuses and for clinicians seeking increased precision and standardization.

### **Grafting materials and strategies in sinus augmentation:**

Modern sinus augmentation has shifted from reliance on large-volume autogenous grafts to the use of biologically active substitutes, composite scaffolds, and graftless approaches. Selection of graft material depends on defect morphology, desired volume stability, healing timeline, and patient-specific considerations.

#### **Autogenous Bone:**

Autogenous bone remains the gold standard due to its osteogenic, osteoconductive, and osteoinductive properties. However, donor-site morbidity, limited availability, and variable resorption rates (up to 28% volume loss within six months) limit its routine use.[49]

#### **Xenografts:**

Deproteinized bovine bone mineral (DBBM) is widely used owing to its biocompatibility, porosity, and slow resorption profile. It provides long-term space maintenance and predictable integration, making it suitable for lateral window procedures.[50]

#### **Allografts:**

Freeze-dried bone allograft (FDBA) offers osteoconductivity, while demineralized freeze-dried bone allograft (DFDBA) exhibits osteoinductive potential due to preserved bone morphogenetic proteins (bmps). Recombinant BMP-2 and BMP-7 provide enhanced osteogenesis when delivered via collagen carriers.[51,52]

### **Synthetic Biomaterials:**

Calcium phosphate ceramics such as biphasic HA/ $\beta$ -TCP, as well as strontium-enriched substitutes, provide customizable resorption rates and excellent osteoconductive scaffolding.[53,54]

### **Platelet Concentrates (PRF / i-PRF):**

Platelet-rich fibrin enhances angiogenesis, early healing, and graft cohesion. I-PRF can be mixed with particulate materials to create “sticky bone,” improving graft stability under the Schneiderian membrane.[55]

### **Graftless sinus augmentation:**

Graftless sinus elevation techniques rely on the angiogenic potential of the Schneiderian membrane and stabilization of the natural blood clot. When primary implant stability is achievable and required vertical augmentation is  $\leq 4$  mm, graftless approaches can yield survival rates of approximately 95% at 5 years, with mean bone formation around 3–4 mm.[56]

### **Advantages include:**

- Reduced morbidity
- Shortened treatment duration
- Lower cost
- Avoidance of foreign biomaterials

These methods reflect a shift toward minimally invasive, biologically driven regeneration.

### **Comparative analysis of sinus augmentation techniques:**

Residual bone height is the primary determinant for selecting a sinus augmentation method.

### **Residual Bone Height <4 mm:**

Lateral window sinus augmentation (rotary or piezoelectric) remains the most predictable option, particularly for large graft volumes and staged implant placement.[57]

### **Residual Bone Height 4–6 mm:**

Minimally invasive techniques such as osseodensification and balloon-assisted elevation offer adequate vertical gain with reduced morbidity.[58]

### **Residual Bone Height >6 mm:**

Transcrestal methods—including Summers technique, hydraulic elevation, and reamer-mediated protocols—provide efficient, conservative augmentation.[59]

### **Evidence Summary:**

Direct sinus lifts consistently produce greater vertical bone gains compared with indirect approaches, with mean increases of 8–12 mm reported in controlled studies.[60–64] A randomized split-mouth trial comparing piezoelectric vs rotary lateral window preparation found similar perforation rates but improved soft tissue preservation with piezosurgery, albeit with longer operative times.[65]

Combined piezo-hydraulic techniques and osseodensification demonstrate superior implant stability and reduced complication rates, supporting their role as modern alternatives to traditional methods.[66,67]

### **Future perspectives:**

The field is progressing toward biologically enhanced, digitally integrated, and minimally invasive workflows.

### **Advanced Biomaterials**

Bioactive glass composites, magnesium-based scaffolds, and nanostructured surfaces are being developed to enhance osseointegration, control resorption, and improve long-term stability.[68–70]

### **Autogenous Dentin Grafts:**

Tooth-derived grafts exhibit osteoconductive and osteoinductive potential with favorable long-term outcomes, minimal cost, and no risk of antigenicity. They represent a promising alternative to xenografts and allografts.[71,72]

### **Digital & AI-Assisted Surgery:**

AI-driven CBCT analysis is emerging for automated mapping of sinus anatomy, vessel location, and optimal window design.[73]

Dynamic navigation, robotic-assisted drilling, and augmented reality overlays improve accuracy, minimize hand-related variability, and standardize sinus augmentation procedures.[74,75]

These developments collectively move implant dentistry toward fully guided, personalized, and biologically optimized sinus augmentation.

### **Conclusion:**

Maxillary sinus augmentation has undergone profound transformation, progressing from invasive conventional

techniques to refined minimally invasive and digitally supported methods. Proper understanding of sinus anatomy, accurate CBCT-based diagnosis, and selection of the appropriate augmentation modality based on residual bone height are essential for predictable implant outcomes.

Emerging technologies—including piezosurgery, osseodensification, hydraulic elevation, advanced biomaterials, and AI-assisted planning—continue to redefine the precision, safety, and biological efficiency of sinus lift procedures. Long-term clinical validation and integration of digital workflows will further enhance patient-centered outcomes in implant dentistry.

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