Minimally invasive sinus elevation techniques in implant dentistry (Review)

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Abstract. Implant placement in the posterior maxilla is often complicated by reduced vertical bone height due to alveolar resorption and maxillary sinus pneumatization. Traditionally addressed by the lateral window sinus lift, this invasive approach has evolved with the advent of minimally invasive sinus elevation (MISE) techniques aimed at reducing surgical trauma and enhancing patient outcomes. The present review discusses contemporary MISE methods, including osteotome-based, hydraulic, balloon-assisted, piezoelectric and guided techniques, highlighting their clinical indications, protocols and comparative advantages. With residual bone heights of 4-8 mm, these methods enable safe, predictable sinus membrane elevation, while often permitting simultaneous implant placement. Enhanced by technologies such as cone-beam computed tomography imaging, endoscopic guidance and dynamic navigation systems, MISE provides precision and safety in anatomically or medically complex cases. By integrating digital planning and biologic adjuncts, these techniques align with the goals of patient-centered, minimally invasive implantology. A comprehensive literature search was conducted using the PubMed, Scopus, Web of Science, and Google Scholar databases, covering articles published between 2010 and 2025. Relevant studies were identified using key words related to minimally invasive sinus elevation, crestal approach and implant placement in the posterior maxilla. Overall, MISE techniques are becoming a critical component of modern implant practice, providing predictable clinical outcomes with reduced morbidity, improved patient comfort and enhanced surgical precision. Their integration with digital planning and biologic adjuncts is expected to further expand treatment possibilities in anatomically challenging posterior maxillary cases

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1. Introduction

Over the past few decades, dental implantology has emerged as a transformative solution for the rehabilitation of edentulous spaces, providing long-term functional stability, enhanced aesthetics and an improved quality of life for patients. Success rates >90% have constituted implants the standard of care for single- and multiple-tooth replacements in clinics (1).

Despite widespread adoption, implant placement in the posterior maxilla remains challenging. Following tooth loss, the posterior maxillary region is prone to progressive alveolar bone resorption, often compounded by the physiological process of maxillary sinus pneumatization (2). Together, these phenomena result in a marked reduction in vertical bone height, leaving insufficient volume for secure anchorage of standard-length implants. This anatomical limitation is particularly common edentulous cases and is a critical barrier to predictable implant placement (3).

In response to these challenges, clinicians have increasingly relied on sinus augmentation procedures to restore lost bone height by elevating the sinus floor and creating a conducive environment for implant integration. The lateral window sinus lift, first introduced by Tatum in 1977 and later refined by Boyne and James (4), became the cornerstone technique. It creates a bony window in the lateral wall of the maxillary sinus to access and elevate the Schneiderian membrane, followed by graft placement (4).

Although effective, particularly in cases with severely resorbed ridges (<4 mm residual bone height), this method is inherently invasive. It is also associated with prolonged surgical times, increased patient morbidity and risks such as membrane perforation, post-operative discomfort and potential sinus complications, including infection and sinusitis. In order to mitigate these drawbacks, the field has witnessed a paradigm shift towards minimally invasive sinus elevation (MISE) techniques, particularly for patients with moderate residual bone height (typically 4-8 mm). These approaches prioritize reduced surgical trauma, short healing times and enhanced patient comfort, aligning well with modern principles of minimally invasive and patient-centered dentistry (5,6). Summers (7) introduced the osteotome sinus floor elevation technique in 1994, a landmark advancement in the field. This transcrestal approach, performed through the existing implant osteotomy site, used calibrated osteotomes to gently fracture and elevate the sinus floor, allowing simultaneous placement of the implant and graft material (7). Although technically sensitive and reliant on tactile feedback, this method provided a marked reduction in morbidity compared to the lateral window technique and opened new avenues for managing moderately resorbed ridges without extensive surgical access. Building on this foundation, newer atraumatic techniques, such as hydraulic sinus elevation, balloon-assisted sinus membrane elevation, piezoelectric-assisted surgery and osseodensification-based crestal lifts, have emerged. These methods share a common goal: To elevate the Schneiderian membrane while preserving its integrity and minimizing perioperative complications. Notably, they also enable simultaneous implant placement, reducing overall treatment time and improving patient acceptance. The present review aimed to provide a comprehensive overview of MISE techniques, including their rationale, clinical indications, technical protocols and comparative outcomes. In doing so, it highlights the evolving role of MISE in modern implant dentistry and its potential to expand treatment possibilities in anatomically and medically challenging cases.

2. Literature screening methods

A comprehensive literature search was conducted across the PubMed, Scopus, Web of Science, and Google Scholar databases using combinations of key words such as 'sinus elevation', 'sinus lift', 'minimally invasive', 'crestal approach', 'osteotome', 'hydraulic', 'balloon' and 'piezoelectric'. Studies were included if they were human clinical investigations with a minimum follow-up of ≥1 year and clearly reported core outcome indicators, such as implant survival, bone gain and complications. Exclusion criteria comprised case reports, animal or *in vitro* studies, review articles and non-English publications. Titles and abstracts were screened independently, followed by full-text evaluation of eligible studies, with discrepancies resolved by consensus. The methodological quality of included studies was assessed using the ROB 2 tool for randomized controlled trials and the MINORS criteria for non-randomized studies.

3. Clinical outcomes, success rates and complications

MISE techniques have exhibited clinical outcomes comparable to, and often superior to, conventional lateral window sinus lift procedures. Reported implant survival rates are typically >95-98%, with mean bone gain of 3-4 mm, demonstrating reliable regenerative potential even in cases with limited residual bone height. Studies such as those by Cobo-Vázquez *et al* (8) and Sirinirund *et al* (9) highlighted similar implant success rates, although with significantly reduced morbidity, operative time and patient discomfort.

Intraoperative complications. Intraoperative complications primarily include Schneiderian membrane perforation, which remains the most common adverse event during sinus elevation procedures. Although the incidence is lower in MISE techniques compared to lateral approaches, it may still occur due to excessive force, inadequate bone thickness, or anatomical variations such as sinus septa (10).

Post-operative complications. These are generally mild and transient, including pain, facial swelling and sinus congestion. In some cases, patients may develop sinusitis or localized infection, particularly if aseptic protocols are compromised or membrane integrity is breached during surgery (11).

Long-term complications. Long-term complications may involve marginal bone loss or graft resorption, which can affect implant stability over time. In rare instances, implant failure may occur due to inadequate osseointegration or persistent sinus pathology (12).

Overall, careful case selection, meticulous surgical technique and thorough pre-operative planning are essential to minimize complications and ensure long-term success of MISE procedures.

Careful cone-beam computed tomography (CBCT)-based planning, controlled hydraulic or piezoelectric elevation and atraumatic instrumentation are key to minimizing these risks. Overall, MISE provides a predictable, less traumatic and patient-friendly alternative to conventional sinus lift methods, while maintaining comparable implant stability and bone regeneration outcomes.

4. Anatomical considerations and diagnostic planning

The success of any sinus elevation procedure, particularly those employing minimally invasive techniques, depends on a comprehensive understanding of maxillary sinus anatomy and meticulous pre-operative diagnostic planning. Since minimally invasive approaches do not provide direct visual access to the sinus cavity, clinicians must rely on a thorough knowledge of anatomical variations and detailed imaging to safely manipulate the sinus membrane and achieve optimal implant placement.

The maxillary sinus is a paired, air-filled cavity located within the body of the maxilla, lined by the Schneiderian membrane, a thin, vascularized mucous membrane that is highly susceptible to perforation during elevation. This membrane, while delicate, plays a vital role in sinus health, and any trauma to it can result in complications, such as graft migration, sinusitis or implant failure. The shape, volume and internal architecture of the sinus vary significantly between individuals, and these variations influence the ease and safety of the elevation procedure (2,13). In some patients, sinus

septa, thin bony partitions, may be present and often remain undetected on standard radiographs. These septa can obstruct membrane elevation and increase the risk of perforation, particularly when using crestal sinus elevation techniques (14). Additionally, the thickness of the Schneiderian membrane itself can vary. Membranes with a thickness >2 mm, which are often observed in smokers or patients with chronic periapical infections or periodontitis, may pose added resistance during elevation, but are paradoxically less prone to rupture (15,16).

Residual bone height is a key determinant in selecting the appropriate sinus elevation method. When the residual bone height is >8-10 mm, implant placement may be feasible without any augmentation. Heights between 5-8 mm are generally considered ideal for minimally invasive approaches, in which indirect membrane elevation can be performed safely, often in conjunction with simultaneous implant placement. Conversely, bone height <4 mm typically necessitates a lateral window approach to allow adequate graft containment and healing (17).

To guide this decision-making process, the classification by Zitzmann and Schärer (18) published in 1998 is widely used and remains one of the most accepted protocols. It categorizes sinus augmentation approaches based on residual bone height as follows: Residual bone height >10 mm, implant placement without sinus augmentation; residual bone height 7-10 mm, crestal (osteotome-based) sinus floor elevation with simultaneous implant placement; residual bone height 4-6 mm, crestal approach with or without grafting, depending on primary stability; residual bone height <4 mm, lateral window sinus lift, often with delayed implant placement.

CBCT has emerged as the gold standard imaging modality in the pre-operative assessment of sinus augmentation. Unlike conventional two-dimensional radiographs, CBCT provides high-resolution, three-dimensional visualization of the posterior maxilla. The following parameters need to be carefully assessed (19): i) Residual bone height: This determines the feasibility of implant placement and choice of sinus elevation technique; ii) Schneiderian membrane thickness: Thin membranes are more prone to perforation, while thicker membranes may indicate underlying pathology; iii) presence of sinus septa: Bony partitions that may complicate membrane elevation and increase perforation risk; iv) posterior superior alveolar artery: Identification is crucial to avoid intraoperative bleeding complications; v) position of adjacent tooth roots: This helps prevent root damage and guides implant angulation. A decision tree illustrating the selection of sinus elevation techniques based on residual bone height is presented in Fig. 1.

5. Minimally invasive sinus elevation techniques

Mechanical tapping/compression-based techniques

Indications. It is typically indicated when the residual bone height is ≥5-6 mm, constituting it a viable option for cases requiring modest elevation (20).

Operation point. Mechanical tapping or compression-based sinus elevation represents one of the earliest minimally invasive approaches developed to lift the sinus membrane. These techniques utilize controlled manual forces applied through the alveolar crest to gently elevate the Schneiderian membrane by indirectly displacing the sinus floor (9). Among these, the osteotome technique is most commonly used. This method involves creating a crestal osteotomy followed by the sequential insertion of osteotomes of increasing diameter. The instruments are carefully tapped using a surgical mallet to fracture the sinus floor and compress the surrounding bone apically, thereby creating a space beneath the membrane for graft placement and subsequent implant insertion (21).

Various systems assist in the safe and precise execution of this method. Commercially available kits such as the Summers Osteotome kit (Zimmer Biomet), CAS-KIT (Osstem Implant) and the SCA Kit (Neobiotech) include depth-marked or stopper-fitted osteotomes that help control penetration depth and minimize the risk of membrane perforation. Supporting instruments, such as torque-controlled handpieces, bone compactors and surgical mallets further enhance precision and operator control (21).

Advantages. One of the clinical advantages of this approach is that it promotes bone densification during insertion, which may enhance the primary stability of implants, particularly beneficial in the posterior maxilla with low-density bone (22).

An advancement to traditional osteotome-based methods is the use of Densah® burs, which operate on a principle known as osseodensification. These specially designed burs, used in a counterclockwise (non-cutting) mode, laterally compact rather than remove bone, thereby densifying the osteotomy site (23). When applied for crestal sinus lift procedures, Densah® burs allow for controlled elevation of the sinus floor, while simultaneously preserving and condensing the surrounding trabecular bone (24,25). This not only minimizes trauma to the Schneiderian membrane, but also enhances the structural integrity of the bone, contributing to improved implant stability. Additionally, the rotary motion of the burs eliminates the need for percussive force, reducing patient discomfort and making the procedure more tolerable without sedation (26).

Limitations. Despite its clinical utility and cost-effectiveness, given the minimal requirement for advanced equipment, this technique is not without limitations. The percussive tapping may cause patient discomfort and anxiety, particularly in cases not performed under sedation (27).

Complication rates. Membrane perforation remains the most common complication, with its incidence varying depending on anatomical complexity and operator skills (8,28).

Hydraulic pressure-assisted techniques

Indications. Hydraulic pressure-assisted sinus lifts are particularly beneficial in cases with narrow posterior ridges, where mechanical tapping would be less predictable, and in situations where minimizing trauma to the sinus membrane is critical, such as in elderly patients or those with a thin or fragile sinus lining. Additionally, this method can be safely employed in the presence of minor sinus septa, provided elevation is done gradually and with caution (29).

Operative points. Hydraulic sinus elevation is a refined, minimally traumatic method that uses the principle of fluid dynamics to elevate the Schneiderian membrane in a controlled, uniform manner, without the need for direct mechanical manipulation. Instead of physically fracturing the sinus floor with osteotomes or drills, this technique leverages sterile fluids or injectable graft materials to create a gentle hydrostatic force beneath the sinus membrane, pushing it upward and creating a cavity for grafting or implant placement (21,30).

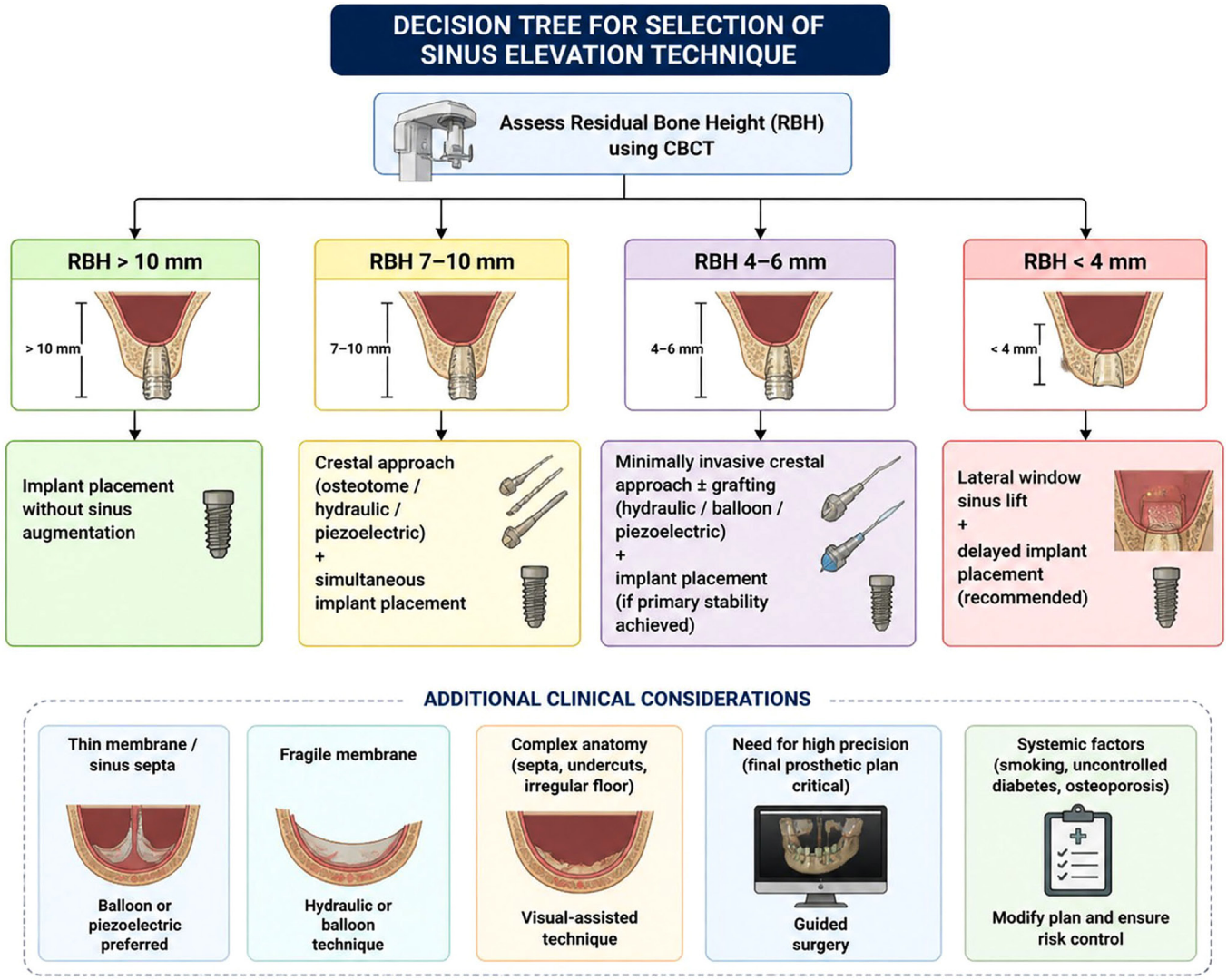

Figure 1. Decision tree illustrating the selection of sinus elevation techniques based on RBH and key anatomical considerations. CBCT assessment guides the choice between implant placement without augmentation, crestal approaches, or lateral window techniques, with additional factors influencing technique selection. RBH, residual bone height; CBCT, cone-beam computed tomography.

The clinical procedure begins with a crestal osteotomy, typically up to 1-2 mm short of the sinus floor, as verified by depth measurements or radiographic planning. Once this is achieved, sterile saline or a flowable bone substitute, such as injectable calcium phosphate cement, is slowly introduced through the osteotomy site using a specialized syringe or pressure-controlled device (30). As the fluid fills the space, it exerts hydrostatic pressure in all directions, lifting the membrane in a dome-like fashion. The elevation is monitored through tactile resistance and back-pressure, requiring clinical finesse to avoid membrane rupture (31).

A wide range of materials have been explored to optimize both the hydraulic effect and regenerative outcomes. Sterile saline remains the most commonly used fluid for elevation, although alternatives such as hyaluronic acid gel, radiopaque contrast media, or even albumin-concentrated growth factors have been employed to enhance healing and visualization (27-30). Flowable grafts, such as calcium phosphosilicate putty, injectable calcium phosphate and platelet-rich fibrin provide added regenerative potential while also serving as hydraulic agents (31-33). Particulate materials, including allografts, β-tricalcium phosphate, nano-hydroxyapatite, xenografts and even autogenous bone chips may be introduced following membrane elevation (9,34-40).

Several dedicated systems have been designed to perform this technique with enhanced safety and control. Commercially available kits, such as the Crestal Approach Sinus (CAS) kit (Osstem Implant), Sinus Crestal Approach (SCA) kit (Neobiotech) and Flusilift System (Meta) employ pressure-regulated syringes and one-way valve mechanisms to deliver uniform hydraulic force. Other systems, such as the Hydraulic Sinus Lift Implant Device [Tallarico *et al* (41)], integrate internal fluid channels within the implant design, enabling simultaneous membrane elevation and implant placement. The choice of system depends on the expertise of the surgeon, available equipment and case complexity (21,29,41).

Advantages. This technique provides a controlled, uniform and atraumatic elevation of the Schneiderian membrane, reducing the need for mechanical force. It allows for precise membrane lifting with improved patient comfort and can be effectively combined with regenerative materials to enhance outcomes (42).

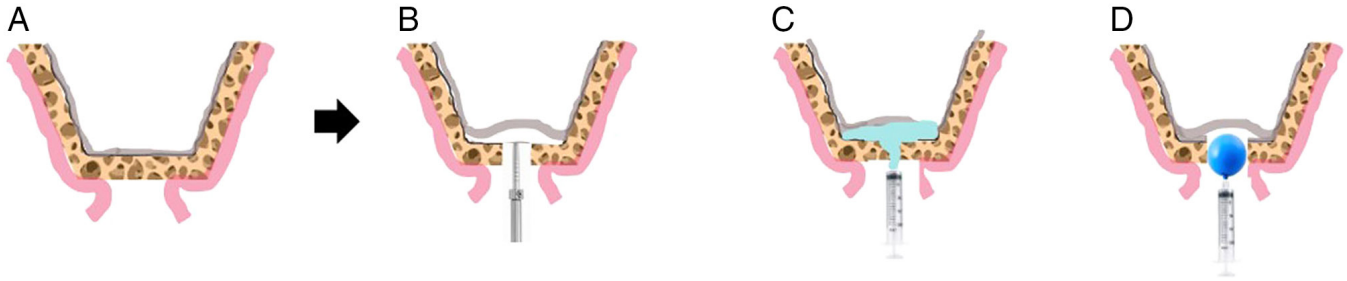

Figure 2. Illustration of minimally invasive sinus elevation approaches. (A) Pre-operative view before sinus elevation; (B) osteotome sinus lift technique; (C) hydraulic pressure-assisted sinus lift; (D) balloon-assisted sinus lift.

Limitations. The technique demands precision and experience, as excessive pressure can cause sudden rupture of the sinus membrane, compromising grafting and implant stability. Proper control of fluid delivery and tactile feedback is essential (42).

Complication rates. Complication rates are generally low, with membrane perforation being the primary risk if pressure is not adequately controlled (42).

Balloon-assisted sinus membrane elevation

Indications. This technique is particularly suitable in cases with thin sinus floors, minor septa, or irregular sinus anatomy, where membrane integrity is at higher risk. It is also indicated for moderately atrophic posterior maxillae and cases where atraumatic, controlled elevation is desired (43).

Operative points. Balloon-assisted techniques represent a gentle, controlled approach to sinus membrane elevation, using inflatable devices to mechanically lift the Schneiderian membrane after crestal access. This method combines the precision of minimally invasive access with the safety of gradual, uniform elevation, rendering it particularly advantageous in anatomically sensitive cases (44).

This technique begins with a crestal osteotomy performed with drills or trephines, terminating 1-2 mm short of the sinus floor. The thin bony floor is then carefully breached with a hand instrument or osteotome, ensuring the Schneiderian membrane remains intact. A deflated balloon catheter, specifically designed for sinus augmentation, is introduced into the osteotomy site and gradually inflated with sterile saline or contrast medium. Controlled, stepwise inflation gently elevates the sinus membrane in a dome-shaped fashion, with inflation pressure and volume continuously monitored using manometers or calibrated syringe systems to avoid overexpansion or perforation (45). After achieving the desired lift, the balloon is deflated and withdrawn, and the newly created subantral space is packed with bone graft material such as xenografts, allografts, or synthetic substitutes. In the event that adequate primary stability is attainable, an implant may be placed simultaneously (45).

Multiple commercially available balloon-based systems have been engineered to provide precise, pressure-controlled elevation of the Schneiderian membrane during crestal sinus lift procedures. Among the most widely used are the Antral Membrane Balloon Elevation (AMBE) System (OsseoDent®), the SinuLift® Balloon System (Meisinger) and the Kyung Balloon Lift Control (BLC) System (Osstem Implant). These systems utilize pressure-regulated inflation mechanisms that permit gradual, uniform membrane elevation, ensuring predictable lifting, while minimizing the risk of overexpansion or perforation (44).

Advantages. The technique provides notable clinical advantages, such as the slow, uniform expansion of the balloon minimizes trauma, enhances precision and improves patient comfort by avoiding the tapping forces of osteotomes (44).

Limitations. The method requires specialized balloon catheters (adapted from ENT use), involves additional cost and demands operator training to master pressure control and avoid overexpansion.

Complication rates. Complication rates are generally very low, with membrane perforation being rare when proper pressure control is maintained (44).

Ultrasonic/piezoelectric-assisted techniques

Indications. This technique is particularly valuable in cases with limited residual bone height, delicate sinus membranes, or complex maxillary sinus anatomy where precision and safety are critical (46,47).

Operative points. Piezoelectric surgery utilizes ultrasonic micro vibrations to cut mineralized tissue, while preserving adjacent soft tissues, providing a significant advantage in sinus elevation procedures. In both crestal and lateral approaches, piezoelectric tips allow precise osteotomy of the sinus floor with minimal trauma and without the tapping forces associated with osteotomes. This selective cutting ability reduces the incidence of Schneiderian membrane perforation, which is one of the most common complications in sinus lift surgery (48).

Once the bony window or crestal access is created, the sinus membrane can be carefully detached under enhanced control, often in combination with hydraulic pressure or other minimally invasive aids. Clinical studies have demonstrated low perforation rates (2-3%) and high implant survival, even in cases with limited residual bone height (49). Patients also benefit from reduced post-operative discomfort and swelling compared with conventional techniques (50).

A range of piezoelectric systems are available for clinical use, including Piezosurgery® (Mectron), VarioSurg® (NSK) and Implant Center® 2 (Acteon). These devices operate at ultrasonic frequencies (25-30 kHz), allowing micrometric cutting of bone, while sparing adjacent soft tissue and vital structures, such as the Schneiderian membrane or blood vessels (50).

Table I. Overview of recent clinical evidence on minimally invasive sinus elevation techniques and implant outcomes.

Authors, year of publication	Technique	Key outcomes	Literature quality/blinding risk	(Refs.)
Alajami *et al*, 2024	Balloon vs. osseodensification (RCT)	Survival: 100%; bone: significant gain; complications: Minimal; follow-up: 12 months	Low risk (ROB2; RCT)	(56)
Samir *et al*, 2024	Osseodensification vs. PISE (RCT)	Survival: High; bone: Increased density and gain; complications: Low; Follow-up: Short-term	Low risk (ROB2; RCT)	(57)
Hashem *et al*, 2023	Osteotome vs. piezo vs. densah (RCT)	Survival: High; bone: Increased; complications: fewer with densah; Follow-up: 6 months	Low risk (ROB2; RCT; short follow-up)	(58)
Gaspar *et al*, 2024	Osseodensification vs. lateral window (RCT)	Survival: High; bone: comparable; complications: Lower morbidity; follow-up: NR	Low risk (ROB2; RCT)	(59)
Veluri *et al*, 2025	Osseodensification vs. CAS kit (RCT)	Survival: High; bone: Improved stability; complications: Low; Follow-up: NR	Low risk (ROB2; double-blinded RCT)	(60)
Zhou *et al*, 2021	Transcrestal vs. lateral sinus lift (RCT)	Survival: >95%; bone: Significant gain; complications: Comparable; Follow-up: 2 years	Low risk (ROB2; RCT)	(61)
Sulyhan-Sulyhan *et al*, 2024	Osseodensification (clinical study)	Survival: High; bone: Good gain; complications: Minimal; Follow-up: NR	Moderate risk (MINORS; non-randomized)	(62)

RCT, randomized controlled trial; NR, not reported.

Table II. Comparison of minimally invasive sinus elevation techniques.

Technique	Applicable bone height (RBH)	Degree of trauma	Membrane perforation risk	Equipment cost	Learning curve	Recommended scenarios
Osteotome (mechanical)	≥5-6 mm	Moderate	Moderate	Low	Moderate	Routine cases with adequate bone height
Hydraulic	≥4-5 mm	Low	Low	Moderate	Moderate	Fragile membrane, narrow ridges
Balloon-assisted	≥4 mm	Very low	Very low	High	High	Thin membrane, septa, delicate anatomy
Piezoelectric	≥4 mm	Low	Very low	High	High	Complex anatomy, high-risk cases
Visual-assisted	Any	Low	Very low	High	High	Revision or anatomically complex cases
Guided surgery	Any	Minimal	Very low	Very high	High	Precision-demanding, full-arch cases

RBH, residual bone height.

Advantages. This technique provides precise and selective bone cutting with minimal soft tissue damage, resulting in reduced membrane perforation rates and improved surgical safety. It also enhances patient comfort by minimizing trauma, pain and post-operative swelling (50).

Limitations. Despite its advantages, the technique requires specialized equipment, involves higher costs and has a longer learning curve compared to conventional methods (50).

Complication rates. Complication rates are low, with reported membrane perforation rates of ~2-3%.

Visual-assisted techniques (endoscopic or microscopic guidance)

Indications. Visual-assisted techniques are particularly valuable in complex cases with thickened membranes, septa, or previous surgical interventions or proximity to critical anatomical structures. They are also useful in anatomically challenging cases and for training purposes (49).

Operative points. These techniques integrate real-time imaging, most often via endoscopy or dental microscopy, to directly visualize the Schneiderian membrane during elevation. Unlike traditional tactile-only methods, they provide continuous visual feedback, enhancing precision, safety, and operator confidence (49,50).

The procedure combines standard crestal or lateral approaches with visualization tools, such as 0˚/30˚ rigid endoscopes or dental operating microscopes. Following sinus access, the membrane is elevated under direct observation, allowing early detection of tension, microperforations, or tethering and enabling immediate corrective action. High-resolution endoscopes with fiber-optic or LED illumination, or dental microscopes with magnification and coaxial light, are commonly used, often paired with irrigation and suction for a clear field (51-53).

Advantages. These methods provide the direct visualization of the sinus membrane, improving precision and reducing the risk of perforation. They enhance operator confidence, allow the early detection and management of complications, and support conservative, patient-specific interventions (51).

Limitations. The technique requires specialized equipment, additional operator training, and longer setup and operative time, which may limit routine use (51).

Complication rates. Complication rates are very low due to improved visualization and control during membrane elevation (51).

Guided surgery-based elevation

Indications. These methods are particularly valuable in full-arch rehabilitations, complex anatomical regions, or cases where minimal residual bone height demands extreme accuracy (52).

Operative points. This technique represents the integration of digital technology into sinus augmentation procedures, providing high precision and predictability. It involves the use of computer-guided tools, either static surgical guides fabricated in advance or dynamic navigation systems that track instrument position in real time, to perform the sinus lift with controlled accuracy (54,55).

The procedure begins with detailed preoperative planning using CBCT scans and digital impressions. Virtual simulation allows clinicians to evaluate anatomical constraints, determine the ideal implant position, and predefine the osteotomy site and depth. Once planning is finalized, a CAD/CAM-generated guide (static) or real-time tracker (dynamic) is used intraoperatively to direct the drills and instruments through a precise trajectory (54). This planned path facilitates not only implant placement, but also the elevation of the sinus membrane using compatible instruments such as crestal drills, piezoelectric inserts, or hydraulic applicators (55).

A variety of digital systems are currently available for guided sinus elevation. Widely used static systems include NobelClinician® (Nobel Biocare) and coDiagnostiX® (Dental Wings, Canada), while dynamic navigation platforms such as X-Guide® (Dentsply Sirona) and Navident® (ClaroNav) provide real-time positional tracking and visual guidance. These technologies enable flapless procedures, improved patient comfort and enhanced operator confidence, particularly in anatomically complex or limited bone height scenarios (55).

Advantages. Guided approaches enable flapless surgery, improve patient comfort and significantly reduce chairside guesswork and operator stress. However, they are not without drawbacks (53).

Limitations. The technique requires access to high-quality imaging, digital planning software, and advanced equipment, leading to increased cost. Additionally, outcomes are highly dependent on accurate planning, proper guide fit, and operator proficiency (53).

Complication rates. Complication rates are generally very low when protocols are followed, owing to the high precision and controlled execution of the procedure.

These minimally invasive approaches are schematically illustrated in Fig. 2. Several recent clinical studies have evaluated MISE techniques in terms of implant survival, complication rates, and patient-reported outcomes. A summary of the key findings is presented in Table I (56-62).

The key differences among minimally invasive sinus elevation techniques, including indications, complexity, and complication risk are summarized in Table II.

6. Conclusion

Minimally invasive sinus elevation techniques provide safer, less traumatic alternatives to traditional lateral window approaches for implant placement in the posterior maxilla. Each method, whether osteotome-based, hydraulic, balloon-assisted, piezoelectric, or guided, provides unique advantages tailored to specific clinical scenarios. These approaches reduce patient morbidity, enhance precision and support flapless or limited-flap surgeries. With advancing digital tools and biologic adjuncts, MISE techniques are becoming integral to modern implant practice, expanding treatment possibilities even in anatomically challenging cases.

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Authors' contributions

AS and NS contributed to the conception and design of the study, performed the literature search, and prepared the initial draft of the manuscript. RB, DGK and RC participated in the critical revision, editing and refinement of the manuscript to

ensure intellectual accuracy and coherence. All authors have read, reviewed and approved the final version of the manuscript for publication. Data authentication is not applicable.

Ethics approval and consent for publication

Not applicable.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Use of artificial intelligence tools

During the preparation of this work, AI tools were used to improve the readability and language of the manuscript or to generate images, and subsequently, the authors revised and edited the content produced by the AI tools as necessary, taking full responsibility for the ultimate content of the present manuscript.

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