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CASE REPORTS

TRANSCRESTAL SINUS FLOOR ELEVATION WITH INJECTABLE BONE SUBSTITUTES: EXPANDING THE INDICATIONS WITHIN BIOLOGICAL LIMITS.

Claudio Stacchi[1]*, Paolo Savadori[2], Maarten Boogaard[3], Riccardo Pasquali[4], Teresa Lombardi[5], Antonio Rapani[4]

[1] Department of Medicine, LUM University, Casamassima (BA), Italy.

[2] Surgical, Medical and Dental Department of Morphological Sciences related to Transplant, Oncology and Regenerative Medicine, University of Modena and Reggio Emilia, Modena, Italy.

[3]Department of Oral Health Sciences, Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, Netherlands.

[4] Department of Medicine, Surgery and Health Sciences, University of Trieste, Trieste, Italy.

[5] Department of Medical and Surgical Specialties, Radiological Sciences and Public Health, University of Brescia, Brescia, Italy.

***Corresponding author:** professor Claudio Stacchi, Department of Medicine, LUM University, Casamassima (BA), Italy.
e mail: claudio@stacchi.it

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ABSTRACT

In maxillary sinus floor elevation, the least invasive technique capable of achieving equivalent regenerative outcomes should be preferred, and this choice is primarily dictated by sinus anatomy. Among anatomic variables, sinus width, more than residual bone height, should guide the approach: narrow sinuses, regardless of access (lateral or crestal), inherently permit rapid vascular ingrowth from opposing walls and stable clot organization. The key difference lies in sinus membrane detachment: indirect transcrestal elevation yields a predictable, uniform elevation only in narrow sinuses; in wide sinuses, the lateral window is more reliable.

Using injectable grafts in narrow sinuses via a small crestal osteotomy permits fast and controlled hydrodynamic membrane elevation and excellent space adaptation. However, when injectable materials are used, immediate placement is strongly recommended to provide a tenting effect that counteracts sinus pressure and helps maintain graft volume during healing. Radiographic follow-ups of illustrative clinical cases demonstrate significant vertical bone gain, while histology at implant placement shows mature, well-vascularized regenerated bone. When case selection is performed appropriately on the basis of a thorough preoperative diagnosis, particularly sinus width assessment, transcrestal sinus elevation is a truly minimally invasive alternative to the lateral window, achieving equivalent regenerative outcomes with significantly improved patient comfort.

***Keywords*:** transcrestal sinus floor elevation, injectable graft, minimally invasive surgery, maxillary sinus.

INTRODUCTION

1. Maxillary Sinus Floor Elevation: Biological Foundations

Successful bone regeneration after maxillary sinus floor elevation results from a coordinated cascade of events that begins immediately after surgery[1]. Detachment of the periosteal layer of the Schneiderian membrane from the bony sinus floor induces bleeding into the newly created compartment, leading to the formation of a fibrin clot. This clot is not a passive filler but a biologically active matrix rich in platelets and growth factors such as BMPs, PDGF, TGF-β, IGFs, FGF, and VEGF[2]. These molecules regulate the recruitment and proliferation of mesenchymal progenitor cells, which predominantly migrate from the bone marrow of the surrounding maxillary bone[3,4]. Neovascularization is central to this process: capillary sprouts from the vascularized lateral and medial bony walls penetrate the clot, supplying oxygen, nutrients, and osteoprogenitor cells required for new bone deposition[5]. Consequently, bone formation proceeds in a centripetal pattern, advancing from the sinus walls toward the center of the grafted space[6]. The Schneiderian membrane itself appears to play a minor role in this process: while *in vitro* models have shown some osteogenic potential[7,8], clinical evidence indicates its contribution as negligible compared to that of the osseous walls[9].

One of the most important variables influencing healing after sinus augmentation is the anatomy of the maxillary sinus, particularly its bucco-palatal width. Narrow sinuses permit rapid and complete vascular colonization of the augmented space, leading to higher proportions of vital bone at earlier stages. In contrast, wide sinuses require longer angiogenic distances, leaving central regions poorly vascularized and slowing bone formation[10,11].

This difference is evident even within the same sinus: histologic studies have demonstrated significantly more new bone in the narrower mesial portion of the cavity than in the wider distal portion[12].

This anatomical factor directly influences the choice of surgical technique. In wide sinuses, the lateral window approach, although it cannot overcome the inherent limitation of longer angiogenic distances, allows direct visualization and elevation of the Schneiderian membrane from the entire perimeter, including both medial and lateral walls. This ensures maximal exposure of vascularized bone surfaces and optimizes the regenerative environment within the given anatomical constraints. In the transcrestal approach, sinus membrane elevation is achieved indirectly by the pressure of graft material or saline, without direct visualization and control. In narrow sinuses (≤12 mm bucco-palatal width at ~10 mm above the crest), this technique can predictably achieve complete and correct detachment of the membrane from both medial and lateral walls, creating a vascularized compartment that supports substantial new bone formation. In wide sinuses (>12 mm), by contrast, it often results in an incomplete, centrally confined detachment, leaving the peripheral walls unreached and much of the grafted space isolated from vascularized bone, thereby limiting regenerative potential[13–15].

In contemporary practice, the selection between the lateral and transcrestal approaches should no longer be dictated primarily by residual bone height, as was traditionally the case[16]. Advances in technique, particularly hydrodynamic or gel-assisted transcrestal methods, can reliably achieve mean vertical gains of 10 mm or more, making initial bone height a less decisive factor[17–19]. Instead, a biologically-driven choice should be made, in which the bucco-palatal width of the sinus guides the surgical plan, aligning the approach with the vascularization potential of the site and placing the augmented compartment in the most favorable regenerative conditions possible.

2. Transcrestal Sinus Floor Elevation

Modern transcrestal sinus floor elevation (tSFE) techniques are based on the original method described by Robert Summers in 1994[20] and have since developed into a wide variety of procedural approaches, with current evidence showing no clear superiority of one over another. Consequently, the choice of technique is largely determined by the surgeon's training, experience, and intraoperative preference. Despite their differences in execution, all of these methods are characterized by two main operative phases:

- crestal access to the maxillary sinus
- elevation and detachment of the Schneiderian membrane.

Interruption of the sinus floor continuity to gain crestal access to the sinus cavity can be achieved using: (1) manual or electric-driven osteotomes, often equipped with mechanical depth stops to control apical advancement and reduce the risk of membrane perforation[21–23]; (2) dedicated rotary burs, either with differential cutting geometry to modulate bone removal at the apical portion or designed for osseodensification, compacting and displacing bone laterally and apically to improve density[24,25]; or (3) piezosurgical inserts, utilizing ultrasonic microvibrations for selective bone cutting while minimizing the risk of Schneiderian membrane injury[26,27].

Regardless of the access method, this phase aims to achieve controlled penetration of the cortical bone of the sinus floor, maintain the integrity of the sinus membrane, and prepare an optimal recipient site for graft placement and eventual subsequent implant installation.

Once crestal access to the maxillary sinus has been achieved and the integrity of the Schneiderian membrane has been carefully verified, typically by means of the Valsalva maneuver, the procedure advances to the second step, which is critical for achieving favorable regenerative outcomes: the meticulous elevation of the sinus membrane.

Specific membrane elevators designed for the transcrestal approach are commercially available. Although current literature does not provide sufficient evidence to conclusively support their routine use, when handled with care they can facilitate the initial circumferential detachment of the membrane around the created access point[28]. The actual elevation of the membrane, with subsequent exposure of the lateral and medial bony walls, is generally accomplished by the hydrodynamic pressure generated during insertion of the graft material, either well-hydrated granules or injectable biomaterials. In some techniques, this process may be preceded by preliminary membrane detachment using either free saline solution or a balloon-assisted systems[29,30].

As previously emphasized, the key determinant of predictable success in this phase is accurate preoperative diagnosis. Only a sinus with a narrow mediolateral dimension offers the mechanical conditions required for a reliable membrane elevation via the transcrestal route[4]. In transcrestal sinus floor elevation, sinus width appears to influence membrane perforation risk in the opposite way to the lateral approach. A multicenter study on 430 patients reported very low perforation rates in narrow sinuses and a higher incidence in wide sinuses[31]. This aligns with biomechanical data showing that the force

required for membrane detachment increases with the size of the elevated area; when this force exceeds the membrane's elastic limit, tearing can occur[32]. In narrow sinuses, the smaller elevation area allows greater vertical displacement before perforation, whereas in wide sinuses the larger area increases the risk. This contrasts sharply with the lateral approach, where narrow anatomy is associated with higher perforation rates[33].

2.1 Material Selection and Healing Dynamics

At this stage of the procedure, the clinician must determine, based on the quantity and quality of the residual bone, the extent of endosinus regeneration required. When 4–5 mm of good quality residual bone height is present, extensive volumetric regeneration is generally unnecessary. In such situations, it may be sufficient to place a collagen sponge, platelet-derivative membranes, or even no grafting material at all between the sinus membrane and the sinus floor, combined with the simultaneous placement of a dental implant longer than the residual crestal height[34–36]. Immediate implant placement is essential, as the apical portion of the implant will protrude into the sinus cavity, acting as a 'tent pole' to maintain membrane elevation and achieve, on average, an additional 3–4 mm of vertical bone height.

Conversely, when less than 4–5 mm of residual bone height is available, a substantial regenerative effort is required, both in terms of quantity and quality, as the newly formed bone will provide the majority of the implant's long-term support. Under these conditions, the use of a bone substitute for transcrestal sinus floor elevation is often recommended to avoid excessive shrinkage of the tented space[37]. In these cases, the primary function of the bone graft, provided in an adequate volume, is to achieve proper elevation of the Schneiderian membrane and to expose the lateral and medial bony walls[14]. This circumferential detachment increases the available surface area for osteogenic activity and facilitates vascular invasion, both of which are essential for predictable new bone formation. By acting as a space-maintaining scaffold, the graft material preserves the volumetry of the compartment against the positive pressure exerted by the membrane, allowing it to be progressively replaced by vital bone during the healing process[15].

Bone substitutes commonly used for transcrestal sinus floor elevation are available as granules, injectable bone pastes, or gels. Granular bone substitutes (ideally with small particle size, rounded morphology, and, when possible, collagenation to reduce the risk of membrane damage after placement into the subantral space[38]) generally provide good dimensional stability during healing, especially for xenografts and specific classes of synthetic materials. However, they also present some operative challenges. Granules must be introduced in small increments through the crestal access, thoroughly hydrated, and compacted with an osteotome. When the goal is to introduce a sufficient volume to fully occupy the subantral space and elevate the Schneiderian membrane from the surrounding bony walls, this process can be relatively time-consuming, often requiring up to 20–30 minutes. Furthermore, in the event of a membrane perforation, accidental dispersion of the particulate material into the sinus cavity may occur. Such migration can potentially lead to complications including sinusitis or obstruction of the ostiomeatal complex (OMC), the same type of adverse events that can be encountered following a lateral sinus floor elevation procedure.

2.2 Injectable Bone Substitutes

Among the injectable materials used for transcrestal sinus floor elevation, both xenogeneic and synthetic bone substitutes are available. Xenogeneic preparations generally consist of micronized porcine or equine-derived mineral particles with variable collagen content (typically 20% to 40% by weight) to enhance cohesiveness and handling during delivery[18,19]. Synthetic options include aqueous pastes of nanocrystalline hydroxyapatite dispersed in water, providing an osteoconductive surface that can be gradually replaced by vital bone[39,40]. Another group includes calcium phosphosilicate particles, typically delivered with a water-soluble carrier containing polyethylene glycol and glycerine. These materials function as osteoconductive scaffolds; however, in the context of transcrestal sinus floor elevation, available evidence is still preliminary and histologic outcomes vary across studies.[41–43].

Injectable bone substitutes represent a practical alternative to particulate grafts, as they can be delivered through narrow osteotomies without the need for manual compaction. Their flowable consistency allows adaptation to the irregular contours of the subantral compartment while simultaneously detaching the Schneiderian membrane and filling the newly created space. Compared with granular substitutes, this phase can be completed in significantly less time (often within seconds) rather than the several minutes typically required for particulate placement.

Moreover, the use of injectable grafts may offer significant advantages in cases of accidental material dispersion into the maxillary sinus cavity. In the event of a Schneiderian membrane perforation, granular bone substitutes could spread within the sinus and potentially compromise OMC patency, thereby increasing the risk of foreign body sinusitis. In contrast, gel grafts are more

likely to be physiologically eliminated through the OMC by mucociliary clearance, thanks to their pasty consistency and the extremely particle size[44].

2.2.1 Case Example 1

An illustrative clinical case demonstrates the handling advantages of injectable grafts. Transcrestal sinus floor elevation was performed in the region of tooth #26, where the residual crestal bone height was approximately 2.8 mm, and a bucco-palatal Underwood septum was present immediately distal to the planned augmentation site (Fig. 1). Crestal access was created using manual osteotomes with mechanical stops (Smart Lift, Meta, Reggio Emilia, Italy)[21,23]. After confirming membrane integrity via the Valsalva maneuver, a syringe of porcine-derived xenograft, micronized to 300 µm and dispersed into 40% porcine collagen of types I and III (Gel 40 Osteobiol, Tecnoss, Giaveno, Italy), was injected through the crestal antrostomy (Fig. 2). The gel effectively separated the membrane from the septum and uniformly filled the subantral space, enabling immediate placement of a 10-mm implant (Fig. 3). Although the septum increased the risk of membrane perforation, it also provided a regenerative advantage by serving as an additional bony wall, potentially enhancing vascular and cellular support for bone formation. After six months of healing, despite a slight volumetric contraction, the graft appeared consolidated and the implant showed complete osseointegration (ISQ = 85; Osstell, Gothenburg, Sweden) (Fig. 4). The five-year follow-up radiograph demonstrated stable marginal bone levels around the implant and a well-consolidated graft with preserved volumetric contours, indicating long-term maintenance of the augmented sinus area (Fig. 5).

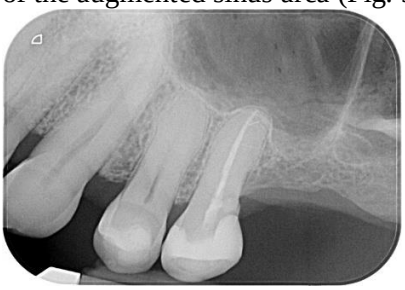

Figure 1 Pre-operative periapical radiograph of 2.6 area showing limited crestal height (2.8 mm) and the presence of a high Underwood septum with bucco-palatal orientation

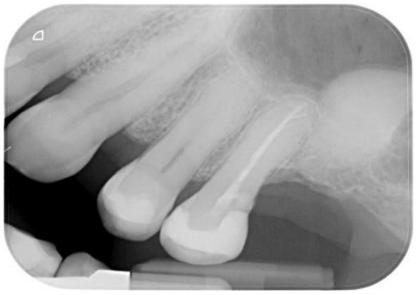

Figure 2. Radiographical check after the injection of a porcine-derived xenograft in the sub-antral space

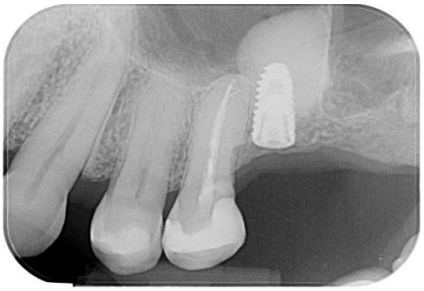

Figure 3. A 10-mm implant was immediately placed

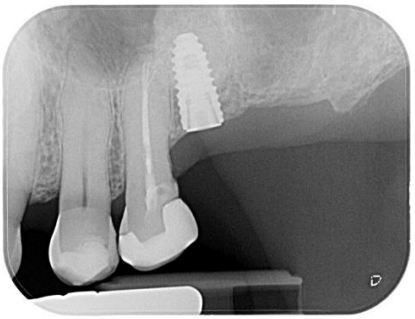

Figure 4. After six months of healing, the graft appeared consolidated and the implant showed complete osseointegration.

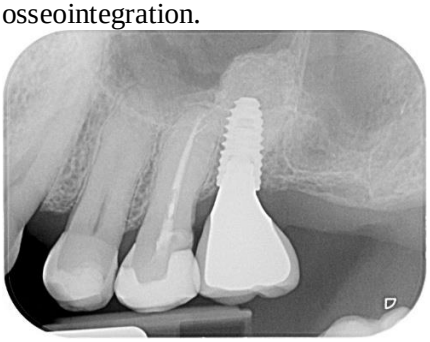

Figure 5. Periapical radiograph at five-year follow-up showing stable marginal bone levels and volumetrically preserved graft within the augmented sinus area.

2.2.2 Case Example 2

Another clinical case illustrates a two-stage tSFE which, notably, allowed histological assessment of the regenerated area after 6 months of healing. This represents an uncommon opportunity in transcrestal

sinus floor elevation, particularly when injectable materials are used, since implant placement is almost always performed simultaneously with the sinus lift. The procedure was carried out in the region of tooth #26, where the residual crestal bone height was less than 1 mm, making immediate implant stabilization impossible (Fig. 6). The sinus was narrow, with a bucco-palatal width of 11.6 mm at 10 mm from the crest, providing a favorable indication for a transcrestal approach (Fig. 7)[4]. Crestal access was created with a piezoelectric diamond insert (OT5, Piezosurgery Touch, Mectron, Carasco, Italy), as the minimal residual bone height precluded the safe use of osteotomes or dedicated drills, and the graft was injected directly into the subantral space (Fig. 8-9). The material used was a porcine-derived xenograft, micronized to a maximum particle size of 300 µm and combined with 20% porcine collagen of types I and III (Putty Osteobiol, Tecnoss, Giaveno, Italy).

Sequential periapical radiographs taken at baseline, 2 months, 4 months, and 6 months showed a gradual but limited volumetric reduction of the grafted compartment (Fig. 10). Despite this reduction, in this case the final volume at 6 months was adequate for implant placement with good primary stability. Histological analysis of a core biopsy retrieved during implant site preparation revealed complete resorption of the graft material, consistent with previous findings for the same bone substitute[45] (Fig. 11). Histomorphometric analysis demonstrated 49.2% newly formed bone and 50.8% marrow spaces. The regenerated bone appeared mature, well vascularized, and rich in osteocyte-containing lacunae, with direct contact between bone trabeculae, confirming excellent regenerative quality.

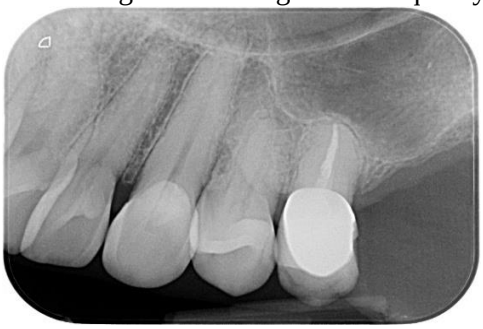

Figure 6. Pre-operative periapical radiograph of #2.6 area showing crestal height <1 mm.

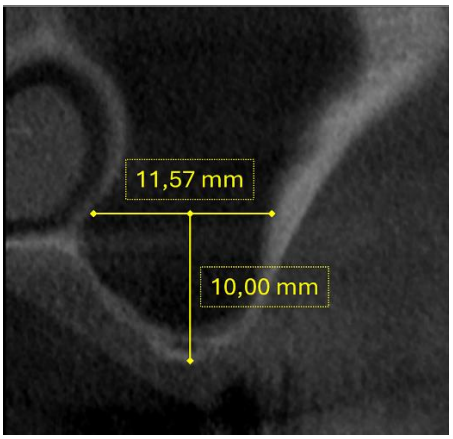

Figure 7. CBCT cross-section confirming the extremely limited residual crestal height and the presence of a narrow maxillary sinus.

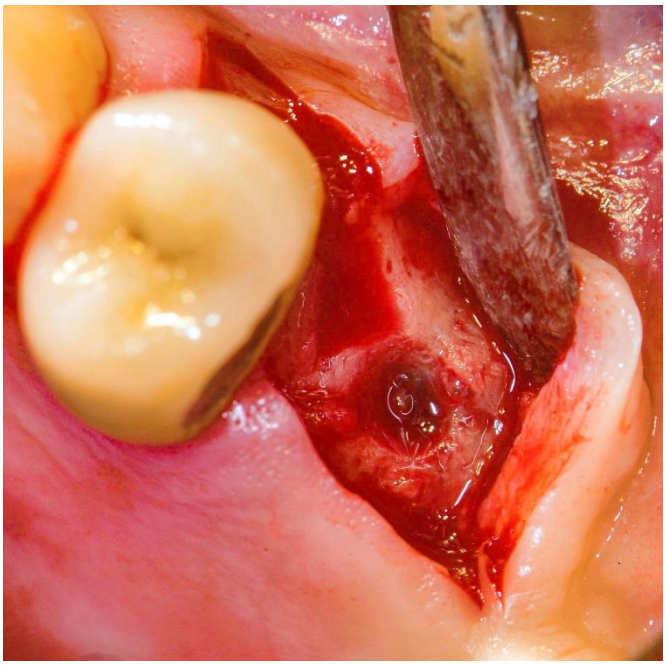

Figure 8. Crestal access was created with a piezoelectric insert eroding the sinus floor.

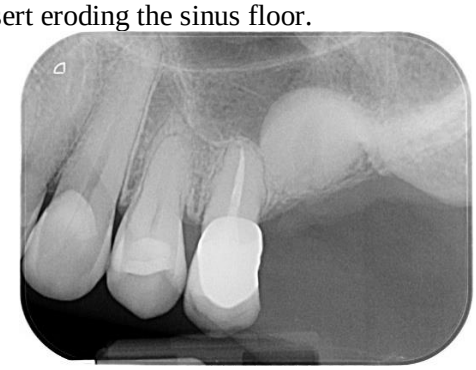

Figure 9. Radiographical check after the injection of a porcine-derived xenograft in the sub-antral space.

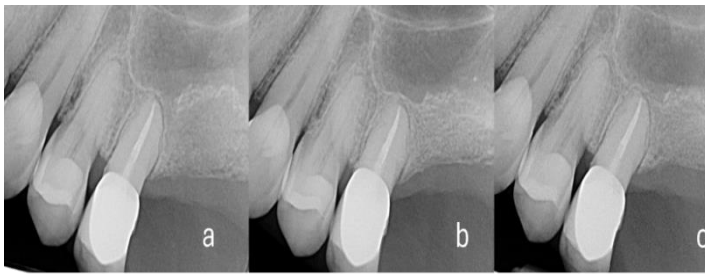

Figure 10. Radiographic follow-up after 2 months (a), 4 months (b) and 6 months (c) of healing, showing a progressive, but limited, volumetric contraction of the grafted area.

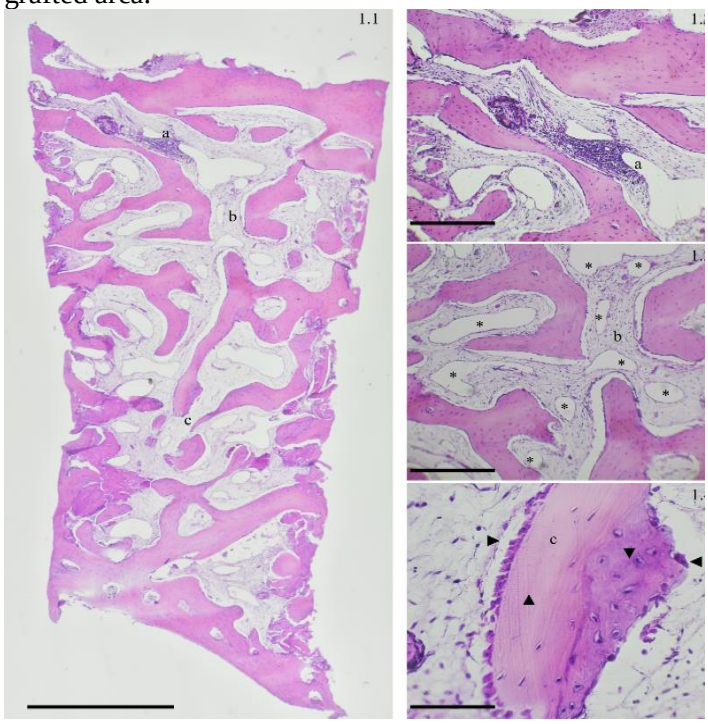

Figure 11. Images of a section of the analyzed bone biopsy. Overall, the sample shows well-structured, organized bone tissue, with good vascularization and no fibrosis or relevant signs of inflammation. **1.1:** Representative image of the entire sample, oriented so that the lower part corresponds to the deepest portion of the biopsy; scale bar = 1 mm. **1.2:** The image highlights the only cluster of inflammatory cells. No other signs of tissue damage are present, and overall the tissue structure in this area appears more than satisfactory; magnification 100×, scale bar = 300 µm. **1.3:** Detail of vascularization. The bone tissue shows widespread vascularization, with capillaries, including some of considerable size (* = blood vessels). These are arranged within an intra-trabecular tissue composed of loosely organized connective tissue, uniformly but not intensely cellularized; magnification 100×, scale bar = 300 µm. **1.4:** Image of a bone trabecula undergoing regeneration. The bone tissue appears metabolically active, with areas of mature bone (▲) in continuity with areas of bone in the maturation phase (▼). Osteoblasts actively depositing bone matrix (►) and osteoclasts (◄) are clearly visible; magnification 400×, scale bar = 150 µm.

2.2.3 Case Example 3

In this clinical case, tSFE was performed using a synthetic injectable graft composed of calcium-phosphosilicate particles suspended in a water-soluble carrier (polyethylene glycol and glycerine), delivered by cartridge (NovaBone Dental Putty, NovaBone Products, Jacksonville, FL, USA). Preoperative clinical and radiographic assessment documented periodontal health and residual bone height < 5 mm (Fig. 12). Crestal access through the sinus floor was prepared with Summers osteotomes[20]; after verification of Schneiderian membrane integrity via the Valsalva maneuver, the bone substitute was injected into the subantral compartment. An implant was placed immediately and, after 4 months of submerged healing, restored with a screw-retained metal–ceramic crown. At crown delivery, radiographic and clinical findings suggested ongoing consolidation and maturation of the grafted area (Fig. 13). Radiographic evaluation after 8 years of functional loading demonstrated a stable condition, with the implant apex surrounded by mature bone, with a cortical layer delineating the apical boundary of the grafted compartment (Fig. 14).

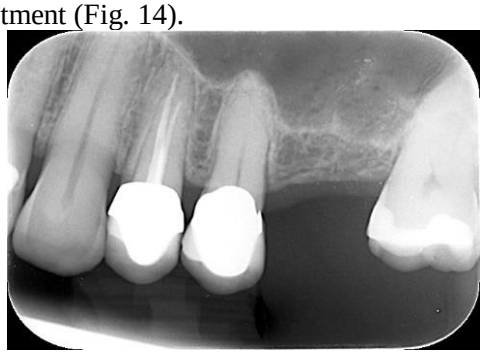

Figure 12. Pre-operative periapical radiograph of #2.6 area showing crestal height <5 mm.

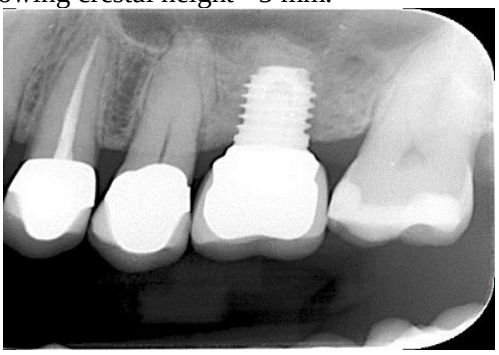

Figure 13. At crown delivery, radiographic findings suggested ongoing consolidation and maturation of the area grafted with calcium-phosphosilicate injectable bone substitute.

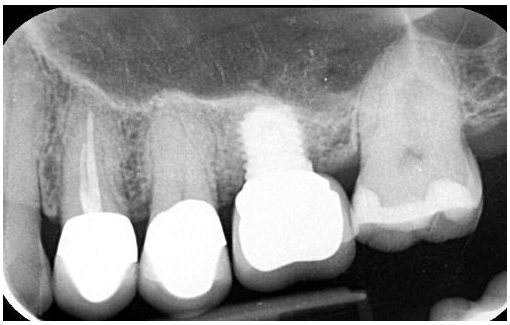

Figure 14. Radiograph at 8 years: stable implant with apex surrounded by mature bone with a corticalized boundary of the grafted compartment.

2.3 Limitations of Injectable Grafts

The main drawback of injectable grafts in maxillary sinus augmentation is their limited dimensional stability during healing, as they remain under continuous positive pressure from the Schneiderian membrane. Injectable gels with high collagen content may lack the mechanical strength to adequately support the membrane during this period. In one study on a collagenated xenogeneic gel, multivariate analysis identified immediate implant insertion as the most important factor for minimizing graft shrinkage (%GS) and found a significant inverse correlation between %GS and implant length[18]. As previously noted for graftless transcrestal approach, simultaneous implant insertion exerts a "tenting" effect on the sinus membrane, mechanically stabilizing the grafted compartment and counteracting the constant positive air pressure in the sinus cavity, thereby improving graft volume preservation during healing. Importantly, although injection of gel-form grafts produces hydrodynamic elevation of the Schneiderian membrane, this technique likewise does not appear reliable in wide sinus cavities (>12 mm) for achieving sufficient detachment to expose the lateral and medial bony walls. As with particulate grafts, tSFE in a wide sinus typically yields a dome-shaped elevation, with lack of contact between the graft and the surrounding bony walls, thereby limiting the site regenerative potential.

3. CONCLUSIONS

Transcrestal sinus floor elevation has evolved into a biologically oriented procedure that relies on accurate diagnosis and a thorough understanding of the regenerative potential of the maxillary sinus. Careful evaluation of sinus width, residual bone, and graft material properties is essential to guide the surgical plan and to position the augmented compartment under the most favorable vascular conditions. The application of tSFE has progressively expanded from small augmentations in sites with relatively great residual bone volume to more atrophic cases, where, under appropriate selection, it can achieve regenerative outcomes comparable to those obtained with the lateral approach. Injectable bone substitutes not only simplify graft delivery but, in properly selected cases with narrow sinuses, allow for effective and controlled membrane elevation. These advantages broaden the indications of this technique, even in situations with minimal crestal bone, although the limited dimensional stability of injectable materials underscores the need for simultaneous implant placement whenever feasible. Current evidence and clinical experience suggest that, when biology is respected and patient selection is accurate, this approach can achieve stable bone regeneration and predictable long-term function. Nevertheless, additional studies focusing on long-term implant survival are required to further validate the reliability of injectable substitutes and consolidate their role in daily practice.

DECLARATION

Conflict of Interest

There are no conflicts of interest.

Financial support

None

Consent Statement

Written informed consent was obtained from the patients for publication of this case report and accompanying images.

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