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Vertical Bone Gain Post-Sinus Lifting and Simultaneous Implant Placement With Osseodensification: A Retrospective Study

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ABSTRACT

Objective: To determine the bone height gain (BHG) achieved after sinus floor elevation (SFE) with osseodensification (OD).

Materials and Methods: Patients from an implantology learning center presenting one missing teeth in the posterior maxilla and insufficient residual bone height (RBH) were included. SFE with simultaneous implant placement was performed using Densah drills. Demineralized bovine bone mineral, hydroxyapatite+β-TCP, calcium phosphosilicate, and autologous leukoplakelet fibrin were used as graft biomaterials. BHG was obtained by subtracting the implant length from the initial bone height.

Results: Sinus membrane perforation occurred in 4.8% of 144 cases. One hundred and thirty-seven patients were analyzed for BHG. RBH equaled 5.4 ± 1.8 mm, with 42 (30.7%) cases having < 5 mm. The average implant length (AIL) was 8.8 ± 1.1 mm, resulting in a mean BHG of 3.4 ± 1.7 mm. BHG was significantly higher in cases with RBH < 5 mm (5.23 ± 1.45 mm) than ≥ 5 mm (2.62 ± 1.15 mm) ($p < 0.001$). Greater gains were observed in first molars (3.70 ± 1.72). Implant brand and graft type did not influence BHG. The survival rate of the implants reached 97% after 6 months of osseointegration.

Conclusions: OD with simultaneous implant placement was effective for SFE, applying a variety of implant brands and type of bone substitute, resulting in clinically relevant BHG, adequate AIL, and low complication rates.

1 | Introduction

After tooth extraction in the posterior maxilla, significant alveolar crest atrophy and potential maxillary sinus pneumatization are expected. In such cases, sinus floor elevation (SFE) may be necessary to create sufficient vertical bone volume for planned osseointegrated implants [1–3]. In this regard, SFE has become a fundamental procedure in implantology to manage cases where there is insufficient residual bone height (RBH) in the posterior maxilla for single or multiple implant placement. Various methodologies have been proposed, with the lateral window (LW) technique being the most commonly used and scientifically evaluated. This technique involves creating an osteotomy window in the sinus wall and carefully manipulating the membrane to accommodate bone graft insertion [4, 5]. Another frequently used approach is Summers' technique, which accesses the sinus through the prepared implant site, performing osteotome sinus floor elevation (OSFE) with specific osteotomes and simultaneous implant placement, sometimes with associated graft materials [6–10]. Each technique offers distinct advantages and limitations, differing in terms of invasiveness, complexity, healing time, and success rates [11–15].

While these techniques provide safe solutions for SFE, they still present significant challenges. The LW technique, despite its effectiveness and safety, may result in high morbidity due to the need for a large mucoperiosteal flap with associated vertical incisions and the creation of a surgical window in the sinus wall. This can cause substantial bleeding during the procedure, postoperative discomfort, swelling, and potential complications such as delayed healing, bleeding, and infections [16–18]. The OSFE technique, which uses a hammer and osteotome to compact bone and introduce graft material into the implant site, carries the risk of excessive force application. This raises concerns about potential damage to adjacent structures, exacerbating postoperative discomfort and potentially impacting procedure success. Additionally, both the LW and OSFE techniques present a risk of sinus membrane perforation (SMP) during the procedure. For instance, perforation rates of up to 40% have been reported for LW and 18% for Summers' technique. SMP can lead to complications, including sinus infections or graft failure, requiring additional interventions and/or compromising procedure success [18].

In recent years, the osseodensification (OD) technique emerged as an innovative method [19]. Unlike conventional techniques, OD comprises the use of specially designed drills to densify and compact bone during osteotomy preparation, optimizing regeneration and increasing bone density, thereby enhancing primary and secondary implant stabilities. OD is an additive osteotomy technique that does not involve excavation. When OD burs are operated in a noncutting direction (counterclockwise-CCW) with sufficient irrigation, they generate a hydraulic wave at the point of contact, compacting and autografting bone into the trabecular space both apically and laterally [19]. In the context of SFE, OD offers a unique advantage by simultaneously preparing the implant site, improving its initial stability, with initial clinical studies indicating reasonable predictability [20]. Furthermore, when OD drilling protocol is applied near the sinus floor, the apical hydraulic compaction wave generated by the autogenous bone slurry exerts controlled pressure on the Schneiderian membrane. This pressure causes the membrane to elevate the sinus, accompanied by autografts that are placed between the membrane and the sinus floor. Nevertheless, the biological principles of OD still need to be clinically evaluated in a larger number of patients and the occurrence of trans- and pos-operative complications. For instance, one retrospective study demonstrated minimal SMPs and a cumulative implant survival rate of 97% after follow-ups of up to 64 months [20]. Additional data regarding the effectiveness of OD for SFE in terms of vertical bone gain and final implant length that may be achieved are also lacking. Therefore, this study aimed to evaluate the efficacy of OD in SFE with simultaneous implant placement using different types of implants and graft materials.

2 | Materials and Methods

2.1 | Study Sample

This retrospective clinical study included patients treated and followed up at a private Implantology and Periodontics center (Implanteperio, São Paulo, Brazil). Patients with one or more missing teeth in the posterior maxilla requiring dental implants and presenting insufficient RBH were included. All patients were treated between October 2018 and October 2023, receiving SFE using the OD technique followed by implant placement. Inclusion criteria were as follows: age ≥ 18 years; systemically healthy; absence of one or more teeth in the posterior maxilla; minimum RBH of 1 mm below the sinus floor. Exclusion criteria included the following: age < 18 years; uncontrolled or untreated periodontal disease; pregnant or lactating women; history of alcoholism or drug abuse in the past 5 years; uncontrolled hypertension or diabetes; maxillary sinus pathologies; patients with malignant tumors; patients using bisphosphonates or daily steroids; patients with a history of chemotherapy or radiotherapy in the past 5 years.

2.2 | Interventions

All surgical and prosthetic procedures were performed by four Periodontics and Implantology specialists with a minimum of 5 years of OD experience, following standardized techniques. All SFE surgeries were performed with simultaneous implant placement. All participants received prophylactic antibiotic therapy before surgery (2 g of amoxicillin 1 h before surgery). Patients rinsed with a chlorhexidine digluconate solution (0.12%) for 1 min before starting the procedure. All surgeries were performed under local anesthesia with 4% articaine hydrochloride with epinephrine (1:100000). A full-thickness mucoperiosteal flap without vertical incisions was elevated to expose the alveolar crest, assisted by intrasulcular incisions on the adjacent teeth. The implant site was prepared with Densah drills (Versah LLC, Jackson, MI, USA) rotating counterclockwise at 1200 rpm with abundant irrigation, according to the manufacturer's instructions (described in the Densah Sinus Elevation Protocols I, II, and III provided by Versah). The protocol of the manufacturer indicates that up to 3 mm of autograft bone may be achieved in residual ridges with a height of 6 mm or more, suggesting that there is no need for the use of additional bone substitute for sinus lifting. However, in this study, the use of bone substitute was deemed necessary independently of the RBH as a clinical criterion during the drilling process. Therefore, when the use of a bone substitute was deemed necessary, each operator chose the type of graft to be used according to the availability at the study center; therefore, a great variability of biomaterials were used over the study period including demineralized bovine bone mineral (Bio-oss, Geistlich, Switzerland and Bone fill mix, Bionnovation, Brazil), 70% hydroxyapatite/30% β-TCP (Plenum oss, Plenum Bioengenharia, Brazil), calcium phosphosilicate (NovaBone, USA), and autologous leukoplakelet fibrin (L-PRF) in combination with some bone substitute.

In cases where only autograft was used, after selecting the ideal implant for the site, the drilling sequence was determined and used counterclockwise at 1200 rpm with irrigation until reaching the sinus floor, following the ideal sequence until gently breaking through the cortical bone. The original protocol of the manufacturer suggests for a 1-mm increment entry up to 3 mm beyond the sinus floor to lift the membrane; nevertheless, in this study, the entry in the sinus did not exceed 1 mm after reaching the sinus membrane, as a choice of the researchers. The drill depth was periodically checked by

digital periapical radiographs to confirm that autogenous bone derived from the osteotomy was pushed apically. Sequentially larger drills were used similarly to continue the SFE process, adding more autogenous bone to the sinus cavity with digital radiographic verification for final BHG (bone height gain) measurement. Afterward, the selected implant was inserted followed by another radiograph to check for the presence of autogenous bone above the implant apex.

In cases where graft materials were used, the previous steps were conducted until reaching the desired drilling width, and the graft material was placed in the osteotomy site, and then the last drill used to prepare the osteotomy was rotated counterclockwise at 50 rpm without irrigation to push the graft apically toward the sinus. The validated protocol of the manufacturer indicates that a 100–150-RPM speed rotation should be used; however, in this study, we reduced the speed for graft insertion in the sinus to 50 RPM due to different particle shapes of the graft materials used, minimizing the rupture of the membrane. This movement was repeated until the desired SFE was achieved, and a digital radiograph was taken to verify that the bone graft did not cause rupture of the membrane. Then, the implant was installed followed by another radiograph to verify the presence of graft material above the implant apex.

In clinical situations where RBH was between 1 and 3 mm, no pilot drill and narrower Densah drills (2.0 and 2.3) were used. The Densah drill used to advance beyond the sinus floor and push the graft material was chosen based on the diameter of the implant selected for the site, following the same graft pushing protocol and radiographs after the graft and implant. Interrupted sutures were performed with a 5–0 nylon thread and were removed after 7–10 days.

The implant platform choice was determined according to the region of the tooth to be rehabilitated: molars received implants with a minimum diameter of 4.0 mm, and premolars received implants with a minimum diameter of 3.3 mm. A variety of implant brands were available at the center over the time of the study conduction, and no specific criteria were defined a priori to choose one brand or another. The implant length was determined using the radiograph taken after the end of graft insertion. This radiograph allowed us to estimate the amount of graft pushed apically, and the implant length defined was always at least 1 mm shorter than the measured height value.

Direct membrane integrity was visually checked clinically during the surgery under magnification using 3.3x dental loupes in every preparation step [21]. An intact membrane showed a grayish and reflective shadow, without discontinuity. A dark spot/hole indicated a perforation, which could range from a small tear to a complete perforation involving the entire osteotomy circumference [22]. In cases of membrane perforation, nor sinus grafting, nor implant placement was performed, interrupting the surgery closing the flap and scheduling a new surgical approach after at least 3 months. Participants were instructed to use an ice pack for the first 24 h and rinse with 0.12% chlorhexidine digluconate solution twice daily for 7–10 days. Antibiotics were prescribed for all patients postoperatively (875 mg of amoxicillin every 12 h for 7 days). For postoperative pain control, patients were instructed to take 100 mg of nimesulide every 12 h, supplemented by 500 mg of paracetamol for pain spikes.

Implants underwent osseointegration for a minimum of 6 months. Implant reopening was performed by the same four operators with local anesthesia and a small full-thickness flap. Osseointegration was assessed at the time of cover screw removal. Figure 1 describes one of the cases of the study.

2.3 | Data Collection

All patients underwent tomographic examination before treatment. DICOM files were obtained from all patients for RBH measurement in the central section of the edentulous area to receive the implant. Data on age, sex, average implant length (AIL), graft type, implant brand, implant dimensions (diameter and length), and intraoperative or postoperative complications were collected. The primary outcome of this study was BHG, considering the initial residual bone in relation to the final installed implant length. BHG was obtained by subtracting the implant size from the RBH.

2.4 | Ethical Aspects

This retrospective analysis followed the principles of the Declaration of Helsinki of the World Medical Association. All patients treated at the research center provided consent for data use, maintaining their records and individual data always confidential. This study was reviewed and approved by the Ethics Committee of the São Leopoldo Mandic College.

2.5 | Data Analysis

Statistical analyses were performed using Stata software (Stata version 14 for Macintosh, Texas USA). The individual was the unit of analysis. The significance level was set at 5%. The primary outcome (BHG) was expressed as mean and standard deviation. Comparisons were performed using the independent samples *t*-test and one-way ANOVA with the Bonferroni post hoc test. BHG was compared according to sex, age, implant location, implant platform, and RBH. Stratified analysis was performed by dichotomizing the sample into RBH <5 mm and ≥ 5 mm. Multiple linear regression was applied to evaluate the association of these variables with BHG.

3 | Results

A total of 144 patients were treated. Among the 144 installed implants, 139 were conical implants at the bone level and 5 were cylindrical implants at the tissue level. SMP occurred in seven patients (4.8%). Considering the perforations that occurred during the procedures, five occurred in scenarios of RBH <5 mm and two in ≥ 5 mm. Therefore, the final sample comprised 137 patients. Table 1 describes the characteristics of the sample. Patients had between 24 and 83 years of age, and the majority were women (66.4%). The larger proportion of implants were installed in the first molar region, had a diameter of

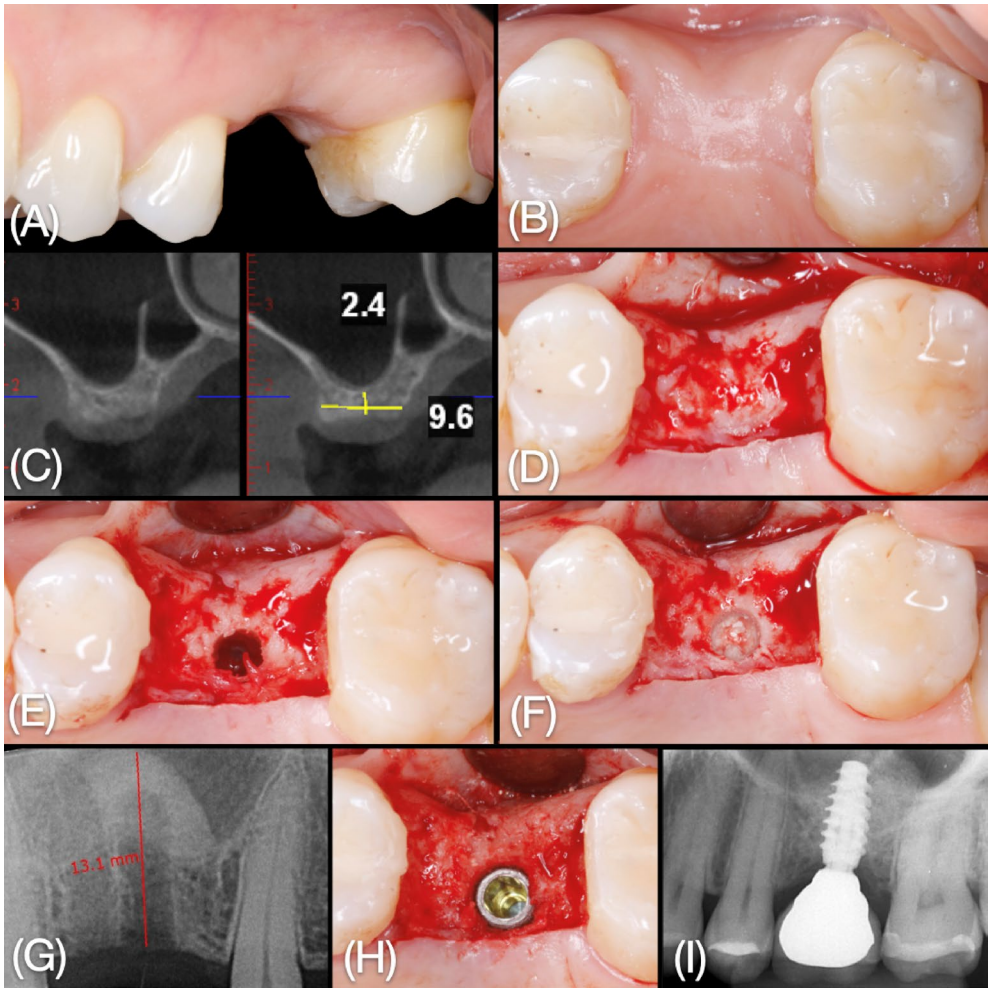

FIGURE 1 | Illustration of the treatment sequence in one case included in the study. (A) Frontal view at baseline, (B) occlusal view at baseline, (C) preoperative CBCT, (D) flap opening, (E) view of the sinus membrane, (F) application of grafting material through crestal approach, (G) radiograph after the end of graft insertion, (H) implant placement, and (I) radiograph after loading.

4.3 mm, and the mean implant lengths equaled 8.8 mm. The average RBH was 5.4 mm. Figure 2 shows the distribution of cases according to RBH categories, demonstrating that the majority of cases had RBH between 6 and 8 mm (45.5%).

The detailed distribution of the types of bone substitutes and implant brands used in the study is described in the supplemental material. In brief, implants from Nobel Biocare (37.9%), Plenum Bioengenharia (22.6%), and Straumann (16.8%) were the most frequently used. Bovine bone mineral (Bio-oss small granules, Geistlich, Switzerland) was used in 50.4% of the cases, followed by hydroxyapatite with betatricalcium phosphate particles (Plenum Bioengenharia, Brazil) (16.9%). The autograft generated by the OD procedure was applied in 11.7% of the cases resulting in no requirement for biomaterial insertion.

Table 2 shows BHG according to sample characteristics. The overall BHG equaled 3.42 mm. There were no significant differences between males and females ($p = 0.95$), age groups ($p = 0.50$), and implant platforms ($p = 0.90$). BHG was significantly higher in first molars than in the second premolars ($p = 0.02$). Also, when RBH was less than 5 mm, the gain was significantly higher compared to RBH ≥ 5 mm ($p < 0.001$).

The stratified analysis according to RBH is demonstrated in Table 3. For both RBH < 5 mm and ≥ 5 mm, there were no significant differences in BHG for all variables analyzed. These findings were maintained in the multiple linear regression model (Table 4). The only significant predictor associated with BHG was RBH, for which BHG was 2.54 mm higher for RBH < 5 mm than ≥ 5 mm.

Four implants were lost after 6 months of osseointegration. All of the lost implants belonged to the group with RBH > 5 mm. Therefore, the survival rate of implants equaled 97%.

4 | Discussion

SFE is a fundamental technique in implantology to increase RBH in the posterior maxilla, enabling the placement of dental implants in areas with significant alveolar crest atrophy and maxillary sinus pneumatization. Traditional techniques, such as the LW and OSFE techniques, have been widely used over decades but still present challenges and limitations, including complications during and after the procedure [23].

In this study, we retrospectively evaluated the efficacy of the OD technique in SFE. OD differentiates itself from conventional

TABLE 1 | Characteristics of the study sample ($n = 137$).

Variable	Statistics
Sex (*n*/%)	
Male	46 (33.6)
Female	91 (66.4)
Age (mean, SD)	58.8 ± 12.6
Implant location (n/%)	
1st premolar	5 (3.7)
2nd premolar	21 (15.3)
1st molar	88 (64.2)
2nd molar	23 (16.8)
Implant platform (n/%)	
3.5 mm	13 (9.5)
3.75 mm	5 (3.7)
3.9 mm	1 (0.7)
4 mm	21 (15.3)
4.1 mm	17 (12.4)
4.2 mm	1 (0.7)
4.3 mm	44 (32.1)
4.5 mm	4 (2.9)
4.8 mm	6 (4.4)
5.0 mm	25 (18.3)
Implant length (mean, SD)	8.8 ± 1.1
Implant length (n/%)	
6 mm	5 (3.7)
8 mm	67 (48.9)
8.5 mm	5 (3.7)
9 mm	2 (1.5)
10 mm	55 (40.2)
11.5 mm	3 (2.2)
Residual bone height (mean, SD)	5.4 ± 1.8

Abbreviation: SD: standard deviation.

techniques by densifying, compacting, and autografting bone during osteotomy preparation, which can optimize bone regeneration and increase implant stability [24]. The clinical results of the OD technique have demonstrated effectiveness in both the short and long terms across various clinical situations, leading to improved primary and secondary stabilities of implants. These promising findings were further supported by a multicenter retrospective clinical study that followed 254 implants with different micro- and macrogeometries over a period of 5 years [25]. Additionally, a multicenter controlled clinical trial revealed that implants placed using the OD technique exhibited significantly higher insertion torque (IT) values and sustainable secondary stability, as measured by the Implant Stability Quotient (ISQ) at

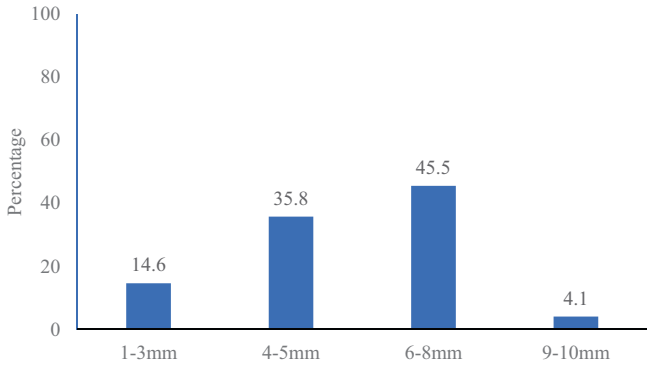

FIGURE 2 | Percentage of patients according to the initial residual bone height prior to sinus augmentation.

3 and 6 weeks, compared to standard drilling protocols applied to various implant designs, regardless of the location—whether in the anterior or posterior regions of the maxilla or in the posterior region of the mandible [26].

In this study, the results demonstrated that OD is effective for SFE. Greater gains in bone height were predicted in molars. Also, in cases with initial bone heights less than 5 mm, the gains in bone height were larger probably as a result of the use of bone substitutes in these cases. Moreover, the rate of SMP was very low, with no other immediate or late postoperative complications reported. It was also demonstrated that the AIL is approximately 9 mm.

Comparing the rate of membrane perforation from this with other studies, a recent comparison of SFE using OD and LW in patients with RBH ≤ 4 mm demonstrated SMP rates of 10% and 40%, respectively [27]. The results also demonstrated that OD is as effective as the LW technique for SFE with simultaneous implant placement but with significantly better patient-reported outcome measures [27]. Alhayati et al. found that in highly atrophic posterior maxillae with an RBH of ≥ 2.0 to < 6.0 mm, OD was effective for crestal sinus elevation without membrane perforation, as confirmed by cone-beam computed tomography. The study also showed greater primary and secondary implant stabilities [28]. A multicenter study evaluating the perforation rates during OD drilling found that the mean RBH was 5.1 mm (± 1.96 mm), ranging from 2 to 7 mm (256 sites had RBH between 3 and 5 mm, 249 sites had RBH > 5 mm, and 165 sites had RBH ≤ 3 mm). Although the SMP rates were low (7.3%), regression analysis indicated that severe atrophy (RBH ≤ 3 mm and between 3 and 5 mm) was identified as a risk factor for membrane perforation. The tooth region (premolar and molar), implant site, healed socket, and fresh socket were not associated as risk factors for SMP [21]. In a recent systematic review, the SMP rate for SFE using the LW technique was reported at 17.7% [29], while another meta-analysis showed a range of 3.6%–41.8%, with an average rate of 23.5% [30]. The frequency of SMP with the OSFE technique varies, with studies reporting rates from 15% to 50% [31, 32], depending on graft-related factors, RBH, and BHG. The OSFE technique is recommended for patients with at least 5 mm of RBH [33–38]. Independently of the variation on SMP perforation rates, it is clear that the rate of 4.8% observed in this study is lower than that previously reported in a large sample study.

TABLE 2 | Mean (standard deviation) of bone height gain ($n = 137$).

Variable	Estimate	p*
Sex (n/%)		
Male	3.44 ± 1.90	
Female	3.42 ± 1.60	0.95
Age		
< 60 years old	3.54 ± 1.92	
≥ 60 years old	3.33 ± 1.57	0.50
Implant location		
1st premolar	2.94 ± 2.32A	
2nd premolar	2.34 ± 1.24AB	
1st molar	3.70 ± 1.72AC	
2nd molar	3.46 ± 1.67A	0.02**
Implant platform		
< 4.2 mm	3.41 ± 1.83	
≥ 4.2 mm	3.44 ± 1.66	0.90
Residual bone height		
< 5 mm	5.23 ± 1.45	
≥ 5 mm	2.62 ± 1.15	< 0.001
Total	3.42 ± 1.73	

*Independent samples t-test.
**One-way ANOVA and Bonferroni.

TABLE 3 | Mean (standard deviation) of bone height gain according to the initial bone height.

	Residual bone height < 5 mm ($n = 42$)		Residual bone height ≥ 5 mm ($n = 95$)	
Variable	Estimate	p*	Estimate	p*
Sex (n/%)				
Male	5.08 ± 1.70		2.38 ± 1.18	
Female	5.34 ± 1.25	0.57	2.73 ± 1.13	0.18
Age				
< 60 years old	5.61 ± 1.45		2.57 ± 1.22	
≥ 60 years old	4.91 ± 1.39	0.11	2.66 ± 1.10	0.70
Implant location				
1st premolar	4.00 ± 0.00		2.67 ± 2.58	
2nd premolar	3.55 ± 0.33		2.21 ± 1.23	
1st molar	5.42 ± 1.47		2.76 ± 0.97	
2nd molar	5.06 ± 1.32	0.26**	2.61 ± 1.15	0.34**
Implant platform				
< 4.2 mm	5.13 ± 1.59		2.54 ± 1.26	
≥ 4.2 mm	5.31 ± 1.35	0.69	2.68 ± 1.07	0.55
Total	5.23 ± 1.44		2.65 ± 1.14	

*Independent samples t-test.
**One-way ANOVA.

Over the years, several studies have demonstrated the use of the OD technique for SFE in different clinical scenarios and with various graft materials. Huwais et al. retrospectively demonstrated a BHG of 7 mm, with no SMP, using autogenous bone graft generated by the technique and particulate allograft in cases requiring more than 3 mm of augmentation [20]. Elsaid et al. reported BHG of 5.33 mm using nanocrystalline hydroxyapatite in an amorphous silica gel matrix, also with no SMP [39]. Recently, another study evaluated the OD technique in regions with an oblique sinus floor, achieving an average BHG of 4.42 mm in patients with RBH between 4 and 7 mm, reporting one SMP using hydrated allograft [22]. In the present study, the overall BHG was 3.4 mm and reached more than 5 mm in average in cases with initial bone height < 5 mm.

Currently, a wide variety of graft materials can be used alone or in combination with different surgical techniques for SFE. Among graft materials, autogenous bone is considered the gold standard due to its osteogenic, osteoinductive, and osteoconductive properties. However, the use of autogenous bone has significant disadvantages, such as limited intraoral supply, donor site morbidity, increased operative time, the necessity for two surgical sites, partial resorption tendency, and postoperative complications [12]. Also related to the choice of the type of bone substitute, the survival of implants placed in areas grafted with different types of grafts has been discussed in the literature. A systematic review of SFE and implant success rates, with follow-up ranging from 12 to 102 months, showed a success rate of 92% for implants placed in autogenous grafts, 93.3% for allograft bone, 81% for alloplastic material, and 95.6% for pure xenograft [40]. Another retrospective study with 15 years of follow-up, 757 implants were placed in 472 bone grafts, resulting in an overall success rate of 97.2%, showed that the xenograft group had the highest success rate (99.5%, $n = 182$), followed by the autogenous group (97.0%, $n = 197$) and the alloplastic group (98.9%, $n = 92$) [41]. These results are in line with comparative studies analyzing the performance of various bone substitutes, indicating that different graft materials achieve similar implant success rates [42, 43]. Although the results related to implant survival are similar, concerns about the quality of the newly formed bone are still discussed in the literature, particularly regarding the amount of vital bone and the presence of residual graft particles. Reports indicate that xenograft materials are not completely resorbed over time, potentially reducing the bone-to-implant contact (BIC) percentage, which could affect the long-term survival of the implant. In a recent randomized clinical trial for alveolar ridge preservation using different graft materials, the allograft demonstrated the highest percentage of vital bone and the lowest amount of residual particles. Both the allograft and alloplast exhibited significantly greater amounts of newly regenerated bone compared to the xenograft. Conversely, the xenograft showed the highest percentage of residual particles, which was significantly greater than that observed in the other groups [44]. In this context, a systematic review conducted by De Risi et al. revealed that xenografts and alloplasts produced the highest levels of residual

TABLE 4 | Linear regression models for bone height gain.

	Simple models		Final multiple model	
Variable	**Beta**	***p***	**Beta**	***p***
Sex (*n*/%)				
Male	Ref.		Ref.	
Female	−0.02 ± 0.31	0.96	0.41 ± 0.23	0.07
Age				
< 60 years old	Ref.		Ref.	
≥ 60 years old	−0.20 ± 0.30	0.50	−0.10 ± 0.21	0.66
Implant location				
1st premolar	Ref.		Ref.	
2nd premolar	−0.60 ± 0.84	0.47	−0.22 ± 0.62	0.72
1st molar	0.76 ± 0.77	0.33	0.53 ± 0.57	0.36
2nd molar	0.52 ± 0.92	0.52	0.23 ± 0.62	0.71
Implant platform				
< 4.2 mm	Ref.		Ref.	
≥ 4.2 mm	0.04 ± 0.30	0.90	0.02 ± 0.23	0.92
Residual bone height				
≥ 5 mm	Ref.		Ref.	
< 5 mm	2.60 ± 0.23	< 0.001	2.54 ± 0.23	< 0.001

Abbreviation: Ref., reference category.

particles, exceeding 35% over a 7-month follow-up period, while allografts showed the lowest percentage of residual particles, ranging from 12.4% to 21.11%. In terms of vital bone, allografts achieved the highest mean value at the 3-month mark, whereas xenografts exhibited the lowest percentage of vital bone after 5 months [45]. Bovine-derived bone mineral has demonstrated osteoconductive properties as a grafting material for maxillary SFE. Evidence suggests that this material can be detected in the regenerated tissue for up to 20 years after the procedure, gradually decreasing in percentage but not completely disappearing. Over time, it has been observed that the volume of the newly formed mineralized bone remains stable, in contrast to nonmineralized bone, which tends to increase in volume in response to bone remodeling [46]. In the present study, various types of biomaterials were used for grafting, including autograft bone generated by the technique, particulate xenograft, synthetic grafts, pure L-PRF, xenograft particulate combined with L-PRF, L-PRF combined with autologous dentin, and L-PRF combined with synthetic grafts.

Another important discussion regarding graft materials relates to resorption rates. It was demonstrated that autogenous bone presents up to 45% resorption around implants within the first 24 months post-graft [47–50]. In contrast, the resorption of organic or synthetic bone graft materials is comparatively lower, approximately 18%–22% within the first 24 months [51–53] and 10%–20% after 2 years of loading [42]. It has been shown that the horizontal and vertical resorption rates of grafts for OSFE decreased rapidly within the first 12 months and stabilized thereafter [51]. Following over 5 years of a sample of 155 implants placed with OSFE, Lombardo et al. observed a change from a preoperative average of 4.45 mm to 9.25 mm immediately after implant placement, stabilization around 6.35 mm at prosthesis delivery, and 5.25 mm at the 5-year follow-up, representing a substantial short-term BHG, followed by stabilization and slight reduction over time [52]. Another recent study evaluated BHG variations using the OD technique immediately post-surgery and after 12 months using standardized radiographic measurements, demonstrating significant graft contraction and a reduction of 0.90 ± 0.49 mm [53].

In this study, the AIL reached was 8.8 ± 1.1 mm, which clinically represents an excellent option for the posterior maxilla region. A recent meta-analysis comparing clinical outcomes of using short (≤ 8 mm) versus standard implants (≥ 10 mm) after SFE in the atrophic posterior maxilla with insufficient RBH found high implant survival rates in both groups (short implants: 97.0%, standard implants: 96.8%), and marginal bone loss showed no significant differences [54]. These results align with a retrospective study evaluating the survival of short and extra-short implants placed after OSFE. After 5 years, the overall implant survival rate was 94.84%, with specific survival rates of 93.75%, 94%, and 100% for implants 5.0 mm, 6.0 mm, and 8.0 mm in length, respectively, reiterating that implants > 8 mm can achieve long-term success in areas with SFE and simultaneous implant placement [52].

The present study should be interpreted considering its strengths and limitations. Since the majority of studies on this field are preclinical, the design of this study involving clinical cases conducted over up to 5 years in daily basis in an implantology learning center is one of the methodological strengths. Moreover, to the best of the authors' knowledge, this is the first study to compare various factors that may be associated with the efficacy of OD for SFE within the same patient sample. On the contrary, at the present moment, clinical and tomographic medium- to long-term evaluations are still lacking to assess graft bone reduction in height and volume over the years in the present sample. Additionally, BHG was determined based solely on the implant apex as the final measure, which may not accurately reflect the volumetric and structural changes of the final vertical bone height achieved. These issues should be considered in future research to improve the accuracy and applicability of the results in the conduction of future randomized trials.

5 | Conclusions

OD demonstrated to be effective for SFE with simultaneous implant placement. Clinically relevant vertical bone gain was achieved with appropriate implant length.

Author Contributions

Conceptualization: Cássio Cardona Orth, Robert Carvalho da Silva, Alex Nogueira Haas. Methodology: Cássio Cardona Orth, Alex Nogueira Haas, Julio Cesar Joly. Formal analysis and investigation: Cássio Cardona Orth, Alex Nogueira Haas. Surgical procedures: Cássio Cardona Orth, Robert Carvalho da Silva, Paulo Fernando Mesquita de Carvalho, Guilherme Paes de Barros Carrilho. Writing: Cássio Cardona Orth, Julio Cesar Joly, Alex Nogueira Haas. Writing – review and editing: Cássio Cardona Orth, Julio Cesar Joly, Alex Nogueira Haas.

Consent

Written informed consent was obtained from all individuals participating in the study.

Ethics Statement

This study was performed in line with the Declaration of Helsinki. Approval was granted by the São Leopoldo Mandic College Ethics Committee number 81595524.3.0000.5374.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available because of privacy or ethical restrictions.

References

1. S. Hansson and A. Halldin, "Alveolar Ridge Resorption After Tooth Extraction: A Consequence of a Fundamental Principle of Bone Physiology," *Journal of Dental Biomechanics* 3 (2012): 1758736012456543, https://doi.org/10.1177/1758736012456543.

2. G. Pagni, G. Pellegrini, W. V. Giannobile, and G. Rasperini, "Postextraction Alveolar Ridge Preservation: Biological Basis and Treatments," *International Journal of Dentistry* 2012 (2012): 151030–151043, https://doi.org/10.1155/2012/151030.

3. S. Alqahtani, A. Alsheraimi, A. Alshareef, et al., "Maxillary Sinus Pneumatization Following Extractions in Riyadh, Saudi Arabia: A Cross-Sectional Study," *Cureus* 12 (2020): e6611, https://doi.org/10.7759/cureus.6611.

4. H. Tatum, Jr., "Maxillary and Sinus Implant Reconstructions," *Dental Clinics of North America* 30 (1986): 207–229.

5. G. M. Raghoebar, P. Onclin, G. C. Boven, A. Vissink, and H. J. A. Meijer, "Long-Term Effectiveness of Maxillary Sinus Floor Augmentation: A Systematic Review and Meta-Analysis," *Journal of Clinical Periodontology* 46, no. Suppl 21 (2019): 307–318, https://doi.org/10.1111/jcpe.13055.

6. R. B. Summers, "A New Concept in Maxillary Implant Surgery: The Osteotome Technique," *Compendium* 15, no. 2 (1994): 154–156.

7. A. Wimalarathna, "Indirect Sinus Lift: An Overview of Different Techniques," *Biomedical Journal of Scientific & Technical Research* 33 (2021): 26101–26105, https://doi.org/10.26717/BJSTR.2021.33.005447.

8. S. M. Balaji, "Direct v/s Indirect Sinus Lift in Maxillary Dental Implants," *Annals of Maxillofacial Surgery* 3 (2013): 148–153, https://doi.org/10.4103/2231-0746.119228.

9. A. Rawat, H. Thukral, and A. Jose, "Indirect Sinus Floor Elevation Technique With Simultaneous Implant Placement Without Using Bone Grafts," *Annals of Maxillofacial Surgery* 9 (2019): 96–102, https://doi.org/10.4103/ams.ams_11_19.

10. B. E. Pjetursson and N. P. Lang, "Sinus Floor Elevation Utilizing the Transalveolar Approach," *Periodontology 2000* 66 (2014): 59–71, https://doi.org/10.1111/prd.12043.

11. M. M. Harlos, T. B. da Silva, P. G. Montagner, L. N. Teixeira, A. V. Gomes, and E. F. Martinez, "Histomorphometric Evaluation of Different Graft Associations for Maxillary Sinus Elevation in Wide Antral Cavities: A Randomized Controlled Clinical Trial," *Clinical Oral Investigations* 26 (2022): 1–9, https://doi.org/10.1007/s00784-022-04515-9.

12. L. Castagna, W. D. Polido, L. G. Soares, and E. M. Tinoco, "Tomographic Evaluation of Iliac Crest Bone Grafting and the Use of Immediate Temporary Implants to the Atrophic Maxilla," *International Journal of Oral and Maxillofacial Surgery* 42, no. 9 (2013): 1067–1072, https://doi.org/10.1016/j.ijom.2013.04.020.

13. S. A. Danesh-Sani, P. M. Loomer, and S. S. Wallace, "A Comprehensive Clinical Review of Maxillary Sinus Floor Elevation: Anatomy, Techniques, Biomaterials and Complications," *British Journal of Oral & Maxillofacial Surgery* 54, no. 7 (2016): 724–730, https://doi.org/10.1016/j.bjoms.2016.05.008.

14. H. Y. Jang, H. C. Kim, S. C. Lee, and J. Y. Lee, "Choice of Graft Material in Relation to Maxillary Sinus Width in Internal Sinus Floor Augmentation," *Journal of Oral and Maxillofacial Surgery* 68, no. 8 (2010): 1859–1868, https://doi.org/10.1016/j.joms.2009.09.093.

15. S. Taschieri, A. Lolato, T. Testori, L. Francetti, and M. Del Fabbro, "Short Dental Implants as Compared to Maxillary Sinus Augmentation Procedure for the Rehabilitation of Edentulous Posterior Maxilla: Three-Year Results of a Randomized Clinical Study," *Clinical Implant Dentistry and Related Research* 20, no. 1 (2018): 9–20, https://doi.org/10.1111/cid.12563.

16. S. Nasr, D. E. Slot, S. Bahaa, C. E. Dörfer, and K. M. Fawzy El-Sayed, "Dental Implants Combined With Sinus Augmentation: What Is the Merit of Bone Grafting? A Systematic Review," *Journal of Maxillofacial Surgery* 44, no. 10 (2016): 1607–1617, https://doi.org/10.1016/j.jcms.2016.06.022.

17. N. Elian, S. S. Wallace, S.-C. Cho, Z. Jalbout, and S. J. Froum, "Distribution of the Maxillary Artery as It Relates to Sinus Floor

Augmentation," *International Journal of Oral and Maxillofacial Implants* 20 (2005): 784–787.

18. T. Testori, T. Weinstein, S. Taschieri, and S. S. Wallace, "Risk Factors in Lateral Window Sinus Elevation Surgery," *Periodontology 2000* 81, no. 1 (2019): 91–123, https://doi.org/10.1111/prd.12286.

19. S. Huwais and E. Meyer, "A Novel Osseous Densification Approach in Implant Osteotomy Preparation to Increase Biomechanical Primary Stability, Bone Mineral Density, and Bone-To-Implant Contact," *International Journal of Oral and Maxillofacial Implants* 32 (2017): 27–36, https://doi.org/10.11607/jomi.4817.

20. S. Huwais, Z. Mazor, A. L. Ioannou, H. Gluckman, and R. Neiva, "A Multicenter Retrospective Clinical Study With up-To-5-Year Follow-Up Utilizing a Method That Enhances Bone Density and Allows for Transcrestal Sinus Augmentation Through Compaction Grafting," *International Journal of Oral and Maxillofacial Implants* 33, no. 6 (2018): 1305–1311, https://doi.org/10.11607/jomi.6770.

21. Z. Mazor, J. Gaspar, R. Silva, et al., "Maxillary Sinus Membrane Perforation Rate Utilizing Osseodensification-Mediated Transcrestal Sinus Floor Elevation: A Multicenter Clinical Study," *Clinical Implant Dentistry and Related Research* 26, no. 6 (2024): 1172–1180, https://doi.org/10.1111/cid.13368.

22. M. Shalash, M. Mounir, and T. Elbanna, "Evaluation of Crestal Sinus Floor Elevation in Cases Exhibiting an Oblique Sinus Floor With a Residual Bone Height of 4.0–7.0 Mm Using Densah Burs With Simultaneous Implant Placement: A Prospective Clinical Study," *International Journal of Implant Dentistry* 9 (2023): 41, https://doi.org/10.1186/s40729-023-00510-1.

23. M. Esposito, M. G. Grusovin, J. Rees, et al., "Effectiveness of Sinus Lift Procedures for Dental Implant Rehabilitation: A Cochrane Systematic Review," *European Journal of Oral Implantology* 3, no. 1 (2010): 7–26.

24. C. C. Orth, A. N. Haas, D. C. Peruzzo, et al., "Primary Stability of Dental Implants Installed Using Osseodensification or Bone Expansion Drilling Systems: A Comparative Clinical Study," *Journal of the International Academy of Periodontology* 24 (2022): 165–174.

25. B. Tanello, S. Huwais, I. Tawil, P. Rosen, and R. Neiva, "Osseodensification Protocols for Enhancement of Primary and Secondary Implant Stability – A Retrospective 5-Year Follow-Up Multi-Center Study," *Clinical Oral Implants Research* 30, no. S19 (2019): 414.

26. E. T. P. Bergamo, A. Zahoui, R. B. Barrera, et al., "Osseodensification Effect on Implants Primary and Secondary Stability: Multicenter Controlled Clinical Trial," *Clinical Implant Dentistry and Related Research* 23, no. 3 (2021): 317–328, https://doi.org/10.1111/cid.13007.

27. J. Gaspar, J. Botelho, L. Proença, et al., "Osseodensification Versus Lateral Window Technique for Sinus Floor Elevation With Simultaneous Implant Placement: A Randomized Clinical Trial on Patient-Reported Outcome Measures," *Clinical Implant Dentistry and Related Research* 26, no. 1 (2024): 113–126, https://doi.org/10.1111/cid.13294.

28. J. Z. Alhayati and A. M. Al-Anee, "Evaluation of Crestal Sinus Floor Elevations Using Versah Burs With Simultaneous Implant Placement, at Residual Bone Height ≥ 2.0 _ < 6.0 Mm. A Prospective Clinical Study," *Oral and Maxillofacial Surgery* 27, no. 2 (2023): 325–332, https://doi.org/10.1007/s10006-022-01071-0.

29. Y. T. Hsu, P. S. Rosen, K. Choksi, M. C. Shih, S. Ninneman, and C. T. Lee, "Complications of Sinus Floor Elevation Procedure and Management Strategies: A Systematic Review," *Clinical Implant Dentistry and Related Research* 24, no. 6 (2022): 740–765, https://doi.org/10.1111/cid.13086.

30. M. Al-Dajani, "Incidence, Risk Factors, and Complications of Schneiderian Membrane Perforation in Sinus Lift Surgery: A Meta-Analysis," *Implant Dentistry* 25, no. 3 (2016): 409–415, https://doi.org/10.1097/ID.0000000000000411.

31. Ç. Karaca, O. Koç, N. Er, and D. Uçar-Boyacıgil, "Evaluation of Sinus Membrane Perforation in Osteotome Sinus Floor Elevation With and Without Grafting," *Journal of Oral Implantology* 48, no. 6 (2022): 550–556, https://doi.org/10.1563/aaid-joi-D-20-00358.

32. H. L. Chan, T. J. Oh, J. H. Fu, E. Benavides, G. Avila-Ortiz, and H. L. Wang, "Sinus Augmentation via Transcrestal Approach: A Comparison Between the Balloon and Osteotome Technique in a Cadaver Study," *Clinical Oral Implants Research* 24, no. 9 (2013): 985–990, https://doi.org/10.1111/j.1600-0501.2012.02506.x.

33. O. Jensen, L. Shulman, M. Block, and V. Iacono, "Report of the Sinus Consensus Conference of 1996," *International Journal of Oral and Maxillofacial Implants* 13 (1998): 11–45.

34. X. Zhou, X. L. Hu, J. H. Li, and Y. Lin, "Minimally Invasive Crestal Sinus Lift Technique and Simultaneous Implant Placement," *Chinese Journal of Dental Research* 20 (2017): 211–218, https://doi.org/10.3290/j.cjdr.a39220.

35. R. Nedir, N. Nurdin, S. Abi Najm, M. El Hage, and M. Bischof, "Short Implants Placed With or Without Grafting Into Atrophic Sinuses: The 5-Year Results of a Prospective Randomized Controlled Study," *Clinical Oral Implants Research* 28 (2017): 877–886, https://doi.org/10.1111/clr.12893.

36. A. Khehra and L. Levin, "Maxillary Sinus Augmentation Procedures: A Narrative Clinical Review," *Quintessence International* 51 (2020): 578–584, https://doi.org/10.3290/j.qi.a44632.

37. J. Y. Shi, Y. R. Lai, S. J. Qian, S. C. Qiao, M. S. Tonetti, and H. C. Lai, "Clinical, Radiographic and Economic Evaluation of Short-6-Mm Implants and Longer Implants Combined With Osteotome Sinus Floor Elevation in Moderately Atrophic Maxillae: A 3-Year Randomized Clinical Trial," *Journal of Clinical Periodontology* 48 (2021): 695–704, https://doi.org/10.1111/jcpe.13444.

38. F. Correia, S. Gouveia, D. H. Pozza, A. C. Felino, and R. F. Almeida, "Osteotome Technique: Literature Review," *Brazilian Journal of Periodontology* 32, no. 1 (2022): 11–23.

39. M. G. Elsaid, M. F. Aboelhasan, M. A. Shuman, M. M. Alashmawy, A. O. Abdelrahman, and S. S. Elwaseef, "Transcrestal Sinus Lift With Simultaneous Implant Placement Using Osseodensification in Posterior Maxilla With Residual Bone Height of 4-6 Mm," *Brazilian Dental Science* 25 (2022): 1e7, https://doi.org/10.4322/bds.2022.e3403.

40. T. L. Aghaloo and P. K. Moy, "Which Hard Tissue Augmentation Techniques Are the Most Successful in Furnishing Bony Support for Implant Placement?," *International Journal of Oral and Maxillofacial Implants* 22 (2007): 49–70.

41. V. H. Jamcoski, F. Faot, R. M. Marcello-Machado, A. C. M. Melo, and F. N. G. K. Fontão, "15-Year Retrospective Study on the Success Rate of Maxillary Sinus Augmentation and Implants: Influence of Bone Substitute Type, Presurgical Bone Height, and Membrane Perforation During Sinus Lift," *BioMed Research International* 2023 (2023): 9144661, https://doi.org/10.1155/2023/9144661.

42. S. Shanbhag, V. Shanbhag, and A. Stavropoulos, "Volume Changes of Maxillary Sinus Augmentations Over Time: A Systematic Review," *International Journal of Oral and Maxillofacial Implants* 29, no. 4 (2014): 881–892, https://doi.org/10.11607/jomi.3472.

43. M. Tosta, A. R. G. Cortes, L. Corrêa, D. D. S. Pinto, I. Tumenas, and E. Katchburian, "Histologic and Histomorphometric Evaluation of a Synthetic Bone Substitute for Maxillary Sinus Grafting in Humans," *Clinical Oral Implants Research* 24, no. 8 (2013): 866–870, https://doi.org/10.1111/j.1600-0501.2011.02384.x.

44. E. Zampara, M. Alshammari, J. De Bortoli, et al., "A Histologic and Histomorphometric Evaluation of an Allograft, Xenograft, and Alloplast Graft for Alveolar Ridge Preservation in Humans: A Randomized Controlled Clinical Trial," *Journal of Oral Implantology* 48, no. 6 (2022): 541–549, https://doi.org/10.1563/aaid-joi-D-21-00012.

45. V. De Risi, M. Clementini, G. Vittorini, A. Mannocci, and M. De Sanctis, "Alveolar Ridge Preservation Techniques: A Systematic Review

and Meta-Analysis of Histological and Histomorphometrical Data," *Clinical Oral Implants Research* 26, no. 1 (2015): 50–68, https://doi.org/10.1111/clr.12288.

46. P. Valentini and D. D. Bosshardt, "20-Year Follow-Up in Maxillary Sinus Floor Elevation Using Bovine-Derived Bone Mineral: A Case Report With Histologic and Histomorphometric Evaluation," *International Journal of Oral and Maxillofacial Implants* 33, no. 6 (2018): 1345–1350, https://doi.org/10.11607/jomi.6884.

47. R. Kirmeier, M. Payer, M. Wehrschuetz, N. Jakse, S. Platzer, and M. Lorenzoni, "Evaluation of Three-Dimensional Changes After Sinus Floor Augmentation With Different Grafting Materials," *Clinical Oral Implants Research* 19, no. 4 (2008): 366–372, https://doi.org/10.1111/j.1600-0501.2007.01487.x.

48. E. Nyström, H. Nilson, J. Gunne, and S. Lundgren, "A 9-14 Year Follow-Up of Onlay Bone Grafting in the Atrophic Maxilla," *International Journal of Oral and Maxillofacial Surgery* 38, no. 2 (2009): 111–116, https://doi.org/10.1016/j.ijom.2008.10.008.

49. L. Ohayon, "Maxillary Sinus Floor Augmentation Using Biphasic Calcium Phosphate: A Histologic and Histomorphometric Study," *International Journal of Oral & Maxillofacial Implants* 29, no. 5 (2014): 1143–1148, https://doi.org/10.11607/jomi.3516.

50. S. Umanjec-Korac, G. Wu, B. Hassan, Y. Liu, and D. Wismeijer, "A Retrospective Analysis of the Resorption Rate of Deproteinized Bovine Bone as Maxillary Sinus Graft Material on Cone Beam Computed Tomography," *Clinical Oral Implants Research* 25, no. 7 (2014): 781–785, https://doi.org/10.1111/clr.12174.

51. L. Jing and B. Su, "Resorption Rates of Bone Graft Materials After Crestal Maxillary Sinus Floor Elevation and Its Influencing Factors," *Journal of Functional Biomaterials* 15, no. 5 (2024): 133, https://doi.org/10.3390/jfb15050133.

52. G. Lombardo, A. Signoriello, M. Marincola, et al., "Short and Ultra-Short Implants, in Association With Simultaneous Internal Sinus Lift in the Atrophic Posterior Maxilla: A Five-Year Retrospective Study," *Materials (Basel)* 15, no. 22 (2022): 7995, https://doi.org/10.3390/ma15227995.

53. K. Sulyhan-Sulyhan, J. Barberá-Millán, C. Larrazábal-Morón, J. Espinosa-Giménez, and M. D. Gómez-Adrián, "Radiographic Study of Transcrestal Sinus Floor Elevation Using Osseodensification Technique With Graft Material: A Pilot Study," *Biomimetics (Basel)* 9, no. 5 (2024): 276, https://doi.org/10.3390/biomimetics9050276.

54. C. Tang, Q. Du, J. Luo, and L. Peng, "Simultaneous Placement of Short Implants (≤8 Mm) Versus Standard Length Implants (≥10 Mm) After Sinus Floor Elevation in Atrophic Posterior Maxillae: A Systematic Review and Meta-Analysis," *International Journal of Implant Dentistry* 8, no. 1 (2022): 45, https://doi.org/10.1186/s40729-022-00443-1.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.