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Posted Date: February 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8962942/v1

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Additional Declarations: The authors declare no competing interests.

Volumetric Bone Changes After Graftless Sinus Floor Elevation Measured by CBCT: A Prospective Study

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Abstract

This prospective study quantified volumetric bone formation following graftless sinus floor elevation using osteotomes and immediate implant placement. Forty patients with bilateral posterior maxillary edentulism received 80 implants via the OSFE technique, and CBCT scans were acquired preoperatively, at 6 months, and at 24 months. Using semi-automated segmentation, the region of interest around each implant was reconstructed to measure total augmented volume and its distribution along the implant length. Mean augmented volume increased from baseline to 6 months by 195.4 ± 64.2 mm³ and showed minimal resorption between 6 and 24 months (−7.8 ± 15.1 mm³, $p>0.05$). Bone density within the augmented area, assessed in Hounsfield units, gradually shifted from values corresponding to type IV bone at 6 months to type III-like densities at 24 months. Implants with vertical bone gain ≥3 mm exhibited significantly higher insertion torque and ISQ values ($p<0.01$) and lower marginal bone loss. These data confirm that blood clot and membrane elevation alone can lead to stable three-dimensional bone formation around implants.

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1. Introduction

Maxillary sinus floor elevation is a well-established surgical approach for managing vertical bone deficiency in the posterior maxilla and enables the placement of implants of adequate length in anatomically compromised sites. Both lateral window and transcrestal techniques are routinely used in clinical practice, and numerous clinical and radiographic studies have reported high implant survival rates when these procedures are performed under appropriate indications and surgical conditions [1,2]. Beyond implant survival alone, recent research has increasingly focused on three-dimensional bone gain, volumetric changes within the augmented sinus, and the stability of marginal bone levels, as these parameters provide a more comprehensive description of the biological response of the sinus floor after implant loading [3]. Sinus floor elevation can be performed using grafted or graft-free concepts. Traditional lateral window elevation typically relies on bone substitute materials to maintain space beneath the elevated Schneiderian membrane and to support new bone formation [5]. In contrast, graft-free approaches depend on the

stabilization of a blood clot created after membrane elevation, with the implant apex contributing to space maintenance. Randomized and observational studies have demonstrated that graft-free osteotome sinus floor elevation (OSFE) can achieve implant survival rates comparable to those of grafted techniques, although the magnitude of vertical bone gain and early radiographic density is often lower [6,7]. Importantly, a systematic review and meta-analysis specifically addressing implants placed after OSFE without bone grafts reported favorable implant survival and consistent bone formation, while also highlighting substantial heterogeneity and the limited availability of long-term, well-controlled data [8]. This evidence supports the clinical feasibility of graft-free OSFE but also underscores the need for more detailed and standardized evaluation of bone formation patterns.

In recent years, prospective studies from different clinical centers have further supported the use of graft-free OSFE, reporting stable endo-sinus bone formation when implants are placed simultaneously with membrane elevation [9]. These findings suggest that membrane elevation combined with clot stabilization may be sufficient to promote osteogenesis in selected cases. However, compared with grafted procedures, the quantity, spatial distribution, and maturation of newly formed bone after graft-free OSFE remain less clearly characterized. In particular, it is still uncertain how bone forms along different regions of the implant surface and how these patterns evolve under functional loading. Cone-beam computed tomography (CBCT) has substantially improved the assessment of sinus augmentation by enabling three-dimensional visualization and quantitative analysis of augmented bone. Studies focusing on grafted lateral window elevation have shown that graft volume often decreases during the first postoperative year and subsequently stabilizes, with reported volumetric changes varying widely depending on graft material and surgical protocol [10]. Despite these valuable contributions, most CBCT-based investigations have concentrated on grafted techniques and have primarily evaluated total augmented volume rather than the distribution of bone along the implant length. In addition, many studies involve small sample sizes and employ heterogeneous segmentation and measurement protocols, limiting direct comparison across investigations. More recent CBCT-based studies have examined longitudinal changes following transcrestal sinus floor elevation, including OSFE with and without grafting [11]. These reports suggest that although some reduction in augmented height or volume may occur over time, implant stability and vertical bone gain generally remain within clinically acceptable limits for several years [12]. Nevertheless, several important gaps persist in the current literature. Many datasets are retrospective, include limited numbers of implants, or fail to adequately control for initial residual bone height [13]. Furthermore, most studies focus on overall augmented volume and do not analyze how newly formed bone is distributed along the implant surface. Data on changes in bone density within the augmented region are particularly scarce, especially for graft-free OSFE. Consequently, recent reviews have emphasized the need for prospective studies that integrate volumetric CBCT analysis with clinical indicators of implant stability and crestal bone maintenance [14]. Addressing these limitations is clinically relevant, as a

better understanding of three-dimensional bone behavior after graft-free OSFE could refine case selection and improve treatment planning in the posterior maxilla [15]. Clarifying how bone volume, spatial distribution, and density change over time may also help explain differences in implant stability and marginal bone preservation observed in clinical practice.

In this study, a prospective design was used to evaluate volumetric bone changes following graft-free osteotome sinus floor elevation with simultaneous implant placement. CBCT scans obtained before surgery and at 6 and 24 months postoperatively were used to reconstruct a standardized peri-implant region through semi-automated segmentation. This approach allowed quantification of total augmented volume, assessment of bone distribution along the implant length, and longitudinal evaluation of bone density changes. By integrating these radiographic outcomes with insertion torque, implant stability quotient (ISQ) values, and marginal bone level measurements, the study aims to determine whether membrane elevation and blood clot formation alone can support stable three-dimensional bone development around implants over a two-year period. The findings are intended to provide clinically relevant evidence regarding the predictability of graft-free OSFE and to clarify its role in posterior maxillary sites with limited vertical bone height.

2. Materials and Methods

2.1 Sample and Study Setting

This prospective study enrolled 40 adults who presented with bilateral posterior maxillary edentulism and residual bone height of 3–6 mm. A total of 80 implant sites were included. All participants were treated in the same clinical center under a unified surgical protocol. Eligibility required stable general health, an intact sinus membrane on CBCT, and no signs of sinus disease. Patients with uncontrolled systemic illness, previous sinus augmentation, acute sinus infection, or heavy parafunction were excluded. All procedures were performed by one surgeon to reduce technique-related variation. CBCT scans were obtained at baseline, 6 months, and 24 months using the same equipment, voxel size, and patient positioning method.

2.2 Experimental Design and Group Allocation

Each patient contributed two implant sites, which allowed comparisons within the same individual and reduced anatomical variation. All sites were treated with graft-free osteotome sinus floor elevation (OSFE) and immediate implant placement. After surgery, sites were grouped according to vertical bone gain measured at 6 months. Sites with ≥3 mm gain were classified as high-gain, and those with <3 mm gain as low-gain. This cutoff followed common clinical guidelines linking a gain of around 3 mm with stronger primary stability. No graft material was inserted in any site, and no lateral window approach was used. All patients received the same postoperative instructions and follow-up schedule.

2.3 Measurement Procedures and Quality Control

CBCT images were acquired with a 0.2-mm voxel setting and analyzed using semi-automated segmentation. For each implant, a region of interest (ROI) was defined by a 1.5-mm radial zone around the implant from the crest to the apex. Augmented bone volume and height were calculated from the segmented ROI. Bone density values were taken from gray-scale units that corresponded to Hounsfield-unit ranges. Two examiners independently segmented 20% of all scans to assess consistency. Intra- and inter-observer agreement exceeded 0.90 based on intraclass correlation. Implant insertion torque and implant stability quotient (ISQ) were recorded at placement and at 6 months with the same calibrated devices. Standardized periapical radiographs were used to measure marginal bone levels at baseline, 6 months and 24 months.

2.4 Data Processing and Analytical Formulas

Volumetric and linear values were processed using one workflow. Augmented volume was obtained by multiplying the number of segmented voxels by the voxel volume. Vertical changes were calculated by subtracting baseline levels from postoperative levels. Mean bone density and its spread were computed within each ROI. To examine how vertical gain influenced implant stability, a linear regression model was used [16]:

$$ISQ_{6m}=\beta_0+\beta_1(Vertical\ Gain)+\varepsilon.$$

A second model assessed whether augmented volume at 6 months related to marginal bone loss at 24 months:

$$MBL_{24m}=\alpha_0+\alpha_1(Augmented\ Volume_{6m})+\eta.$$

Only complete records were analyzed. Significance was set at $p < 0.05$.

2.5 Ethical Compliance

The study protocol was approved by the institutional ethics board. All patients provided written informed consent. The study was performed in accordance with the Declaration of Helsinki and followed local regulations for research involving human participants.

3. Results and Discussion

3.1 Volumetric changes over the 24-month follow-up

The three-dimensional analysis showed a marked increase in augmented bone volume at 6 months and only small changes thereafter. The mean gain of 195.4 ± 64.2 mm^3 at 6 months confirms that membrane elevation with a blood clot can maintain a stable space for bone formation around the implant. The change from 6 to 24 months (−7.8 ± 15.1 mm^3) was minimal

and not significant. This pattern indicates that most remodelling happens during the early healing phase and that later sinus pneumatization is limited in graft-free OSFE. These findings differ from reports on grafted lateral or transcrestal procedures, where early volume loss of 10–30% has been noted for xenografts and β-TCP during the first postoperative months [17,18]. Fig.1 illustrates the stable curve in our study and supports the idea that, when initial stability is sufficient, graft-free sinus elevation can maintain volume as well as grafted methods, without the additional loss associated with biomaterial resorption.

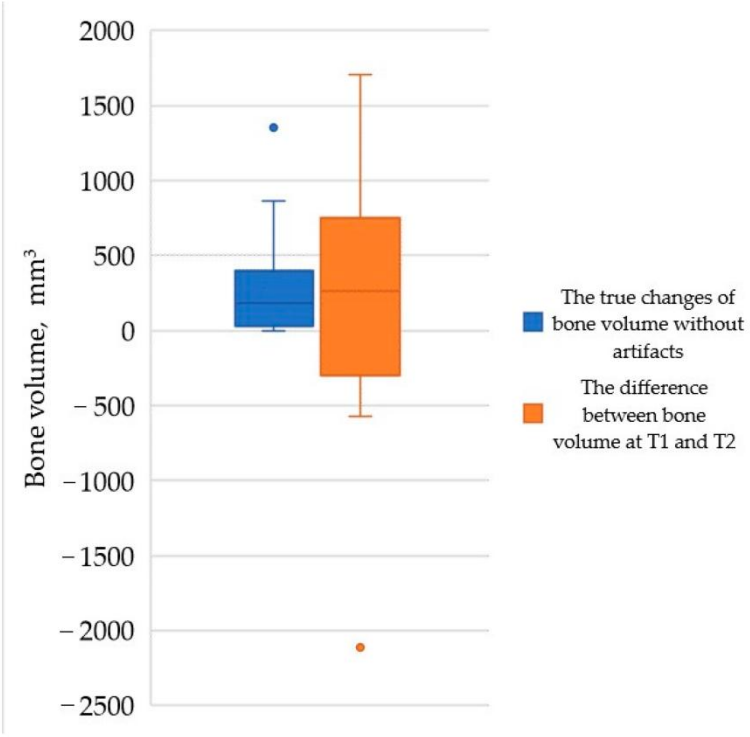


Fig.1. Changes in augmented bone volume at baseline, 6 months and 24 months after graft-free osteotome sinus floor elevation.

3.2 Spatial distribution of augmented bone along the implant

Reconstruction of the region of interest showed that new bone was mainly located in the apical third of the implant and extended about 3–4 mm above the original sinus floor. The coronal and sagittal views confirmed that the augmented area tapered toward the sinus cavity but remained in contact with the implant surface. Sites with ≥3 mm vertical gain contained a greater share of the augmented volume in the apical region, suggesting that the elevation height and clot stability affect the extent of sinus bone formation. Comparable CBCT studies in grafted sinuses also describe a link between elevation height and augmented volume, although those studies examined grafted material rather than clot-derived bone [19]. In our data, the distribution pattern in Fig.1 shows that clot-mediated bone tends to remain close to the implant apex, which helps explain why graft-free OSFE is suited to moderate vertical deficiencies rather than large sinus elevations.

3.3 Bone density changes and implant stability parameters

Within the augmented area, mean grey values in Hounsfield-unit ranges shifted from a pattern similar to type IV trabecular bone at 6 months to values closer to type III bone at 24 months. Although CBCT values cannot be taken as absolute CT numbers, comparisons made with the same machine and settings provide a reliable indication of mineralization over time [20]. Higher vertical gain (≥3 mm) was associated with higher insertion torque and higher ISQ at placement, as well as lower marginal bone loss during follow-up, compared with gain <3 mm. These findings suggest that the extra apical bone not only increases volume but also achieves adequate density to support functional stability. The scatter plots in Fig.2 show this trend but also some overlap, indicating that implant stability depends on several factors, including sinus anatomy, residual bone height and implant design, in addition to the amount of newly formed bone.

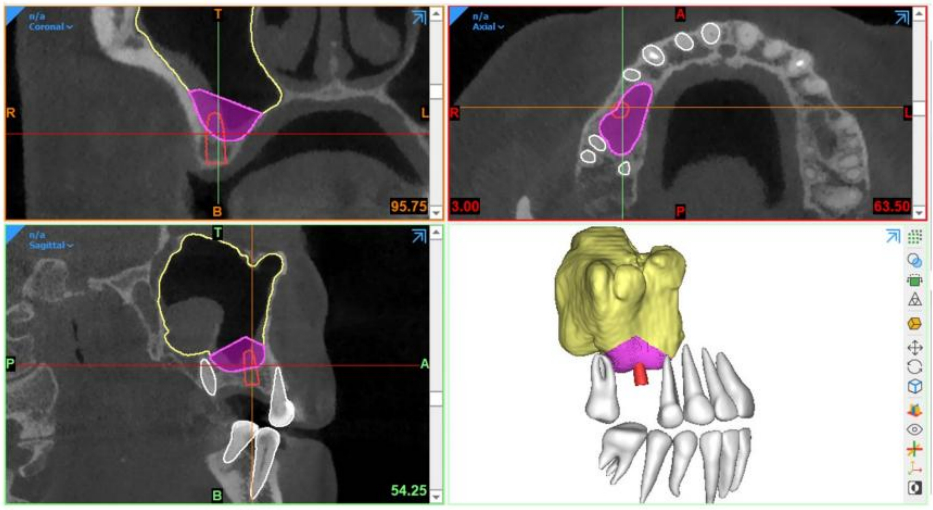


Fig.2. CBCT views showing the segmented augmented bone around the implant in coronal, axial, sagittal and 3D reconstructions.

3.4 Comparison with previous studies and clinical relevance

This prospective study adds new information to graft-free OSFE research by using volumetric and density-based CBCT measurements over a 24-month period, instead of relying only on linear measurements or 2D images. The stable volume and gradual density increase observed here are consistent with CBCT outcomes in grafted sinus augmentation, where xenografts and mixed grafts show limited late volume loss and good long-term maintenance [21,22]. At the same time, our results show that similar stability can be achieved without graft material when residual bone allows for primary stability. Several limitations should be noted. The sample size is moderate and from a single center. HU-equivalent values were not calibrated with a phantom and therefore should be viewed as relative changes. Histologic verification was not available. Only three CBCT time points were obtained due to radiation considerations, which may have missed early changes during the first weeks. Even with these limitations, the combined volumetric, density, and stability findings indicate that graft-free OSFE can produce stable

three-dimensional bone formation around implants in selected posterior maxillary sites and may serve as a simpler alternative to grafted sinus elevation for moderate vertical defects.

4. Conclusion

This study showed that graft-free osteotome sinus floor elevation can form stable bone around implants when primary stability is reached at placement. Augmented bone volume increased at 6 months and stayed largely unchanged to 24 months, while bone density moved toward a more mature pattern during the same period. Sites with greater vertical bone gain also showed higher stability values and less marginal bone loss, indicating that the newly formed apical bone provides meaningful support for the implant. These results suggest that membrane elevation and clot formation alone can maintain a reliable space for new bone growth and may be a practical choice for moderate vertical defects in the posterior maxilla. The approach also avoids issues related to graft material and keeps the procedure simpler. However, the study was limited by its single-center sample, CBCT density readings that were not phantom-calibrated, the absence of histologic samples, and restricted imaging time points. Larger studies with calibrated measurements and more frequent early imaging could help clarify early healing changes and refine the indications for graft-free sinus elevation.

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