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Effect of Different Grafting Strategies with or without Concentrated Growth Factor on Bone Augmentation After Osteotome Sinus Floor Elevation: A Retrospective Study

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Abstract

Background This study aimed to evaluate the effect of concentrated growth factors (CGF) on bone formation following osteotome sinus floor elevation (OSFE) using cone beam computed tomography (CBCT) and Mimics software.

Methods A total of 36 patients (10 males and 26 females) were enrolled and divided into three groups according to the sinus grafting strategy: Group A (OSFE with CGF alone), Group B (OSFE with CGF combined with xenogeneic bone graft), and Group C (OSFE alone without grafting). Baseline characteristics, postoperative discomfort (visual analogue scale, VAS), and radiographic data were collected for all patients.

Results Patients in Groups A and C were reported less postoperative pain than those in Group B ($P < 0.05$). At both immediate and 6-month post-surgery assessments, endo-sinus bone augmentation volume was significantly higher in Groups A (228.0 and 161.2 mm^3) and B (213.9 and 152.1 mm^3) than in Group C (141.2 and 95.8 mm^3) ($P < 0.05$). The maxillary sinus bone density change rate was also significantly higher in Groups A (150.6%) and B (129.3%) than in Group C (62.7%) ($P < 0.05$). However, no significant difference was found in the mean rate of maxillary sinus bone volume change among the three groups ($P > 0.05$).

Conclusion In OSFE with an elevation height ≤ 4 mm, CGF alone or in combination with bone graft materials achieved favorable bone augmentation and promoted new bone formation, with outcomes significantly superior to those of OSFE without any graft material. However, the addition of bone graft materials may aggravate postoperative discomfort.

Trial registration The study protocol was retrospectively registered in the Chinese Clinical Trial Registry. ChiCTR ID is ChiCTR2600124306. Registered on May 10, 2026.

Keywords Osteotome sinus floor elevation, Concentrated growth factor, Bone graft, Imaging evaluation

Background

In the posterior maxillary region, bone tissue is typically porous, and pneumatization of the maxillary sinus may occur, leading to inadequate quantity and quality of residual alveolar bone to satisfy the requirements for dental implant placement. Maxillary sinus floor elevation (MSFE) is a critical method to address this clinical issue[1–3]. Transcrestal sinus floor elevation (TSFE), when strictly indicated, exhibits lower surgical invasiveness and milder postoperative discomfort compared to the lateral window sinus floor elevation (LSFE), and is thus extensively utilized in clinical settings. Among transcrestal techniques, the osteotome sinus floor elevation (OSFE) is the most commonly employed[4]. Although the effectiveness of concurrent bone grafting in OSFE is widely acknowledged, it presents several challenges, including prolonged healing, high economic burden from bone graft materials, the necessity of a second surgical site for autologous bone graft procurement, and limited donor bone available[5].

Plasma-derived matrix products have been utilized in regenerative medicine for decades [6]. Concentrated growth factor (CGF), the latest generation of such products, was introduced in 2006. As it derived from autologous venous blood via differential centrifugation without exogenous anticoagulants, CGF eliminates the risk of blood-borne infections. Its rapid preparation has facilitated its widespread clinical application.

CGF is rich in growth factors, among which vascular endothelial growth factor (VEGF) and transforming growth factor-β (TGF-β) are indispensable for bone healing. VEGF induces neovascularization and directly regulates osteocyte activity to promote bone regeneration, whereas TGF-β enhances osteoblast activity, inhibits osteoclast differentiation, and modulates their balance to stimulate new bone formation[7–10]. CGF improves vascularization at the surgical site by stimulating neovascularization, thereby promoting wound healing and bone tissue formation [11]. Compared to the previous two generations of plasma-derived matrix products—platelet-rich plasma (PRP) and platelet-rich fibrin (PRF)—CGF possesses a denser fibrin matrix, a more abundant repertoire of growth factors, and a slower degradation rate, all of which better support hard and soft tissue healing[12, 13].

In MSFE, controversies remain regarding whether CGF should be combined with bone graft materials and whether this combination can enhance clinical outcomes. Some studies suggest that the co-administration of CGF and bone graft materials yields superior results compared to the use of bone graft materials alone [14]. Chen et al. applied CGF simultaneously during TSFE in patients with a residual bone height (RBH) of 2–4 mm; no implant failure occurred during follow-up, and the endo-sinus bone resorption rate stabilized relatively at 12 months postoperatively [15]. This finding suggests that CGF application in TSFE can achieve reliable clinical outcomes. However, other studies have indicated that the introduction of bone graft materials may exacerbate postoperative discomfort in patients [16]. Some scholars have abandoned the use of bone graft materials to fill the elevated space created during TSFE, instead relying solely on the implant protruding into the maxillary sinus and the surrounding blood clot to support the sinus mucosa. A randomized controlled trial

followed 45 patients for 10 years and found no significant effect of bone graft material addition on implant survival rate or endo-sinus new bone formation [17]. Similarly, the findings of Nedir et al. also indicated that favorable clinical outcomes can be achieved without the use of any filling materials [18].

Factors influencing endo-sinus osteogenesis in the maxillary sinus are highly complex; in addition to the surgical approach and bone grafting strategy employed, individual patient factors may also play a role, and no consensus has been reached to date. The implant protrusion length (IPL) into the maxillary sinus significantly affects new bone formation within the sinus following simultaneous implant placement during OSFE, whereas RBH has not been shown to exert a significant effect on new bone formation [19]. A retrospective study by some scholars demonstrated that when IPL $\leqslant$ 4 mm, endo-sinus new bone formation is positively correlated with IPL; when IPL > 4 mm, the efficiency of new bone formation decreases significantly. This suggests that the elevation height should be appropriately restricted to achieve optimal endo-sinus osteogenesis outcomes [20]. Therefore, establishing an appropriate IPL improves comparability of endo-sinus osteogenesis outcomes and enhances bone formation within the sinus.

Currently, no gold standard exists for evaluating the shape and volume of graft materials within the maxillary sinus [21]. Previous studies have generally relied on two-dimensional analyses using cone beam computed tomography (CBCT) or periapical radiographs to measure parameters such as height and width, while paying less attention to volume changes of endo-sinus graft materials and representative values of bone formation quality, such as Hounsfield units (HU) [22–24].

Therefore, this study included sites with IPL of 3–4 mm, focusing on measuring changes in the volume and HU values of endo-sinus bone graft materials. Simultaneously, clinical indicators such as implant survival rate and postoperative discomfort level (assessed via the Visual Analogue Scale, VAS) were recorded for comprehensive evaluation. The aim of this study was to assess the clinical efficacy of different CGF application strategies during OSFE, thereby providing a reference for clinical practice.

Materials and methods

Ethical consideration

This was a retrospective study conducted in accordance with the guidelines of the *Declaration of Helsinki* (revised 2013). Ethical approval was obtained from the Ethics Committee of Fuzhou University Affiliated Provincial Hospital (approval number: K2026-04-048), and the study was registered with the Chinese Clinical Trial Registry (ChiCTR2600124306).

Study design, grouping and settings

This retrospective study screened patients who attended the Department of Stomatology, Fuzhou University Affiliated Provincial Hospital, from January 2021 to July 2023. Eligible patients were divided into three groups based on the different endo-sinus bone grafting strategies employed: Group A: OSFE + CGF; Group B: OSFE + mixture of CGF and Bio-Oss bone powder; Group C: OSFE without any materials applied simultaneously.

Exclusion and inclusion criteria

Inclusion Criteria: (1) Aged ⩾ 18 years; (2) Single-tooth loss in the maxillary molar region with a missing duration of ⩾ 3 months; (3) Residual bone height (RBH) at the implant site ranging from 4 mm to 7 mm (4 mm ⩽ RBH ⩽ 7 mm); (4) No severe periapical lesions in adjacent teeth, and no inflammation or infection in the intended implant area; (5) No endo-sinus lesions and relatively flat sinus floor.

Exclusion Criteria: (1) Systemic diseases affecting bone healing, such as uncontrolled diabetes, osteoporosis, and AIDS; (2) History of head and neck radiotherapy; (3) Immunodeficiency diseases, pregnancy or lactation, and history of bisphosphonate therapy; (4) Smoking more than 10 cigarettes per day; (5) Uncontrolled or untreated periodontal disease; (6) Acute inflammation of the maxillary sinus.

Preoperative Preparation

Preoperative examinations were completed to rule out surgical contraindications, and written informed consent was obtained from all patients. For patients in Groups A and B, approximately 9 mL of autologous venous blood was collected preoperatively into silica-coated CGF-specific vacuum blood collection tubes. The tubes were immediately balanced and placed in a CGF centrifuge (Medifuge, Silfradenstr, S. Sofia, Italy) for differential centrifugation. After centrifugation, a blood centrifugation product was obtained, which was visually divided into three layers from top to bottom: platelet-poor plasma (PPP) layer, fibrin gel rich in growth factors (i.e., CGF layer), and red blood cell (RBC) layer. During surgery, the middle yellow gelatinous CGF layer was collected into a sterile vessel for later use and

compressed to form a CGF membrane (Figure 1).

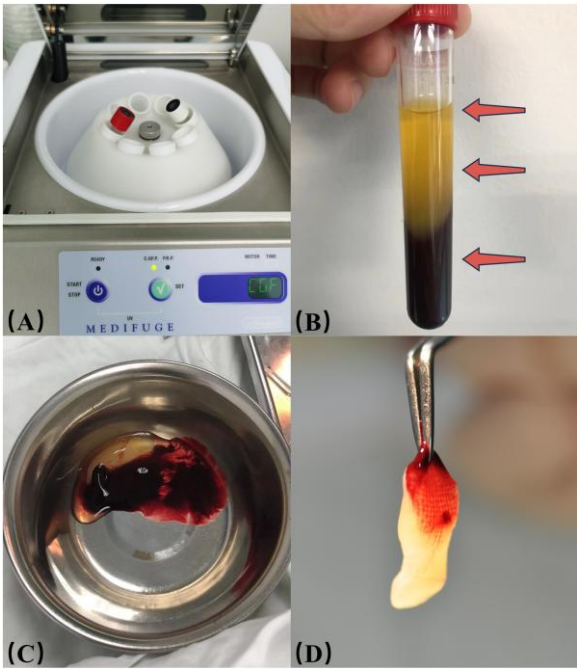


Fig. 1 The preparation process of the concentrated growth factors. (A) CGF centrifuge. (B) Visible liquid stratification in the blood collection tube. (C) Placement of CGF in a sterile container. (D) Compression of CGF into a membrane.

Surgical procedures

All surgical procedures were performed by the same experienced clinician qualified to conduct maxillary sinus floor augmentation. After disinfecting the surgical area and draping, local anesthesia was administered. A mid-crestal incision was made, following which the alveolar ridge was exposed and depth determination. A guide pin was placed to confirm the direction of socket preparation. Sequential reaming drills were performed until only approximately 1–2 mm of bone remains at the sinus floor. Subsequently, a set of osteotomes with different diameters were used to create a "greenstick fracture" of the sinus floor via light hammer taps, achieving sinus floor elevation. The elevation height was controlled at 3–4 mm as preoperatively planned. The integrity of the sinus floor mucosa was checked using a depth gauge, and the Valsalva maneuver (nose-pinching and air-blowing test) was performed to

observe for air bubbles in the implant socket, further confirming the mucosal integrity.

Patients in different groups received different interventions:

- Group A: The pre-prepared CGF membrane was slowly placed into the elevated endo-sinus space.

- Group B: The pre-prepared CGF membrane was cut into pieces, fully mixed with xenogeneic bone (Bio-Oss™, Geistlich, Wolhusen, Switzerland), and then slowly placed into the elevated endo-sinus space.

- Group C: No filling material was placed into the elevated endo-sinus space.

Finally, implants of the corresponding diameter were placed, followed by submerged healing. The incision was sutured, and cotton balls were used for compression hemostasis.

Clinical assessment

Related Complications: Common intra- and post-operative complications of OSFE were recorded, such as maxillary sinus mucoperiosteal perforation, implant displacement into the maxillary sinus, and benign paroxysmal positional vertigo (BPPV).

Implant Survival Rate (ISR): Judged according to the criteria proposed by Professor Cochran [25] in 2002.

Postoperative Discomfort: Sutures were removed 2 weeks postoperatively, and patients were asked to score their postoperative experience using a 100-mm Visual Analogue Scale (VAS; Figure 2) at the same time. A score of 0 indicated extremely intense postoperative pain, 100 indicated no postoperative pain, and scores in between represented different pain

intensities.

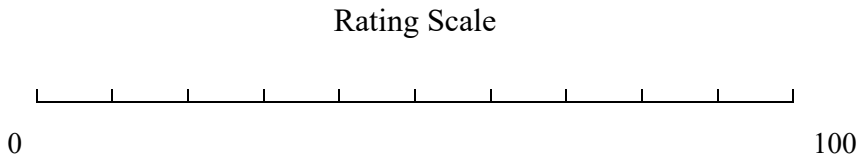


Fig. 2 Visual Analog Scale

Radiographic assessment

CBCT images obtained immediately postoperatively and at 6 months postoperatively were measured and analyzed. The same anatomical structure was used to calibrate the identical position, and the following markings were made on the sagittal plane (Figure 3):

(1) Line *a* coinciding with the long axis of the implant; lines parallel to the long axis of the implant, passing through the mesial and distal sides of the implant, were named a_1 and a_2, respectively.

(2) Line *b* perpendicular to the long axis of the implant, drawn through the point where the maxillary sinus floor contacts the implant; this line was named b_m (mesial side) and b_d (distal side) at the mesial and distal positions, respectively.

(3) Line *c* perpendicular to the long axis of the implant, drawn through the apical side of the implant.

(4) Line *e* perpendicular to the long axis of the implant, drawn through the apical side of the endo-sinus bone graft material or new bone; at the mesial, central, and distal positions of the implant, this line was named e_1, *e*, and e_2, respectively.

(5) Line *f* perpendicular to the long axis of the implant, drawn through the coronal side

where the implant contacts the alveolar bone; this line was named f_m (mesial side) and f_d (distal side) at the mesial and distal positions, respectively.

CBCT datasets acquired immediately postoperatively and at 6 months postoperatively were imported into Mimics software (Mimics 21.0, Materialise, Leuven, Belgium), a tool validated for accurate three-dimensional volumetric measurement of endo-maxillary sinus graft materials [26]. Maxillary sinus bone tissue was reconstructed using the software (Figure 4), and a plane perpendicular to the implant long axis was created at the implant apex. This plane segmented the model into two three-dimensional sub-models: the implant apical region model and the implant region model (Figure 5).

The reconstructed immediate postoperative data were defined as baseline **T**:

- Endo-sinus bone augmentation volume immediately after OSFE: V
- Mean bone density: HU
- Bone augmentation volume in the implant apical region: V_1
- Bone augmentation volume in the implant region: V_2

The 6-month postoperative data were denoted as **T'**:

- Endo-sinus bone augmentation volume at 6 months after OSFE: V'
- Mean bone density: HU'
- Bone augmentation volume in the implant apical region: V_1'
- Bone augmentation volume in the implant region: V_2'

Specific Measurement Parameters:

(1) Implant Protrusion Length into the Maxillary Sinus (IPL): The vertical distance between reference lines *b* and *c*, calculated as the mean value of mesial and distal measurements.

(2) Apical Bone Height (ABH): The vertical distance between reference lines *c* and *e*, calculated as the mean value of measurements taken at the mesial, central, and distal aspects of the implant. A negative value indicates that the bone height at the implant apical region is inferior to the implant apex.

(3) Residual Alveolar Bone Height (RBH): The vertical distance between reference lines *f* and *b*, calculated as the mean value of mesial and distal measurements.

(4) Endo-Sinus Bone Gain (ESBG): Defined as the sum of IPL and ABH. It is denoted as $ESBG_0$ (immediately postoperatively) and $ESBG_6$ (6 months postoperatively).

(5) Crestal bone level (CBL): The vertical distance between reference lines *c* and *f*, calculated as the mean value of measurements taken at the mesial and distal. CBL_0 denotes the value recorded immediately postoperatively; CBL_6 denotes the value recorded at 6 months postoperatively.

(6) Marginal bone loss (MBL): The difference between CBL_0 and CBL_6, quantifying marginal bone resorption around the implant.

(7) Maxillary Sinus Bone Volume Change Rate:

$$\text{Change Rate}=\frac{V\text{-}V'}{V}\times 100\%$$

(8) Implant Apical Region Bone Volume Change Rate:

$$\text{Change Rate}=\frac{V_1\text{-}V_1^{'}}{V_1}\times 100\%$$

(9) Peri-Implant Bone Volume Change Rate:

$$\text{Change Rate}=\frac{V_2\text{-}V_2^{'}}{V_2}\times 100\%$$

(10) Maxillary Sinus Bone Density Change Rate:

$$\text{Change Rate}=\frac{HU^{'}\text{-}HU}{HU}\times 100\%$$

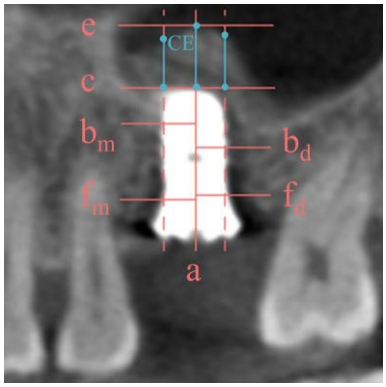


Fig. 3 CBCT cross-sectional view showing the reference lines. *a*: Implant long axis. *b*: Line perpendicular to a at the implant–sinus floor contact point, with b_m (mesial) and b_d (distal). *c*: Line perpendicular to a at the implant apex. *e*: Line perpendicular to a at the apical boundary of the intra-sinus bone graft/newly formed bone, with *e* (central), e_1 (mesial), and e_2 (distal). *f*: Line perpendicular to a at the coronal implant–alveolar bone interface, with f_m (mesial) and f_d (distal).

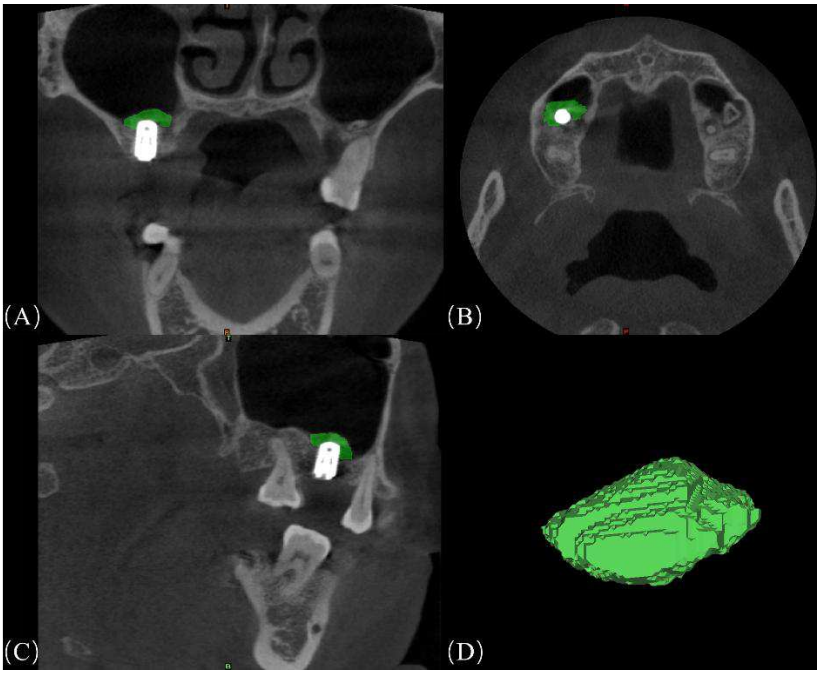


Fig. 4 Volume model of maxillary sinus bone augmentation constructed by Mimics. (A) coronal view; (B) axial view; (C) sagittal view; (D) three-dimensional reconstruction of the bone augmentation in the maxillary sinus

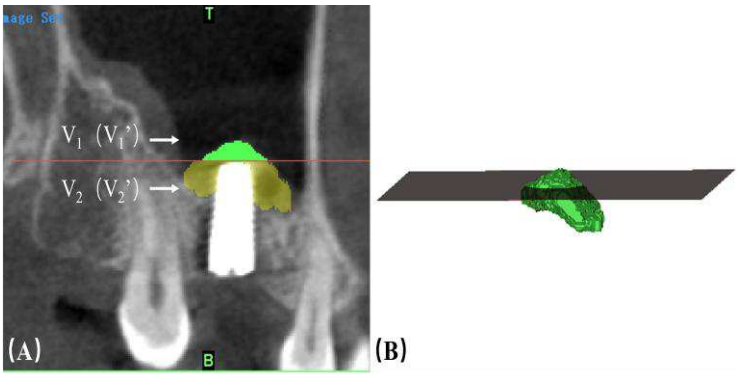


Fig. 5 Mimics-based volume segmentation. (A) Sagittal view: Implant apical region bone augmentation volumes V_1 (baseline) and V_1' (6-month); implant site volumes V_2(baseline) and V_2' (6-month); (B) 3D reconstruction of endo-sinus bone augmentation.

Statistical methods

Quantitative data were tested for normality using the Shapiro-Wilk test. Normally distributed data are reported as mean ± SD ($\bar{x} \pm s$); non-normal data as median (P_{25}, P_{75}). Qualitative data are reported as n (%). For normally distributed data, Levene's test assessed variance homogeneity: two-group comparisons used independent-samples t-test; multi-group

comparisons used one-way ANOVA; ESBG and maxillary sinus bone augmentation volumes used repeated-measures ANOVA. All post-hoc multiple comparisons were Bonferroni-corrected. For non-normal or heteroscedastic data, Mann-Whitney U and Kruskal-Wallis H tests were used, with Bonferroni correction for multiple comparisons. Fisher's exact test compared qualitative variables. Analyses were performed in SPSS 21.0 (IBM SPSS Statistics 21, SPSS Inc., New York, USA); two-tailed P-values < 0.05 was considered significant.

Results

General information

Based on predefined inclusion and exclusion criteria, 36 patients were enrolled in this study, with 14 in Group A, 10 in Group B, and 12 in Group C. No statistically significant differences were observed among the three groups regarding gender ($P = 0.185$), age ($P = 0.797$), implant brand ($P = 0.440$), or implant site distribution ($P = 0.215$) (Table 1).

Table 1 General information and distribution of implant sites

	Group A n=14	Group B n=10	Group C n=12	*F*	*P*
Age (years) mean (±SD)	50.50±16.74	48.90±13.63	46.25±17.05	0.23	0.797
Male n (%)	2 (0.14)	5 (0.50)	3 (0.25)		0.185
Female n (%)	12 (0.86)	5 (0.50)	9 (0.75)		
Implant brand					
Dentium	7	5	9		0.440
Straumann	7	5	3		
Implant site					
16	2	3	7		0.215
17	2	1	3		
26	8	6	1		
27	2	0	1		

Postoperative adverse events

None of the 36 implants demonstrated intraoperative maxillary sinus mucoperiosteal perforation. Immediate postoperative CBCT confirmed a characteristic “tent-like” elevation of the sinus floor, with no discernible fluid level within the sinus cavity. No major or minor adverse events, including implant displacement into the sinus, sinusitis, bone graft infection, or BPPV, were documented during the early postoperative period. All implants survived, with an ISR of 100%.

VAS scores are summarized in Table 2. Groups A (75.1 ± 10.2) and C (74.4 ± 11.4) were higher than those of Group B (61.6 ± 11.4), and the difference among the three groups was statistically significant ($P = 0.010$). Groups A ($P = 0.016$) and C ($P = 0.030$) scored higher than Group B, whereas no difference was detected between Groups A and C ($P = 1.000$) (Figure 6).

Table 2 The table of VAS score $(n = 36, \bar{x} \pm s)$

	Group A n=14	Group B n=10	Group C n=12	*F*	*P*
Score	75.1±10.2	61.6±11.4	74.4±11.4	5.26	0.010

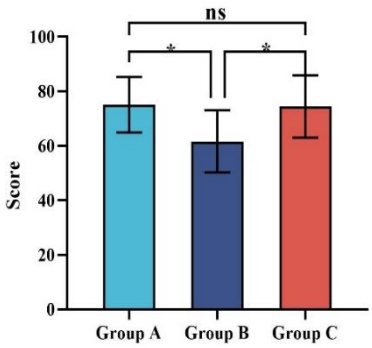


Fig. 6 Post hoc pairwise comparisons of VAS score. *$P < 0.05$; ns = not significant ($P \geq 0.05$)

Radiographic results

The RBH was 4–7 mm in all three groups (P = 0.852) and the IPL was maintained at 3–4 mm with no intergroup differences (P = 0.389). At 6 months post-surgery, MBL occurred to varying extents in all groups, but the differences across groups were not statistically significant (P > 0.05) (Table 3).

Table 3 Comparison of RBH, IPL and MBL in different groups $(\bar{x} \pm s, mm)$

	Group A n=14	Group B n=10	Group C n=12	F	P
RBH (mm)	6.0±0.8	5.8±0.8	5.9±1.0	0.16	0.852
IPL (mm)	3.5±0.4	3.7±0.4	3.5±0.4	0.97	0.389
MBL (mm)	0.26±0.11	0.30±0.14	0.35±0.21	1.00	0.378

Endo-sinus bone gain (ESBG)

Repeated-measures analysis of variance (RM-ANOVA) revealed a significant intergroup difference in ESBG (P = 0.003), a time-dependent reduction in ESBG (P < 0.001), and no significant interaction between time and sinus grafting strategy (P = 0.795).

Immediate post-surgery, ESBG was ordered as Group B (5.4 ± 1.0 mm) > Group A (4.9 ± 0.6 mm) > Group C (4.3 ± 0.7 mm). Group B had a significantly higher mean ESBG than Group C (P = 0.006), while no significant differences were noted between the other two pairs (P > 0.05). At 6 months post-surgery, ESBG followed a similar pattern: Group B (4.3 ± 0.8 mm) > Group A (3.9 ± 0.7 mm) > Group C (3.4 ± 0.6 mm), with group B significantly higher than Group C (P = 0.017) and no significant differences between the other pairs (P > 0.05) (Table 4 and Figure 7).

Table 4 Comparison of ESBG in different groups $(\bar{x} \pm s, mm)$

ESBG (mm)	Group A n=14	Group B n=10	Group C n=12	F	P

immediate post-surgery	4.9±0.6	5.4±1.0	4.3±0.7	5.74	0.007
6 months post-surgery	3.9±0.7	4.3±0.8	3.4±0.6	4.45	0.019

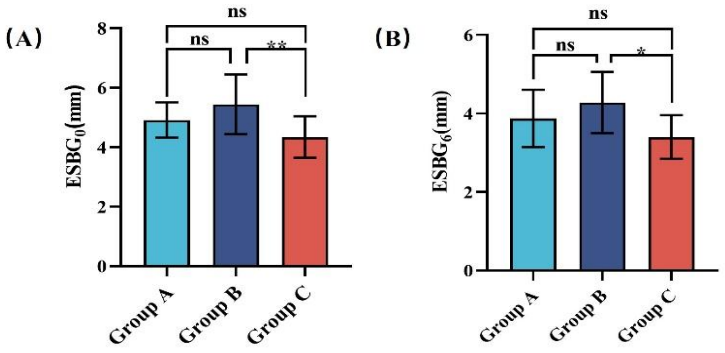


Fig. 7 Post hoc pairwise comparisons of ESBG between groups. (A) immediately after the surgery; (B) 6 months after the surgery. *$P < 0.05$; ** $P < 0.02$; ns = not significant ($P \geq 0.05$)

Endo-sinus bone augmentation volume

Repeated-measures analysis of variance (RM-ANOVA) revealed that both V and V' exhibited a significant time-dependent decrease ($P < 0.001$). A significant interaction between time and sinus grafting strategy was detected ($P = 0.004$), indicating divergent temporal trends in endo-sinus bone augmentation volume (V) across the three groups: Groups A and C showed a more pronounced volume reduction compared to Group B. Moreover, a statistically significant intergroup difference in volume was observed ($P < 0.001$).

At immediate post-surgery, V was highest in Group A (228.0 ± 62.6 mm³), followed by Group B (213.9 ± 38.3 mm³) and Group C (141.2 ± 29.7 mm³). Both Group A ($P < 0.001$) and Group B ($P = 0.003$) had significantly higher V than Group C, while no significant difference was observed between Group A and Group B ($P = 1.000$).

At 6 months post-surgery, *V'* followed the order of Group A (161.2 ± 55.1 mm³) > Group B (152.1 ± 29.3 mm³) > Group C (95.8 ± 20.0 mm³). Consistent with the immediate post-surgery results, Group A ($P = 0.001$) and Group B ($P = 0.007$) had significantly higher *V'* than Group C, with no significant difference between Group A and Group B ($P = 1.000$) (Table 5 and Figure 8).

Table 5 Comparison of endo-sinus bone augmentation volume in different groups ($\bar{x} \pm s, mm^3$)

	Group A n=14	Group B n=10	Group C n=12	*F*	*P*
immediate post-surgery *(V)*	228.0±62.6	213.9±38.3	141.2±29.7	11.96	＜0.001
6 months post-surgery *(V')*	161.2±55.1	152.1±29.3	95.8±20.0	9.86	＜0.001

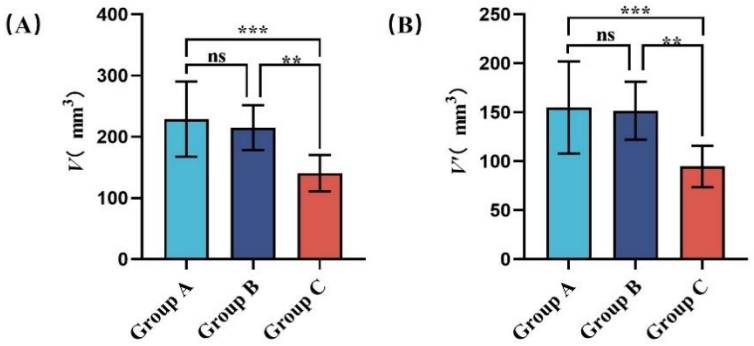


Fig. 8 Post hoc pairwise comparisons of endo-sinus bone augmentation volume between groups. (A) immediately after the surgery; (B) 6 months after the surgery. ** $P < 0.02$; *** $P < 0.001$; ns = not significant ($P \geq 0.05$)

Maxillary sinus bone volume change rate

Three components of bone volume change rate were measured: the maxillary sinus bone volume change rate, the implant apical bone volume change rate (segmented at the plane of the implant apex), and the peri-implant bone volume change rate.

Since no graft material was used to fill the elevated sinus space in Group C, minimal bone augmentation was visible on imaging in the implant apical region. Thus, the comparison of implant apical region bone volume change rate was restricted to Groups A and B, comprising 22 sites in total (two sites in Group A were excluded due to the absence of visible apical bone augmentation on immediate post-surgery imaging). The peri-implant bone volume change rate in Group C was equivalent to its intra-sinus bone volume change rate (Table 6 and 7).

The mean maxillary sinus bone volume change rate increased the order of Group B (28.9%) < Group C (32.1%) < Group A (32.9%), with no statistically significant difference among the three groups ($P = 0.304$). The mean implant apical bone volume change rate was higher in Group A (64.8%) than in Group B (49.6%), but the difference between the two groups was not statistically significant ($P = 0.107$). The mean peri-implant bone volume change rate followed the order of Group B (21.0%) < Group A (23.7%) < Group C (32.1%), with no statistically significant difference among the three groups ($P = 0.165$).

Table 6 Comparison of maxillary sinus bone volume change rate (%) among groups [M (P_{25}, P_{75})]

	Group A n=14	Group B n=10	Group C n=12	*H*	*P*
maxillary sinus bone volume	33.3(28.5, 38.5)	29.5(24.1, 32.5)	30.1(29.3, 37.1)	1.23	0.304
peri-implant bone volume	30.2(8.3, 33.7)	25.7(4.4, 31.6)	30.1(29.3, 37.1)	3.61	0.165

Table 7 Comparison of apical bone volume change rate (%) among groups [M (P_{25}, P_{75})]

	Group A n=12	Group B n=10	*U*	*P*
implant apical bone volume	66.1(38.2, 96.0)	55.7(22.8, 73.5)	35.00	0.107

Maxillary sinus bone density change rate

The mean maxillary bone density change rate was highest in Group A (150.6%), followed by Group B (129.3%) and Group C (62.7%). Both Group A and Group B showed significantly higher rates than Group C ($P = 0.001$ and $P = 0.004$, respectively), with no significant difference between Groups A and B ($P = 1.000$) (Table 8 and Figure 9).

Table 8 Comparison of maxillary sinus bone density change rate (%) among groups [M (P_{25}, P_{75})]

	Group A n=14	Group B n=10	Group C n=12	*H*	*P*
maxillary bone density change rate	129.8(84.8, 197.3)	115.9(105.8, 124.5)	63.4(42.0, 80.1)	15.41	＜0.001

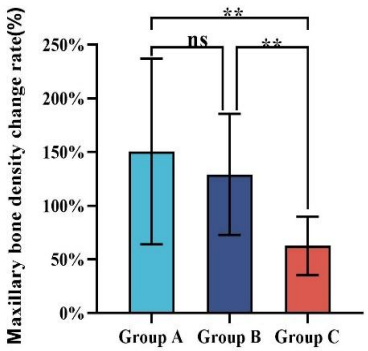


Fig. 9 Post hoc pairwise comparisons of maxillary sinus bone density change rate between groups. ** $P < 0.02$; ns = not significant ($P \geq 0.05$)

Discussion

This study compared the clinical efficacy of different maxillary sinus floor grafting strategies during OSFE. The results demonstrated that CGF, whether used alone or in combination with bone graft materials, achieved favorable bone augmentation effects and promoted new bone formation. Its efficacy was significantly superior to that of OSFE without any graft materials, whereas the addition of bone graft materials had no significant impact on

the outcomes.

To ensure adequate comparability among the groups, the present study imposed certain restrictions on RBH and IPL. RBH is known to significantly influence the choice of surgical approach. According to the 2008 consensus statement of the International Team for Implantology (ITI), OSFE is indicated when RBH is ≥ 6 mm [27]. However, this threshold appears relatively conservative, as several studies have demonstrated that performing OSFE at sites with RBH < 6 mm does not compromise implant success rates [28–30]. A meta-analysis by Claudiu et al. [31] of eight clinical trials on OSFE further revealed that RBH < 4 mm significantly compromises implant survival. Additionally, the intra-sinus portion of the implant may act as a tenting screw, effectively supporting the elevated Schneiderian membrane during OSFE and protecting the underlying blood clot, thereby positively influencing new bone formation within the maxillary sinus [32]. IPL has been reported to be positively correlated with ESBG [19, 33, 34]; however, greater IPL increases the tension exerted on the Schneiderian membrane, thereby elevating the risk of mucosal perforation and potentially compromising implant success [35]. Moreover, a lifting height exceeding 4 mm does not further augment intra-sinus bone volume and may even exert adverse effects [19, 36]. In light of these considerations, all sites included in the present study had RBH ≥ 4 mm and IPL = 3–4 mm. The results confirmed that there were no significant differences among Groups A, B, and C with respect to baseline characteristics, RBH, or IPL, indicating satisfactory comparability across the three groups.

There is still no consensus on the optimal grafting strategy for the sinus-lifted space in OSFE. Bone graft materials carry the risks of residual particles, high costs, and prolonged

healing [37]. CGF has been shown to effectively promote soft and hard tissue regeneration and has recently been introduced in OSFE [38]. However, due to concerns about its poor space-maintaining ability and rapid resorption rate, some researchers have suggested that CGF should be used in combination with bone graft materials during OSFE [39].

In the present study, comparison of ESBG among the three groups revealed that CGF combined with bone graft materials significantly enhanced sinus bone augmentation during OSFE, whereas the effect of CGF alone on increasing sinus bone volume remained inconclusive. Considering that ESBG was measured on CBCT cross-sectional images, it is difficult to ensure that the measured sections at baseline and follow-up were exactly identical. Moreover, the uneven distribution of sinus bone may compromise the representativeness of linear or area measurements. In contrast, the endo-sinus bone augmentation volume (*V*) measured using Mimics software provides more stable and accurate results. Consequently, further observation of V demonstrated that both Groups A (228.0 mm^3 at immediate post-surgery, 161.2 mm^3 at 6 months) and B (213.9 mm^3, 152.1 mm^3) exhibited superior outcomes compared to Group C (141.2 mm^3, 95.8 mm^3). In Group C, the only supporting structures for the elevated Schneiderian membrane were the intra-sinus portion of the implant and the blood clot formed during surgery. However, the blood clot is inherently unstable and provides poor mechanical support, which may lead to collapse of the elevated space and subsequently impair new bone formation within the sinus [40]. In Groups A and B, the application of CGF and bone graft materials not only reduced the collapse of the elevated space but also, through the osteogenic potential of CGF itself, resulted in greater new bone formation compared to Group C. Bone graft materials possesses a porous scaffold structure

that can support the Schneiderian membrane and stabilize the blood clot, and have been shown to significantly increase endo-sinus bone volume in LSFE [5]. However, in the present study, no significant difference in endo-sinus bone augmentation volume (*V*) was observed between Groups A and B ($P > 0.05$). This may be attributable to the fact that the elevated space created during OSFE is smaller than that in LSFE, and both the implant and CGF provide adequate support to the Schneiderian membrane, thus the additional use of bone graft materials did not further augment new bone formation. Overall, OSFE with or without bone grafts effectively increased sinus bone augmentation volume, and the addition of bone substitutes did not significantly affect the outcomes.

No significant difference was observed in maxillary sinus bone volume change rate among the three groups, with a mean resorption rate of 31.5%, which is consistent with the findings of Yong et al. [22]. Comparison of bone volume change rates at different regions revealed that: (1) The apical bone volume change rate was 67.2% in Group A and 49.6% in Group B, significantly higher than the mean sinus bone volume change rate. The degradation of CGF may partly account for the high bone volume change in this region [39]. The higher rate in Group A compared to Group B also suggests that, in the apical region without implant support, bone substitutes with slower resorption provide more effective support to the Schneiderian membrane than CGF. However, given the 100% implant survival rate in all groups, the bone volume in this region did not affect implant survival, and this resorption is considered an inevitable physiological process [28]. (2) Further comparison of the peri-implant bone volume change rate revealed a pattern of Group B (21.0%) < Group A (23.7%) < Group C (32.1%), with no statistically significant differences among the groups.

The bone change rate in the peri-implant region was much lower than that in the apical region, which may be attributed to the mechanical support provided by the implants. Although no significant differences were observed among the three groups, the lower rates in Groups A and B compared to Group C suggest that CGF may reduce shrinkage and collapse of the elevated sinus space and promote new bone formation in the peri-implant region.

Given the close correlation between HU and bone mineral density (BMD), radiographic examination can serve as a reliable method to assess bone quality and, consequently, the quality of newly formed bone [41]. In the present study, the overall HU value of the three-dimensional model of the endo-sinus bone was measured to evaluate the quality of the newly formed bone within the maxillary sinus, thereby avoiding errors caused by uneven bone density distribution. Our results showed that CGF effectively increased the bone density of the endo-sinus new bone and accelerated its calcification. The rates of increase in endo-sinus bone density in Groups A (150.6%) and B (129.3%) were significantly higher than that in Group C (62.7%). Adali et al. [14] performed histological examination 6 months after MSFE and found that the percentage of new bone formation when CGF was combined with allogeneic bone (36.41%) was higher than that with allogeneic bone alone (35.49%); however, the difference was not significant. In contrast, a double-blind randomized controlled trial [42] found that in MSFE, the percentage of new bone formation with CGF alone was significantly higher than that with xenogeneic bone alone. CGF has a dense fibrin network and is rich in growth factors that can accelerate the formation of bone marrow cells and osteogenic differentiation [43, 44]. These findings suggest that in MSFE, CGF alone may be more effective for new bone formation than CGF combined with bone graft materials.

Consistent with this, our study found that the higher bone density increases in Group A (150.6%) than in Group B (129.3%) also suggests that the addition of bone graft materials during OSFE does not appear to promote calcification of the newly formed bone and may even slow it down.

At the time of prosthesis loading, the mean MBL values for Groups A, B, and C were 0.26 mm, 0.30 mm, and 0.35 mm, respectively, with no significant intergroup differences, suggesting that the use of CGF during OSFE did not substantially influence MBL. Although previous studies have confirmed the ability of CGF to promote peri-implant bone regeneration [45], the absence of this effect in the present study may be attributable to the fact that CGF was not applied directly around the implant neck, but rather placed in the maxillary sinus floor elevation space. The MBL prior to functional loading may be related to the osseous trauma induced by implant site preparation and placement, as well as the inflammatory response elicited by bacterial contamination [46].

Postoperative pain is influenced by patient-related factors such as individual pain threshold, as well as procedure-related factors including surgical duration, operator experience, and surgical technique, all of which contribute to the severity of postoperative discomfort. Extensive flap elevation and bone grafting procedures can significantly increase postoperative pain, and even the insertion torque of the implant has been reported to influence this outcome [47, 48]. A systematic review [49] found that the technique used to penetrate the sinus floor cortical bone significantly influenced postoperative discomfort. Compared with grinding, piezosurgery, and modified osteotome techniques, the conventional osteotome technique was associated with the most severe postoperative discomfort, whereas the type of

bone graft material used did not affect this outcome.

In the present study, where the conventional osteotome technique was employed for sinus floor penetration, the VAS scores in Groups A and C were significantly higher than those in Group B, with no significant difference between the former two groups. This finding suggests that the addition of bone graft materials during OSFE increases postoperative discomfort, consistent with the findings of Starch-Jensen et al. [50], who reported that patients receiving bone graft materials during OSFE experienced more severe postoperative pain, masticatory difficulty, and sleep disturbance than those without grafting. Therefore, for OSFE with limited elevation height, the omission of bone graft materials may be a viable option for reducing postoperative discomfort.

Nevertheless, several methodological limitations of this study warrant consideration. Histological assessment, typically performed on small bone biopsies retrieved from the endo-sinus region, is considered the gold standard for evaluating new bone quality [42]. However, as all patients underwent simultaneous implant placement following the OSFE procedure, we were precluded from obtaining such samples for a direct histological comparison between groups. Additionally, the relatively small sample size and the short follow-up duration limit the generalizability of our findings, particularly regarding the medium- and long-term efficacy of CGF. Accordingly, larger-scale and longer-term prospective studies are required to validate its clinical performance.

Conclusion

Within the limitations of this study, OSFE with an elevation height ≤ 4 mm, using CGF

alone or in combination with bone graft materials, effectively promotes sinus bone augmentation and new bone formation, with outcomes significantly superior to those in the non-grafted group. However, the addition of bone graft materials offered no further advantage in endo-sinus bone gain and was associated with greater postoperative discomfort. Moreover, while bone coverage of the implant apical region did not affect implant survival, this area showed a relatively high bone resorption rate.

Abbreviations

MSFE	Maxillary sinus floor elevation
LSFE	Lateral sinus floor elevation
TSFE	Transcrestal technique for sinus floor elevation
OSFE	Osteotome sinus floor elevation
CGF	Concentrated growth factor
PRP	Platelet-rich plasma
PRF	Platelet-rich fibrin
VEGF	vascular endothelial growth factor
TGF-β	Transforming growth factor-β
ESBG	Endo-sinus bone gain
IPL	Implant protrusion length
RBH	Residual bone height
CBCT	Cone beam CT
HU	Hounsfield units

ISR	Implant survival rate
VAS	Visual Analog Scale
BPPV	Benign paroxysmal positional vertigo
ABH	Apical bone height
CBL	Crestal bone level
MBL	Marginal bone loss
BMD	Bone mineral density
mm	Millimeter

Supplementary Information

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Authors' contributions

Authors' contributions: study design: Y-YZ and YL; data collection: Y-YZ, J-WL, C-CD, and Y-NH; data analysis and interpretation: Y-YZ and T-RH; drafting of the manuscript: Y-YZ; critical revision of the manuscript: W-QC and T-RH. All authors read and approved the final manuscript.

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Availability of data and materials

The de-identified participant data and statistical code used in this study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval and consent to participate

This was a retrospective study conducted in accordance with the guidelines of the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of Fuzhou University Affiliated Provincial Hospital (approval number: K2026-04-048). All participants (10 men and 26 women) signed an informed consent form.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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