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# Alveolar Bone Morphologic Predictors for Guided Bone Regeneration Outcome in Anterior Maxilla

Luo-Man Gan [a,1], Qian-Rong Zhou [a,1], Yan Zhang [a,1], You-Cheng Yu [a,b], Zhen-Ze Yu [a], Yang Sun [a], Rui-Xue Li [a], Xing-Wen Wu [a], Fei Yang [a,b*]

[a] Department of Stomatology, Zhongshan Hospital Affiliated to Fudan University, Shanghai, P. R. China
[b] Department of Stomatology, Xiamen Branch, Zhongshan Hospital, Fudan University, Xiamen, P. R. China

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ABSTRACT

*Objectives:* This study aimed to explore the influence of alveolar bone morphologic variables on the outcome of guided bone regeneration (GBR) in the anterior maxilla region.

*Methods:* Twenty-eight patients who received single maxillary anterior tooth delayed implant placed simultaneously with GBR were recruited. Baseline data including age, gender, implant site, implant brand, and bone graft materials were recorded. The resorption rate of the grafted bone (RRGB), labial bone width at 0 mm, 2 mm, and 4 mm apical to the implant platform at Tn ($LBW0_{Tn}$, $LBW2_{Tn}$, $_{LBW4Tn}$), implant angulation (IA), maximum bone graft thickness (MBGT), bone graft volume (BGV), and the initial bone morphologic variables bone concavity depth (BCD) and bone concavity angulation (BCA) were measured. The Pearson correlation analysis, analysis of variance (ANOVA), and optimal binning method were used to explore the potential predictors for GBR.

*Results:* Among 28 patients, the labial bone width of implant and bone graft volume decreased significantly when measured 6 months after surgery. The mean percentage of RRGB was 49.78%. RRGB was not correlated with gender, age, bone graft material, IA, MBGT, bone graft volume at T1, implant site, and implant brand ($P > .05$). BCD and BCA were each moderately correlated with RRGB ($r = -0.872$ [$P < .001$] and $r = 0.686$ [$P < .001$], respectively). A BCD ≥1.03 mm and a BCA <155.30° resulted in a significantly lower percentage of RRGB ($P < .001$).

*Conclusions:* A significant grafted bone materials volume reduction was detected after GBR with collagen membrane and deproteinized bovine bone mineral (DBBM). The initial bone morphology can influence GBR outcome, and a bone concavity with a depth ≥1.03 mm and an angulation <155.30° led to a lower RRGB. BCD and BCA can be used as variables to predict the outcome of GBR.



## Introduction

Anterior teeth have crucial functions in various aspects, including speech, aesthetics, and chewing. The loss of anterior teeth in the maxilla has significant negative impacts on a patient's quality of life.[1] To achieve long-term stability and success, it is essential to place dental implants in positions that are both biologically and prosthetically favourable. However, horizontal and vertical bone resorption in the anterior maxilla zone happens frequently after tooth extraction,[2] leading to insufficient bone volume to support an ideally placed dental implant in the edentulous area.

Guided bone regeneration (GBR) is a commonly utilised bone augmentation technique for the reconstruction of hard

* *Corresponding author.* Department of Stomatology, Zhongshan Hospital Affiliated to Fudan University, No. 180 FengLin Road, Shanghai, 200032, P. R. China; Department of Stomatology, Xiamen Branch, Zhongshan Hospital, Fudan University, No. 668 JinHu Road, Xiamen, 361015, P. R. China.
E-mail address: yang.fei@zs-hospital.sh.cn (F. Yang).
Luo-Man Gan: http://orcid.org/0000-0001-5381-5009
Fei Yang: http://orcid.org/0000-0001-9719-1314

[1] Luo-Man Gan, Qian-Rong Zhou and Yan Zhang contributed equally to this article.

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tissue defects. In this technique, bone replacement materials are used as a scaffold to provide a stable space for bone regeneration. However, previous research[3] has demonstrated that even with sutured incisions without tension, there was a risk of displacement of the bone graft material and collapse of the collagen membrane. The presence of soft tissue pressure, particularly from the labial barrier membrane, can push the membrane into the bone defect, resulting in the formation of fibrous tissue instead of new bone formation.[4] To address this issue, fixation pins and titanium mesh have been used to provide more structural stability for osteogenesis, resulting in less vertical and horizontal alveolar bone resorption.[3,5] Therefore, adequate osteogenic space and stability of grafted bone materials are vital prerequisites for an ideal GBR outcome.

The initial alveolar ridge morphology has been found to affect the outcome of bone regeneration.[6,7] Favourable alveolar morphology is recognised as being beneficial to stabilise the osteogenic space and grafted bone materials. Various alveolar morphology classifications have been established to predict the clinical outcome of GBR. The Terheyden classification[8] is based on the relationship between the alveolar bone height and the expected implant length. Another classification system was established according to the labial bone wall and gingival integrity.[9] However, none of these classifications can quantitatively assess the extent of bone defects and, consequently, there is limited information relating to the prognostic value of initial bone defects on GBR outcomes. A gold standard for guiding treatment strategies based on a classification of bone defects has yet to be established.[10]

Cone-beam computerised tomography (CBCT) provides 3-dimensional (3D) data measurement and visualisation techniques that can improve the evaluation of postoperative outcome and allows the postoperative hard tissue alteration to be directly assessed. This is due to its high 3D diagnostic capability at lower radiation doses when compared with medical multislice CT.[11] In recent years, many studies have used CBCT and digital software to reconstruct 3D models of grafted bone to evaluate hard tissue stability.[12,13]

Analysing the morphologic characteristics of bone defects by CBCT before surgery is helpful to guide clinicians to predict the clinical effect of GBR surgery and adopt the ideal treatment strategy according to the different classifications of bone defects.

Therefore, the main purpose of this study was to explore the potential alveolar bone morphologic factors affecting the bone augmentation effect of GBR surgery and define the critical value of alveolar bone morphologic variables affecting the resorption rate of grafted bone after GBR surgery. We aimed at providing evidence for clinicians to predict the effect of horizontal bone augmentation and to decide reasonable clinical bone augmentation strategy.

## Materials and methods

### Study design

This single-centre and retrospective study was conducted at the Department of Stomatology of the Zhongshan Hospital of Fudan University. Patients who underwent a delayed single maxillary anterior tooth implant placement with a simultaneous GBR surgery were included. This study was approved by the Ethics Committee of Zhongshan Hospital affiliated with Fudan University (Approval Number: B2020-102R2).

### Participants

From September 2015 to August 2021, we recruited 28 patients who received a delayed single maxillary anterior tooth implant placement simultaneously with GBR surgery. The inclusion criteria included (1) adults aged ≥18 years; (2) a single missing maxillary anterior tooth of ≥6 months' duration; (3) preoperative CBCT showing a horizontal bone defect on the labial side without an obvious vertical bone defect; (4) delayed implant placement was carried out simultaneously with GBR (using a resorbable membrane and deproteinized bovine bone mineral (DBBM)); and (5) complete radiographic data included preoperative, postoperative, and 6-month postoperative CBCTs.

We excluded patients who (1) did not have adjacent teeth; (2) had an obvious vertical bone defect; (3) had an incomplete labial bone wall during the operation; (4) smoked heavily (>10 cigarettes/d); (5) had an untreated periodontal disease; and (6) had an uncontrolled systemic disease.

### Clinical procedures

As per our criteria, all implant placement procedures were delayed. All surgical procedures were performed by the same experienced surgeon. Under the local anaesthesia, a full-thickness flap was turned over to fully expose the alveolar crest via a horizontal incision on the top of the alveolar ridge and a mesial or distal vertical incision in the adjacent teeth. The implant was inserted according to the manufacturers' instructions. Following implant placement, the labial horizontal bone defect was augmented with deproteinised bovine bone mineral (Bio-oss small granules or Bio-oss collagen, Geistlich) and blood. The surface was covered with a single layer of resorbable collagen membrane (Bio-Gide, Geistlich). A standard cover screw was inserted into the implant to effect submerged healing. The tension-free incision closure was completed using a 4-0 nonabsorbable suture. Sutures were removed 10 to 14 days after surgery.

The original titanium base was used to maintain the ideal gingival profile during the second stage of surgery. We used a final prosthesis with screw retention when the implant position and the screw insertion position were ideal, and the final prosthesis with adhesive retention was used when the implant position was not ideal. The final prosthesis was created from a zirconia crown and an original titanium base, and all prostheses were made of light occlusal contact.

### Data acquisition

We collected baseline patient characteristics, including age, gender, implant site, implant brand, and bone graft materials. All patients received CBCT scans at 3 time points: prior to surgery (T0), immediately after surgery (T1), and 6 months after surgery (T2).

*The resorption rate of grafted bone (RRGB)*

DICOM data were imported into digitising software (Mimics 21.0) in which virtual models of the operative region were 3-dimensionally reconstructed by utilising threshold and mask editing tools. The established 3D models (M) were denoted as M0, M1, and M2, according to their respective time points (Figure 1A–C). Then, each patient's M0, M1, and M2 models were superimposed by utilising patient-specific anatomic marker points of the teeth (Figure 1D).

Following the superimposition of 3D models, the profiles of grafted bone were outlined (Figure 1E). The perimeters of the grafted bone area on sagittal slices (layer thickness was 0.2 mm) were manually drawn by a mask editing tool, and a virtual model of bone grafts at different time points (T1, and T2) was generated (Figure 1F and G).

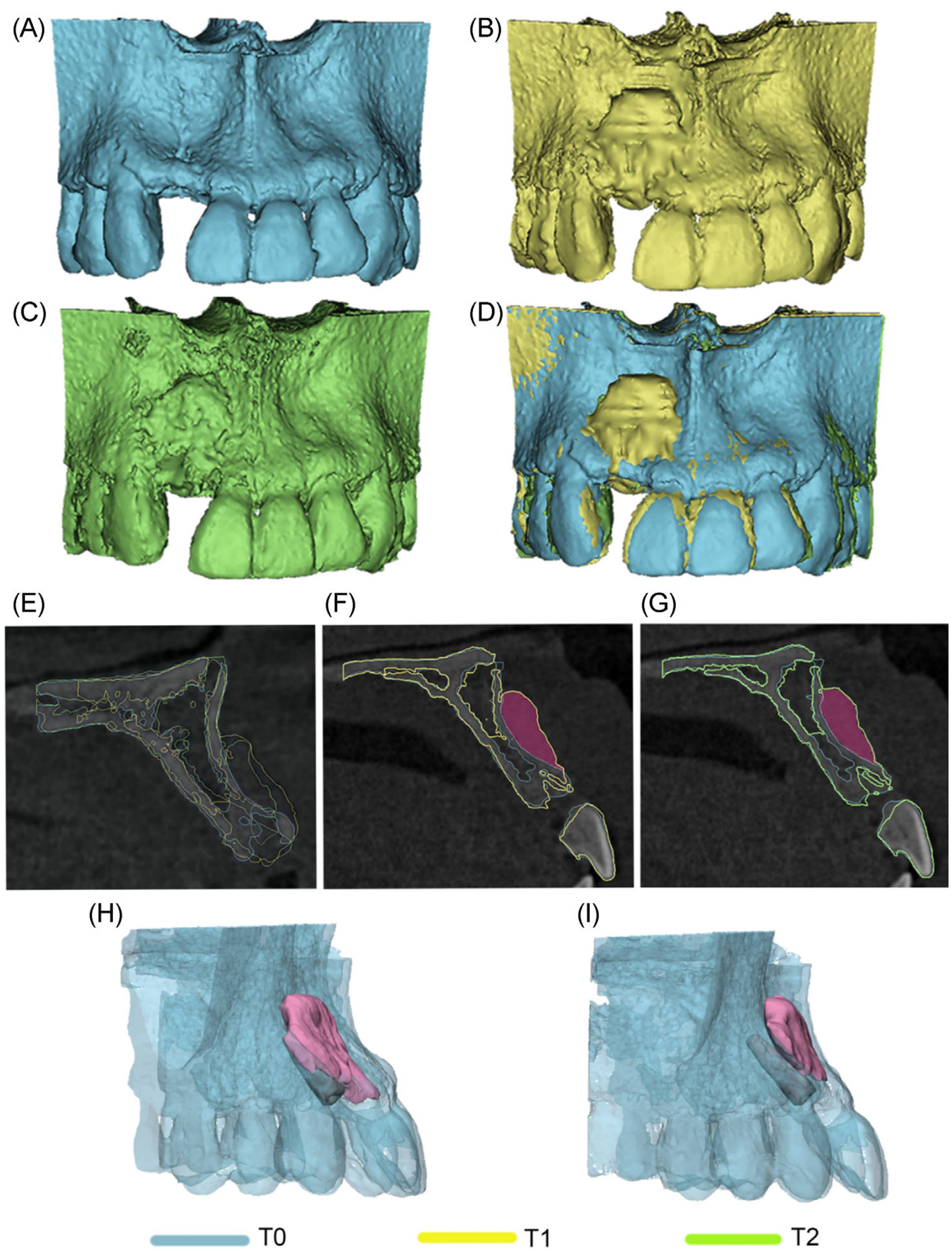


**Fig. 1 – Three-dimensional virtual reconstructions and superimpositions.** A, **M0, preoperative virtual model.** B, **M1, immediate postoperative virtual model.** C, **M2, 6-month postoperative virtual model.** D, **Superimposition of M0, M1, and M2.** E, **Superimposed radiographic image showing grafted bone resorption on a sagittal view (blue line, bony profile at T0; yellow line, bony profile at T1; green line, bone file at T2).** F, **A 3D virtual model of grafted bone at T1 was created using the segment tool on the CBCT sagittal view.** G, **A 3D virtual model of grafted bone at T2 was created using the segment tool on the CBCT sagittal view.** H, **Reconstructive model of the bone graft at T1.** I, **Reconstructive model of the bone graft at T2.**

The 3D reconstruction models of each patient were imported into 3-matic research software (Figure 1H and I) to accurately calculate the volume of bone grafts. The RRGB was calculated as ($BGV_{T1}$ - $BGV_{T2}$) / $BGV_{T1}$ × 100%.

### *Alterations in labial bone width of implant*

$LBW0_{Tn}$: labial bone width 0 mm apical to the implant platform at Tn.
$LBW2_{Tn}$: labial bone width 2 mm apical to the implant platform at Tn.
$LBW4_{Tn}$: labial bone width 4 mm apical to the implant platform at Tn (n = 1, 2, representing T1, T2, respectively).

Taking the measurement method of $LBW0_{T1}$ and $LBW0_{T2}$ as an example (Figure 2A), the sagittal view of CBCT was adjusted to the view with the largest implant diameter. The perpendicular line of the long axis of the implant intersected the implant platform, the yellow line (labial contour line at T1), and the green line (labial contour line at T2) at point C, point A, and point B, respectively. △LBW0, △LBW2, and △LBW4 represent the alterations in labial bone width 0 mm, 2mm, and 4mm apical to the implant platform, respectively.

### *Radiographic measurements*

*Bone concavity depth (BCD):* As shown in Figure 2B, the deepest point of the labial horizontal bone defect was defined as point C. The most prominent points at the apical and crestal side of the bone concavity were denoted as points A and B, respectively. BCD was the vertical distance (line C–D, point D was the vertical foot of line C–D perpendicular to line A–B) between point C and line A–B (line connecting points A and B).

*Bone concavity angulation (BCA):* The angle between line C–A and line C–B (Figure 2B).

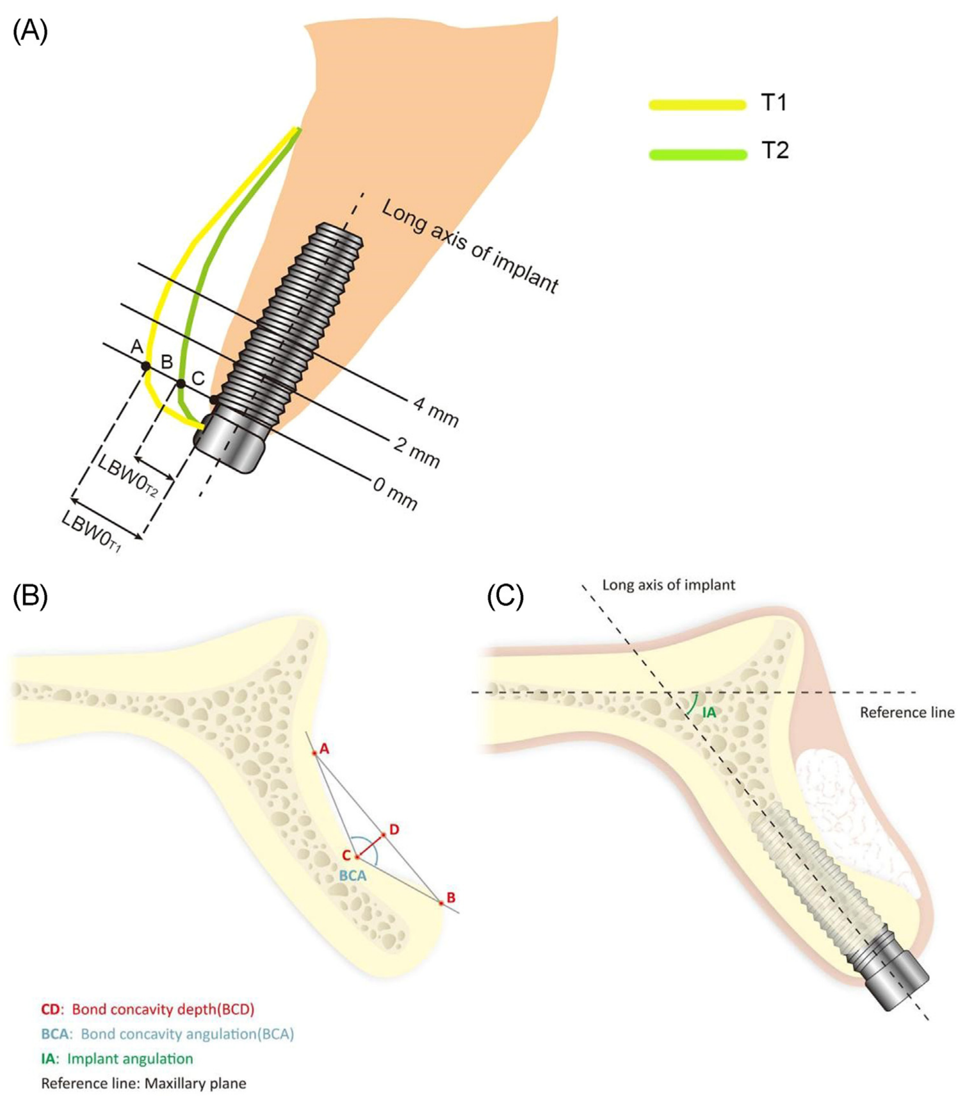


**Fig. 2 – A, Labial bone width measurement. The yellow line represents bony profile at T1; the green line represents bony profile at T2. B, Ridge morphology measurement at T0. C, Implant angulation (IA) measurement at T1.**

*Implant angulation (IA):* The maxillary plane was defined as the reference line that connected the anterior and posterior nasal spine. IA was the angle between the longitudinal axis of the implant and the maxillary plane (Figure 2C).

*Maximum bone graft thickness (MBGT):* MBGT was calculated by using the thickness analysis tool of 3-matic research software.

*Bone graft volume (BGV):* The accurate volume of the grafted bone at T1 ($BGV_{T1}$) and T2 ($BGV_{T2}$) were respectively calculated by 3-matic research software.

### *Sample size calculation*

To investigate the correlation amongst BCD, BCA, and the RRGB, we calculated a target sample size using PASS 2021 software (NCSS LLC). A moderate correlation was considered to be clinically significant. At $\alpha$ = 0.05, power = 0.90, and $r$ = 0.60, we obtained a sample size of at least 24 cases.

### *Statistical analysis*

All data were analysed by SPSS 21.0 (IBM Corp.). The normality of data distribution was tested with the Shapiro–Wilk test, and the homogeneity of sample variance was tested by Levene test. Student *t* tests were used to compare the difference of BGV at different time points. Wilcoxon sign rank test was used to compare the difference of labial bone width at 0 mm, 2 mm, and 4 mm apical to the implant platform at different time points. The change of labial bone width at different sites was compared by Friedman test. A series of Pearson correlations analyses were used to investigate the relationships amongst gender, age, bone graft materials, BCD, BCA, IA, MBGT, $BGV_{T1}$, and RRGB. Analysis of variance (ANOVA) was utilised to investigate the relationship amongst implant site, implant brand, and RRGB. An optimal binning method was used to explore the critical value of BCD and BCA. Statistical significance was set at a threshold of $\alpha$ = 0.05.

## Results

### *Demographics*

A total of 28 patients (17 male and 11 female, aged 47.50 ± 12.13 years) were included (Table 1). Sixteen patients were in the GBR with the Bio-oss granules group, and 12 were in the GBR with the Bio-oss collagen group.

### *Implant survival rate*

At the 6-month follow-up, the implant survival rate was 100% without notable intraoperative or postoperative complications.

### RRGB

We observed various degrees of resorption in the grafted bone at the follow-up. The BGV at T1 ($BGV_{T1}$) and T2 ($BGV_{T2}$) were 120.64 ± 81.52 $mm^3$ and 65.47 ± 75.50 $mm^3$, respectively. The RRGB was 49.78% ± 21.21%.

**Table 1 – Summary of patient demographics and radiographic measurements (n = 28).**

| Characteristics | Value |
|---|---|
| Gender (male/female) | 17/11 |
| Age (y) | 47.50 ± 12.13 |
| Implant site (central incisors/lateral incisors/ canines) | 19/7/2 |
| Implant brand (Nobel/Bego/Straumann) | 21/4/3 |
| Bone graft material (Bio-Oss granules/Bio-Oss collagen group) | 16/12 |
| BCD (mm) | 1.30 ± 0.78 |
| BCA (°) | 150.26 ± 17.28 |
| IA (°) | 58.80 ± 11.03 |
| MBGT (mm) | 2.57 ± 0.78 |

BCD, bone concavity depth; BCA, bone concavity angulation; IA, implant angulation; MBGT, maximum bone graft thickness.

### *Alterations in labial bone width of implant*

The results indicated that at 6 months, $LBW0_{T2}$, $LBW2_{T2}$, and $LBW4_{T2}$ were significantly lower than $LBW0_{T1}$, $LBW2_{T1}$, and $LBW4_{T1}$, respectively [2.03 (1.93, 2.16) mm vs 2.90 (2.55, 3.24) mm; 2.27 (2.07, 2.46) mm vs 3.40 (2.93, 3.98) mm; 2.68 (2.17, 3.31) mm vs 3.73 (3.24, 4.63) mm]. There was no statistical difference between △LBW0, △LBW2, and △LBW4.

### *Radiographic measurements*

The mean values of BCD, BCA, MBGT, and implant angulation for the cohort were presented in Table 1.

### *Potential influencing factors of grafted bone resorption*

Only BCD and BCA were each moderately correlated with RRGB with $r$ = −0.872 ($P$ < .001) and $r$ = 0.686 ($P$ < .001), respectively (Table 2 and Figure 3A and B).

**Table 2 – Pearson correlation and analysis of variance tests for RRGB predictors.**

| Variables | RRGB | | |
|---|---|---|---|
| | $r$ [†] | $F$ [‡] | $P$ value |
| Implant site | - | 2.151 | .126 |
| Implant brand | - | 0.773 | .475 |
| Gender | −0.42 | - | .831 |
| Age | 0.163 | - | .406 |
| Bone graft material | −0.167 | - | .397 |
| BCD | −0.872 | - | <.001 *** |
| BCA | 0.686 | - | <.001 *** |
| IA | 0.075 | - | .705 |
| MBGT | −0.276 | - | .155 |
| $BGV_{T1}$ | −0.293 | - | .131 |

† $r$: Pearson correlation coefficient.
‡ $F$: F score of the analysis of variance.
*** Statistically significant ($P$ < .001).
BCD, bone concavity depth; BCA, bone concavity angulation; IA, implant angulation; MBGT, maximum bone graft thickness; BGVT1, bone graft volume at T1; RRGB, the resorption rate of grafted bone.

### *Critical values of the morphologic variables BCA and BCD*

To identify the critical value of BCA and BCD in affecting the RRBG, we divided the cohort into a low resorption rate group (RRGB < 49.78%) and a high resorption rate group (RRGB ≥ 49.78%) by the optimal binning method based on the RRGB mean value (49.78%); the cut-off values of BCD and BCA were 1.03 mm and 155.30°, respectively.

The independent samples *t* test results showed that at 6 months, a BCD < 1.03 mm led to a significantly higher percentage of RRGB than a BCD ≥ 1.03 mm (*P* < .001). The RRGB was significantly lower in the BCA < 155.30° group than in the BCA ≥ 155.3° group (*P* < .001). There were no significant differences between males and females (*P* > .05) or between Bio-Oss granules and Bio-Oss collagen (*p* > .05) (Figure 3C).

## Discussion

The purpose of the present study was to provide evidence for clinicians to used alveolar bone morphologic parameters to predict the outcome of horizontal bone augmentation and to decide a reasonable clinical bone augmentation strategy. Statistical analysis indicated that different levels of grafted bone material resorption were observed during the healing stage. The initial morphology of the alveolar ridge was correlated with the resorption of grafted bone substitute materials.

Although DBBM has a low replacement rate, it still has varying degrees of resorption after bone augmentation. Perrotti[14] found that osteoclasts could attach to DBBM and induce its resorption. Another in vivo study[15] indicated that the presence of osteoclasts could be observed in shallow resorption pits on the surface of DBBM. Thus, DBBM was absorbed to a certain extent after transplant, and the reason for resorption could be attributed to the activity of osteoclasts.

A previous animal study[3] indicated that even with the implementation of tension-free flap closures, the coronal positioning of the flap inevitably induced displacement of the bone substitute and the collapse of the collagen membrane. Strietzel[4] proposed that the membrane was pushed into the bone defect by the soft tissue pressure from the labial barrier membrane, resulting in the formation of fibrous tissue and hindering the formation of new bone. The high resorption rate of BGV in our present study can also be explained by the collapse of collagen membrane and the displacement of bone graft materials caused by the pressure of the soft tissue of the lip. Although the resorption rate of bone graft volume of 12 patients in this study was ≥49.78%, the average labial bone width at 0 mm, 2 mm, and 4 mm apical to the implant platform in all patients was >2 mm when assessed 6 months after surgery, which met the aesthetic requirement of having at least 2-mm bone thickness in the labial side of the implant.

A recent clinical study[16] demonstrated the effect of initial bone defect morphology of the alveolar ridge on the resorption of grafted bone following GBR. A negative correlation was identified between the standard deviation of the buccal-lingual distance ($BL_{SD}$) and volumetric changes of bone grafts, and these findings were similar to the results in present study. In our study, we further observed that the percentage of grafted bone resorption rate became significantly greater when the bone concavity depth was <1.03 mm.

Garaicoa[17] utilised CBCT to analyse the relationship between morphologic characteristics of the alveolar ridge and horizontal augmentation outcome. These authors reported a negative correlation between concavity angulation (CA) and ridge width (RW) gain and a critical CA value of 150°. Similarly, in our study, we observed a negative relationship between BCA and RRGB. Furthermore, we found that a BCA < 155.3° resulted in a significantly lower RRGB. This is because the deeper bone concavity and smaller concavity angulation of the defect may better support the barrier membrane to maintain the osteogenic space, thus resulting in a lower resorption rate of the bone substitute materials. These findings suggest that the shape of the labial bone concavity in the sagittal plane of the anterior teeth may offer prognostic value for GBR surgery.

Accurate implant placement in the 3D space with appropriate implant angulation is critical to achieve satisfactory aesthetic outcomes in the anterior maxilla area.[18] Nevertheless, there is a lack of evidence to support the fact that implant angulation is significantly correlated with the hard tissue in the anterior maxilla. Tabrizi[19] explored the relationship between implant angulation and peri-implant bone loss in the anterior maxilla and found no correlation between implant angulation and an increased risk of bone loss. Similarly, in the present study, no significant correlation was observed between implant angulation and RRGB. The unloaded implants did not generate stress on the bone during the healing period, which may be the underlying cause of this finding.

Although we utilised an innovative approach to evaluate the stability of bone graft materials after GBR, there are some limitations: First, the number of participants and the follow-up time are limited from a clinical generalisability perspective. In addition, 3D model artifacts can lead to bias in the measurement of grafted bone material resorption rates; thus, the efficacy of this method could not be fully evaluated. Moreover, gingival biotype may be a confounding bias in present study. Previous studies proved the correlation between gingival biotype and marginal bone loss of implant. However, this study did not collect data relating to the gingival biotypes of patients. For these reasons, our conclusions should be validated with a larger sample size in a well-designed prospective study or a randomised controlled study.

## Conclusions

For the patients with a single maxillary anterior tooth missing and a labial bone defect, delayed implant placement with simultaneous GBR surgery can achieve a high implant survival rate and ideal bone augmentation effect (implant labial bone wall thickness ≥2 mm). A reduction of hard tissue volume was observed during the healing stage following GBR with DBBM and resorbable collagen membranes. Furthermore, the present results revealed that the stability of bone substitute material may be affected by initial ridge morphology in the anterior maxilla region. A bone concavity with a depth ≥1.03 mm and an angle <155.30° were found to lead to

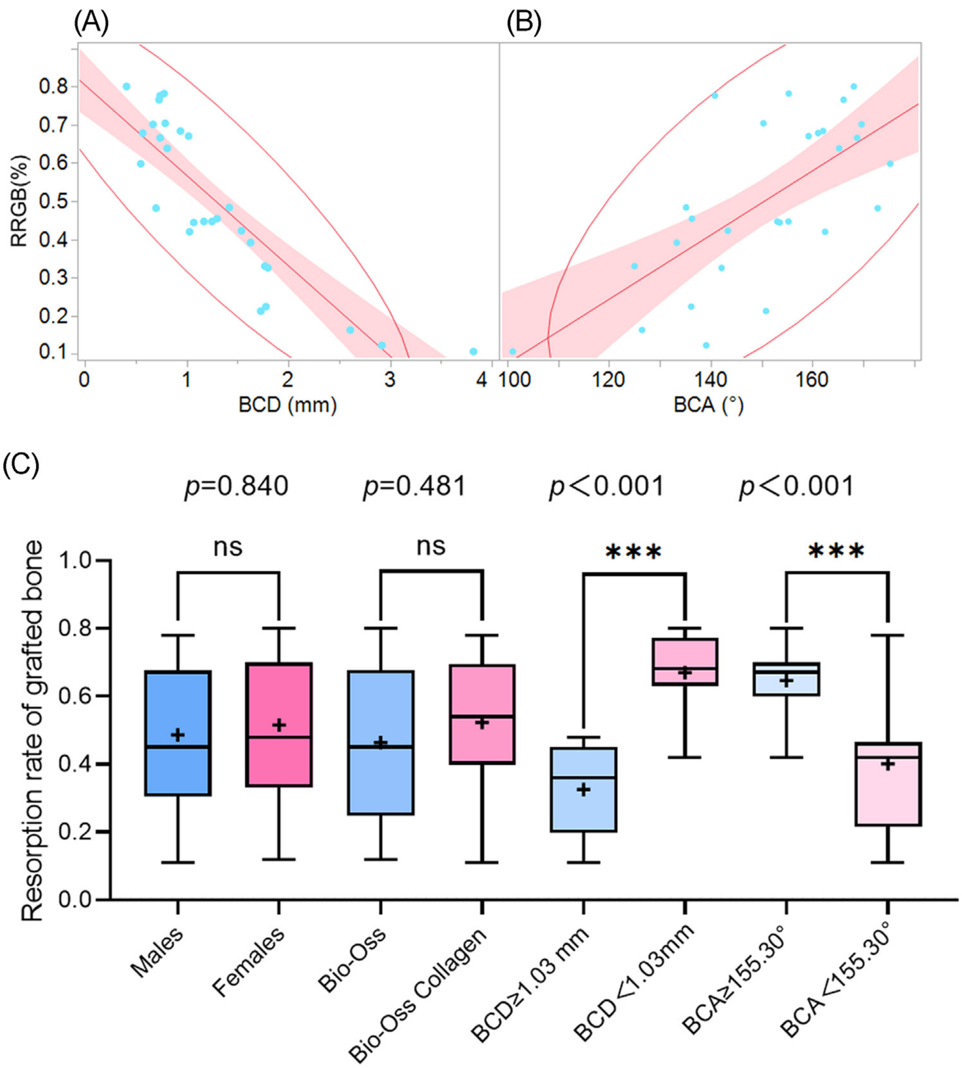


**Fig. 3 – Regression lines for the correlation between the resorption rate of grafted bone (RRGB) and bone concavity depth (BCD)/bone concavity angulation (BCA) (A and B). C, Differences in the RRGB by gender, different bone substitute materials, BCD, and BCA during the 6-month healing period. Statistical analysis: ***P < .001, ns = nonsignificant, + Mean value of RRGB.**

a lower RRGB. The BCD and BCA of labial bone concavity may offer some prognostic value for GBR surgery in the anterior maxilla region.

## Conflict of interest

None disclosed.

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## Author contributions

Luo-Man Gan contributed to idea conception, design, data acquisition and analysis, and writing and revising the manuscript. Qian-Rong Zhou, Yan Zhang, and Fei Yang contributed to idea conception, design, data acquisition and analysis, and revision of the manuscript. You-Cheng Yu contributed to idea conception, design, revision of the manuscript, and performance of the operation. Zhen-Ze Yu, Yang Sun, Rui-Xue Li, and Xing-Wen Wu contributed to idea conception, design, and data acquisition and analysis. Luo-Man Gan, Qian-Rong Zhou, and Yan Zhang contributed equally to this work.

## Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.identj.2023.07.007.

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