Ridge Volume Stability of Maxillary Anterior Implants Placed with Simultaneous Lateral Guided Bone Regeneration during Healing: a Radiographic Analysis

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Objective: *To assess bone volume stability and identify critical bone graft thickness for guided bone regeneration (GBR) simultaneous to implant placement in the maxillary anterior region.*
Methods: *Eighteen patients were included in the study and received placement of one maxillary anterior implant combined with GBR using deproteinised bovine bone mineral (DBBM) and resorbable collagen membrane. The multilevel buccal bone thickness (BT) was measured by CBCT 1 to 2 weeks and 5 to 8 months post-implantation (at implant uncovering surgery).*
Results: *Significant buccal alveolar crest collapse (ACCb 1.20 to 1.70 mm) occurred during the mean healing period of 5.3 months (P = 0.000). A greater percentage of ACCb occurred at the coronal aspect of the implant, with 59.24% ± 19.22% at the implant platform and 34.10% ± 30.50% 6.0 mm below the implant platform, respectively. Linear regression analysis demonstrated that if BT was 1.8 to 2.0 mm at the implant platform at uncovering surgery, then it was estimated to have been 4.1 to 4.5 mm immediately post-implantation.*
Conclusion: *ACCb after maxillary anterior implant placement with simultaneous GBR occurred more coronally than apically. Excessive alveolar ridge augmentation, up to 4.0 mm of hard tissue buccal to the implant platform, should be achieved at the time of surgery to compensate for this potential resorption.*

Key words: *alveolar ridge augmentation, bone regeneration, bone substitute, CBCT, dental implants*
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Guided bone regeneration (GBR) using particulate bone graft with resorbable collagen membrane is a common approach for resolving peri-implant defects[1,2]; however, alveolar ridge stability after GBR, particularly in the maxillary aesthetic zone, remains unpredictable because of its variable alveolar crest collapse (ACC) during healing, as ACC was reported as 20.0% to 67.4% of the alveolar crest during the healing stage[3-7]. Using demineralised freeze-dried bone and bioresorbable membrane to perform GBR alone, Simon et al[7] observed a horizontal alveolar resorption rate of 39.2% to 67.4%, with greater coronal than apical collapse. At 3.0 mm apical to the alveolar crest, a minimum augmentation of 1.5 mm was required to achieve a net bone gain, whereas at 5.0 mm apical to the crest, 1.0 to 1.5 mm was needed[7].

The exact sequence of ACC after GBR with simultaneous implant placement must be elucidated in order to refine the clinical protocols. The purpose of this study was to assess bone volume stability and identify the critical bone graft thickness for GBR simultaneous to implant placement in the maxillary anterior area.

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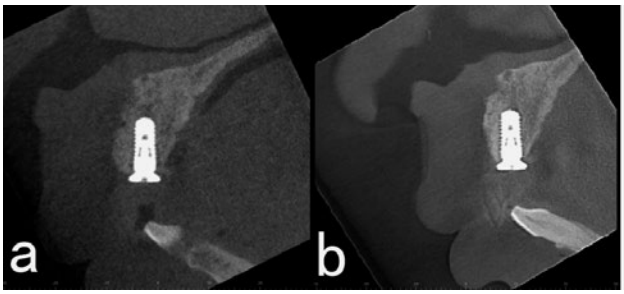

Fig 1 CBCT sagittal view of implant placement simultaneous to GBR **(a)** immediately and **(b)** 8 months after surgery.

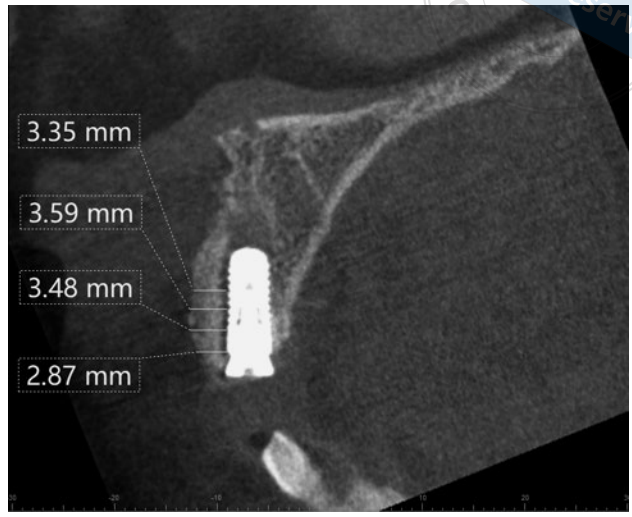

Fig 2 Measurement of buccal bone graft thickness. The long axis of the implant was perpendicular to the cross-section, while the oblique sagittal plane passed through the long axis of the implant and was perpendicular to the cross-section. Buccal BT was measured at 0.0 mm, 2.0 mm, 4.0 mm and 6.0 mm apical to the implant platform; these BT values are indicated in yellow.

Materials and methods

Patient selection

This study was conducted in accordance with the Helsinki Declaration of 1975 as revised in 2000 and approved by the local ethics committee (Institutional Review Board of Peking University School and Hospital of Stomatology, approval number PKUSSIRB-202000544). Specifics from 18 patients (5 men and 13 women, mean age 40.9 ± 11.0 years) were collected retrospectively.

The inclusion criteria were as follows:

- aged ≥ 20 years;
- single-tooth edentulism in the maxillary aesthetic zone (from the maxillary right first premolar to the maxillary left first premolar) for at least 2 months;
- periodontally healthy adjacent teeth;
- presence of a dehiscence at implant placement that required a simultaneous GBR procedure.

The exclusion criteria were as follows:

- smoking > 10 cigarettes per day;
- uncontrolled diabetes (fasting blood glucose > 9 mmol/l);
- other systemic diseases or general health conditions contraindicating oral surgery.

Surgical protocol and radiographic evaluation

Prior to surgery, each patient signed an informed consent form and rinsed with 0.2% chlorhexidine mouthrinse for 1 minute. The surgical area was anaesthetised with 4% articaine with 1:100,000 adrenaline (Septocaine; Septodont, Saint-Maur-des-Fossés, France) via local infiltration. After alveolar crest exposure through elevation of a facial mucoperiosteal flap, sequential osteotomies and implant insertion were performed according to the manufacturer's instructions (Straumann, Basel, Switzerland). A 3.3- × 10.0-mm (Straumann Bone Level NC) or 4.1- x 10.0-mm implant (Straumann Bone Level RC) was placed at the level of the alveolar crest and then connected to either a 2.0-mm-tall healing abutment or cover screw. The buccal dehiscence at each implant was augmented with deproteinised bovine bone mineral (DBBM) (Bio-Oss; Geistlich, Wolhusen, Switzerland) and then covered by a resorbable collagen membrane (Bio-Gide, Geistlich). The implants were submerged and tension-free primary wound closure was obtained in all cases using horizontal mattress and interrupted sutures (4-0 Vicryl Rapide, Ethicon, Somerville, NJ, USA). Each patient was prescribed postsurgical medication including antibiotics (250 mg amoxicillin, tid for 5 days), analgesics (300 mg ibuprofen, prn) and mouthrinse (0.2% chlorhexidine, tid for 2 weeks). Sutures were removed 2 weeks postoperatively and healing abutments were placed 5 to 8 months (mean 5.3 months) postoperatively.

A CBCT scan (Morita, Osaka, Japan) was taken for each patient at 1 to 2 weeks (stage I) and 5 to 8 months (stage II) following implant placement with GBR (Fig 1). Radiographic buccal bone thickness (BT, dimension of hard tissue including residual crest and any graft material) was measured in millimetres using the distance measurement tool in the i-Dixel One Volume Viewer software (Morita, Kyoto, Japan). The buccopalatal section perpendicular to the implant axis at the midbuccal aspect of the implant was used to measure BT at stage I (BT I) and stage II (BT II) at four different levels: 0.0, 2.0, 4.0 and 6.0 mm apical

Table 1 Mean BT and ACCb after maxillary anterior implant placement with simultaneous GBR at different measurement levels.

Variable	0.0 mm	2.0 mm	4.0 mm	6.0 mm
BT I, mm	2.98 ± 1.15	3.72 ± 1.08	3.78 ± 1.16	3.72 ± 1.15
BT II, mm	1.31 ± 0.69	2.02 ± 0.88	2.42 ± 0.97	2.52 ± 1.12
P value	0.000	0.000	0.000	0.000
ACCb, mm	1.68 ± 0.79	1.70 ± 1.02	1.36 ± 1.10	1.20 ± 1.11
ACCb, %	59.24 ± 19.22	44.11 ± 23.05	34.57 ± 24.07	34.10 ± 30.50

0.0 mm, 2.0 mm, 4.0 mm and 6.0 mm refer to distances apical to the implant platform.

Table 2 Statistical significance of mean BT and ACCb between different measurement levels.

Levels		*P* value			
		BT I, mm	BT II, mm	ACCb, mm	ACCb, %
0.0 mm	2.0 mm	0.073	0.030	0.960	0.068
	4.0 mm	0.052	0.001	0.318	0.003
	6.0 mm	0.072	0.000	0.137	0.003
2.0 mm	4.0 mm	0.877	0.223	0.295	0.249
	6.0 mm	0.992	0.128	0.124	0.217
4.0 mm	6.0 mm	0.885	0.760	0.620	0.935

0.0 mm, 2.0 mm, 4.0 mm and 6.0 mm refer to distances apical to the implant platform.

to the implant platform (Fig 2). One trained and calibrated examiner (YGH) performed all measurements. The mean buccal alveolar crest collapse (ACCb) per measurement level was calculated by subtracting the mean BT II from the mean BT I. The mean percentage of ACCb at each level was calculated by dividing the mean ACCb by the mean BT I.

Statistical analysis

All data were analysed using SPSS version 22.0 (IBM, Armonk, NY, USA) by one examiner (YGH) who underwent intraexaminer calibration to ensure reliability. Mean parameter differences were tested using an independent samples *t* test. A one-way analysis of variance (ANOVA) was used to determine differences between measurement levels. Correlation analyses were used to identify factors related to BT II; for linear regression, a prerequisite value of 1.8 to 2.0 mm was set for BT II. For all tests, the level of significance was set at $P < 0.05$.

Results

Eighteen patients (5 men and 13 women, mean age 40.9 ± 11.0 years), each with one edentulous site in the maxillary aesthetic zone, were included in the present study. A maxillary implant was placed at the central incisor (n = 8), lateral incisor (n = 5), canine (n = 3) or first premolar site (n = 2). Out of 18 implants, 33.3% (n = 6) had dimensions of 3.3 × 10.0 mm and 66.7% (n = 12) had dimensions of 4.1 × 10.0 mm, and 83.3% (n = 15) were connected to healing abutments and 16.7% (n = 3) were connected to cover screws at the time of implantation. Up to 8 months after implant surgery with GBR, all patients experienced uneventful healing except for one who had a minor infection from a loose healing abutment and then experienced uneventful healing after implant uncovering surgery.

Each of the 18 implant sites demonstrated significant ACCb along the implant surface, with greater coronal collapse during the healing stage (Table 1). The mean ACCb was 1.68 ± 0.79 mm (−59.24% ± 19.22%) at the implant platform and 1.20 ± 1.11 mm (−34.10% ± 30.50%) at 6.0 mm apical to the implant platform (Table 1). A one-way ANOVA revealed significant differences in mean BT II and mean percentage of ACCb between 0.0 mm and some of the other measurement levels; neither mean BT I nor mean ACCb differed significantly between levels (Table 2).

Positive correlations were detected between BT I and BT II (except at 2.0 mm apical to the implant platform) and between BT I and ACCb, but not between BT I and the percentage of ACCb at each measurement level (Table 3). Regression analysis indicated that BT I was an independent prognostic factor affecting BT II; regression equation prediction models are summarised in Table 4. Achieving a BT II level of 1.8 to 2.0 mm at the implant platform, for example, would require a BT I of 4.1 to 4.5 mm.

Discussion

Clinically substantial ACC may ensue after performing GBR using particulate bone material with a collagen membrane and proceeds in two consecutive stages: early bone graft displacement and delayed ACC.

Table 3 Correlation analysis of mean BT and ACCb at different measurement levels.

Variable		0.0 mm	2.0 mm	4.0 mm	6.0 mm
BT II – BT I	*P* value	0.000	0.500	0.042	0.025
	R	0.741	0.469	0.484	0.527
ACCb – BT I	*P* value	0.000	0.004	0.005	0.033
	R	0.809	0.648	0.630	0.504
Percentage of ACCb – BT I	*P* value	0.332	0.350	0.400	0.882
	R	0.243	0.234	0.211	0.038

0.0 mm, 2.0 mm, 4.0 mm, and 6.0 mm refer to distances apical to the implant platform.

Table 4 Linear regression analysis of the relation between BT I and BT II.

Level	Prediction model (X, BT I; Y, BT II)	BT II, mm	BT I, mm
0.0 mm	Y = 0.445X – 0.023	1.8–2.0	4.100–4.546
2.0 mm	Y = 0.384X + 0.596	1.8–2.0	3.135–3.656
4.0 mm	Y = 0.405X + 0.889	1.8–2.0	2.248–2.743
6.0 mm	Y = 0.515X + 0.604	1.8–2.0	2.322–2.711

Immediately after GBR, the surgical site is particularly vulnerable to bone graft displacement. During initial healing, the tissue surrounding the bone graft transforms from blood clot to granulation tissue to provisional connective tissue to woven bone[8,9]. Before it consolidates into a more solid structure (premineralised osteoid-like matrix encapsulated by dense connective tissue), the bone graft may collapse under the pressure applied by the labium superius oris[10], an idea supported by a histological study that described the apical dislocation of bone graft granules and membranes 9 weeks after GBR[11]. If granulation tissue fails to completely encase graft granules (a situation that may arise from extensive particulate placement, the specific wound healing capacity of an individual and a limited number of existing defect walls), soft tissue dehiscence and graft exfoliation occur. A more favourable osteogenic condition such as a three-walled bony defect[12], addition of autogenous bone graft[13,14] or growth factor use[15,16] allows for more rapid revascularisation and osteoblast recruitment from the ridge bed, accelerating bone graft consolidation and mitigating early bone graft displacement. Using a tenting screw, buried healing abutment, titanium mesh or titanium-reinforced nonresorbable membrane fixed with pins may counteract the pressure from the overlying lip and prevent early bone graft displacement[17-20].

Mechanical stimulation also accelerates both DBBM resorption and delayed ACC. Histological studies on orthodontic movement in bone defects augmented with DBBM found partial graft resorption in sites under pressure; the particles in stress-free sites remained as inactive filler material[21,22]. Despite the comparatively slow resorption rate of DBBM, delayed ridge collapse persists, as demonstrated by radiographic studies reporting total bone graft volume resorption rates between 12.5% and 53.8%[13,14].

Our analysis showed ACC of 34.0% to 59.0% that was most prominent at the implant platform (59.0%) at a mean of 5.3 months (range 5 to 8 months) after implant placement with GBR, a result that corresponds to findings from studies on GBR alone or simultaneous to implant placement[7,12]. This pattern of ACC is partly explained by pressure from the superior lip muscle, especially during function. As the coronal portion of the graft protrudes against the upper lip, where the region experiences higher pressure, this results in greater ACC.

Preserving maxillary anterior implant aesthetics and function in the long term requires sufficient buccal bone volume, particularly at the coronal aspect of the implant; a prerequisite buccal thickness of at least 2.0 mm has been suggested[23,24]. Spray et al[25] determined that BT approximating 1.8 to 2.0 mm led to less bone loss between implant placement and stage II exposure; a mean decrease in facial BT of 0.7 mm was detected between time points for integrated implants. Miyamoto et al[26] noted that implant soft tissue recession was minimised when labial alveolar BT was 1.2 mm at the cervical aspect 6 months post-implantation; integrating their findings with the mean facial resorption (0.7 mm) documented by Spray et al[25], they recommended maintenance of at least 1.9 mm of buccal bone (1.2 mm + 0.7 mm) to prevent mucosal recession.

We found a moderate to strong positive correlation between BT immediately following implant placement with GBR (BT I) and that measured at implant expos-

ure (BT II); that is, the wider the buccal hard tissue (residual ridge plus graft) immediately after grafting, the wider the buccal hard tissue at the time of exposure, which contrasted with the animal studies by Baffone et al[27] and Bengazi et al[28] showing greater horizontal resorption at implants installed in the recipient site with bone ridge 2.0 mm in width compared to 1.0 mm in width. This discrepancy could be due to the fact that the buccal bone plate was so thin that no bone could be resorbed after 1.0 mm bone resorption. We determined that at the implant platform, a minimum buccal BT of 4.1 to 4.5 mm was required to attain a BT II of 1.8 to 2.0 mm, a finding that agreed with a suggestion from Capelli et al[29], who concluded that at least 4.0 mm buccal hard tissue as measured from the implant surface to the external aspect of graft material is needed at the time of immediate implant placement to optimise aesthetics. Although we buried healing abutments in 83.3% of cases, we did not use other pressure-relieving modalities, such as tenting screws, titanium mesh, titanium-reinforced nonresorbable membranes or graft with autogenous bone[13,14,18-20]. Had these collapse-counteracting, osteogenesis-inducing methods been applied, the requisite buccal BT at the implant platform may have been less than 4.1 mm.

The present study has several methodological limitations. First, the sample size was small. Second, healing time was not standardised for cases; a longer healing time was applied in cases with more serious buccal dehiscence and may have improved results. Third, the residual buccal bone present post-implantation but prior to GBR was not measured clinically or radiographically; the initial peri-implant defects were not quantified, though the volume and configuration of native bone may have altered ACC.

Conclusion

Significant ACC, between 19.1% and 59.2%, occurred at mean 5.3 months after maxillary anterior implant placement with simultaneous GBR using DBBM and collagen membrane. This resorption was not distributed uniformly along the vertical implant surface; more loss occurred coronally than apically, which may be due to crestal graft compression by the lip muscle. To meet the 1.8 to 2.0 mm aesthetic prerequisite of buccal BT after implant osseointegration, a minimum of 4.1 to 4.5 mm of buccal hard tissue thickness, composed of residual crest and/or graft, is recommended.

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Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Drs Guo Hua YE and Deng Hui DUAN conceived and designed the study, contributed to data acquisition, analysis and interpretation and drafted the manuscript; Dr En Bo WANG critically revised the manuscript for important intellectual content and gave final approval.

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