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Overlay Analysis of Cone-beam Computed Tomography Volumes Acquired Before and After Alveolar Ridge Augmentation

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ABSTRACT

Introduction: Prior studies assessing increases in ridge width following horizontal alveolar ridge augmentation (HRA) have relied predominantly upon direct intraoperative measurements using calipers.

Objective: The purpose of this observational study was to assess ridge width changes following horizontal ridge augmentation (HRA) surgery using a novel analysis technique.

Materials and Methods: CBCT volumes from 65 HRA sites in 57 patients were available for analysis. We used three-dimensional analysis software to overlay preoperative and follow-up CBCT volumes, then analyzed alveolar ridge width changes considering a panel of patient-, site-, and procedure-related explanatory variables.

Results: Mean increase in horizontal alveolar ridge dimension (HRD) 3 and 5 mm apical to the alveolar crest amounted to 2.3 ± 1.6 and 2.4 ± 1.3 mm, respectively. Membrane fixation (2.5 ± 1.5 vs. 1.1 ± 2.3 mm, $p = 0.038$) and nonresorbable membrane use (2.5 ± 1.6 vs. 1.4 ± 1.5 mm, $p = 0.034$) were associated with significantly greater gains in HRD at the 3-mm level. No statistically significant difference in HRD was detected for augmented sites with and without tenting screw use.

Conclusions: Compared with the direct intraoperative measurement protocols utilized in prior studies, the alveolar ridge assessment method applied in this investigation may improve accuracy by assuring a consistent assessment level for baseline and follow-up recordings. Within the limitations of this observational study, only two procedure-related variables were associated with greater HRD gains following HRA: membrane fixation and nonresorbable membrane use.

KEYWORDS: Alveolar ridge augmentation; bone regeneration, cone-beam computed tomography; dental implants; treatment outcome

INTRODUCTION

Alveolar ridge deficiency is a common oral condition caused primarily by bone resorption following tooth loss, surgical trauma during dental extractions, inflammatory bone loss related to periodontitis or endodontic infection, oral pathologic lesions, and trauma to the maxilla and mandible. One investigator estimated that over half of dental implant sites require alveolar ridge augmentation in order to establish sufficient bone volume for peri-implant tissue health and stability.[1] Principal methods of alveolar ridge augmentation include guided bone regeneration (GBR), distraction osteogenesis, alveolar ridge expansion (ridge split), and block grafting.[2-11] Of these, GBR is the most widely used technique.[2]

Prior investigators have assessed treatment outcomes following ridge augmentation procedures. Predominantly reported outcome measures have included frequency of implant placement following ridge augmentation, implant survival or success in augmented sites, frequency of postoperative complications, and mean increases in alveolar ridge dimensions.[7-11] Our department published a retrospective observational study investigating the anticipated buccal bone thickness adjacent to dental implants following GBR.[12] This study suggested that clinicians can anticipate buccal bone thickness > 1.9 mm (a critical value for peri-implant tissue stability) at approximately 70% of implant sites following GBR.[12] However, approximately 30% of sites may require additional grafting at the time of implant surgery if buccal bone thickness > 1.9 mm is a clinical goal.[12] GBR resulted in actual dental implant placement at > 96% of sites in this study.[12]

Review of methodologies previously used for measuring changes in alveolar ridge dimensions following ridge augmentation is necessary. Most researchers who have assessed post-augmentation horizontal ridge dimension changes simply used calipers to record baseline and follow-up ridge widths (at GBR surgery and at re-entry for dental implant placement). The mesiodistal measurement position was an established distance from a fixed reference point, such as an adjoining tooth, and the vertical position of measurement was a standardized distance from the alveolar crest. One obvious problem with this measurement protocol is that the alveolar crest is not a fixed reference point. The alveolar crest may, as a result of graft placement, shift superiorly following ridge augmentation. Likewise, postsurgical bone resorption may reduce the vertical height of bone, particularly if wound closure is not maintained during the early postoperative period. Thus, a caliper measurement at re-entry surgery may occur at the baseline mesiodistal position but at a very different vertical position along the alveolar ridge. In cross section, the buccolingual dimension of the human mandible is typically narrower near the crest and inferior border, widening in the zone between these two boundaries. Prior studies, therefore, may have been biased toward overestimating gains following ridge augmentation.

Specific methodologies used in prior studies

Buser and coworkers performed ridge augmentation on 66 sites in 40 subjects using ePTFE membranes, membrane fixation screws, autogenous block grafts from the chin or ramus, block fixation/tenting screws, and bone chips.[6] The surgeon intraoperatively used calibers to measure the ridge to the nearest quarter millimeter at a point 2 mm apical to the osseous crest at the site of planned implant placement.[6] The distance from the measurement site to the adjacent tooth was recorded in order to repeat the measurement upon re-entry.[6] The mean horizontal augmentation attained was 3.53mm (range 1.0 mm to 6.5 mm).[6]

Von Arx and Buser augmented 58 deficient alveolar ridge sites in 42 patients using a combination of block grafts with anorganic bovine bone matrix (ABBM) and collagen membranes.[7] Preoperative and postoperative ridge measurement locations were not standardized with a guide or template.[7] For single-tooth edentulous sites, the middle of the edentulous span was utilized.[7] A protocol was employed to determine measurement locations for multiple adjacent missing teeth and distal extension situations.[7] Measurements were recorded 1 mm apical to the osseous crest using calipers to the nearest half millimeter.[7] The calculated mean gain in horizontal ridge thickness was 4.6mm (range 2 to 7 mm).[7]

Geurs et al. laterally augmented 98 potential dental implant sites in 51 patients using synthetic membranes and a combination of DFDBA and cortical cancellous chips in a thermoplastic biologic carrier.[8] The alveolar ridge was measured at a single horizontal position along the deficient ridge both at the crest and 4 mm apical to the crest before augmentation and at re-entry.[8] The ridge width increased from 2.4 mm to 5.2 mm at the crest and from 4.4 mm to 7.5 mm at a vertical position 4 mm apical to the crest.[8]

Beitlitum and coworkers performed GBR utilizing a ribose cross-linked collagen membrane and FDBA with or without the addition of autogenous bone chips in a bi-layered grafting technique. There were 27 subjects in the FDBA group and 23 subjects in the bi-layered graft group. Addition of autogenous bone chips did not statistically enhance horizontal or vertical ridge augmentation. The mean horizontal ridge augmentation was 5.0 mm and 3.6 mm for the FDBA and bilayered graft groups, respectively. During the GBR procedure, the minimum ridge width was measured clinically, and the point of measurement was indexed to the nearest tooth or implant for repeat measurement at the second surgery (implant placement or implant uncovering).[9]

Urban and colleagues published a prospective GBR case series utilizing a resorbable polymer membrane and particulate autogenous bone with or without addition of anorganic bovine bone. Twenty-five surgical sites were evaluated in 22 subjects, with 58 implants placed after GBR healing. Intrasurgical initial (at GBR surgery) and final (prior to implant placement) horizontal ridge width was recorded using calipers at a single point, 2 mm apical to the osseous crest. The mean gain in ridge width following GBR was 5.56mm. The implant survival rate was 100 percent after an average of 45.88 months of follow-up.[10]

Block and coworkers evaluated a series of 12 patients who received GBR procedures in the anterior maxilla using particulate bovine xenograft and resorbable membranes. Eight patients received collagen membranes placed under the flap (not fixed with tacks). Four patients received polyglyolic acid/polylactic acid (PGA/PLA) foils fixed with PGA/PLA tacks. The width of the alveolar ridge was measured at three vertical positions from the osseous crest (designated as crestal, midway, and apical ridge thickness) using an iCAT CBCT scanner (Imaging Sciences International). CBCT images were acquired at 5 time points (pre-operatively, immediately after augmentation, 3 to 6 months after augmentation, immediately after implant placement, and after osseointegration). At the crest, the mean change in ridge with was minimal (< 1mm) at all postoperative time points. At the longest postoperative time point, the mean changes in ridge width at the midway and apical vertical positions were 2.69mm and 2.75mm, respectively.[11]

PURPOSE

The purpose of this retrospective observational study was to assess ridge width changes following horizontal ridge augmentation (HRA) surgery using a novel analysis technique.

MATERIALS AND METHODS

This study consists of a retrospective analysis of existing cone-beam computed tomography (CBCT) volumes. Patients who received diagnostic CBCT scans before and after ridge augmentation surgery were included in the study. Baseline and follow-up CBCT scans were uploaded into analysis software (Dolphin 3D, Patterson Dental, St Paul, MN), which permitted overlaying the two scans (Figure 1). A single investigator recorded the changes in horizontal alveolar ridge width 3 mm and 5 mm apical to the baseline alveolar crest ($\Delta H3$ and $\Delta H5$), Figure 2. Additionally, the investigator assessed the following explanatory variables: age, sex, ethnicity, smoking status, hemoglobin A1c, use of membrane fixation, use of tenting screws, and membrane type. Finally, the investigator re-measured the overlaid scans for a second time. This process allowed intra-rater reliability analysis during data analysis. In all analyses, we used the average of the duplicate recordings.

RESULTS

CBCT volumes from 57 patients met inclusion criteria for this study. Eight patients had received two HRA procedures at separate alveolar locations. Thus, CBCT volumes from 65 sites were available for analysis. Eighty-four dental implants were planned; 77 (92%) implants were actually placed following the HRA. Five patients were unavailable to complete implant installation, accounting for five implants planned but not placed (Table 1).

Factors Influencing Postoperative Alveolar Ridge Dimensions

Multiple linear regression models identified statistically significant factors influencing each dependent variable. The final model for ΔH3 included membrane fixation, tenting screw use, time between CBCT images, and BRW5. Only membrane fixation ($\beta = 1.36$, $p = 0.42$) exhibited a statistically significant association with ΔH3. The final model for ΔH5 included region (anterior vs. posterior) and membrane type (non-resorbable vs. resorbable). Anterior sites ($\beta = 0.73$, $p = 0.040$) and sites receiving non-resorbable membranes ($\beta = 0.61$, $p = 0.024$) exhibited significantly greater ΔH5 (Table 2).

DISCUSSION

The present study analyzed HRA at 65 sites utilizing 130 CBCT volumes with the objective to illustrate the efficacy of a novel methodology for assessing changes in horizontal ridge width. Prior investigations reporting horizontal ridge dimension (HRD) changes following ridge augmentation procedures predominantly have relied on serial intraoperative caliper recordings. Unlike the recording methods used in these studies, our overlay protocol assured a consistent alveolar position for baseline and post-augmentation comparison capturing both horizontal and vertical changes. Intuitively, postoperative variations in the vertical dimension may bias the estimated HRD gain in studies relying upon direct intraoperative measurements.

Considering the relative importance of reported HRA outcomes, the magnitude of HRD increase may rank lower than implant success/survival, long-term peri-implant tissue stability, percent vital bone achieved, and other parameters. In fact, the amount of horizontal augmentation required to produce an “ideal” alveolar ridge varies from site to site; a modest augmentation does not necessarily imply a less favorable treatment outcome. Nevertheless, experienced clinician scientists have reported HRD gains following ridge augmentation surgery.[2-11] These reports may serve to guide expectations and suggest limitations considering a range HRA protocols.

In the present study, two factors, membrane fixation and non-resorbable membrane use, were associated with statistically significant increases in HRD at the 3-mm level (Table 2). These observations are consistent with prior reports, although multiple investigators have reported satisfactory HRA outcomes utilizing either resorbable or non-resorbable barrier membranes. Five sites in the present study received acellular dermal matrix (ADM) barriers. Although limited data support use of ADM for alveolar ridge augmentation/preservation, sites in the present study receiving the ADM biomaterial tended to exhibit less favorable treatment outcomes. In fact, the only HRA site assessed that could not accommodate implant placement utilized an ADM barrier.

Understanding the degree to which HRA sites maintain short- and long-term dimensional stability is of practical importance to implant surgeons. Continued remodeling of the alveolar ridge in the long-term—following the implant phase—may result in unfavorable esthetics and predispose the site toward biologic complications. In the short-term, if ridge dimensions at HRA sites remain relatively stable, practitioners may choose to acquire CBCT volumes early. This approach would facilitate HRA outcome assessment, implant planning, and surgical guide fabrication, while permitting additional maturation prior to the implant phase. In the present study, the interval between baseline and postoperative CBCT volumes did not correlate with the observed HRD increase. These findings suggest that over a range of healing intervals from about two to nine months, post-augmentation CBCT HRD measurements do not exhibit large dimensional changes. Thus, from a practical perspective, a clinician might choose to image a site early to expedite implant planning, while allowing an additional maturation period before implant surgery.

Viewed in context with prior investigations, our findings reiterate the significance of space provision in alveolar ridge augmentation. Consistent with previous reports, most sites assessed herein included barrier membrane fixation, and these sites exhibited a statistically greater mean HRD increase compared with sites not using membrane fixation. Especially when utilizing a relatively rigid barrier, such as dense polytetrafluoroethylene, membrane fixation may maintain the space available for augmentation and also increase wound stability. Also, no statistically significant difference was detected in mean HRD increase at sites receiving and not receiving tenting screws (Table 2). Mixed observations appear in the literature regarding this topic. Although controlled clinical research is necessary, practitioners may consider avoiding tenting screw use unless clearly beneficial in specific cases.

Multiple clinicians performed the procedures included in the present study, and various faculty members, with individual preferences and treatment philosophies, supervised these procedures. The augmentations did not employ a standardized graft material and barrier membrane combination. Furthermore, the patient sample may not necessarily be representative of the broader population. Despite clinical protocol variations and clinician preferences, our indirect assessment method permitted simultaneous HRD and VRD evaluation while assuring baseline and post-augmentation recordings at the same alveolar ridge position.

Compared with direct *in situ* recording, the described protocol—and methods involving new technologies such as optical scanning—may achieve a more complete characterization of dimensional changes at alveolar ridge augmentation sites.

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FIGURES

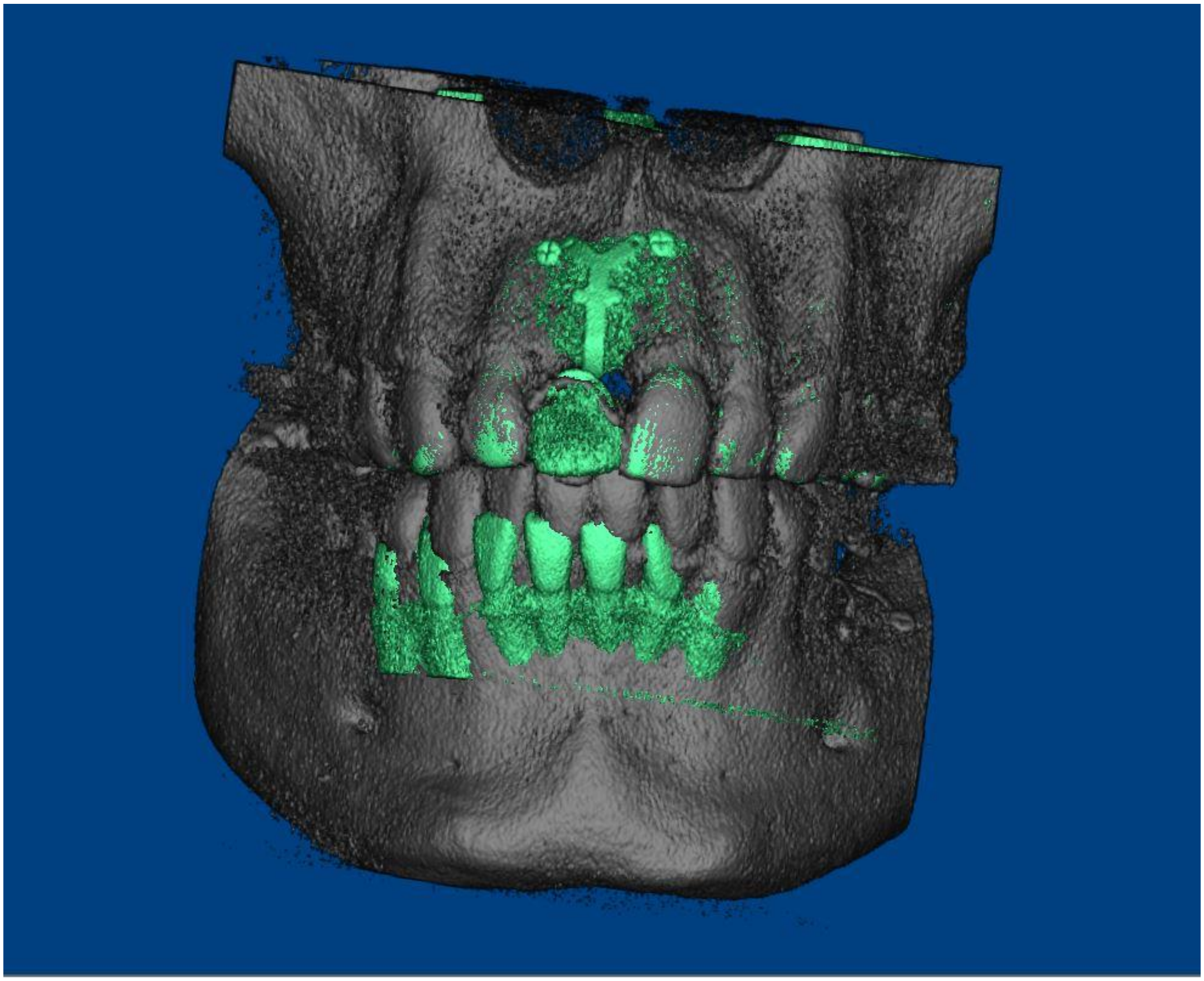

Figure 1. Example cone-beam computed tomography scan overlay. The green area in the tooth #8 position represents the gain in alveolar ridge volume following guided bone regeneration. The grey-colored tissue represents the baseline condition. Note that in the baseline scan, the patient was in maximum intercuspation. In the follow-up scan, the patient's mouth was open. Thus, the scans of the mandibular arch are not aligned.

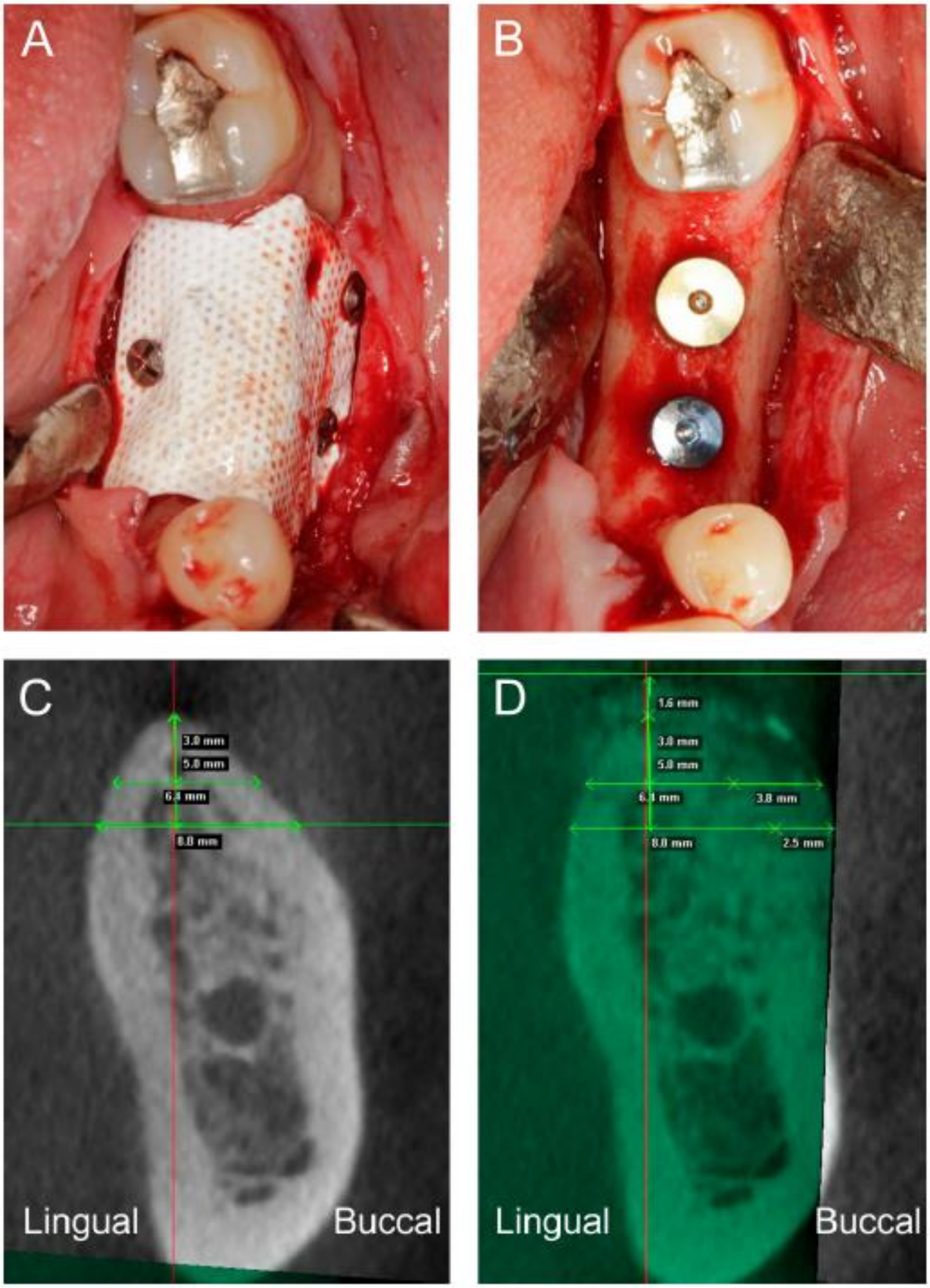

Figure 2. Example cone-beam computed tomography overlay (posterior site). A) Titanium-reinforced dense polytetrafluoroethylene membrane with three fixation screws. The site received a freeze-dried bone allograft. B) Appearance of the alveolar ridge at implant surgery. C) Baseline CBCT volume. D) Overlay of baseline and post-augmentation CBCT volumes with measurements of ΔH3 and ΔH5.

TABLES

Table 1. Study population characteristics

Patient level (n = 57)					
Gender male/female	41 (72%)			16 (28%)	
Race/ethnicity	26 (46%) African American	6 (9%) Hispanic	1 (2%) Asian	23 (40%) Caucasian	1 (2%) unknown
Age [years]	mean 39.3 ± 11.0, range 21 - 67				
Smoking status	45 (79%) never smoked	6 (11%) former smokers	6 (11%) smokers	0 (0%) heavy smokers	
Site level (n = 65)					
Gender male/female	47 (72%)			18 (28%)	
Race/ethnicity	32 (49%) African American	6 (9%) Hispanic	1 (2%) Asian	25 (38%) Caucasian	1 (2%) unknown
Age [years]	mean 39.5 ± 10.9, range 21 to 67				
Smoking status	53 (82%) never smokers	6 (9%) former smokers	6 (9%) smokers	0 (0%) heavy smokers	
Site type	21 (32%) anterior			44 (68%) posterior	
Dental arch	22 (34%) maxillary			43 (66%) mandibular	
Graft or biomaterial	5 (8%) autogenous bone		9 (14%) autogenous bone combined with ABBM or FDBA		51 (78%) allogeneic bone derivative (FDBA or solvent-dehydrated bone allograft)
Barrier membrane	53 (82%) non-resorbable	5 (8%) resorbable collagen	5 (8%) acellular dermal matrix	1 (2%) no barrier membrane	
Membrane reinforcement	18 (28%) titanium reinforced membrane			47 (72%) non-reinforced membrane or no membrane used	
Tenting screw use	14 (22%) sites received tenting screws			51 (78%) sites did not receive tenting screws	
Membrane fixation	58 (89%) sites received membrane fixation			7 (11%) sites did not receive membrane fixation	
Interval between preoperative and follow-up CBCT volumes [months]	mean 6.5 ± 2.2, range 3.0 - 13.0				
Baseline HRD, 3 mm apical to crest [mm]	mean 6.0 ± 1.9, range 0.8 - 11.0				
Baseline HRD, 5 mm apical to crest [mm]	mean 7.2 ± 2.4, range 0.6 - 12.7				
Preoperative CBCT volume FOV	14 (22%) Ø 100 × height 100 mm	21 (32%) Ø 80 × height 80 mm	24 (37%) Ø 60 × height 60 mm	6 (9%) Ø 40 × height 40 mm	
Follow-up CBCT volume FOV	9 (14%) Ø 100 × height 100 mm	19 (29%) Ø 80 × height 80 mm	25 (38%) Ø 60 × height 60 mm	12 (18%) Ø 40 × height 40 mm	

ABBM = anorganic bovine bone mineral; FDBA = freeze-dried bone allograft; CBCT = cone-beam computed tomography; HRD = horizontal alveolar ridge dimension; FOV = field of view

Table 2. One-way analysis of variance and two-sample t test results

Variable	Level	ΔH3 Mean ± SD (mm)	p value	ΔH5 Mean ± SD (mm)	p value
Sex	Female n = 18	2.02 ± 1.84	0.362	2.23 ± 1.47	0.547
	Male n = 47	2.44 ± 1.55		2.45 ± 1.27	
Race/ ethnicity	Asian n = 1	2.30	0.889	1.35	0.905
	African American n = 32	2.41 ± 1.65		2.30 ± 1.18	
	Caucasian n = 25	2.23 ± 1.67		2.51 ± 1.36	
	Hispanic n = 6	2.05 ± 1.76		2.53 ± 2.13	
	Unknown n = 1	3.80		2.55	
Smoking status	Former smoker n = 6	2.60 ± 1.16	0.880	2.19 ± 1.44	0.928
	Never smoked n = 53	2.28 ± 1.60		2.40 ± 1.29	
	Smoker n = 6	2.47 ± 2.44		2.45 ± 1.75	
Dental arch	Mandibular n = 43	2.56 ± 1.48	0.106	2.24 ± 1.10	0.281
	Maxillary n = 22	1.87 ± 1.83		2.68 ± 1.67	
Region	Anterior n = 21	1.90 ± 1.50	0.152	2.75 ± 1.49	0.130
	Posterior n = 44	2.53 ± 1.66		2.22 ± 1.21	
Graft or biomaterial type	Autogenous bone n = 5	1.19 ± 2.58	0.241	1.85 ± 1.01	0.310
	Autogenous bone combination n = 9	2.66 ± 1.10		2.93 ± 1.11	
	Allogeneic bone derivative n = 51	2.38 ± 1.59		2.35 ± 1.37	
Membrane type	Resorbable n = 11	1.38 ± 1.52	0.034	1.78 ± 1.36	0.092
	Non-resorbable n = 54	2.52 ± 1.59		2.51 ± 1.29	
Titanium reinforced membrane	No n = 47	2.22 ± 1.53	0.388	2.47 ± 1.44	0.411
	Yes n = 18	2.61 ± 1.88		2.17 ± 0.96	
Membrane fixation	No n = 7	1.09 ± 2.27	0.038	2.06 ± 1.36	0.496
	Yes n = 58	2.47 ± 1.49		2.43 ± 1.40	
Tenting screw use	No n = 51	2.16 ± 1.63	0.124	2.33 ± 1.27	0.547
	Yes n = 14	2.92 ± 1.54		2.57 ± 1.53	

ΔH3 = change in horizontal dimension of the alveolar ridge (3 mm apical to the baseline osseous crest); ΔH5 = change in horizontal dimension of the alveolar ridge (5 mm apical to the baseline osseous crest); SD = standard deviation