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Vertical Dimensional Changes Following Horizontal Alveolar Ridge Augmentation

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ABSTRACT

Background: Researchers commonly distinguish horizontal alveolar ridge augmentation (HRA) procedures from those aiming to augment the vertical dimension of the edentulous ridge. However, incidental vertical changes occurring after HRA remain poorly characterized in the periodontics literature.

Purpose: The objective of this study was to assess vertical dimensional changes following HRA.

Materials and Methods: This study included CBCT volumes from 65 HRA sites in 57 patients. Baseline and postoperative CBCT volumes were superimposed using three-dimensional analysis software. Changes in the vertical alveolar ridge dimensional (VRD) were recorded considering a panel of patient-, site-, and procedure-related explanatory variables.

Results: VRD changes ranged from -2.9 to 3.0 mm, more than half the anterior sites losing alveolar ridge height. Overall, 24 HRA sites (37%) lost VRD, 24 sites (37%) gained VRD, and 17 sites (26%) exhibited no change in the vertical dimension of the alveolar ridge. In a two-sample test of proportions, 11 of 21 anterior sites (52%) and 13 of 31 posterior sites (30%) exhibited decrease in VRD. This difference was not statistically significant ($p = 0.074$). Four factors in the present study were associated with a mean reduction in VRD—anterior site, maxillary site, lack of membrane fixation, and use of a resorbable barrier membrane.

Conclusion: Minor alterations in the VRD following HRA may be of limited clinical consequence, particularly at posterior sites. However, loss of VRD is generally undesirable, and as such may compromise esthetics and/or limit effectiveness of personal hygiene practices. Findings of the

present study suggest that variables affecting post-HRA VRD reduction are partially under the control of the clinician.

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

INTRODUCTION

The 2017 World Workshop on Classification of Periodontal and Peri-implant Diseases and Conditions defines a hard tissue deficiency prior to implant placement to exist when alveolar ridge dimensions do not accommodate a standard dental implant fully anchored in native alveolar bone.[1] Various authors have estimated that forty percent or more dental implant sites require some form of bone augmentation.[2-4] Schropp et al. reported approximately 50% reduction in horizontal ridge width within the first 3 months after tooth extraction, with much smaller changes in the vertical dimension.[5] Techniques used for alveolar ridge augmentation include distraction osteogenesis, guided bone regeneration (GBR), autogenous block grafting, "tent pole" procedures, and the use of titanium mesh with biologic amplifiers such as Bone Morphogenetic Protein-2 (BMP-2). Researchers assessing clinical outcomes typically distinguish vertical (VRA) from horizontal alveolar ridge augmentation (HRA) procedures, and a number of authors have reported the mean increase in vertical alveolar ridge dimension (VRD) following VRA (Table 1).[6-13] Conversely, the literature is essentially silent on the incidental vertical changes that occur following HRA procedures. Unlike the direct intraoperative measurement protocols used to assess ridge width in prior HRA studies, cone-beam computed tomography (CBCT) offers the opportunity to simultaneously assess horizontal and vertical alveolar ridge changes.

PURPOSE

The purpose of this study was to characterize vertical alveolar ridge changes that occur after HRA using superimposed cone-beam computed tomography (CBCT) volumes.

MATERIALS AND METHODS

The Human Research Protections Office reviewed this protocol (#2019-0802) and determined our research to be exempt from regulatory requirements of 32CFR§219 in accordance with paragraph 104(d)(4)(ii). This report complies with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. In this study, we retrospectively identified CBCT volumes from patients receiving HRA procedures in our department. Baseline and follow-up CBCT volumes were superimposed and analyzed using three-dimensional analysis software (Dolphin 3D, Patterson Dental, Saint Paul, MN, USA) (Figure 1). Vertical dimensional changes were recorded, considering a panel of patient-, site-, and procedure-related explanatory variables.

Inclusion Criteria

CBCT volumes acquired for patients undergoing HRA procedures at a postgraduate residency program from July 1, 2012 through July 10, 2020, were assessed. All CBCT volumes were acquired using a single scanner (3D Accuitomo 170, J. Morita, Suita-chi, Osaka, Japan) in the routine course of treatment planning for dental implant placement and surgical guide fabrication. CBCT field of view (FOV) was ø40 x height 40 mm (isotropic 80-µm voxel), ø60 x height 60 mm (isotropic 125-µm voxel), ø80 x height 80 mm (isotropic 160-µm voxel), or ø100 x height 100 mm (isotropic 250-µm voxel). All scans utilized a 360º arc of rotation, peak tube potential 90 kV, current 5 to 8 mA, and exposure time 10.5 to 30.8 sec.

Augmented sites included in the study required diagnostic baseline and follow-up CBCT volumes and that the surgical goal was primarily HRA in preparation for dental implant placement. Sites were excluded if no implant was planned, the augmentation occurred

simultaneously with implant placement, the surgical goal was primarily vertical ridge augmentation, the site had received previous alveolar ridge augmentation, or either CBCT volume (baseline or follow-up) was not acquired. Baseline CBCT acquisition greater than 8 weeks prior to the augmentation procedure also excluded sites from this study. Patient records were reviewed to confirm the treatment plan and assess patient-, site-, and procedure-related explanatory variables: gender, age, race/ethnicity, smoking status, dental arch, region (anterior/posterior), graft type, membrane type, membrane fixation, titanium reinforcement in the membrane, tenting screw use, time between baseline and follow-up CBCT scans, and baseline ridge width in the mesiodistal center of the augmentation site.

CBCT Volume Alignment

For all cases meeting inclusion criteria, Digital Imaging and Communications in Medicine (DICOM) files were exported from the CBCT scanner system (i-Dixel, version 2.3.0.3, J. Morita, Suita-chi, Osaka, Japan) and imported to an analysis software. Baseline and post-augmentation CBCT volumes were superimposed using fixed anatomical landmarks such as the inferior border of the mandible, the subantral floor, the anterior nasal spine, the mental foramen, and other fixed landmarks appearing in both volumes. We assessed the quality of CBCT volume alignment by closely inspecting the anatomical landmarks in the superimposed images.

CBCT Measurements

The outcome variable of interest in this study was the change in vertical position of the alveolar crest (ΔV). All recordings were made in the mesiodistal center of the augmented site. A positive value of ΔV indicated gain in the vertical alveolar ridge dimension (VRD), and a negative value of ΔV denoted VRD reduction.

Statistical Analyses

Descriptive statistics were calculated for all qualitative and quantitative variables using statistical software (SAS 9.4, SAS Institute, Cary, NC, USA), reported as means ± standard deviations. The significance level was set at 0.05. Individual multiple linear regression models were established to determine associations between ΔV and the explanatory variables. Each explanatory variable was first examined in a bivariate model. Explanatory variables significant at the 0.2 alpha level in a simple linear model were used to build a multiple linear regression model. Akaike Information Criterion (AIC) were examined for each possible model, and the model with the lowest AIC was determined to be the best model for each outcome variable. One-way ANOVA (independent variables having at least three categories) and two sample t-tests (independent variables having only two categories) were used to assess differences in ΔV among the levels of the categorical independent variables. Tukey-Kramer tests were used to assess for multiple comparisons when a one-way ANOVA was statistically significant. A two-sample test of proportions was calculated to determine if the percentage of sites exhibiting reduced VRD was different for anterior versus posterior sites. Intraclass correlation coefficients (ICCs) were calculated to estimate intra-examiner reliability.

RESULTS

Fifty-seven patients met inclusion criteria for this study (Table 2). A total of 65 pairs of CBCT volumes (baseline and follow-up) were available for analysis. Mean ΔV was 0.11 ± 1.15 (range -2.9 to 3.0 mm). The final multiple linear regression model for ΔV included dental arch, membrane fixation, and baseline ridge width 3 mm apical to osseous crest (BRW3). Only membrane fixation ($\beta = 0.86$, $p = 0.046$) and BRW3 ($\beta = 0.16$, $p = 0.022$) were statistically

significant factors affecting ΔV. Table 3 presents one-way ANOVA and two-sample t-test results. Posterior sites exhibited significantly greater mean ΔV compared with anterior sites (0.4 ± 1.4 vs. -0.4 ± 1.0 mm, p = 0.012). Mandibular sites exhibited statistically greater mean ΔV compared with maxillary sites (0.3 ± 1.2 vs. -0.3 ± 1.0 mm, p = 0.028). Membrane fixation, compared with no membrane fixation, was associated with significantly greater mean ΔV (0.2 ± 1.1 vs. -0.7 ± 1.1 mm, p = 0.042). Sites receiving non-resorbable rather than resorbable membranes also experienced significantly greater mean ΔV (0.2 ± 1.2 vs. -0.6 ± 0.7 mm, p = 0.037). Overall, 24 HRA sites (37%) lost VRD, 24 sites (37%) gained VRD, and 17 sites (26%) exhibited no change in the vertical dimension of the alveolar ridge. In a two-sample test of proportions, 11 of 21 anterior sites (52%) and 13 of 31 posterior sites (30%) exhibited decrease in VRD. This difference was not statistically significant (p = 0.074).

DISCUSSION

The aim of the present study was to characterize vertical alveolar ridge changes after HRA procedures. Direct ridge width measurements used in previous HRA studies did not account for or record vertical changes. Although the mean change in VRD observed in this study was quite small, the range of values spanned 6 mm (-2.9 mm to 3.0 mm), and several explanatory factors were predictive of VRD loss. Minor alterations in the VRD following HRA may be of limited clinical consequence, particularly at posterior sites. However, loss of VRD is generally undesirable, and as such may compromise esthetics and/or limit effectiveness of personal hygiene practices. Four factors in the present study were associated with a mean reduction in VRD— anterior site, maxillary site, lack of membrane fixation, and use of a resorbable barrier membrane. We observed VRD reduction at more than *half* of anterior HRA

sites. Moreover, in the multiple linear regression analysis, baseline alveolar ridge width correlated negatively with VRD, suggesting that, as expected, thin alveolar ridges may be particularly vulnerable to untoward dimensional changes following HRA. Most sites in the present study utilized membrane fixation, and sites lacking membrane fixation exhibited a mean reduction in VRD. 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.

CONCLUSION

Loss of VRD following HRA may in some cases comprise clinical and patient-centered outcomes. Findings of the present study suggest that some variables affecting post-HRA reduction in VRD are under the control of the clinician.

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FIGURES

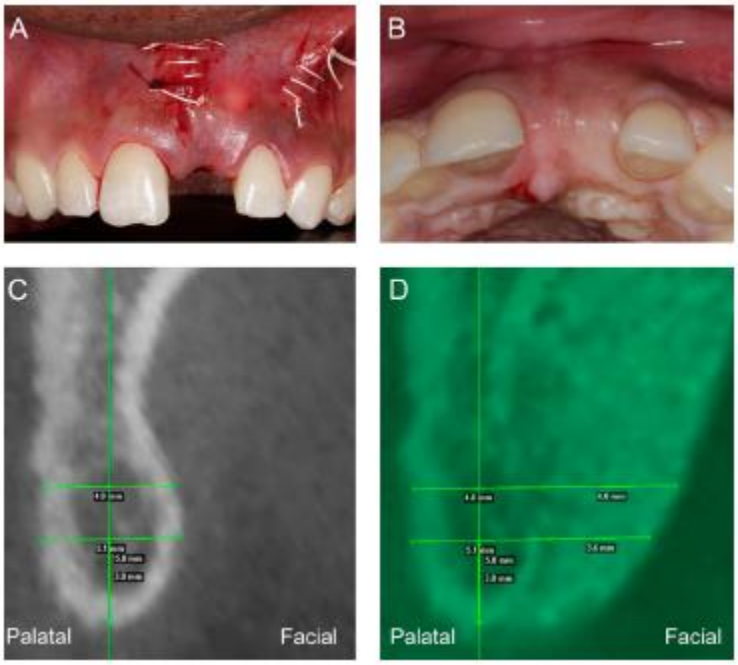

FIGURE 1 Example CBCT Overlay (anterior site). A) Wound closure for primary intension healing. The #9 site received a dense polytetrafluoroethylene membrane with fixation and a freeze-dried bone allograft. B) Incisal view of the site five months following ridge augmentation. C) Baseline CBCT volume. D) Superimposed baseline and post-augmentation CBCT volumes. In this case, $\Delta V = 0$.

TABLES

Table 1. Studies reporting changes in the vertical dimension following vertical alveolar ridge augmentation

Study	Graft/biomaterials	Patient /sites	Measurement technique	Mean vertical gain (mm)	Range (mm)
Tinti et al, 1996	Autogenous bone GBR and Ti reinforced Gore-Tex membrane	6/14	Intrasurgical (after implant placement) taken with a calibrated probe from the top of the cover screw to the peri-implant bone crest at the mesial & distal aspects before and after treatment	5.0	0-7
Chan et al, 2015	Encore combination allograft particulate bone and Porous titanium mesh	5/11	Cone beam computed tomography (CBCT) scans were taken preoperatively, immediately, and 5 months after VRA	2.4	Not reported
Urban et al, 2015	1:1 ratio of autogenous bone and bovine hydroxyapatite and Ti-Cytoplast dPTFE membrane	6/18	Parallelized periapical radiographs measuring from implant neck to the coronal most portion of the interproximal bone level.	5.8	3-9
Fontana et al, 2008	GBR Allograft + e-PTFE titanium-reinforced Membrane (test)	5/5	Distance from bone to head of Ti screw	4.7	Not reported
Simion et al, 1998	PTFE-e titanium-reinforced membrane + DFDBA	20/20	Probe to measure exposed implant surface	3.1	Not reported
Proussaefs et al, 2005	Mandibular block autografts + inorganic bovine mineral (Bio-Oss)	12/12	Radiographic evaluation, laboratory evaluation using stone casts, histomorphometric evaluation	4.8	4-8
Llambes et al, 2007	Autogenous bone/graft + slow resorption collagen membrane	11/11	Measurements from implant shoulder to alveolar bone at stage 1 and stage 2 surgeries and on a PA 1 year after implant load	3.0	Not reported
Simion et al, 2001	Gr A: Blood clot, Gr B: Allograft, Gr C: Autograft + e-PTFE Ti reinforced membrane	49/53	Radiographs measuring the distance between the top of implant head shoulder and the first visible bone–implant contact	Gr A: 2.7 Gr B: 1.4 Gr C: 1.3	Not reported

Table 2. Characteristics of study sample

Patient level (n=57)					
Gender male/female	41% (72%)			16 (28%	
Race/ethnicity	26 (46%) B	6 (9%) H	1 (2%) A	23 (40%) C	1 (2%) U
Age (years)	mean 39.3 ± 11.0, range 21 - 67				
Smoking status	45 (79%) NS	6 (11%) FS	6 (11%) S	0 (0%) HS	
Site level (n=65)					
Gender male/female	47 (72%) M			18 (28%) F	
Race/ethnicity	32 (49%) B	6 (9%) H	1 (2%) A	25 (38%) C	1 (2%) U
Age (years)	mean 39.5 ± 10.9, range 21 to 67				
Smoking status	53 (82%) NS	6 (9%) FS	6 (9%) S	0 (0%) HS	
Site type	21 (32%) anterior		44 (68%) posterior		
Dental arch	22 (34%) maxillary		43 (66%) mandibular		
Graft or biomaterial	5 (8%) AB	9 (14%) AB + ABBM or FDBA		51 (78%) ABD	
Barrier membrane	53 (82%) NR	5 (8%) RC	5 (8%) ADM	1 (2%) None	
Membrane reinforcement	18 (28% TR		47 (72%) NTR		
Tenting screw use	14 (22%) TS		51 (78%) no TS		
Membrane fixation	58 (89%) MF		7% (11% no MF		
Interval between preoperative and follow-up CBCT volumes (months)	mean 6.5 ± 2.2, range 3.0 - 13.0				

B = Black, H = Hispanic, A = Asian, C = Caucasian, U = unknown, NS = never smoked, FS = former smoker, S = smoker, HS = heavy smoker, M = male, F = female, AB = Autogenous bone, ABD = allogeneic bone derivative (FDBA or solvent dehydrated bone allograft), ABBM = anorganic bovine bone mineral, FDBA = freeze-dried bone allograft, NR = nonresorbable, RC = resorbable collagen, ADM = acellular dermal matrix, TR = titanium reinforced membrane, NTR = non-reinforced membrane or no membrane used, TS = tenting screw use, MF = membrane fixation, CBCT = cone-beam computed tomography, FOV = field

Table 3. Studies reporting changes in the vertical dimension following vertical alveolar ridge augmentation

Variable	Level	ΔV Mean ± SD (mm)	p value
Sex	Female (n=18)	-0.2 ± 1.1	0.200
	Male (n=47)	0.2 ± 1.2	
Race/ ethnicity	Asian (n=1)	0.0	0.251
	Black (n=32)	0.2 ± 1.1	
	Caucasian (n=25)	0.1 ± 1.3	
	Hispanic (n=6)	-0.8 ± 0.5	
	Unknown (n=1)	1.6	
Smoking status	Former smoker (n=6)	0.6 ± 0.7	0.515
	Never smoked (n=53)	0.0 ± 1.2	
	Smoker (n=6)	0.3 ± 1.3	
Dental arch	Mandibular (n=43)	0.3 ± 1.2	0.028
	Maxillary (n=22)	-0.3 ± 1.0	
Region	Anterior (n=21)	-0.4 ± 1.0	0.012
	Posterior (n=44)	0.4 ± 1.1	
Graft or biomaterial type	Autogenous bone (n=5)	-1.0 ± 1.3	0.059
	Combination graft (n=9)	0.5 ± 1.1	
	Allogeneic bone (n=51)	0.1 ± 1.1	
Membrane type	Resorbable (n=11)	-0.6 ± 0.7	0.037
	Non-resorbable (n=54)	0.2 ± 1.2	
Titanium reinforced membrane	No (n=47)	-0.0 ± 1.0	0.090
	Yes (n=18)	0.5 ± 1.4	
Membrane fixation	No (n=7)	-0.7 ± 1.1	0.042
	Yes (n=58)	0.2 ± 1.1	
Tenting screw use	No (n=51)	0.0 ± 1.1	0.214
	Yes (n=14)	0.5 ± 1.1	

ΔV = change in vertical dimension of the alveolar ridge relative to baseline osseous crest; SD= standard deviation