Impact of the periodontal phenotype in premolar and molar sites on bone loss following full thickness mucoperiosteal flap. A 1-year prospective clinical trial.

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Running title: Bone loss following full thickness mucoperiosteal flap

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ABSTRACT

Background: Full thickness mucoperiosteal flap (FTF) elevation could potentially affect the periodontium of the involved teeth; it is not clear if the periodontal phenotype of teeth involved in a FTF may influence these changes. The aim of this study was to evaluate the impact of FTF on teeth periodontium, as well as assessing the impact of periodontal phenotype on bone remodeling.

Methods: In this single arm prospective clinical trial, 26 subjects and a total of 52 adjacent teeth were included. Patients receiving implant surgery in the posterior area, at the time of implant site preparation, an FTF was extended one tooth mesial and distal to the planned site, and the flap was elevated both facially and lingually. Vertical and horizontal bone linear changes were measured on both adjacent teeth, using superimposed cone-beam computerized tomography (CBCT) images taken prior to implant placement (T0) and at 12 months (T1). Baseline digital scans of models and DICOM files were superimposed to assess the periodontal phenotype.

Results: Vertical bone changes from T0 to T1 were statistically significant ($p=0.013$), with changes were significantly higher at the mesial (-0.31± 0.30 mm) and facial ($p<0.05$) sites. Horizontal dimensional changes 5 mm subcrestally were similar among different locations ($p=0.086$) and the bone width loss was higher closest to the crest ($p=0.001$). No correlation was found between soft tissue thickness and bone changes. However, bone thickness at baseline appears to influence the extent of horizontal bone remodeling. Overall, the magnitude of bone loss either vertically or horizontally was clinically insignificant (≤0.4 mm).

Conclusion(s): Marginal bone changes in maxillary and mandibular posterior teeth following FTF at 12 months are very minimal, and mainly influenced by bone rather than soft tissue thickness. Overall, FTF does not seem to have deleterious effects on adjacent teeth periodontium.

INTRODUCTION

Full thickness mucoperiosteal flaps (FTF) are often used in surgical procedures to gain access to bone and root surfaces. FTF involve soft tissue dissection and separation of the periosteum from the alveolar bone proper [1]. Several studies since the 1960s have demonstrated that the direct physical and biological trauma to the alveolar bone caused by flap elevation induced osteoclastic activity resulting in necrosis and subsequent bone resorption [2-8]. Crestal bone loss was at least in part due to the interruption of blood supply derived from the periosteum. On the contrary, some animal studies did not demonstrate a significant difference in alveolar bone loss between flapless, FTF and split thickness flap (STF elevation [1, 9]. It is difficult to draw definitive conclusions from these studies due to study design heterogeneity (animal vs. human, coronal vs apical flap approach, FTF vs. STF, interdental vs. crestal changes, density, or volume changes).

Although not applicable in many periodontal and implant-related surgeries, an STF is suggested as an alternative to an FTF. Whereas STFs demonstrated less surgical trauma and discomfort compared to FTFs, neither flap technique seems to completely avoid bone loss [1, 10, 11]. While peri-implant bone changes have been thoroughly studied [11], it is unclear if and to what extent the periodontium of the adjacent teeth is affected by FTF elevation during implant placement surgery. Although flapless implant surgery with the accuracy that current implant treatment planning methods provide present as an appealing alternative, it is not always applicable [12]. Moreover, it is yet to be determined if the bone resorption caused by FTF elevation is significant enough to cause long lasting detrimental effect to the periodontium of the adjacent natural teeth.

The periodontal as well as the peri-implant phenotypes [13, 14] add another layer of complexity to the alveolar bone changes following FTF reflection. It is widely acknowledged that thin gingival phenotype (≤1.5mm) tends to exhibit greater gingival recession [15-20]. In 1996, Berglundh and Lindhe observed that when the supracrestal tissue height (STH) ≤ 2 mm, greater bone resorption and angular bony defects were noted when FTF was used for implant placement [21]. This was later confirmed by Linkevicius and co-workers [22-24]. Essentially, when FTF were used sites with a taller STH, there was significantly less bone remodeling compared to sites exhibiting shorter STH [22]. On the contrary, Spinato and coworkers found that implants restored with long abutments (3 mm) had less than twice the amount of bone loss compared to identical implants restored with short abutments (1 mm), irrespective of STH (groups with <2 mm or >2 mm) [25]. In addition, studies have been shown that facial bone thickness prior to extraction is strongly associated with the dimensional changes of the alveolar ridge [26, 27]. Lastly, the American Academy of Periodontology's best evidence consensus review concluded that the association between facial bone thickness and periodontal phenotype is variable, depending on tooth position and location of the measured point, hence there is no current consensus on this, thus far [17]. Consequently, bone morphotype is a factor of interest when evaluating the causes of facial bone loss.

Therefore, the primary aim of this prospective clinical trial was to assess the impact of FTF during implant surgery on vertical and horizontal bone loss at adjacent teeth involved in the FTF. The secondary aim was to evaluate the impact of a patient's periodontal phenotype on the bone loss.

MATERIALS AND METHODS

Ethical Approval and Registration

Approval for the experimental protocol was obtained from the University of Michigan Health Science Institutional Review Board (HUM00095933). The study was registered in the National Institutes of Health (NIH) database for clinical studies, under the clinicaltrials.gov identifier NCT02925078. Participants signed the written consent form before participated in this study.

Eligibility Criteria and Recruitment

The clinical component of this study was conducted at the University of Michigan, School of Dentistry, Ann Arbor, MI, USA between November 2016 and December 2019. Adult subjects who expressed interest in participating in this study were pre-screened. Each subject received information about the study design, risks, benefits, and timeline of the study. Patients were eligible if they fulfilled all the following criteria: 1) aged >18 years, 2) partially edentulous at a maxillary or mandibular premolar or first molar region, 3) adjacent teeth present mesial and distal to the edentulous site, 4) residual bone height >9mm and bone width >5mm, 5) >2mm width of Keratinized mucosa (KM), 6) optimal oral hygiene (full-mouth plaque scores of <10%), and 7) clinical gingival health on an intact or a reduced periodontium. Exclusion criteria were as follows: 1) need for bone augmentation, 2) current smoking or smoking cessation of <1 year, 3) current or planned pregnancy, 4) uncontrolled systemic disease, 5) conditions known to alter bone metabolism (e.g., diabetes, osteopenia, osteoporosis, hyperparathyroidism), 6) current or historical use of oral or intravenous bisphosphonates, 7) history of radiation therapy, 8) need for active periodontal therapy or 9) poor oral hygiene.

Clinical procedures

This clinical study was designed as a single arm prospective clinical trial. A total of 26 patients from a cohort undergoing implant placement in the posterior area were recruited[28]. Implants were placed in premolar or molar position at identical proportion (n=13/13). Prior to implant placement, standardized intraoral radiographs utilizing customized putty bite blocks and cone-beam computerized tomography (CBCT)[§] were taken on the region of interest (T0). Additionally, an alginate impression was taken of each subject to fabricate dental casts for the surgical guide and digital analysis. All surgical interventions were performed under local anesthesia with 2% lidocaine with 1:100,000 and 1:50,000 epinephrine by the same surgeon (HL. W). Mid-crestal incision was made on the partial edentulous site bisecting the keratinized mucosa followed by intrasulcular incisions on the adjacent teeth. A FTF was elevated and extended one tooth mesially and distally on the facial and lingual/palatal aspect, including the papilla of second adjacent teeth from both sides as shown in (Fig.1). Then, implant site preparation and placement were performed according to the implant system manufacturer recommendations. The smooth-rough junction along the implant collar was placed at the level of the bone crest, whereas the machined portion of the implant was placed supracrestal as described in a previous publication [28]. Depending on the specific anatomical variations in each individual, the length of the implant selected ranged between 9 mm to 12 mm, the diameter of the implant ranged between 3.8 mm to 4.5 mm, and the implant platform diameter ranged between 3.5 mm to 4.6 mm[**]. Following implant placement, a 4 mm tall healing abutment with a regular emergence profile ($<30^\circ$) was seated and tightened. A standardized periapical radiograph was taken to verify final implant position and seating of the healing abutment. Finally, the flap was reapproximated and secured with single interrupted sutures utilizing 3-0 dense polytetrafluoroethylene sutures[††]. Post-operative instructions included rinsing with warm salt water once a day for 2 weeks and amoxicillin 500 mg three times a day for 10 days. If the patient reported allergy to amoxicillin, a 5-day dose pack of azithromycin 250 mg was prescribed. Pain medication including ibuprofen 600mg was recommended. Post-operative follow-up appointments were planned at 2 weeks, 1, and 4 months. At the 2 weeks post-operative visit, sutures were removed.

Prosthetic protocol and follow-up

Final crown impressions were obtained 3 to 5 months after implant placement. Final crowns were placed between 2 to 4 weeks post final impression. Custom, screw-retained implant prostheses were fabricated. The post-delivery adjustment was individualized for each subject according to their needs. Clinical measurements on the implant were obtained at the time of implant placement, crown delivery, 6 months, and 12 months (T1) post final crown placement. Patients also received supportive periodontal and implant therapy using mechanical instrumentation at 6 and 12 months. A new standardized CBCT was also taken 12 months post final crown placement for radiographic analysis purposes.

Digital measurements:

A total of ten random sites were selected to perform all the digital measurements by the same examiner (E.C.Q) to verify that an inter-class correlation coefficient of at least 0.9 was achieved, after which data collection ensued.

Bone Linear measurements

To ensure data quality, one independent calibrated examiner (ECQ) performed all linear dimensional measurements in mm on the DICOM files from the CBCT scans obtained at baseline and 1 year after implant placement using a software package (Romexis, Planmeca, v.5.2.1 Hoffman Estates, IL, USA). DICOM files were automatically superimposed by matching between 8 to 10 points from the same hard tissue landmarks (i.e., teeth). When the superimposition was unprecise, the alignment was manually refined utilizing reproducible anatomical landmarks as references (i.e., palatal vault, mental foramen, alveolar process). For consistency of assessment, vertical and horizontal bone linear changes were obtained on the adjacent teeth where the implant was placed using a reproducible landmark (i.e., a line connecting the CEJ of the adjacent teeth). Mid-facial and mid-lingual/palatal vertical bone changes were assessed on the mesial, middle, and distal sites of each adjacent teeth. Horizontal bone linear changes were quantified at three predetermined reference points located 1, 3, and 5mm from the highest corresponding baseline facial or lingual/palatal crestal points on the mesial, middle, and distal sites of the adjacent teeth, as described elsewhere [29] and as shown in (Fig.2.)

Local phenotypic characteristics measurements

Baseline stone models poured from alginate impressions were digitally scanned using a laboratory scanner (3shape Trios Scanner - Copenhagen, Denmark) to obtain high-quality standardized tessellation language (STL) files. Baseline STL and DICOM files were imported to a software package (Romexis, Planmeca, v.5.2.1 Hoffman Estates, IL, USA) and automatically superimposed by matching at least 8 points from the same hard tissue landmarks. The alignment was manually refined when the superimposition was noticeably unprecise. Once the superimposition was complete, the same independent calibrated examiner (ECQ) performed the linear measurements. As described previously [30], a sagittal section at the middle of the adjacent teeth was obtained. The facial/lingual bone thickness was measured 1mm apical to the baseline facial/lingual alveolar bone crest. Also, the facial/lingual soft tissue thickness was measured 1mm apical to the facial/lingual gingival margin. Finally, the facial/lingual bone thickness changes were analyzed by measuring the bone thickness at the same reference points, when possible, using a reproducible landmark between CBCTs taken at baseline and 1 year after implant placement as shown in Fig.2.

Statistical Analysis

Statistical analysis consists of a description of categorical (absolute and relative frequencies) and continuous (mean, standard deviation, range, IQR, and median) variables. At tooth-level, multi-level linear models using generalized estimation equations (GEE) were conducted to assess linear dimensional changes over time according to different factors such as location, baseline facial soft tissue thickness, baseline facial bone tissue thickness, gender, or implant position. Wald's Chi^2 statistic was used to conclude the main effects on the dimensional bone changes and possible local phenotypic factors that could play a role. Regarding the power analysis, a post-hoc estimation was performed. The power analysis determined a sample size of 52 independent teeth provides 94.3% power at confidence 95% to detect mean changes since T0 to T1 of medium effect size (d=0.5) as significant using a linear model. Considering that teeth were not independent, this power must be corrected because of the two-level structure of data. Each patient provided 2 teeth and within-subject correlation CCI=0.05 (moderate) was assumed, leading to a correcting coefficient D-1.5. Therefore, 52 dependent teeth provide the same power as 35 independent teeth, offering power at 81.9%.

Results

A total of 26 patients (16 male and 10 female) with a mean age of 56.54 years who received implant surgery with the described approach completed the 1-year study. A subtotal of n=17 implants were placed in the mandible (13 molars and 4 premolars) and n=9 in the maxilla (9 premolars). A total of 52 adjacent teeth were included in this study. The mean facial gingival tissue thickness at T0 was 1.16 ± 0.43 mm (range 0.40-2.10) while the mean facial bone thickness was 1.25 ± 0.51 mm (range 0.20-2.20) (Supplementary Fig. 1). The mean lingual gingival tissue thickness at T0 was 1.67 ± 0.47 mm (range 0.80-2.60) while the mean lingual bone thickness was 2.17 ± 1.45 mm (range 0.70-7.75) (see Figure S1 in online Journal of Periodontology).

Vertical dimensional changes

Vertical bone changes from T0 to T1 was statistically significant (p=0.013). Loss of facial height loss was similar between male and female patients (mesial p=0.723, mid p=0.596 and distal p=0.993) at all three locations. Loss of lingual height loss was similar between male and female patients at mid (p=0.740) and distal (p=0.679). However, there were significant differences at mesial sites (p=0.042). Facially, at the mesial sites, changes were significantly higher (-0.31± 0.30 mm) than in the mid (-0.20 ± 0.22 mm) and distal (-0.24± 0.24 mm) area (Fig. 3). Lingually, the vertical bone change from T0 to T1 was -0.19 ± 0.21

at mesial sites, -0.17 ± 0.26 at mid sites and -0.13 ± 0.21 at distal sites (Fig. 3). Comparison between facial and lingual from T0 to T1 revealed more bone loss ($p<0.05$) facially on the mesial (-0.31mm vs. -0.19mm) and distal sites (-0.24mm vs. -0.13mm) but not at the mid sites (-0.20mm vs. -0.17mm). A regression model was conducted with the change in facial height (T1-T0), lingual height (T1-T0), as dependent variables and the facial and lingual soft tissue thickness respectively at T0 as a covariate. No correlation was found between both variables.

Effect of the relative position of the tooth to the implant on vertical dimensional changes

In teeth positioned mesial to the implant, mean loss of facial height was -0.23 and -0.21 mm in mesial/mid sites, and -0.33 mm in distal sites. However, statistical significance was not reached ($p=0.256$). In teeth positioned at distal to the implant, mean loss of facial height was -0.18 and -0.16 mm in mid/distal sites, and -0.39 mm in mesial sites, implying significant differences ($p<0.001$) (Fig. 3). For the lingual height, for teeth positioned at mesial to the implant, mean loss was -0.17 and -0.22 mm in mesial/mid sites, and -0.23 mm in distal sites. No significant differences were found ($p=0.389$). In teeth positioned at distal to the implant, mean loss of lingual height was -0.13 and -0.03 mm in mid/distal sites, and -0.21 mm in mesial sites, implying significant differences ($p=0.008$) (Fig 3). Figure 4 is an illustration that gives a general view of the pattern of vertical bone loss facially and lingually on the mesial and distal adjacent teeth.

Horizontal dimensional changes

The mean bone width loss from T0 to T1 at 1, 3 and 5 mm subcrestally is shown in (Fig. 5). Generally, the thicker the bone thickness at T0 was, the less significant the bone loss was. However, this trend reached statistical significance only on the lingual surface ($P<0.001$) (Table 1A). In fact, that effect was very clear, that a preventive effect from bone loss was noticed for bone thickness > 2mm (see Figure S1 in online Journal of Periodontology). It may be of value to note that bone thickness lingually was thicker than facially at T0 (see Figure S2 in online Journal of Periodontology). When the model was adjusted by facial and lingual soft tissue thickness at T0, a confounding effect of soft tissue on either surface was not detected for facial ($p=0.277$) or lingual soft tissue ($p=0.140$). At 1 and 3 mm, bone change was significant at each location ($p<0.001$) and similar among locations ($p>0.05$). 5mm subcrestally, at mesial sites there were not significant difference ($p=0.115$) between T0 and T1. However, significant difference was found at mid and distal sites ($p<0.001$). Changes were similar among different locations ($p=0.086$) 5mm subcrestally. Bone width loss was higher closest to the crest ($p=0.001$). Differences were significant when 1mm was compared to 3 mm ($p=0.025$*), 1mm vs 5mm ($p<0.001$***), but not between 3mm vs. 5mm ($p=0.292$). A regression model was conducted with the change in facial width 1, 3 and 5mm subcrestally

(T1-T0) as dependent variable and the facial soft tissue thickness at T0 as a covariate (Table 1B). No correlation was found between both variables.

Effect of the relative position of the tooth to the implant on horizontal dimensional changes

In teeth positioned at mesial to the implant, at (1, 3, and 5 mm), the mean loss in width was (-0.29, -0.22, +0.04 mm) in the mesial, (-0.26, -0.24, -0.15 mm) in mid sites, and (-0.46, -0.43, -0.22 mm) in the distal sites, respectively. Statistically significant difference among sites was found only at 1mm (Fig. 5). In teeth positioned at distal to the implant, at (1, 3, and 5 mm), the mean loss in width was (-0.4, -0.18, -0.26 mm) in the mesial, (-0.28, -0.25, -0.07 mm) in mid sites, and (-0.25, -0.12, -0.25 mm) in the distal sites, respectively. Statistically significant difference among sites was found only at 1mm (Fig. 5).

Discussion

The results of the present study showed that at 12 months after implant placement, there were statistically significant but clinically minimal bone loss at adjacent teeth. The vertical dimensional changes showed a slight decrease in facial and lingual bone levels with a greater loss occurring facially on mesial (-0.31 mm) followed by distal (-0.24 mm) and mid sites (-0.2 mm). As far as the horizontal dimensional changes were concerned, it seems to be influenced by the bone thickness. The thicker the bone at baseline, the less bone remodeling. The most bone loss was noted at the crest with a loss of -0.35 mm, -0.27 mm, and -0.35 mm at mesial, mid, and distal sites respectively.

While there are no other clinical studies performing a comparative analysis, a study by Girbes-Ballester et al., addressed this topic [31]. They compared intrasulcular incision consisting of buccal and lingual/palatal flaps exposing the underlying bone to para-marginal incision during implant placement. They found minimal interproximal bone loss (-0.09 mm intrasulcular; -0.10 mm para-marginal) of adjacent teeth irrespective of the incision utilized and no significant difference in bone loss between the two incision groups. A major difference between both studies however is that the mentioned study utilized only standardized periapical radiographs while the present study used CBCT for our assessment, thus also reporting only vertical bone changes[31]. In a re-entry study, Van der zee et al. monitored changes in vertical bone levels at adjacent teeth following different hard tissue augmentation procedures. Their results demonstrated a minor vertical bone resorption of -0.34 mm at the end of 12 months and concluded that the bone loss observed was not clinically relevant [32]. Our findings showed that the most vertical changes occurred on the facial were distal sites on teeth positioned mesial to the implant lost -0.33 mm and mesial sites on teeth positioned distal to the implant lost 0.39 mm. These findings seem to be remarkably similar to those found by Van der zee et al[32]. A similar trend was noted on the changes in the mean lingual height (-0.23 mm in distal sites of mesial teeth; -0.21 mm in mesial sites of distal teeth). Perhaps the key inference from these and similar studies is that flap reflection during surgery results in minimal loss of vertical bone height in teeth involved in flap reflection, as assessed either radiographically or clinically. Few unique aspects about the present study are that: A) It was able to measure horizontal bone width changes through CBCT (which if pronounced may be a risk indicator for future recession), and B) Attempting to find a correlation between tissue thickness and the degree of expected bone loss following flap elevation. While this study confirmed bone loss of varying magnitudes in the horizontal dimension, we found no significant correlation between the soft and hard tissue thickness and any of the dimensional changes noted.

While the common notion associated with FTFs is that they cause bone loss, the effect of flap elevation on alveolar bone has been a topic of contention for a long time. There is conflicting evidence regarding significant benefit or lack thereof, of a flapless surgical procedure compared to traditional flap elevation. In studies evaluating single implants placed via flapless or minimally invasive approach, similar MBL was noted when compared to a flapped implant placement [11, 33-35]. Specific to tooth extraction and alveolar ridge preservation procedures, animal studies did not demonstrate a significant difference in alveolar bone loss between flapless, FTF or STF elevation [1, 9]. Similarly, no histologic and histomorphometric differences were reported between flap and flapless approach in humans [36]. In contrast, Barone et al., with their human study and Fickl et al., in a canine study, showed that more bone resorption occurred with a full thickness flap in post extractive sockets [37, 38]. However, whether the magnitude of the loss is clinically meaningful or not, the evidence remains inconclusive [39]. The main concerns with the available evidence being lack of long-term clinical studies, inclusion of a control group for comparison and heterogeneity of the existing data, which limits the possibility of drawing any definitive conclusions. While there have been several clinical studies conducted to explore peri-implant bone changes following flap versus flapless surgery, there is scarce evidence evaluating the effect on adjacent teeth. Flapless surgery has certain benefits such as decreased surgical time and post-operative discomfort, minimal bleeding, and inflammation [33, 40]. However, it is important to note that bone remodeling should be expected even when a dental implant is placed via a flapless approach and should be considered as a natural sequela of the surgery itself. But the question remains if the resultant bone loss during FTF elevation is significant enough to cause a long-lasting detrimental effect affecting either the implant success or periodontium of the adjacent teeth. The evidence, including the current findings do not seem to support the aforementioned statement.

One of the main limitations of this study is that it exclusively looked at teeth in the posterior area, which usually has thicker bony plates. This fact may have influenced the magnitude of bone remodeling. This may as well explain the tendency of bone loss to be more at 1mm compared to 3 and 5 mms. The same should be considered true for distal bone which is typically thicker than mesial bone [41, 42]. It is important to keep notice that this study population was made up of the same cohort of a randomized clinical trial involving implant placement in the edentulous site adjacent to two teeth (which were included in the present study) [28]. To control for KM as a confounder in the mentioned cohort, presence of ≥ 2 mm of KM was considered in the inclusion criteria. This made the assessment of KM (being a component of the periodontal phenotype) as an independent variable not possible.

The pattern of bone loss seemed also to be related to proximity of the implant site, most likely related to surgical trauma [43]. The inclusion of a control group (flapless) would have allowed a comparative analysis, perhaps a direction that future studies can take. Since our study included only premolar and molar regions, the morphology of the roots could have played a role in the bone remodeling [44]. The FTF only included the adjacent teeth, as well as the presence of scattering at T1 in the CBCTs due to the presence of the dental implant [45, 46], which could influence the measurements performed at the adjacent teeth, hence the findings must be interpreted accordingly. Though difficult to perform, it would be interesting if a similar study was performed using STF elevation, which may concur or refute previous claims of superiority of STF elevation in terms of preserving bone dimensions [1] when compared to control [9]. Finally, the adjacent teeth at implant sites were periodontally healthy. The impact of fixed restorations at adjacent teeth and less ideal situations such as presence of periodontal disease is unknown and was beyond the scope of the current study.

Conclusion

A preventive effect from bone loss maybe expected for surfaces with bone thickness > 2mm, and bone thickness at baseline appears to influence the extent of horizontal bone remodeling. The amount of bone remodeling seems to be more pronounced at the facial bone crest as compared to the lingual. The overall magnitude of bone loss following FTF either vertically or horizontally seems to be very minimal (<0.4 mm) and is not of clinical significance, at least for the posterior regions included in this study. FTF can thus be utilized during periodontal and implant surgery in the posterior zone for better access and visibility.

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Table and Figures Legends

Table 1: 1A. Changes in facial and lingual bone by bone thickness at T0. Results of linear model using GEE. **1B.** Changes in the facial width at level 1, 3, and 5 mms by Facial soft tissue thickness at T0. Results of linear model using GEE.

Figure 1: Sequence of clinical incisions for implant placement. (A) Presurgical baseline (B) Mid-crestal and intrasulcular incisions on the adjacent teeth. (C) Full mucoperiosteal flap elevate on prior to implant placement.

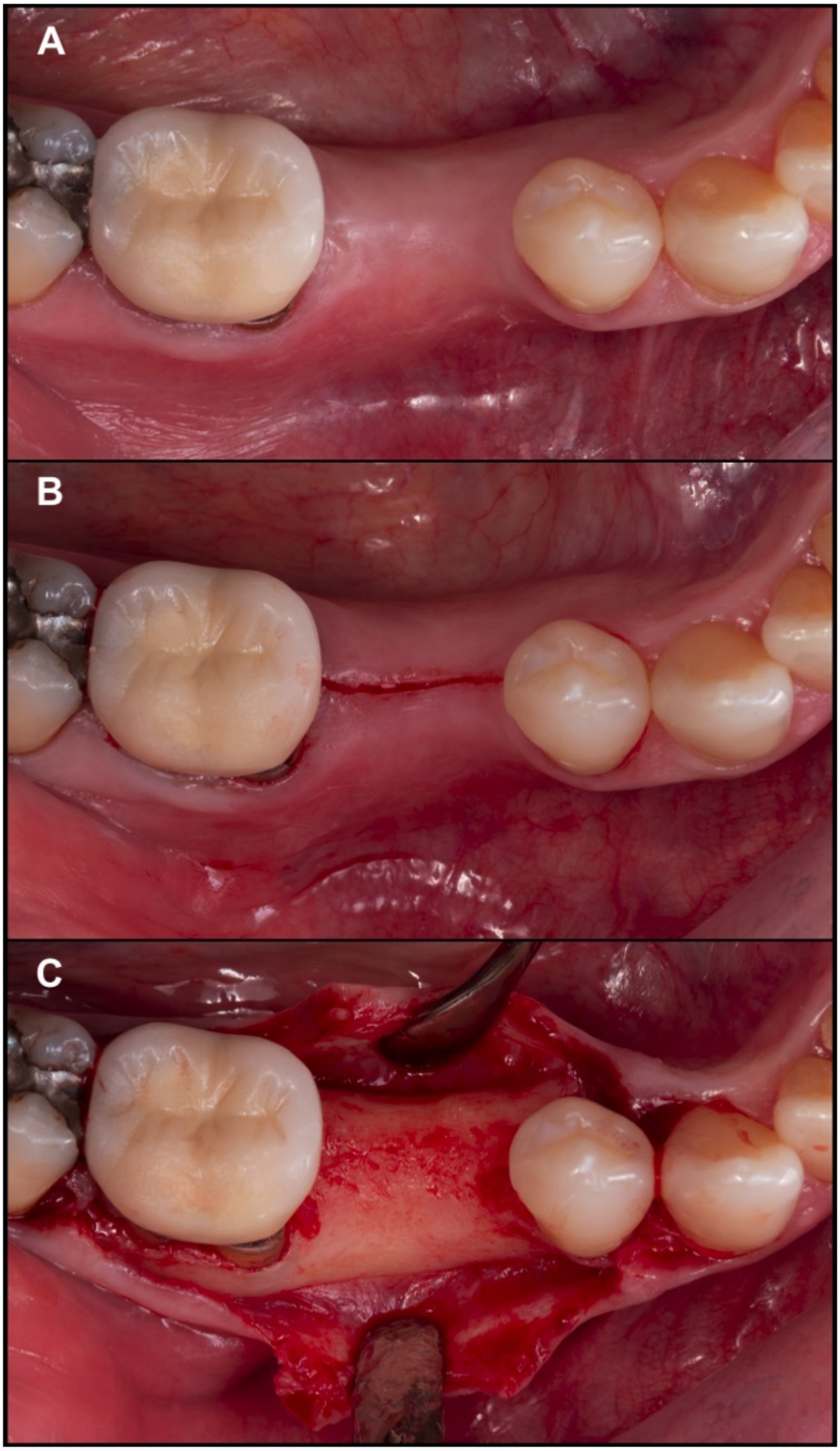
A
B
C

Figure 2: Multi-panel illustrating linear measurements. **(A)** Sagittal section was made at the mesial, middle, and distal of the adjacent teeth. Horizontal reproducible landmark (yellow line), vertical mid-facial and mid-lingual/palatal bone measurements (green lines), highest baseline mid-facial or mid-lingual line + 1, 3 and 5 mm (blue dotted) and horizontal bone changes at the predetermined reference points (white lines) of each adjacent tooth. **(B)** Sagittal section was made at the middle of each adjacent teeth. Blue line represents the superimposition of an STL onto a DICOM file. Facial/lingual soft (green line) and bone (yellow line) tissue thickness at baseline.

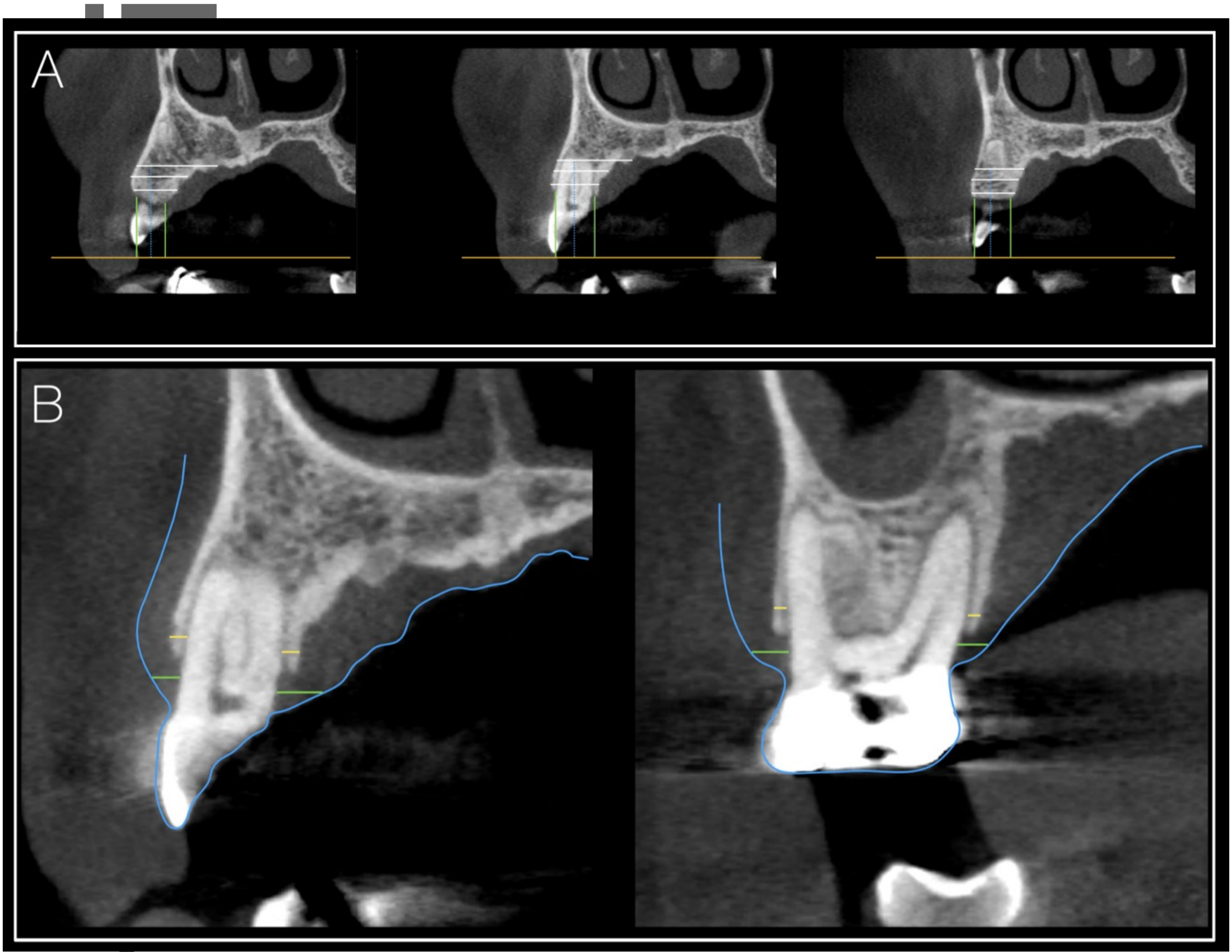

Figure 3: **A-** Changes in the facial heights over time by location; **B-** Changes in facial height over time by site and relative position of the tooth; **C-** Changes in the lingual heights over time by location; **D-** Changes in facial height over time by site and relative position of the tooth.

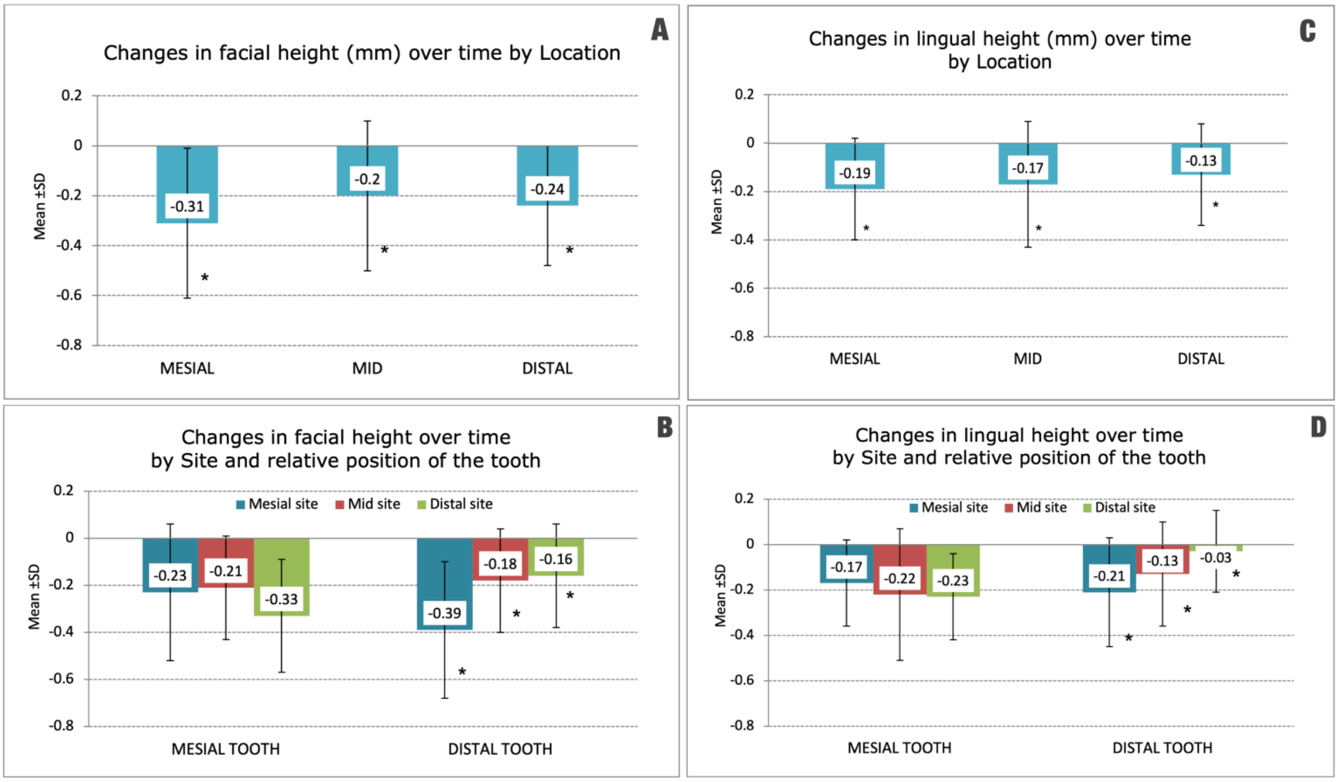

Figure 4: An illustration portraying the vertical bone lost facially and lingually on the mesially and distally adjacent teeth. *The magnitude of bone loss in this illustration is not standardized with the CBCT values. For an accurate depiction of the amount of bone loss, please check the values reported in Figure 3.

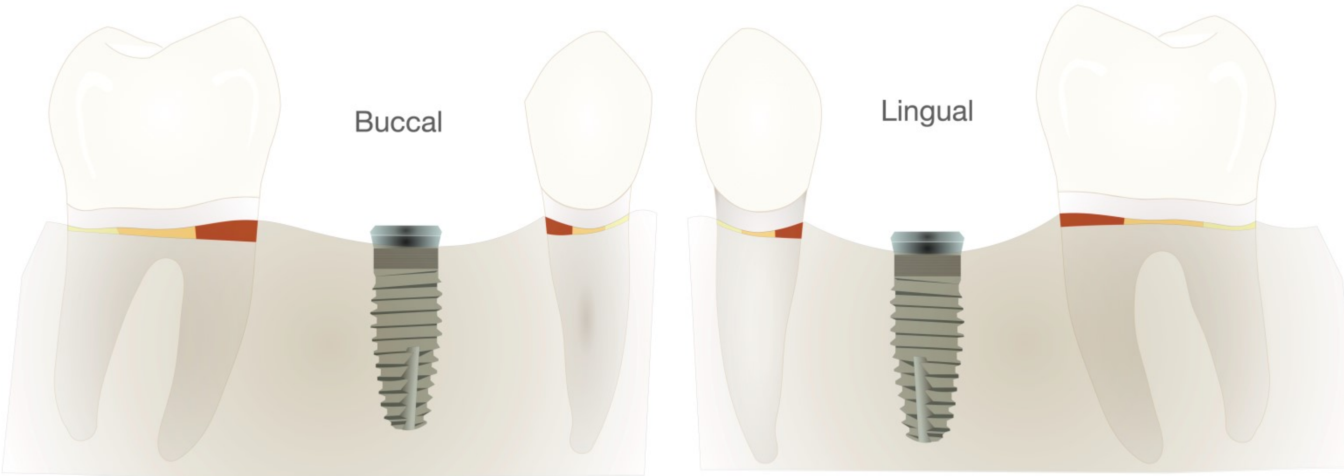

Figure 5: A- Changes in width at 1 mm over time by location; **B-** Changes in width at 1 mm over time by site and relative position of the tooth. **C-** Changes in width at 3 mm over time by location; **D-** Changes in width at 3 mm over time by site and relative position of the tooth. **E-** Changes in width at

5 mm over time by location; **F-** Changes in width at 5 mm over time by site and relative position of the tooth.

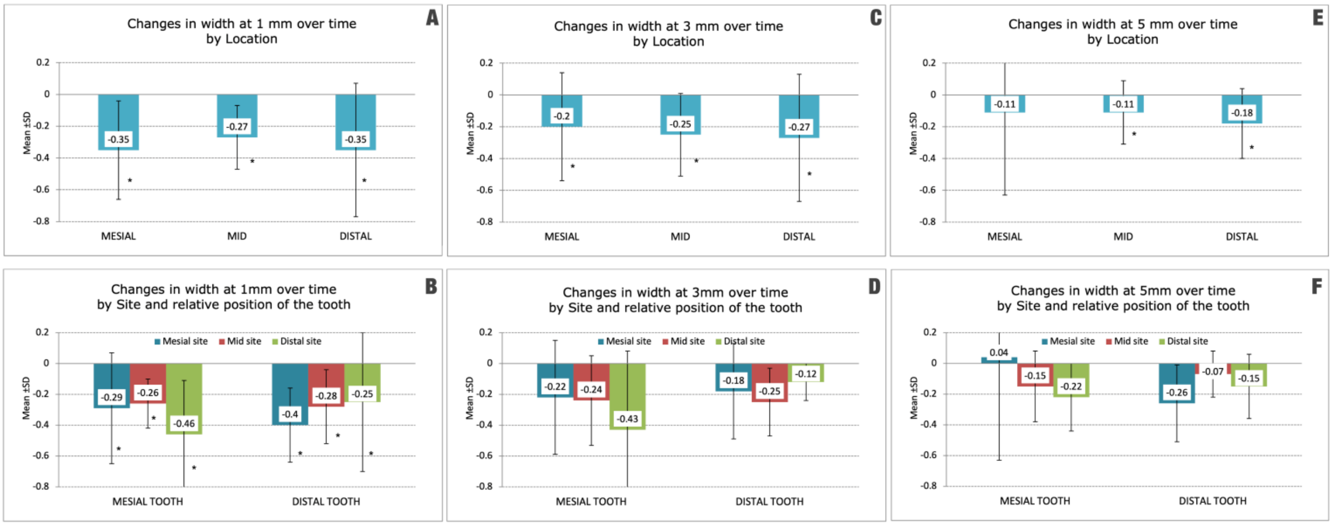

Figure S1 (see figure S1 in online Journal of Periodontology)**:** Lingual bone loss by lingual bone thickness at T0 demonstrated a quadratic relationship between both parameters. Bone loss was very high when the baseline bone thickness was thinner (≈1-1.5mm). Wider thickness represented a good control of bone loss. For bone thickness higher than 2mm, slight or no bone loss was observed.

Figure S2 (see figure S2 in online Journal of Periodontology)**:** A) Facial and lingual tissue thickness at T0 compared to T1. B) Facial and lingual bone thickness at T0 compared to T1.

Table 1A. Changes in facial and lingual bone by bone thickness at T0. Results of linear model using GEE.

Bone Thickness at T0	**MESIAL**	
	Beta (95% CI)	**p-value**
Facial bone thickness at T0	0.05 mm (-0.02 0.12 mm)	0.151
	Beta (95% CI)	**p-value**
Lingual bone thickness at T0	0.18*** mm (0.12 0.24 mm)	<0.001

*p<0.05; **p<0.01; ***p<0.001

Table 1B. Changes in the facial width at level 1, 3, and 5 mms by Facial soft tissue thickness at T0. Results of linear model using GEE.

	Dimensional Changes	MESIAL		MID		DISTAL	
		Beta (95% CI)	**p-value**	**Beta (95% CI)**	**p-value**	**Beta (95% CI)**	**p-value**
Facial soft tissue thickness at T0	**Changes in width at 1mm**	0.05 mm (-0.13 0.23 mm)	0.573	-0.05 mm (-0.18 0.07 mm)	0.386	0.05 mm (-0.15 0.25 mm)	0.629
		Beta (95% CI)	**p-value**	**Beta (95% CI)**	**p-value**	**Beta (95% CI)**	**p-value**
	Changes in width at 3 mm	0.07* mm (-0.11 0.26 mm)	0.437	-0.11 mm (-0.25 0.04 mm)	0.155	-0.07 mm (-0.20 0.206 mm)	0.280
		Beta (95% CI)	**p-value**	**Beta (95% CI)**	**p-value**	**Beta (95% CI)**	**p-value**
	Changes in width at 5 mm	-0.20 mm (-0.55 0.16 mm)	0.280	-0.02 mm (-0.13 0.10 mm)	0.773	-0.14 mm (-0.30 0.02 mm)	0.092

*p<0.05; **p<0.01; ***p<0.001

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** Tapered Tissue Level implant, BioHorizons®, Birmingham, AL.
†† dPTFE, Osteogenics Biomedical, Lubbock, TX.