

Volumetric Facial Contour Changes of Immediately Placed Implants with and without Immediate Provisionalization

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I-Ching Wang contributed to conception, design, data acquisition and interpretation, statistical analyses and draft of manuscript.

Hsun-Liang Chan contributed to the data analysis and critical review of manuscript.

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Hom-Lay Wang Contributed to conception, design, surgery, data interpretation, and critically revised the manuscript.

Abstract

Introduction: Whether immediate provisionalization can preserve facial tissue contour remains undetermined. The goal of this 12-month randomized controlled clinical trial was to compare 3-dimensional (3D) ridge changes after immediate implant placement with and without immediate provisionalization. **Methods:** Forty participants with an unrestorable maxillary anterior or premolar tooth were randomized to receive either a provisional crown (test) or standard healing abutment (control) after immediate implant placement. In each participant, three digital models taken before implant surgery, final crown delivery (4-month) and final follow-up (12-month) were registered to analyze linear deviation in 3D and volume changes of ridge contour at the implant site. **Results:** The mean value of mid-facial linear 3D spatial resorption ranged from 0.1 to 0.7 mm. Significant difference of linear changes of facial contour was noted over time and not between the groups. Facial volume changes at

12 months remained significantly higher in the control group than in the test group (17.4 vs. 11.9%, $p=0.04$).

Conclusion: Linear changes of facial soft-tissue resorption at immediately placed implants were independent of immediate provisionalization. However, immediate provisionalization showed better volume preservation at the esthetic concern area (mid-facial margin and 2 to 6mm above) at the final 12-month follow-up.

One-sentence summary: Immediate provisionalization showed potential to preserve ridge contour volume at mid-facial region.

Introduction

In the era of unprecedented prevalence of dental implant therapy, post-extraction immediate implant remained an alluring choice to the clinician and patients on the strength of instant esthetics and reduced total treatment time. Following the quest for long-term survival outcome^{1,2}, the focus of implant therapy has now transformed into the pursuing of implant success in esthetics. The esthetic outcome of implant therapy was not just examined the harmonious of soft tissue architecture^{3,4}, but also the stability of facial tissue topography following post-extraction bone remodeling^{5,6}.

The dimensional changes following immediate placed implant into freshly extraction socket proved to be inevitable^{7,8}. The most common concern of immediately placed implant is the mid-facial mucosal recession following the tissue remodeling after extraction^{2,4,9}. So far, several techniques have been developed in an attempt to overcome this challenge, these including but are not limited to: immediate provisionalization^{10,11}, flapless surgical approach^{1,12}, CT graft^{13,14}, and lingualized or cingulum implant placement^{15,16}.

Thick buccal plate (≥ 1 mm), thick mucosal phenotype (>1 mm) and ideal 3-dimensional (3D) position have been advocated for optimizing the esthetic outcome and for minimizing the concerns of immediate implant placement^{6, 17, 18}. Moreover, immediate provisionalization was endorsed as one possible way to support the surrounding soft and hard tissues^{19, 20}. Yet, the contribution of simultaneously immediate provisionalization to the esthetic outcome of immediate implants remains controversial²¹⁻²⁴. Thus, the purpose of this study was to assess the three-dimensional volumetric hard and soft tissue changes following immediate implant with or without immediate provisionalization.

Material and Methods

This randomized controlled study randomly assigned 40 participants with an unrestorable maxillary anterior or premolar tooth into either the test (fabricated to support the peri-implant soft tissues following tooth extraction) or the control (healing abutment occupying the most of socket size) group. This study was approved by the human subject review committee of the University of Michigan (protocol # HUM00070747) and was conducted in accordance with the Helsinki Declaration of 1975, as revised in 2013. The study was registered at clinical trial.org under NCT01925339. Participants who participated in the study were given informed consent in both oral and written format. All participants signed the informed consent before proceeding with the study. Study group randomization, allocation, and participant flow was reported in supplementary Figure 1 (see supplementary Figure 1 in online Journal of Periodontology). This study was focused only on the volumetric changes after immediate implant with or without immediate provisionalization. Briefly, all implants were placed at the cingulum position, aiming for 3 mm below the mid-facial mucosal margin, and achieved primary stability ≥ 30 N-cm. The gap between the implant and socket wall was filled with particulate allografts⁵. Clinical procedures of intervention and corresponding radiographs in both groups were illustrated in supplementary Figure 2 (see supplementary Figure 2 in online Journal of Periodontology). Baseline buccal bone thickness (measured 1mm apical of

the crest) > 1.0 mm was regarded as thick buccal bone, and thickness ≤ 1.0 mm was deemed as thin bone wall phenotype⁵. Similarly, baseline mucosal thickness > 1.0 mm was categorized as thick mucosal phenotype, and mucosal thickness ≤ 1.0 mm was considered as thin mucosal phenotype²⁵. CBCT scans[¶] at baseline and 4-month postop were superimposed using 3D imaging software[¶] to linearly measure the crestal bone changes and bone thickness changes at early healing stage [supplementary Figure 3, (see supplementary Figure 3 in online Journal of Periodontology)]. In current paper, additional stratified analysis based on bone morphotype, gingival biotype, and tooth location (anterior vs. posterior) were carried out to detect the differences of tissue alteration represented on the digital model.

3D spatial deviation analysis

Three digital models were obtained by scanning the stone models obtained at baseline (T0), 4-months postop visit (T1) and the final visit (T2) using a laboratory optical scanner[‡]. The average resolution of 3D sensor without thinning was 30 μ m with 20 μ m standard deviation. STL files of digitalized models were introduced into 3D digital inspection software[§]. Each comparison was carried out using T0 model as the baseline. In attempt to achieve the best 3D registration, X, Y, and Z coordinates were aligned first using unchanged reference point-based approximation (all tooth surfaces) and then the “global registration” using automated algorithm of point clouds. The “3D compare” built-in function allowed the 3D spatial deviation value to be generated as spatial discrepancy between two digitalized models. The average distance between two surfaces was depicted in 3D color map, and the global deviations at various points were measured at 2 mm intervals (from the mucosal margin to 10 mm above; 2-mm-radius point data) in 3 cross-sectional planes (mid-facial, mesial, and distal papilla) (Fig. 1). Furthermore, standardized and repeatable measurements on the cross-sectional planes were accomplished by the reference of 1 x 1 x 1 mm grid lines, which were in accordance with the 3D coordinate system of individual model. The final measurements

were narrowed down to 0.2-mm-radius point data to eliminate any potential inaccurate points caused by defective model or unwanted areas.

Volumetric analysis

For the purpose of detecting volume changes, the region of interest (ROI) at each of the three digital models was chosen with the lower and upper boundaries at 2 mm and 6 mm above the mid-facial margin, respectively, and enclosed by two bucco-lingual cross-sectional planes crossing the mesial and distal papilla. In order to standardize the measurement, the coordinate X-Z axes of each model was aligned to the reference model with the X-axis antero-posteriorly perpendicular to the tangent line connecting the most buccal surfaces of the adjacent teeth at the mid-facial point). The coronal, apical, mesial and distal boundaries of the ROI were flattened surfaces automatically selected by the software with the tangent “filling” technique. Finally, the polygon object was generated by closing the boundaries, and the volume (mm^3) was calculated and compared the volumetric changes over time and between groups in percentage (%) (Fig. 2).

One independent masked-examiner (IW) performed the repeated measurements 3 times every other week at randomly chosen 5 participants. Only when the intra-examiner *Cohen's kappa* values were > 0.8 were the remaining measurements started.

Statistical analysis

All data were first analyzed descriptively and expressed as mean values (\pm standard deviation [SD]). The normal distribution of observing data of present study was determined by the Shapiro-Wilk test ($p > 0.05$). Accordingly, independent t-tests were performed to analyze the difference of volumetric measurements between two groups. Repeated measures two-way ANOVA tests were conducted to compare the differences of 3D deviation analysis within group and between three time-points. The interactions of categorical variates (tissue phenotype) on the main outcomes were compared using three-way ANOVA, and the

effects of continuous covariate such as bone/ soft tissue thickness (in mm) was analyzed by general linear model (ANCOVA with Bonferroni adjustment). Pearson correlation coefficient (r) was calculated to evaluate the relationship between the dimension changes and tissue phenotype. All statistical tests were performed by a software package[†] and the level of significance was set at $\alpha = 0.05$.

Results

Totally, 38 participants (test: 18 and control: 20) completed the study at 12 months and were included in the study analysis. Among them, the test group was comprised of 10 anterior teeth and 8 premolars; the control group included 10 anterior teeth and 10 premolars. Table 1 illustrates the baseline data between test and control group and between anterior and posterior teeth. All baseline data showed no statistical significant different ($p > 0.05$) except implant apico-coronal position between two groups (test vs. control: 2.7 ± 0.7 vs. 3.4 ± 0.6 mm, $p < 0.01$) and lingual gap [0.3 ± 0.4 in test and 0.9 ± 0.9 in control group ($p < 0.01$)].

Dimensional changes of bone crest based on CBCT scan at 4 months

The global changes of bone crest at 4-month post-implant were reported in another part of this clinical trial²⁶ that 1.6 ± 0.6 and 1.7 ± 0.6 mm were found in test and control group, respectively. This includes 1.5 ± 0.7 vs. 1.4 ± 0.6 mm horizontal bone resorption and 0.3 ± 0.4 vs. 0.7 ± 0.6 mm vertical bone resorption (test vs. control, respectively). Only the vertical resorption of buccal bone crest showed test group resorbed significantly less than the control group ($p = 0.02$). On the palatal side, the resorption of bone crest was similar between two groups (test vs. control: horizontally: 0.6 ± 0.6 vs. 0.6 ± 0.5 mm; vertically: 1.0 ± 0.5 vs. 1.1 ± 0.7 mm; overall: 1.1 ± 0.45 vs. 1.3 ± 0.74 mm). The additional three-way ANOVA analysis of current report didn't reveal any significant influence from bone phenotype or mucosal phenotype on the difference of crestal changes (buccal or palatal) between the two groups.

Further stratified analysis of tooth location didn't show further significant impact on the difference between two groups, except for palatal crest horizontal resorption (mean: 0.4 mm in anterior, 0.8 mm in premolar area, $p=0.02$). The highest crestal spatial changes on the buccal aspect occurred in the control group with thin mucosal phenotype and thin bone phenotype jointly in the anterior sextant (2.3 ± 1.4 mm); however, there was no significant difference between the two groups nor the influence of tooth location ($P>0.05$).

Dimensional changes of bone thickness based on CBCT scan at 4 months

The horizontal resorption of buccal bone plate at the implant platform added up to 23.9% (test) and 23.3% (control), and of the palatal bone wall was 18.2% (test) and 28.0% (control). All the reduction of bone thickness at different levels (2-mm interval above the implant platform) failed to show significant difference between two groups; furthermore, after adjusting the covariate of implant vertical position, bone phenotype or mucosal thickness fails to show significant difference.

Collectively, the percentage of horizontal resorption in anterior region at 4 mm above platform was significantly higher (28.2 vs. 10.7%, $p=0.02$) compared to premolar area; although not reaching the significance, but the horizontal resorption at implant platform and 2 mm above platform presented with dramatic difference (28.2 vs 18.9% and 23.2 vs 12.1%, respectively). At the palatal aspect, the horizontal changes of crest bone were significantly lower in the anterior zone (0.4 vs. 0.8 mm, $p=0.02$), and similar result was found in the horizontal reduction of bone thickness at the palatal platform level (14.5 vs. 32.4% (0.2 vs 0.5 mm), $p=0.04$).

In the test group, 8 participants had thin bone phenotype, and 10 had thick bone phenotype. In the control group, thin versus thick was 8 versus 12 participants. In thin bone phenotype, the percentage of horizontal bone resorption at 2 mm above platform was significantly higher than thick bone phenotype (25.5 vs. 12.7%, $p=0.05$), and similar pattern was found in 4 mm

(28.3 vs. 14.5%) and 6 mm (15.9 vs. 28.8%) above the platform. In terms of palatal side, no significant differences were found, but thick phenotype exhibited much higher horizontal resorption at the palatal platform (29.2 vs. 13.3%, $p=0.07$).

For the mid-facial mucosal thickness, in test group, 15 had thin tissue phenotype and 2 possessed thick tissue phenotype while in the control group, 15 had thin phenotype and 4 had thick tissue phenotype. Overall, there was a moderately positive correlation between mid-facial mucosal thickness and buccal bone thickness at platform ($r=0.36$, $p=0.03$), 2mm ($r=0.44$, $p=0.01$), 4mm ($r=0.46$, $p=0.01$), 6 mm ($r=0.43$, $p=0.02$), and 8 mm above the platform ($r=0.48$, $p=0.05$). The reduction of bone thickness at 2mm ($r= -0.46$, $p= 0.01$) and 4mm (-0.45 , $p< 0.01$) above platform significantly negatively correlates to the mid-facial mucosal thickness and this significant difference lies in the anterior sextant ($r= -0.59$, $p< 0.01$ and -0.58 , $p=0.01$, respectively).

The distance between the implant and the outer surface of buccal bone plate was negatively associated with the horizontal reduction percentage at the platform and 2 mm above platform ($r=-0.4$, $p=0.02$).

3D spatial deviations

The majority of the mean 3D spatial deviation from baseline model in linear measurements were significantly higher at T2 than at T1 in both groups, suggesting there was a continuous change between 4- and 12-months after implant placement (Table 2). Negative value of 3D spatial deviation indicates the resorption of ridge contour compared to the baseline digital model. General trends of the mean deviation in the control group was higher than that in the test group but without statistical significance in all measured sites on the facial side at both time points. (Figure 3)

After adjusting for mid-facial mucosal thickness, the 3D deviation after 1 year (T2) demonstrated a significant difference between the two groups at 4 mm level, especially in the premolar area (test vs. control: -0.34 ± 0.12 mm vs. -0.84 ± 0.13 mm (mean \pm SE), $p=0.02$).

Volumetric reduction

At T1 (post-op 4 months), volume reduced to 94.2% (test) and 92.2% (control) with a p-value of 0.08. The test group with immediate provisionalization preserved significantly higher percentage of tissue volume at T2 (1-year) compared to the control group at esthetic-concerned area ROI (remaining volume 88.1% vs. 82.6%, $p=0.04$) (Fig. 4). In other words, loss of volume in test group (11.9%) was significantly lower than the control group (17.4%). Difference between two groups in the anterior sextant and the premolar area was not significant ($p > 0.05$). Although two-way ANOVA didn't find significant interaction effect between mucosa phenotype and bone phenotype on volume reduction at T2 ($p > 0.05$), but they both showed a tendency that higher reduction occurred in the thin mucosal phenotype and bone phenotype.

Discussion

In the present study, early contour changes of buccal bone plate were analyzed at separate level. Foremost, for the horizontal dimension of bone crest, the remodeling on the buccal aspect was similar between two groups; on the contrary, the vertical dimension demonstrated significantly less resorption in test group. Secondly, the bone plate thickness at the implant platform reduced approximately 24% (buccally), which was in agreement with the previous animal reports with similar diminution amount of grafted (25%)²⁷, and non-grafted sockets (30%)²⁸.

Botticelli et al. had observed the spontaneous healing at 4-month re-entry following immediate implant installation with flap elevation, they reported a buccal crestal resorption of 1.9 ± 0.9 mm horizontally and 0.3 ± 0.6 mm vertically; moreover, the buccal bone plate underwent horizontal resorption of 56% ⁷. In another clinical study at 4-month re-entry following immediate implants with natural healing, a 36% horizontal resorption of buccal crest (1.1 mm) and vertical reduction of 1.0 mm was denoted ²⁹. Recently, the same group published the results of dimensional variations when grafted the gaps with deproteinized bovine bone minerals with 10% collagen (DBBM-C) which stated a significantly difference of buccal crest reduction horizontally between grafted and non-grafted- sites (1.1 mm (29%) vs. 1.6 mm (38%)) with similar 0.3 mm vertical crest reduction ³⁰. In current investigation, the horizontal resorption of buccal bone wall was comparatively less which could be attributed to the grafting with allograft bone particles ³¹, flapless surgical protocol ^{12, 32, 33} and lingualized (cingulum) implant position ^{34, 35}.

On the other hand, the vertical buccal crest resorption in current investigation (pooled mean: 0.5 ± 0.6 mm, 0.2 mm [test] vs. 0.7 mm [control]) was comparable to the results of 0.3 mm revealed by Botticelli et al. with semi-submerged natural healing ⁷ or 0.1 mm ³⁴ to 0.3 mm ³⁰ in sites grafted with bovine bone; yet, much less than other studies with flap elevation protocol after natural healing, such as 1.0 mm by Sanz et al. ²⁹, or 1.3 mm by Chen et al. ³⁴. Vertical component of crestal bone changes mainly are under the influences of surgical trauma ³⁶, the vertical position of rough-to-smooth surface junction of the implant ³⁷, post-extraction physiological bone modeling/remodeling related to different periodontal phenotype ^{5, 35, 38}, and "critical gap size" with or without grating to sustain the new bone formation and compensate for the crestal resorption ^{39, 40}. It has been shown in an animal study that lingualized and deeper implant position had less vertical resorption of buccal bone crest compared to centered position in extraction sockets ⁴¹. In the present study, the implant platform was flush with the buccal bone crest indicating 0.5 mm subcrestally placement and in combination with lingualized (cingulum) position, may compensate for the bone

remodeling as well as for the reformation of biologic width vertically. This was in line with previous observations reported by Chen et al³⁴.

Another attempt in the current experiment was to analyze the influence of different periodontal phenotype among individuals and the different tissue response between incisors and premolar area. It has been shown that there's significant difference of the mean thickness of buccal bone between anterior and premolar sites (0.8 vs. 1.1 mm), and majority (87.2%) of buccal walls in the anterior sites had a width \leq 1mm, and the corresponding percentage in posterior area was 59.3%⁴². Similar results were also revealed by a CBCT investigation, significant difference between anterior and premolar sites was also found (0.8 vs. 1.1 mm, median)⁴³. However, the observation in the current study was more profoundly different (1.0 vs. 1.6 mm, $p=0.02$); 55% (anterior) and 22% (posterior) were presented with thin phenotype. In a report by Chappuis et al., the fate of facial bone wall after extraction at 8 weeks can amount to a median vertical loss of 7.5 mm (62%) in thin bone phenotype, and 1.1mm (9%) in the thick bone phenotype in the esthetic zone⁵. For immediate implant in spontaneous socket healing, Ferrus et al. found that the vertical bone loss of buccal crest after 4-month can be twice at the anteriors as the premolar area³⁵. It was concluded the bone phenotype significantly affects the crest bone change that thick bony wall or larger gap exhibits smaller reduction of the height and width of the crest, which was in concordance with the findings in current study that the wider the distance between outer bone surface to the implant surface which included the bone thickness and buccal gap, the less the horizontal reduction in percentage ($r= -0.4$).

The benefits of immediate provisionalization are postulated to preserve the osseous and soft tissue architecture^{19, 20, 44, 45}. A recent study with 4-year follow-up showed significantly better tissue volume maintenance without any grafting for immediate implant provisionalization in the intact socket⁴⁶. Results from this study showed the volume of ROI (2-6 mm above the mid-facial margin) significantly demonstrated less resorption in test group after 1-year, and

the significant difference of linear changes in 3-dimension lies in the 4 mm coronal to mid-facial mucosa after adjusting for mid-facial gingiva thickness. In the present study, although bone modeling at 4 months didn't show significant difference between two groups; the buccal 3D deviation at the esthetic concern area (mid-facial margin and 2 to 6mm above) after 1 year demonstrated the tendency that test group rendered less resorption than the control group. It may be hypothesized that the more divergent sub-lingual contour (30 degree) found on the temporary abutment of current implant system compared to healing abutment (15 degree) preserve more soft tissue volume by mimicking the shape of anatomic root. It has been suggested that modifications in the facial "subcritical contour" elicit different modeling responses from peri-implant soft tissue⁴⁷. This is in agreement with the dual-zone concept proposed by Chu et al, which showed placing bone graft with an anatomic provisional crown reduces facial-lingual ridge collapse to less than 0.2 mm and increased peri-implant soft tissue dimension by 0.5-1 mm^{48, 49}. Linkevicius et al. showed vertical thickness of soft tissue strongly associated with crestal bone loss in healed ridge⁵⁰, whether the soft tissue volume preservation at crestal level can lessen the vertical bone loss in immediate implant placement requires future studies to clarify. A limitation in the current study would be the 3D analysis was attained from the stone cast at different time-points, which could express certain degree of deviation of accuracy.

The major obstacles of immediate implant therapy are the surgical skill for precise implant placement in the socket and the ability to predict amount of tissue remodeling after implant placement. These two challenges impede the wide application of this technique into daily practice^{2, 51}. Nonetheless, tissue remodeling after immediate implant is a dynamic process under multifactorial influence. It was generally acknowledged that thick tissue phenotype and bone thickness in addition to intact socket wall are the prerequisites for success of immediate implant^{6, 20}; with that in mind, on the basis of ideal 3D implant position, immediate provisionalization might further contribute to peri-implant tissue preservation.

Conclusion

Linear changes in three-dimension of facial soft-tissue resorption at immediately placed implants were independent of immediate provisionalization. However, immediate provisionalization showed higher volume preservation at the esthetic concern area (mid-facial margin and 2 to 6mm above) at the final 12-month follow-up.

Footnotes

[§] Puros[®], Zimmer Biomat Dental Inc., Carlsbad, CA, USA

[¶] Accuitomo 170 unit, JMorita Corp., Japan

^{||} Invivo Dental 5, Anatomage, San Jose, CA, USA

[‡] Activity 101 Dental 3D Scanner, Smart Optics, Germany

[§] Geomagic Control, 3D systems, Inc., USA

[†] IBM SPSS Statistics for Mac, Version 25.0, Armonk, NY: IBM Corp

Figures & Tables

Figure 1. 3D spatial deviation analysis (A) In the process of standardized 1-mm grid formation. (B) cross-sectional plane across the mid-facial gingival margin along the standardized Z-axis (also applied to mesial and distal papilla) (C) 3D deviation at different points of 0, 2, 4, 6, 8, 10 mm above mid-facial margin, mesial, and distal papilla were obtained based on the preset 2 mm-wide-radius; final measurement was acquired by average of the deviations in a 0.2 mm radius of point data

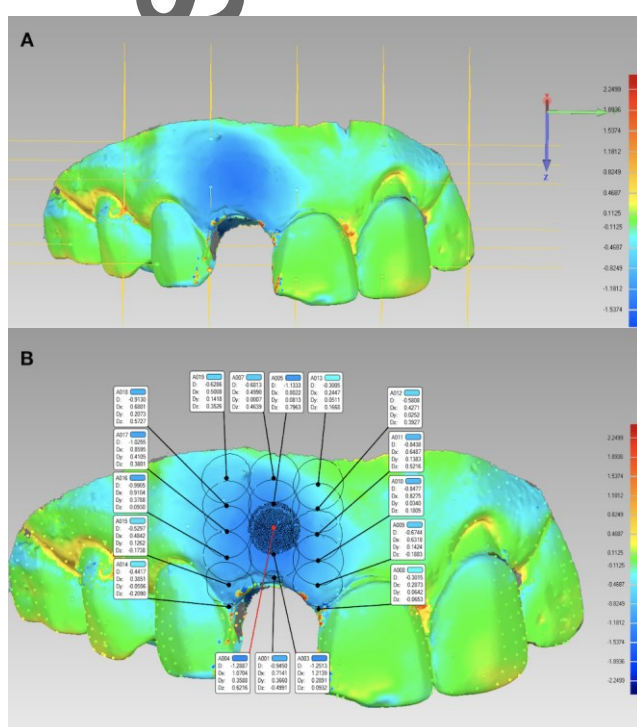


Figure 2. Volumetric analysis. Region of interest (ROI) was chosen as a rectangle area with a lower and upper limit at 2 mm (A) and 6 mm (B) above mid-facial margin. The mesial and distal limit of ROI was dictated by the parallel cross-sectional planes through adjacent papillae. (C) after trimming away the unwanted areas of mesh (D) edges of four mesh surfaces were “bridged” with flat surfaces by built-in function of Geomagic software. (E) Finally, the volume (mm^3) was calculated automatically and compared the volumetric changes in unit of percentage (%).

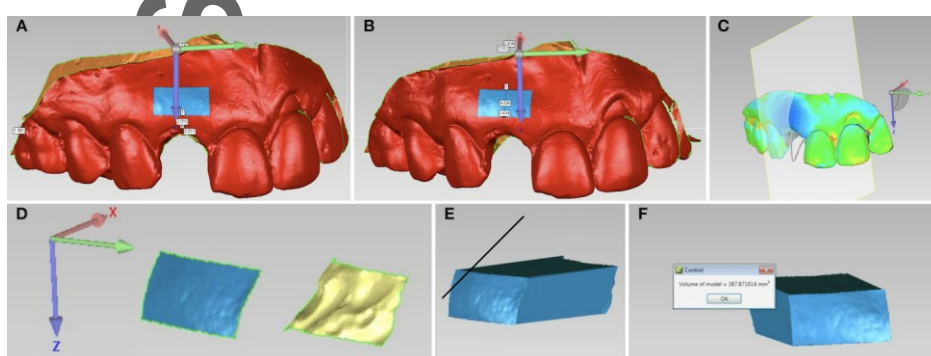


Figure 3. Box-plots of 3D spatial deviation (only presented with buccal surface) at 2-mm interval. Median and interquartile range were displayed at different height level above mid-facial mucosal margin. Left implant with temporary abutment exhibits more divergent profile compared to the right implant with healing abutment; and the implant platform was at 3 mm above the mid-facial mucosal margin.

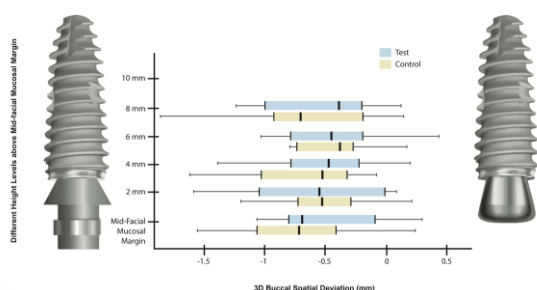


Figure 4. Changes of remaining volume at ROI region at different time-points. The difference between test and control group reached significance at T2 (post-op 1 year) (88.1% vs. 82.6%, test vs. control, *p=0.04).

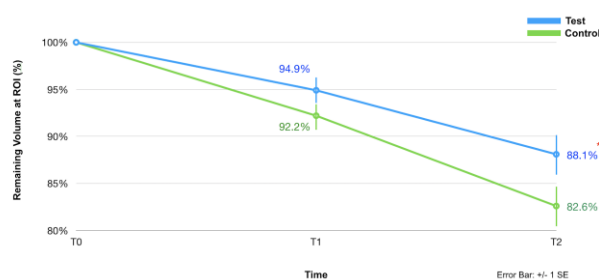


Table 1. Illustrates the baseline clinical characteristics between groups and tooth positions (anterior and posterior teeth).

Table 1. Baseline clinical characteristics between groups and tooth positions								
Mean±SD	Mid-facial mucosa thickness	Mucosal phenotype (Thin/thick)	Buccal bone thickness	Bone Phenotype (Thin/thick)	Buccal bone dehiscence depth	Implant apico-coronal depth	Buccal gap	Lingual gap
Test (n=18)	0.6±0.2	15/2	1.1±0.5	8/10	1.0±1.1	2.7±0.7	2.6±0.8	0.3±0.4
Control (n=20)	0.7±0.4	15/5	1.3±0.8	8/12	0.5±0.7	3.4±0.6	2.7±0.8	0.9±0.9
P-value	0.38	0.76	0.33	0.78	0.08	0.004*	0.8	0.009*
Anterior	0.6±0.2	2/17	1.0±0.6	11/9	1.0±1.0	3.1±0.7	2.4±0.8	0.3±0.5
Posterior	0.7±0.4	4/13	1.4±0.7	5/13	0.4±0.9	3.1±0.7	3.0±0.6	1.0±0.2
P-value	0.35	0.58	0.05*	0.09	0.10	0.9	0.01*	0.001*

Table 2. 3D spatial deviations from baseline. *represented significant difference of 3D deviation values ($p < 0.05$) between groups or between time-points **indicated that significant difference between different time points within control group, but not significant in the test group;

Table 2. Three-dimensional deviation at different levels above mid-facial gingival margin, mesial papilla, distal papilla, and mid-palatal gingival margin

Measuring position	Time-points	Differences between groups			between time-points
		Test	Control	p-value	p-value
Mid-facial margin (MF)	T1	-0.5 ± 0.5	-0.7 ± 0.5	0.18	<0.01*
	T2	-0.5 ± 0.5	-0.7 ± 0.5	0.19	
2mm above MF	T1	-0.3 ± 0.4	-0.4 ± 0.4	0.75	<0.01*
	T2	-0.5 ± 0.5	-0.5 ± 0.4	0.67	
4mm above MF	T1	-0.2 ± 0.4	-0.3 ± 0.6	0.26	<0.01*
	T2	-0.5 ± 0.4	-0.7 ± 0.5	0.32	
6mm above MF	T1	-0.3 ± 0.3	0.1 ± 0.4	0.45	<0.01*
	T2	-0.4 ± 0.4	-0.5 ± 0.5	0.74	
8mm above MF	T1	-0.2 ± 0.2	0.1 ± 0.3	0.2	<0.01*
	T2	-0.5 ± 0.5	-0.9 ± 0.6	0.63	
Facial Mesial papilla	T1	-0.3 ±	-0.5 ±	0.23	<0.01*

			0.4	0.6		
		T2	-0.2 ± 0.4	-0.4 ± 0.6	0.19	
	2mm above FMP	T1	-0.2 ± 0.3	-0.3 ± 0.4	0.11	<0.01*
		T2	-0.2 ± 0.3	-0.3 ± 0.3	0.14	
	4mm above FMP	T1	-0.1 ± 0.3	-0.1 ± 0.3	0.99	<0.01*
		T2	-0.1 ± 0.3	-0.3 ± 0.3	0.23	
	6mm above FMP	T1	-0.03 ± 0.4	0.01 ± 0.3	0.9	0.02*
		T2	-0.1 ± 0.4	-0.2 ± 0.2	0.65	
	8mm above FMP	T1	-0.02 ± 0.2	0.1 ± 0.1	0.19	0.048*
		T2	-0.2 ± 0.4	-0.2 ± 0.1	0.83	
	Facial Distal papilla (FDP)	T1	-0.3 ± 0.4	-0.5 ± 0.6	0.17	<0.01*
		T2	-0.2 ± 0.4	-0.6 ± 0.7	0.07	
	2mm above FDP	T1	-0.2 ± 0.3	-0.3 ± 0.3	0.4	<0.01*
		T2	-0.2 ± 0.3	-0.4 ± 0.5	0.14	
	4mm above FDP	T1	-0.1 ± 0.3	-0.04 ± 0.3	0.34	<0.01*
		T2	-0.2 ± 0.3	-0.3 ± 0.6	0.3	
	6mm above FDP	T1	-0.1 ± 0.3	0.1 ± 0.3	0.07	<0.01*
		T2	-0.2 ± 0.4	-0.4 ± 0.5	0.44	

8mm above FDP	T1	0.05 ± 0.3	0.03 ± 0.3	0.9	0.03*
	T2	-0.3 ± 0.6	-0.5 ± 0.7	0.25	
Mid-palatal margin (MP)	T1	-0.03 ± 0.3	-0.5 ± 0.5	<0.01*	<0.01*
	T2	-0.2 ± 0.4	-0.4 ± 0.5	0.07	
2mm above MP	T1	-0.1 ± 0.4	-0.5 ± 0.4	0.01*	<0.01*
	T2	-0.2 ± 0.3	-0.3 ± 0.4	0.27	
4mm above MP	T1	0.01 ± 0.4	-0.4 ± 0.4	<0.01*	0.01*
	T2	-0.04 ± 0.3	-0.2 ± 0.4	0.22	
6mm above MP	T1	-0.1 ± 0.3	-0.4 ± 0.4	0.05	0.04*
	T2	-0.1 ± 0.2	-0.2 ± 0.4	0.75	
8mm above MP	T1	-0.4 ± 0.4	-0.4 ± 0.4	0.38	0.02*
	T2	-0.2 ± 0.3	-0.1 ± 0.3	0.2	
Palatal Mesial papilla (PMP)	T1	0.04 ± 0.3	-0.3 ± 0.3	<0.01*	0.17**
	T2	-0.1 ± 0.5	-0.1 ± 0.5	0.58	
2mm above PMP	T1	-0.05 ± 0.3	-0.2 ± 0.4	0.02*	0.65**
	T2	-0.03 ± 0.4	-0.02 ± 0.3	0.95	
4mm above PMP	T1	0.06 ± 0.3	-0.3 ± 0.4	<0.01*	0.19**
	T2	-0.07 ±	-0.05 ±	0.69	

			0.3	0.3		
6mm above PMP	T1	0.07 ± 0.4	-0.2 ± 0.3	0.01*	0.69**	
	T2	-0.04 ± 0.3	-0.01 ± 0.3	0.67		
8mm above PMP	T1	0.01 ± 0.2	-0.1 ± 0.3	0.24	0.41	
	T2	-0.1 ± 0.5	-0.1 ± 0.3	0.86		
Palatal Distal papilla (PDP)	T1	-0.03 ± 0.4	-0.3 ± 0.5	0.07	0.02*	
	T2	-0.1 ± 0.3	-0.2 ± 0.4	0.07		
2mm above PDP	T1	0.02 ± 0.2	-0.2 ± 0.3	0.07	0.03*	
	T2	-0.1 ± 0.3	-0.1 ± 0.3	0.27		
4mm above PDP	T1	0.08 ± 0.3	-0.2 ± 0.3	0.02*	0.048*	
	T2	-0.1 ± 0.3	-0.1 ± 0.3	0.81		
6mm above PDP	T1	0.04 ± 0.4	-0.1 ± 0.3	0.26	0.46	
	T2	-0.03 ± 0.3	-0.1 ± 0.3	0.76		
8mm above PDP	T1	-0.04 ± 0.3	-0.1 ± 0.4	0.6	0.14	
	T2	-0.2 ± 0.3	-0.2 ± 0.3	0.76		

Supplementary material

Figure S1. CONSORT Study flow chart indicating screening visits, randomization and allocation and numbers of participants available for data analysis based on the CONSORT 2010 Statement.

Figure S2. Clinical steps of intervention and corresponding radiographs in both groups. Blue arrow indicates the flat (or concave) subgingival contour of immediate provisionalization.

Figure S3. (A, B) Voxel-based registration of two sets of DICOM data (white color image represents the pre-op baseline; green color image represents the post-op 4 months). (C) White dotted line represents the pre-op buccal bone plate/crest; black dotted line represents the post-op 4 months buccal bone plate/crest. The linear measurement of bone crest resorption and buccal bone thickness reduction can be analyzed at different level above the implant platform (2 mm-interval).

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