

Original Research

Received 02 June 2026

Revised 10 July 2026

Accepted 24 July 2026

Natural Resources for Human Health 2026, Vol. 6 (13s): 856–874

KEYWORDS:

3D volumetric assessment, Keratinized mucosa, Mucosal thickness, Peri-implant mucosa, Peri-implant soft tissue, Plaque index

Three-Dimensional Digital Quantification of Peri-Implant Mucosal Volume Using Intraoral Scanning

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ABSTRACT:

Background:

Peri-implant soft-tissue dimensions play an important role in maintaining peri-implant health and achieving stable esthetic outcomes. Three-dimensional (3D) volumetric assessment may provide additional quantitative information on peri-implant soft-tissue changes beyond conventional linear clinical measurements.

Aim:

To evaluate changes in peri-implant mucosal volume and thickness and to determine their associations with selected clinical and soft-tissue parameters over a 6-month follow-up period.

Materials and Methods:

This prospective comparative clinical study included 40 participants who were evaluated at baseline, 3 months, and 6 months. Peri-implant soft-tissue characteristics were assessed using 3D digital volumetric measurements and conventional clinical parameters. Peri-implant mucosal thickness, keratinized mucosa width, probing depth, plaque index, and bleeding on probing were recorded at the specified examination points. Changes in peri-implant mucosal volume were assessed over time and between groups, and correlation analysis was performed to determine associations between percentage mucosal volume gain and selected clinical parameters. Measurement reproducibility was

evaluated using intra- and inter-examiner intraclass correlation coefficients (ICCs).

Results:

Peri-implant mucosal volume demonstrated progressive changes over the 6-month follow-up period. At 6 months, percentage mucosal volume gain showed a strong positive correlation with mucosal thickness in Group A ($r=0.68$, $p<0.001$) and a moderate positive correlation in Group B ($r=0.55$, $p=0.012$). Keratinized mucosa width was positively correlated with volumetric gain in both groups, with a statistically significant association observed in Group A ($r=0.46$, $p=0.041$). Probing depth showed a significant inverse correlation with percentage volume gain in Group A ($r=-0.51$, $p=0.021$). Bleeding on probing demonstrated a borderline inverse association with volume gain in Group A ($r=-0.44$, $p=0.050$). At 6 months, the mean plaque index was 0.38 ± 0.21 in Group A and 0.59 ± 0.27 in Group B, with a statistically significant intergroup difference ($p=0.011$). The reproducibility of 3D volumetric measurements was excellent, with intra-examiner and inter-examiner ICCs of 0.96 and 0.93, respectively.

Conclusion:

3D volumetric analysis demonstrated excellent measurement reproducibility and provided quantitative assessment of peri-implant mucosal changes over 6 months. Percentage mucosal volume gain was associated with mucosal thickness, keratinized mucosa width, and selected clinical peri-implant parameters. Lower plaque accumulation was also observed in Group A at 6 months. 3D volumetric assessment may serve as a useful adjunct to conventional clinical evaluation of peri-implant soft-tissue stability.

INTRODUCTION

The clinical success of implant-supported rehabilitation is influenced by both hard- and soft-tissue stability around the implant. Although osseointegration and preservation of peri-implant bone are fundamental determinants of implant survival, the peri-implant mucosa also plays an important role in maintaining tissue health and achieving a favorable restorative outcome. Adequate soft-tissue dimensions contribute to the formation of a stable peri-implant seal, protection of the underlying structures, maintenance of peri-implant tissue health, and development of an appropriate emergence profile. In addition, the quantity and contour of peri-implant mucosa are closely related to the esthetic integration of implant-supported restorations, particularly in areas with high esthetic demands [1].

Following implant placement and prosthetic rehabilitation, peri-implant soft tissues may undergo dimensional remodeling. Changes in mucosal thickness, height, and contour can occur during healing and after restoration and may affect both the biological environment and the visual appearance of the implant-supported prosthesis. Therefore, assessment of peri-implant soft-tissue characteristics has become increasingly relevant during implant treatment planning, restorative procedures, and longitudinal maintenance. Conventional clinical evaluation commonly includes probing depth, mucosal recession, keratinized tissue measurements, and assessment of mucosal thickness using periodontal or transgingival techniques [2].

Although these conventional approaches provide valuable clinical information, most measurements are obtained at predetermined points and therefore provide only a limited representation of the complex three-dimensional (3D) soft-tissue architecture. Furthermore, transgingival measurements are invasive and may be associated with patient discomfort and measurement-related variability. Linear measurements may also fail to adequately describe localized changes in tissue contour or overall alterations in the volume of the peri-implant mucosa. These limitations have encouraged the development of non-invasive digital techniques for more comprehensive documentation of peri-implant soft-tissue morphology [3].

Digital dentistry has introduced 3D approaches that permit detailed recording of the oral surface anatomy. Intraoral scanners acquire optical surface data and generate digital models of the dentition and surrounding soft tissues without the need for

conventional impression materials. Their application in implant dentistry has expanded considerably because digital impressions can be rapidly obtained, stored electronically, and reproduced for subsequent analysis. Importantly, digital datasets obtained at different clinical stages can be superimposed, allowing spatial changes in the peri-implant region to be assessed over time [4].

3D digital analysis provides an opportunity to move beyond isolated linear measurements and evaluate the morphology of the peri-implant mucosa across a defined region of interest (ROI). By comparing sequential digital surface models, changes in tissue contours can be identified and expressed quantitatively as dimensional or volumetric differences. Such an approach may facilitate objective evaluation of soft-tissue remodeling after implant placement, provisional restoration, definitive prosthetic rehabilitation, or soft-tissue augmentation procedures [5]. Volumetric assessment is particularly relevant because peri-implant tissue remodeling may not occur uniformly. Localized thickening, flattening, or contraction of the mucosal contour may be difficult to characterize using measurements obtained from only one or a few reference points. 3D volumetric analysis can potentially capture these spatial variations and provide a more comprehensive representation of the overall change in soft-tissue morphology. It may also permit standardized comparison of tissue volume between different treatment stages and clinical conditions [6]. Another potential advantage of intraoral scanning is its non-invasive and repeatable nature. Once a digital scan has been acquired, the resulting 3D model can be archived and subsequently compared with additional scans obtained during follow-up. This approach may reduce the need for repeated invasive measurements while providing a permanent digital record of the peri-implant soft-tissue contour. The availability of sequential digital datasets may therefore be useful for monitoring tissue maturation, evaluating restorative procedures, and documenting changes following peri-implant soft-tissue interventions [7]. Despite these technological developments, several methodological considerations remain important when using intraoral scans for volumetric evaluation. Accurate definition of the ROI, consistent scan acquisition, reliable alignment of sequential datasets, and appropriate determination of reference boundaries are essential for obtaining reproducible volumetric measurements.

Differences in scanning conditions, soft-tissue mobility, surface geometry, and digital superimposition procedures may influence the calculated volume and should therefore be carefully controlled when designing quantitative studies [8], [9].

Consequently, standardized 3D assessment of peri-implant mucosal volume may provide an objective and clinically relevant method for characterizing soft-tissue morphology. Establishing a reproducible digital workflow could facilitate longitudinal monitoring and improve understanding of peri-implant soft-tissue changes following implant therapy. The present study was therefore undertaken to evaluate peri-implant mucosal volume using 3D intraoral scanning and digital volumetric analysis, with the aim of assessing the feasibility of this non-invasive approach for quantitative characterization of peri-implant soft-tissue morphology.

MATERIALS AND METHODS

Study Design and Ethical Considerations

A prospective comparative clinical study was conducted at a tertiary care centre from July 2025 to June 2026 to evaluate changes in peri-implant soft-tissue dimensions and 3D peri-implant mucosal volume over a 6-month follow-up period. The study included 40 implant sites in 40 patients, with each participant contributing one implant site to the analysis. The participants were allocated equally into two groups of 20 patients each according to the predetermined implant-planning protocol.

Group A underwent digitally optimized 3D implant planning using an integrated CBCT and intraoral scanning workflow.

Group B underwent conventional implant planning based on clinical examination and two-dimensional (2D) radiographic assessment.

The implant-planning approach constituted the principal methodological difference between the two groups. Following implant placement and completion of definitive implant-supported prosthetic rehabilitation, all participants underwent identical clinical and digital follow-up assessments at baseline, 3 months, and 6 months. Thus, the study evaluated longitudinal peri-implant soft-tissue changes following rehabilitation in relation to the implant-planning approach used during treatment.

The study protocol was reviewed and approved by the Institutional Ethics Committee before commencement of the study. The study was conducted in accordance with the principles of the Declaration of Helsinki. All participants received information regarding the study procedures, potential benefits, and possible risks and provided written informed consent before participation.

Study Population

Patients requiring single implant-supported rehabilitation were screened for eligibility. Participants fulfilling the predefined eligibility criteria were enrolled and allocated to the respective study groups according to the predetermined implant-planning protocol. Each participant contributed a single implant site to avoid clustering of multiple implant sites within the same individual. Clinical examinations and standardized digital intraoral scans were performed at baseline (T0), 3 months (T1), and 6 months (T2).

Inclusion Criteria

Participants were eligible for inclusion if they fulfilled all of the following criteria:

- Adults aged ≥ 18 years requiring single implant-supported rehabilitation
- Presence of a clinically stable osseointegrated implant suitable for definitive prosthetic rehabilitation
- No clinical evidence of implant mobility or peri-implant infection at baseline
- Clinically acceptable peri-implant soft-tissue condition at baseline, with no active peri-implant inflammatory disease
- Adequate peri-implant soft-tissue dimensions permitting standardized clinical and digital assessment
- Presence of a definitive implant-supported restoration with accessible peri-implant margins for clinical examination
- Adequate oral hygiene permitting reliable longitudinal assessment
- Willingness to maintain oral hygiene throughout the observation period
- Willingness to attend the scheduled baseline, 3-month, and 6-month follow-up examinations
- Provision of written informed consent

Exclusion Criteria

Participants were excluded if any of the following conditions were present:

- Uncontrolled systemic disease or medical conditions that could adversely affect wound healing or peri-implant tissue health
- Active periodontal disease or untreated peri-implant mucositis or peri-implantitis
- Clinical evidence of implant instability, mobility, or implant failure
- Previous radiotherapy involving the head and neck region or other treatment expected to substantially influence peri-implant tissue healing
- Current smoking or tobacco use, if applicable according to the predefined study protocol
- Poor oral hygiene that could interfere with standardized assessment or maintenance
- Acute oral infection or inflammatory conditions involving the study site
- Prosthetic or soft-tissue complications preventing reliable clinical or digital measurements
- Inability to obtain a reproducible intraoral scan because of excessive saliva, restricted mouth opening, patient movement, or other technical limitations

- Requirement for additional surgical intervention at the study site during the observation period
- Any other condition considered by the investigator to interfere substantially with the study outcomes or interpretation of the measurements
- Participants who failed to attend scheduled follow-up examinations were considered lost to follow-up and were handled according to the predefined missing-data analysis strategy rather than being classified as an initial exclusion criterion.

Implant-Planning Protocol

Group A: Digitally Optimized 3D Implant Planning

For Group A, implant planning was performed using an integrated 3D digital workflow. CBCT imaging was obtained using a Carestream CS 9300 (Carestream Dental LLC, Atlanta, GA, USA) with a field of view (FOV) of 10×10 cm, voxel size of 0.18 mm, tube voltage of 90 kVp, and tube current of 10 mA. Exposure parameters were selected according to the anatomical region, patient characteristics, and manufacturer's recommendations. A digital intraoral surface dataset was obtained using a 3Shape TRIOS 5 Wireless intraoral scanner (3Shape A/S, Copenhagen, Denmark). The CBCT and intraoral surface datasets were digitally aligned using stable dental and anatomical reference structures. The integrated 3D dataset was used to evaluate the available bone dimensions, prosthetic emergence profile, proposed restoration, implant angulation, and spatial relationship between the planned implant and adjacent anatomical structures. Virtual implant positioning was performed according to the prosthetic requirements, available anatomical dimensions, restorative objectives, and anatomical safety considerations. Implant diameter, length, angulation, and 3D position were determined during virtual planning. The digitally planned implant position was subsequently transferred to the clinical surgical procedure according to the predetermined treatment protocol.

Group B: Conventional Implant Planning

For Group B, implant placement was planned using conventional clinical examination and 2D radiographic assessment. Panoramic radiographic imaging was obtained using a Carestream panoramic imaging system (Carestream Dental LLC, Atlanta, GA, USA) according to the manufacturer's recommended exposure settings. The panoramic radiograph was used for assessment of the implant site, adjacent teeth, relevant anatomical structures, and approximate vertical bone availability. When additional site-specific radiographic information was required, intraoral periapical radiographs were obtained using a Carestream intraoral X-ray unit (Carestream Dental, Rochester, NY, USA) with a Carestream RVG 6200 CMOS digital intraoral sensor (Carestream Dental, Rochester, NY, USA). Exposure parameters were adjusted according to patient anatomy and the manufacturer's recommendations. Implant position, diameter, length, and angulation were determined on the basis of clinical examination, conventional radiographic findings, available anatomical information, and prosthetic requirements. No CBCT-based virtual implant planning, integration of CBCT data with the intraoral digital scan, or computer-assisted 3D implant-positioning workflow was used in Group B. Thus, the principal methodological distinction between the groups was the implant-planning approach. Group A used an integrated CBCT–intraoral scanning 3D planning workflow, whereas Group B used conventional clinical and 2D radiographic assessment.

Clinical Examination

Clinical examinations were performed by calibrated examiners using a standardized protocol at baseline (T0), 3 months (T1), and 6 months (T2). The following peri-implant clinical parameters were recorded.

Peri-implant Mucosal Thickness

It was measured at the predetermined mid-facial aspect of the implant using a standardized transgingival probing technique. Following administration of local anesthesia, the measuring instrument fitted with a standardized silicone stop was positioned perpendicular to the mid-facial mucosal surface and advanced gently until contact with the underlying hard tissue was achieved. The distance between the external mucosal surface and the underlying hard-tissue contact point was measured in millimetres (mm) and recorded as peri-implant mucosal thickness. The same mid-facial anatomical reference point was used at all three assessment time points. Care was taken to minimize tissue compression during measurement.

Width of Keratinized Mucosa

The width of keratinized mucosa was measured at the mid-facial aspect of the implant as the distance between the peri-implant mucosal margin and the mucogingival junction. The measurement was recorded in millimetres using a calibrated periodontal probe.

Peri-implant Probing Depth

Peri-implant probing depth was measured from the mucosal margin to the base of the peri-implant sulcus/pocket using a calibrated periodontal probe. Measurements were obtained at six standardized sites:

- mesiobuccal;
- mid-buccal;
- distobuccal;
- mesiolingual;
- mid-lingual; and
- distolingual

Gentle, standardized probing pressure was used. The same sites were evaluated at each follow-up examination.

Bleeding on Probing

It was assessed following gentle peri-implant probing and recorded as present or absent at each predetermined examination site. Bleeding occurring within 30 seconds after probing was considered positive. The same examination sites and protocol were used at all assessment time points.

3D Scanning

Standardized digital impressions of the implant region were obtained in both groups using 3Shape TRIOS 5 Wireless intraoral scanner (3Shape A/S, Copenhagen, Denmark). The scanner was operated according to the manufacturer's recommendations. Before scanning, the implant region was isolated from excessive saliva and debris, and the scanning field was maintained as dry as clinically feasible. Scanning was initiated from a predetermined posterior reference region and continued systematically toward the implant site. The occlusal, buccal, and lingual/palatal surfaces were sequentially captured to obtain complete coverage of the implant-supported restoration and surrounding peri-implant soft tissues. Particular attention was given to the peri-implant mucosal margin and adjacent soft-tissue contours. The scanner was maintained at a consistent working distance and orientation as far as clinically feasible. Areas showing incomplete image acquisition, stitching errors, or scanning artifacts were rescanned before completion of the digital impression. The completed digital dataset was inspected for missing surfaces, stitching errors, and artifacts before export for analysis. The identical scanning protocol was used for both groups at baseline, 3 months, and 6 months. Therefore, the intraoral scanning procedure itself did not constitute a difference between the study groups.

Digital 3D Volumetric Analysis

The digital datasets obtained using the TRIOS 5 intraoral scanner was used for quantitative assessment of peri-implant soft-tissue morphology. A standardized 3D ROI was established around each implant-supported restoration using reproducible anatomical and prosthetic reference landmarks. The ROI was centered on the predetermined mid-facial reference point of the implant-supported restoration and extended 2.5 mm mesially and 2.5 mm distally, resulting in a standardized 5-mm mesiodistal width. The apicocoronal limits of the ROI were defined using reproducible anatomical and prosthetic reference landmarks established before commencement of the analysis. The same landmarks and boundaries were applied at baseline (T0), 3 months (T1), and 6 months (T2). The buccolingual extent included the complete clinically visible peri-implant mucosal contour within the predefined ROI. Baseline and follow-up intraoral scan datasets were imported into 3Shape Dental System (3Shape A/S, Copenhagen, Denmark) and superimposed using stable anatomical and prosthetic reference surfaces located outside the peri-implant soft-tissue region. The peri-implant soft-tissue region under investigation was excluded from the

primary registration area to minimize the influence of actual soft-tissue changes on longitudinal scan alignment. Following registration, the predefined ROI was applied consistently to each time-point dataset. The peri-implant mucosal surface within the ROI was isolated and reconstructed as a 3D surface for volumetric analysis. The corresponding enclosed volume within the predefined ROI was calculated and expressed in cubic millimetres (mm³).

Digital Outcome Parameters

The following digital parameters were recorded:

- Peri-implant mucosal volume (mm³) at baseline, 3 months, and 6 months
- Absolute change in mucosal volume from baseline to 3 months
- Absolute change in mucosal volume from baseline to 6 months
- Percentage change in mucosal volume from baseline to 3 months and 6 months

The percentage change in mucosal volume was calculated as:

Percentage volume change = [(Follow-up volume – Baseline volume) / Baseline volume] × 100

Positive values represented an increase in peri-implant mucosal volume relative to baseline, whereas negative values represented a reduction in volume.

Clinical measurements of peri-implant mucosal thickness, width of keratinized mucosa, probing depth, and BOP were analyzed separately as clinical soft-tissue outcomes.

Standardization of Digital Measurements

Identical ROI boundaries, anatomical reference landmarks, digital registration procedures, and volumetric analysis protocols were used at all assessment time points. Digital datasets were reviewed for scanning artifacts before analysis. When a region was inadequately captured, the intraoral scan was repeated clinically rather than estimating the missing region digitally. The examiner responsible for volumetric analysis was trained in the use of the 3D analysis software before commencement of the study. The measurement protocol and ROI boundaries were established before analysis of the study datasets to minimize observer-related variation.

Intra- and Inter-Examiner Reliability

Measurement reliability was evaluated using 10 randomly selected digital datasets from the 40 participants. The primary examiner repeated the volumetric measurements after an interval of 2 weeks to minimize recall of the initial measurements. A second calibrated examiner independently performed the same measurements using the identical analysis protocol. Intra-examiner and inter-examiner reliability were assessed using intraclass correlation coefficients (ICCs) with corresponding 95% confidence intervals (CIs). The mean absolute difference between repeated measurements was also calculated where applicable.

Follow-up Schedule

Assessments were performed at three predefined time points:

- **Baseline (T0):** after completion of the definitive implant-supported prosthetic rehabilitation and before initiation of the longitudinal follow-up period
- **3 months (T1):** intermediate evaluation of peri-implant soft-tissue changes
- **6 months (T2):** final evaluation of the primary study outcomes

At each time point, the clinical parameters and standardized 3D digital intraoral scans were obtained using the same examination, measurement, and scanning protocols to ensure consistency and comparability across follow-up visits.

Study Outcomes

Primary Outcome

The primary outcome was the absolute change in peri-implant mucosal volume from baseline to 6 months.

Secondary Outcomes

Secondary outcomes included:

- Absolute change in peri-implant mucosal volume from baseline to 3 months
- Percentage change in peri-implant mucosal volume
- Change in peri-implant mucosal thickness
- Change in the width of keratinized mucosa
- Change in peri-implant probing depth
- Change in bleeding on probing
- Intergroup differences in peri-implant soft-tissue changes over the 6-month observation period

Statistical Analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS), IBM SPSS Statistics for Windows, version 29.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean $\pm$ standard deviation (SD) for approximately normally distributed data and as median with interquartile range where appropriate. Categorical variables were expressed as frequencies and percentages. The Shapiro–Wilk test, together with graphical assessment of the data distribution, was used to evaluate the normality of continuous variables. Baseline demographic and clinical characteristics were summarized for both groups. Between-group comparisons of continuous variables at individual time points were performed using the independent-samples t-test for approximately normally distributed data and the Mann–Whitney U test for non-normally distributed data, as appropriate. Categorical variables were compared using Fisher's exact test. Longitudinal changes in continuous clinical and volumetric outcomes were evaluated using a linear mixed-effects model, with treatment group, time, and the group $\times$ time interaction included as fixed effects and participant included as the subject-level random effect to account for the correlation between repeated observations within the same participant. The group $\times$ time interaction represented the principal test of whether changes over time differed between the two treatment groups.

When significant effects were identified, predefined pairwise comparisons were performed with an appropriate multiplicity adjustment, such as the Bonferroni correction. Model assumptions were assessed using residual diagnostics. Associations between volumetric changes and clinical parameters were evaluated using Pearson's correlation coefficient when the assumptions for parametric analysis were satisfied and Spearman's rank correlation coefficient otherwise. Where appropriate, correlations were based on changes from baseline rather than isolated follow-up measurements. Effect estimates, 95% confidence intervals, and p-values were reported. Effect sizes were reported where applicable. All statistical tests were two-tailed, and a p-value <0.05 was considered statistically significant.

RESULTS

Table 1 & Figure 1 summarize the study population and allocation of participants. A total of 40 implant sites from 40 patients were enrolled in this prospective comparative study. The participants were evenly divided into two groups, with 20 implant sites assigned to each group. Group A underwent 3D digitally optimized implant planning, whereas Group B was managed using conventional implant-planning methods. Clinical assessments and intraoral scans were obtained at baseline and repeated at 3 and 6 months to evaluate changes over the follow-up period.

Table 1: Study population and group distribution

Group	Description	n	Percentage
Group A	3D digitally optimized implant planning	20	50.0%
Group B	Conventional implant planning	20	50.0%
Total		40	100.0%

■ Group A ■ Group B

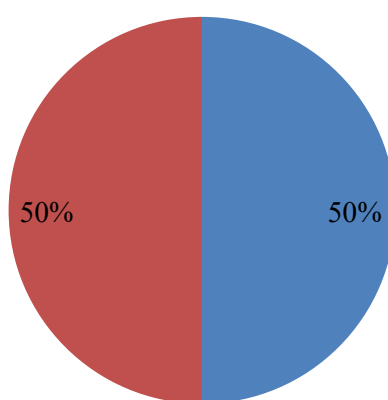


Figure 1: Flow diagram showing participant allocation and the schedule of clinical and intraoral scanning assessments

Table 2 & Figure 2 describe the baseline demographic characteristics and clinical parameters of the study participants. The mean age was 39.85 ± 7.62 years in Group A and 40.60 ± 8.14 years in Group B, with no statistically significant difference between the groups ($p=0.757$). Males accounted for 55.0% of participants in Group A and 50.0% in Group B. The baseline clinical findings were also comparable between the two groups, suggesting that the participants had broadly similar characteristics before the respective implant-planning approaches were implemented.

Table 2: Demographic and baseline characteristics

Parameter	Group A (n=20)	Group B (n=20)	p-value
Age (years), mean $\pm$ SD	39.85 ± 7.62	40.60 ± 8.14	0.757
Male, n (%)	11 (55.0)	10 (50.0)	0.752
Female, n (%)	9 (45.0)	10 (50.0)	0.752
Baseline probing depth (mm)	2.91 ± 0.42	2.95 ± 0.45	0.774
Baseline mucosal thickness (mm)	1.82 ± 0.36	1.79 ± 0.34	0.789
Baseline keratinized mucosa width (mm)	3.06 ± 0.58	3.01 ± 0.61	0.792

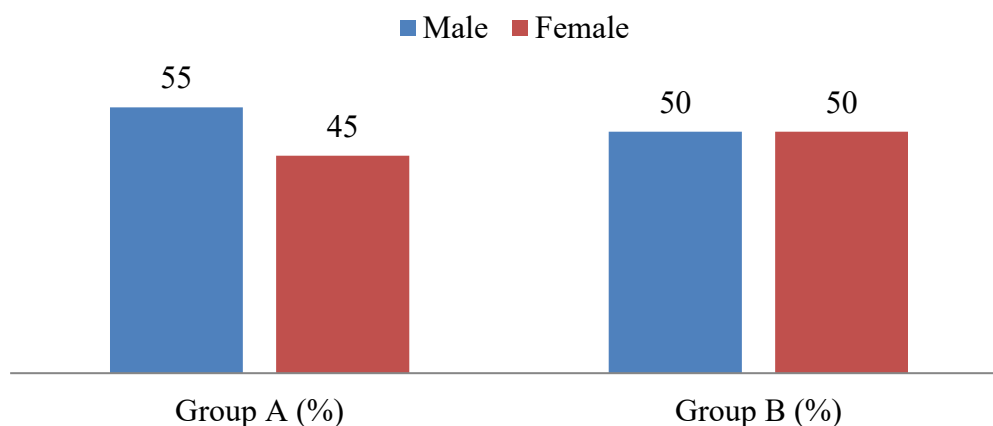


Figure 2: Comparison of baseline demographic and clinical characteristics between Group A and Group B

Table 3 & Figure 3 demonstrate the changes in peri-implant soft-tissue volume assessed through 3D intraoral scan superimposition over the follow-up period. In Group A, the mean peri-implant mucosal volume increased from $286.4 \pm 38.7 \text{ mm}^3$ at baseline to $318.7 \pm 40.1 \text{ mm}^3$ at 3 months and $334.8 \pm 42.5 \text{ mm}^3$ at 6 months. In Group B, the corresponding mean volumes were $284.9 \pm 40.2 \text{ mm}^3$, $302.1 \pm 41.7 \text{ mm}^3$, and $309.6 \pm 43.1 \text{ mm}^3$, respectively. The overall increase in peri-implant soft-tissue volume was greater in Group A. Between baseline and 6 months, Group A exhibited a mean volumetric gain of $48.4 \pm 18.6 \text{ mm}^3$ (16.9%), compared with $24.7 \pm 17.9 \text{ mm}^3$ (8.7%) in Group B. The intergroup difference in volumetric gain was statistically significant ($p < 0.001$).

Table 3: 3D peri-implant mucosal volume

Time point	Group A (mm ³)	Group B (mm ³)	Intergroup p-value
Baseline	286.4 ± 38.7	284.9 ± 40.2	
3 months	318.7 ± 40.1	302.1 ± 41.7	
6 months	334.8 ± 42.5	309.6 ± 43.1	
Gain at 3 months (mm ³)	32.3 ± 5.4	17.2 ± 4.8	<0.001
Gain at 6 months (mm ³)	48.4 ± 8.6	24.7 ± 7.9	<0.001

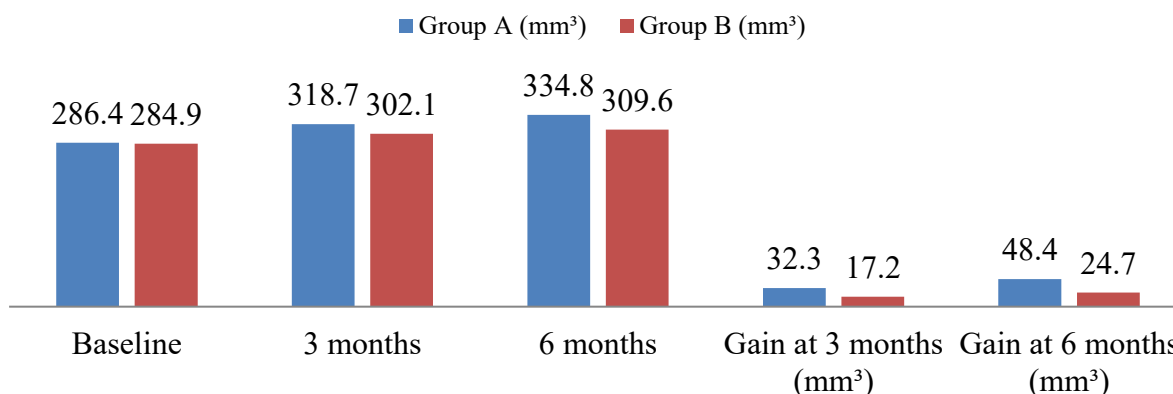


Figure 3: Comparison of peri-implant mucosal volume changes between Group A and Group B from baseline to 6 months

Table 4 & Figure 4 present the longitudinal changes in 3D peri-implant mucosal volume within both study groups. In Group A, the mean mucosal volume increased from $286.4 \pm 38.7 \text{ mm}^3$ at baseline to $318.7 \pm 40.1 \text{ mm}^3$ at 3 months and $334.8 \pm 42.5 \text{ mm}^3$ at 6 months. Repeated-measures analysis revealed a statistically significant change across the three assessment intervals ($p < 0.001$).

Table 5 presents the pairwise comparisons of peri-implant mucosal volume across the different follow-up intervals. In Group A, a statistically significant increase was observed from baseline to 3 months ($p < 0.001$) and from baseline to 6 months ($p < 0.001$). A further significant increase was observed between 3 and 6 months ($p = 0.003$). In Group B, the mean peri-implant mucosal volume increased from $284.9 \pm 40.2 \text{ mm}^3$ at baseline to $302.1 \pm 41.7 \text{ mm}^3$ at 3 months and $309.6 \pm 43.1 \text{ mm}^3$ at 6 months. The overall change across the three time points was statistically significant ($p < 0.001$). Pairwise comparisons showed significant increases from baseline to 3 months ($p = 0.001$) and from baseline to 6 months ($p < 0.001$). The difference between 3 and 6 months was also statistically significant ($p = 0.018$). Overall, both groups exhibited a significant and progressive increase in 3D peri-implant mucosal volume throughout the 6-month follow-up period. However, the magnitude of volumetric change was greater in Group A than in Group B.

Table 4: Intragroup comparison of 3D peri-implant mucosal volume

Time point	Baseline	3 Months	6 Months
Group A	286.4 ± 38.7	318.7 ± 40.1	334.8 ± 42.5
Group B	284.9 ± 40.2	302.1 ± 41.7	309.6 ± 43.1

Table 5: Pairwise comparison of 3D peri-implant mucosal volume across different follow-up intervals in groups A and B

Comparison	Group A p-value	Group B p-value
Baseline vs. 3 months	$<0.001^*$	0.001^*
Baseline vs. 6 months	$<0.001^*$	$<0.001^*$
3 months vs. 6 months	0.003^*	0.018^*

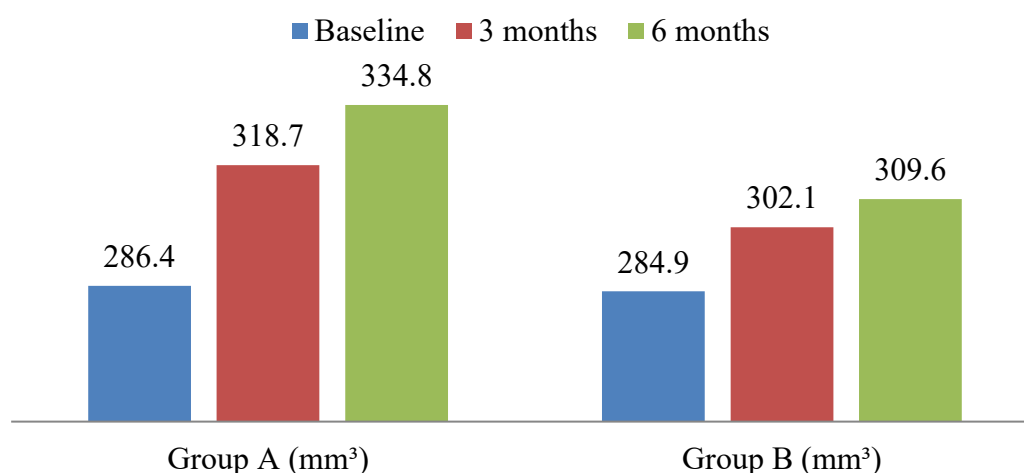


Figure 4: Longitudinal changes in 3D peri-implant mucosal volume within Group A and Group B over the 6-month follow-up period

Table 6 & Figure 5 present 3D surface analysis demonstrated a progressive increase in facial peri-implant contour from 3 to 6 months in both groups. At the 3-month evaluation, the mean facial contour change was $0.61 \pm 0.23 \text{ mm}$ in Group A and 0.39

± 0.21 mm in Group B, with a statistically significant difference between the groups ($p=0.003$). By 6 months, the mean contour change had increased to 0.84 ± 0.27 mm in Group A, compared with 0.52 ± 0.24 mm in Group B, with the intergroup difference remaining statistically significant ($p<0.001$). Overall, Group A exhibited a greater increase in facial peri-implant contour than Group B at both follow-up intervals, with a larger between-group difference observed at 6 months.

Table 6: Intergroup comparison of 3D surface/contour change

Parameter	Group A	Group B	p-value
Facial contour change at 3 months (mm)	0.61 ± 0.23	0.39 ± 0.21	0.003
Facial contour change at 6 months (mm)	0.84 ± 0.27	0.52 ± 0.24	<0.001

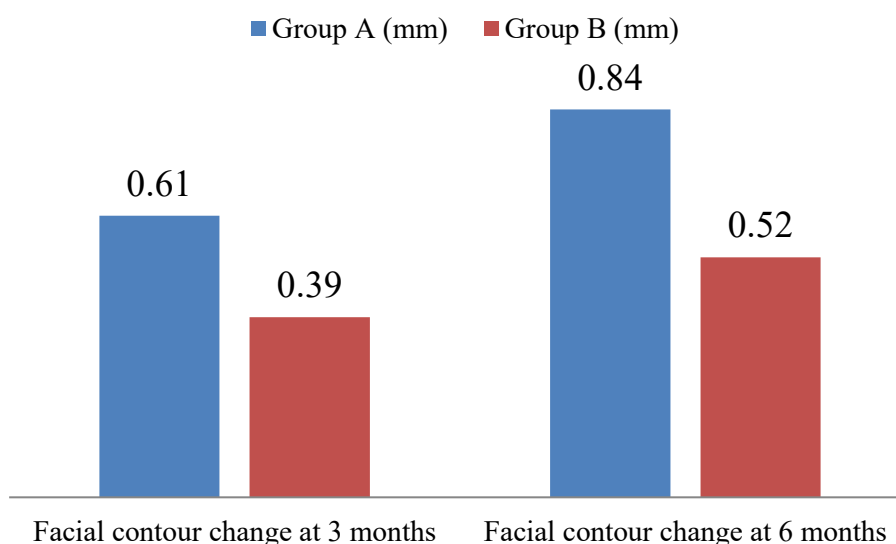


Figure 5: 3D surface analysis showing changes in facial peri-implant contour at 3 and 6 months in Groups A and B

Table 7 & Figure 6 present the baseline peri-implant mucosal thickness. The mean mucosal thickness was 1.82 ± 0.36 mm in Group A and 1.81 ± 0.34 mm in Group B, with no statistically significant difference between the groups ($p=0.789$), indicating comparable baseline mucosal thickness. At 3 months, mucosal thickness increased to 2.03 ± 0.41 mm in Group A, whereas Group B showed a mean thickness of 1.63 ± 0.37 mm. The difference between the groups was statistically significant ($p=0.003$). At the 6-month assessment, Group A demonstrated a further increase in mean mucosal thickness to 2.15 ± 0.43 mm, compared with 1.74 ± 0.38 mm in Group B, with the intergroup difference remaining statistically significant ($p=0.004$). Overall, peri-implant mucosal thickness showed a progressive increase in Group A throughout the follow-up period and was significantly greater than that in Group B at both 3 and 6 months, whereas the groups exhibited comparable measurements at baseline.

Table 7: Intergroup comparison of peri-implant mucosal thickness

Time point	Group A (mm)	Group B (mm)	p-value
Baseline	1.82 ± 0.36	1.81 ± 0.34	0.789
3 months	2.03 ± 0.41	1.63 ± 0.37	0.003
6 months	2.15 ± 0.43	1.74 ± 0.38	0.004

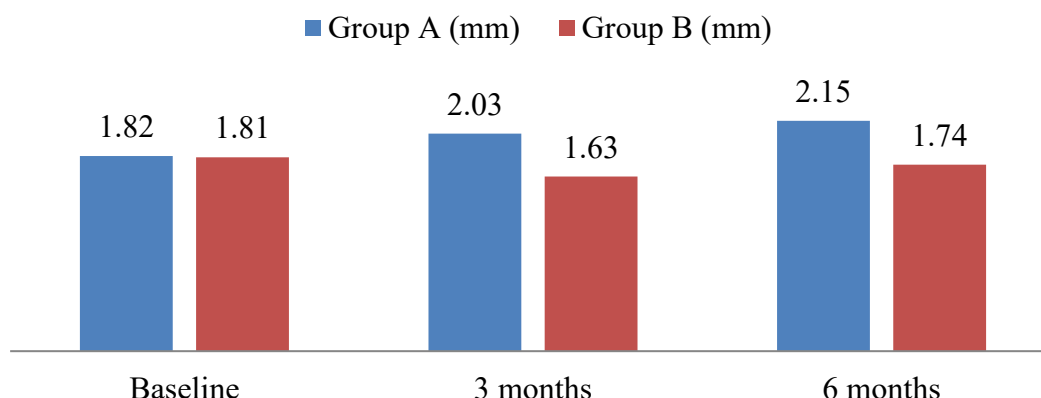


Figure 6: Comparison of peri-implant mucosal thickness between Groups A and B at baseline, 3 months, and 6 months

Table 8 & Figure 7 present the changes in probing depth between the two groups over the follow-up period. At baseline, the mean probing depth was 2.91 ± 0.42 mm in Group A and 2.95 ± 0.45 mm in Group B, with no statistically significant intergroup difference ($p=0.774$), indicating comparable baseline measurements. At 3 months, probing depth decreased to 2.12 ± 0.35 mm in Group A and 2.47 ± 0.41 mm in Group B. The intergroup difference was statistically significant ($p=0.007$), with Group A showing a lower mean probing depth. At 6 months, the mean probing depth further decreased to 1.88 ± 0.31 mm in Group A, compared with 2.34 ± 0.39 mm in Group B, and the difference remained statistically significant ($p=0.002$). Overall, probing depth showed a progressive reduction in both groups throughout the follow-up period. However, Group A demonstrated significantly lower probing depth than Group B at both 3 and 6 months, while the groups were comparable at baseline.

Table 8: Intergroup comparison of probing depth between the groups

Time point	Group A (mm)	Group B (mm)	p-value
Baseline	2.91 ± 0.42	2.95 ± 0.45	0.774
3 months	2.12 ± 0.35	2.47 ± 0.41	0.007
6 months	1.88 ± 0.31	2.34 ± 0.39	0.002

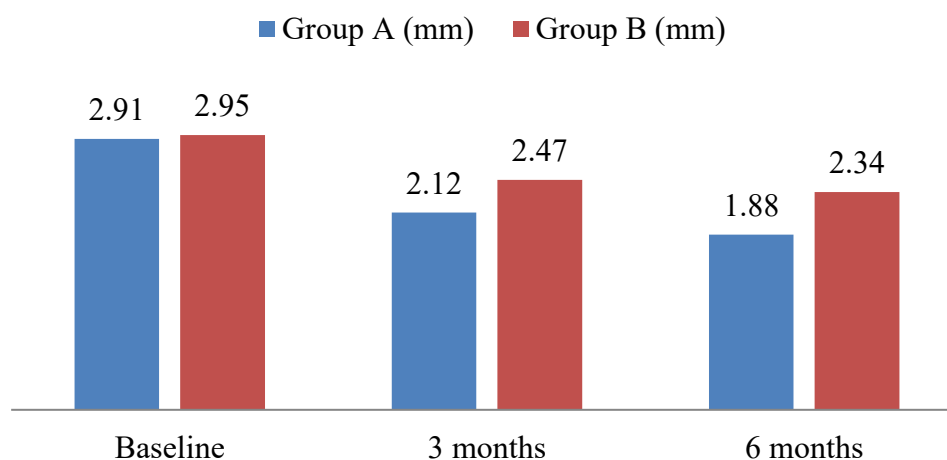


Figure 7: Intergroup comparison of mean probing depth at baseline, 3 months, and 6 months

Table 9 & Figure 8 present the intergroup comparison of the width of keratinized mucosa at different assessment points. At baseline, the mean width was 3.06 ± 0.58 mm in Group A and 3.01 ± 0.61 mm in Group B, with no statistically significant difference between the groups ($p=0.792$), indicating comparable baseline measurements. At 3 months, the mean width increased to 3.28 ± 0.55 mm in Group A, whereas Group B showed a mean value of 2.78 ± 0.50 mm. The intergroup difference was statistically significant ($p=0.006$), with Group A demonstrating a greater mean width. At 6 months, the width further increased to 3.42 ± 0.56 mm in Group A, compared with 2.91 ± 0.52 mm in Group B. This difference remained statistically significant ($p=0.023$). Overall, the width of keratinized mucosa increased over the follow-up period in both groups. However, Group A exhibited a significantly greater mean width than Group B at both 3 and 6 months, whereas no significant intergroup difference was observed at baseline.

Table 9: Intergroup comparison of width of keratinized mucosa between the groups

Time point	Group A (mm)	Group B (mm)	p-value
Baseline	3.06 ± 0.58	3.01 ± 0.61	0.792
3 months	3.28 ± 0.55	2.78 ± 0.50	0.006
6 months	3.42 ± 0.56	2.91 ± 0.52	0.023

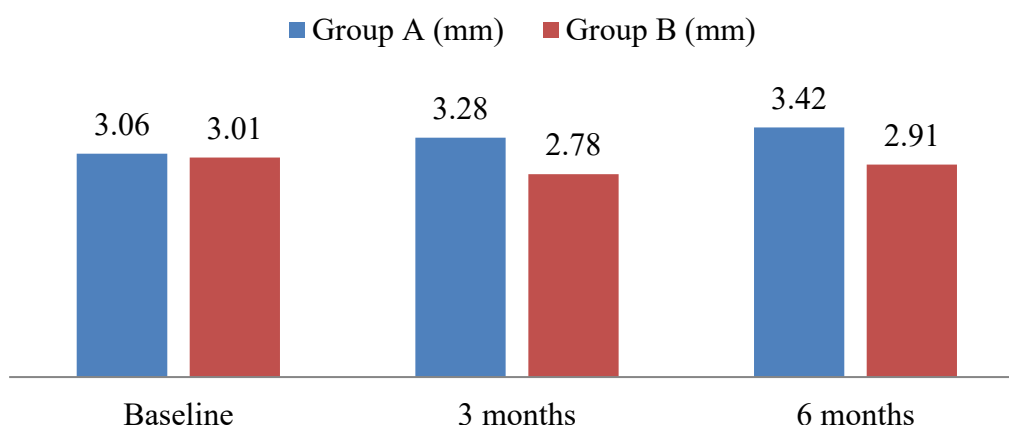


Figure 8: Intergroup comparison of mean width of keratinized mucosa at baseline, 3 months, and 6 months

Table 10 & Figure 9 present the clinical peri-implant inflammatory parameters assessed at 6 months. The mean plaque index was 0.38 ± 0.21 in Group A and 0.59 ± 0.27 in Group B, with a statistically significant intergroup difference ($p=0.011$). Group A therefore exhibited lower plaque accumulation at the 6-month assessment. The mean percentage of sites with bleeding on probing was $15.0 \pm 10.8\%$ in Group A compared with $27.5 \pm 14.2\%$ in Group B. This difference was statistically significant ($p=0.003$), indicating a lower proportion of bleeding sites in Group A. Suppuration was recorded at 1 (5.0%) implant site in Group A and 3 (15.0%) implant sites in Group B. Although the occurrence of suppuration was numerically lower in Group A, the intergroup difference was not statistically significant ($p=0.291$). Overall, at 6 months, Group A showed significantly lower plaque accumulation and bleeding on probing than Group B, whereas no statistically significant difference was observed between the groups with respect to suppuration.

Table 10: Intergroup comparison of plaque and bleeding on probing

Parameter	Group A at 6 months	Group B at 6 months	p-value
Plaque index	0.38 ± 0.21	0.59 ± 0.27	0.011
Bleeding on probing (%)	15.0 ± 10.8	27.5 ± 14.2	0.003
Suppuration, n (%)	1 (5.0)	3 (15.0)	0.291

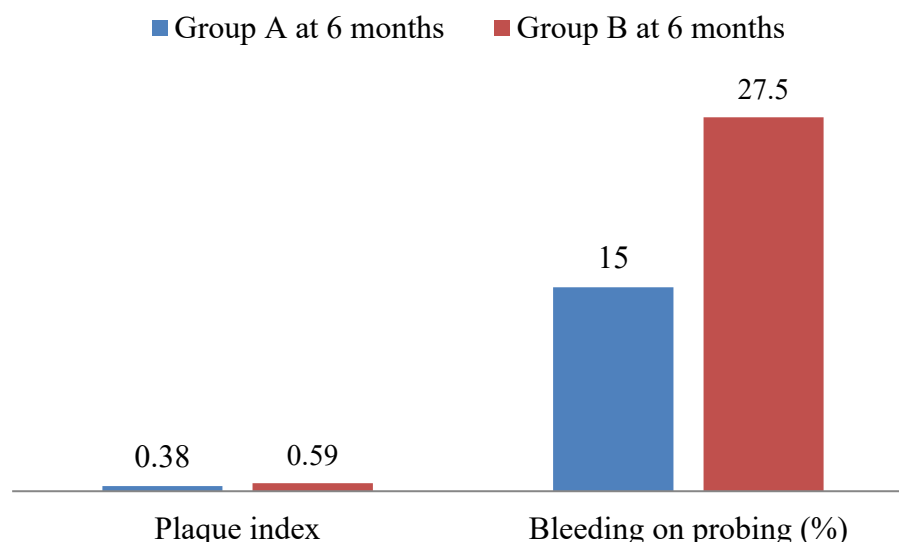


Figure 9: Intergroup comparison of plaque index, bleeding on probing, and suppuration at 6 months

Table 11 presents the correlation analysis between the percentage change in peri-implant mucosal volume and selected peri-implant soft-tissue parameters at 6 months. In Group A, mucosal volume gain demonstrated a strong positive correlation with mucosal thickness ($r=0.68$, $p<0.001$), whereas a moderate positive correlation was observed in Group B ($r=0.55$, $p=0.012$). A positive association was also identified between volumetric gain and the width of keratinized mucosa in both groups; however, statistical significance was observed only in Group A ($r=0.46$, $p=0.041$). In Group A, mucosal volume gain was significantly and inversely correlated with probing depth ($r=-0.51$, $p=0.021$), while the corresponding correlation in Group B was negative but did not reach statistical significance ($r=-0.43$, $p=0.058$). Similarly, bleeding on probing showed negative correlations with volumetric gain in both groups. This association was borderline significant in Group A ($r=-0.44$, $p=0.050$) but was not statistically significant in Group B ($r=-0.35$, $p=0.130$). Overall, greater peri-implant mucosal volume gain was associated with greater mucosal thickness and a wider band of keratinized mucosa, whereas increased probing depth and bleeding on probing tended to be associated with lower volumetric gain.

Table 11: Relationship between mucosal volume and clinical parameters

Variable correlated with 6-month volume gain	Group A		Group B	
	Pearson r	p-value	Pearson r	p-value
Mucosal thickness	0.68	<0.001*	0.55	0.012*
Keratinized mucosa width	0.46	0.041*	0.37	0.107
Probing depth	-0.51	0.021*	-0.43	0.058
Bleeding on probing	-0.44	0.050*	-0.35	0.130

*Statistically significant at $p<0.05$.

Table 12 presents the intra- and inter-examiner reliability of the 3D volumetric measurements. Intra-examiner reliability was excellent, with an ICC of 0.96 (95% CI: 0.93–0.98), while inter-examiner reliability was also excellent, with an ICC of 0.93 (95% CI: 0.88–0.96). The mean absolute difference between repeated measurements was $7.2 \pm 5.6 \text{ mm}^3$, indicating high consistency and reproducibility of the volumetric measurements.

Table 12: Reliability of intraoral scan measurements

Reliability measure	Value
Intra-examiner ICC	0.96 (95% CI: 0.93–0.98)
Inter-examiner ICC	0.93 (95% CI: 0.88–0.96)
Mean absolute difference	7.2 ± 5.6 mm ³

DISCUSSION

The present study investigated peri-implant mucosal morphology using 3D intraoral scanning and digital volumetric analysis. The findings highlight the potential of digital surface-based assessment as a non-invasive approach for quantifying peri-implant soft-tissue morphology. Unlike conventional clinical techniques that generally provide measurements at selected reference points, 3D digital analysis permits evaluation of the spatial characteristics of the peri-implant region over a defined area. This distinction is clinically relevant because peri-implant soft-tissue remodeling may involve simultaneous changes in contour, thickness, height, and volume that cannot always be adequately represented by a limited number of linear measurements. The feasibility of digitally recording peri-implant soft-tissue morphology has previously been demonstrated.

Monaco et al. [10] described a fully digital workflow for reproducing peri-implant soft-tissue contours and the emergence profile in the esthetic zone. Their approach demonstrated that digital surface information could be incorporated into restorative planning while preserving the spatial relationship between the implant restoration and surrounding soft tissues. The present study extends this concept by using digital surface data not only for restorative reproduction but also for quantitative assessment of peri-implant mucosal morphology. This application may be particularly useful for longitudinal evaluation, where subtle changes in tissue contour can be assessed through comparison of sequential digital models.

Liu et al. [11] similarly reported a digital technique for replicating peri-implant soft-tissue contours and emergence profiles. Their findings support the ability of digital workflows to capture clinically relevant 3D information surrounding implant-supported restorations. In the present context, preservation of the 3D tissue contour is important because remodeling may occur unevenly across the peri-implant surface. For example, localized contraction or alteration of the facial and cervical contour may occur without producing a proportional change in a single linear measurement. Digital surface analysis therefore offers the possibility of characterizing such spatial alterations more comprehensively.

A particularly relevant aspect of the present study is the assessment of soft-tissue volume. Galibourg et al. [12] demonstrated that digital impressions could be used to quantify the volume of unsupported peri-implant soft tissue and evaluate changes in the emergence profile over time. Their findings provide direct methodological support for volumetric assessment of peri-implant tissues using digital surface datasets. Volumetric measurements may provide information that complements conventional measurements of mucosal thickness or height because they incorporate changes across a defined 3D region. This may be especially valuable when remodeling is distributed irregularly across the peri-implant mucosa. At the same time, the reliability of digital volumetric assessment depends on the behavior of the soft tissue during scanning.

Li et al. [13] evaluated dynamic changes in peri-implant soft tissue following removal of an interim restoration during digital intraoral scanning and demonstrated that unsupported peri-implant tissues can undergo positional changes. This finding has important implications for the interpretation of digitally derived measurements. The recorded surface may be influenced by the clinical condition of the tissue, the presence or removal of the restoration, and the duration and circumstances of scanning. Therefore, consistency in scan timing, restoration status, tissue exposure, operator technique, and acquisition protocol is essential when sequential scans are compared. Standardization of these factors can reduce the possibility that apparent volumetric differences reflect changes in scanning conditions rather than true biological remodeling.

Zimmermann et al. [14] further demonstrated the clinical application of digital replication of peri-implant soft-tissue contours associated with implant-supported crowns. Their technique reinforces the value of digital records for reproducing and documenting the peri-implant emergence architecture. From a research perspective, an important advantage of such digital records is their ability to be stored and subsequently compared with newly acquired datasets. Sequential digital models can

therefore provide a longitudinal record of peri-implant morphology and may facilitate assessment of tissue changes after provisionalization, definitive restoration, modification of emergence profiles, or soft-tissue augmentation.

The relevance of 3D digital assessment has also been demonstrated in more recent clinical research. Ramadan et al. [15] evaluated soft-tissue changes following placement of healing abutments with different emergence-profile designs using 3D analysis. Their findings illustrate how digital measurements can be applied to investigate treatment-related differences in peri-implant soft-tissue morphology. The use of 3D assessment in this setting is particularly relevant because healing-abutment design may influence the spatial configuration of the developing peri-implant mucosa. Such changes may involve alterations in both tissue dimensions and overall contour and may therefore be better represented by a combination of linear and volumetric parameters.

Taken together, previous studies demonstrate the progressive development of digital approaches for peri-implant soft-tissue assessment. Early applications primarily focused on reproducing peri-implant contours and emergence profiles, whereas more recent investigations have extended digital analysis to volumetric assessment and evaluation of treatment-related morphological changes. However, peri-implant soft tissues are deformable and may change position during scanning, indicating that digital measurements are influenced by the conditions under which image acquisition is performed. Therefore, standardized scanning protocols, consistent restoration conditions, clearly defined ROI, and reproducible digital alignment are essential for obtaining reliable measurements. An important advantage of volumetric analysis is its ability to capture spatially distributed changes in tissue morphology rather than relying exclusively on measurements obtained from predetermined points. Changes in mucosal contour, thickness, and 3D configuration may occur simultaneously and may not be adequately represented by a single linear measurement. Digital volumetric assessment can therefore provide complementary information regarding the external morphology of peri-implant tissues and may be particularly useful for longitudinal evaluation of tissue remodeling. Nevertheless, digital volumetric measurements should be interpreted in conjunction with conventional clinical parameters. Intraoral scanning records the external surface of the peri-implant mucosa and does not directly characterize the histological or complete internal thickness of the tissue. Measurement accuracy may also be influenced by scanner performance, tissue mobility, scan strategy, dataset superimposition, and ROI definition. Consequently, digital assessment is best considered a complementary method rather than a substitute for comprehensive clinical examination.

Overall, the present findings support the feasibility of non-invasive, 3D quantitative assessment of peri-implant soft-tissue morphology using intraoral scanning. By extending evaluation beyond isolated linear measurements, volumetric analysis may provide a more comprehensive description of peri-implant tissue remodeling. Further prospective research with standardized acquisition and analytical protocols is required to establish the reproducibility and clinical significance of digitally measured volumetric changes and to clarify their relationship with implant position, emergence-profile design, soft-tissue phenotype, and esthetic outcomes

LIMITATIONS

This study has several limitations that should be considered when interpreting the findings. First, the relatively limited sample size may have reduced the ability to detect smaller differences and associations between peri-implant soft-tissue parameters. Second, the follow-up period was restricted to 6 months, which limits the assessment of the long-term stability of peri-implant mucosal volume and thickness. Longer observation periods would be necessary to determine whether the volumetric changes observed during the study are maintained over time. Third, 3D volumetric measurements may be influenced by variations in scanning conditions, soft-tissue positioning, patient movement, and the reproducibility of the scanning procedure, although the high intra- and inter-examiner ICC values in the present study indicate good measurement reliability. In addition, clinical parameters such as probing depth and bleeding on probing may be affected by probing force, angulation, and examiner technique. The study was conducted under controlled clinical conditions, but these factors cannot be completely eliminated. Finally, the observed correlations between volumetric changes and clinical or soft-tissue parameters represent associations and should not be interpreted as evidence of a causal relationship. Other factors, including implant position, prosthetic characteristics, oral hygiene, patient-related factors, and individual soft-tissue healing patterns, may also influence peri-implant mucosal dimensions. Further studies with larger samples, longer follow-up periods, standardized digital protocols, and adjustment for potential confounding factors are warranted to validate and extend the present findings.

CONCLUSION

3D volumetric assessment provided a reliable and reproducible method for monitoring peri-implant mucosal changes. Greater mucosal volume gain was associated with increased mucosal thickness and keratinized mucosa width, while greater probing depth and bleeding on probing tended to accompany lower volumetric gain. These findings support the value of 3D volumetric analysis as a complementary tool for evaluating peri-implant soft-tissue stability.

Conflicts of Interest: Nil

Financial Support: None

REFERENCES

- [1] Monje A, González-Martín O, Ávila-Ortiz G. Impact of peri-implant soft tissue characteristics on health and esthetics. *J Esthet Restor Dent*. 2023 Jan;35(1):183-196. doi: 10.1111/jerd.13003. Epub 2023 Jan 17. PMID: 36650691.
- [2] Jung RE, Becker K, Bienz SP, Dahlin C, Donos N, Hammächer C, Iglhaut G, Liñares A, Ortiz-Vigón A, Sanchez N, Sanz-Sánchez I, Thoma DS, Valles C, Weng D, Nart J. Effect of peri-implant mucosal thickness on esthetic outcomes and the efficacy of soft tissue augmentation procedures: Consensus report of group 2 of the SEPA/DGI/OF workshop. *Clin Oral Implants Res*. 2022 Jun;33 Suppl 23(Suppl 23):100-108. doi: 10.1111/clr.13955. PMID: 35763020; PMCID: PMC9543632.
- [3] Bhat PR, Thakur SL, Kulkarni SS. The influence of soft tissue biotype on the marginal bone changes around dental implants: A 1-year prospective clinico-radiological study. *J Indian Soc Periodontol*. 2015 Nov-Dec;19(6):640-4. doi: 10.4103/0972-124X.168489. PMID: 26941514; PMCID: PMC4753708.
- [4] Canullo L, Camacho-Alonso F, Tallarico M, Meloni SM, Xhanari E, Penarrocha-Oltra D. Mucosa Thickness and Peri-implant Crestal Bone Stability: A Clinical and Histologic Prospective Cohort Trial. *Int J Oral Maxillofac Implants*. 2017 May/June;32(5):675–681. doi: 10.11607/jomi.5349. Epub 2017 Mar 15. PMID: 28296981.
- [5] Khorshed A, Vilarrasa J, Monje A, Nart J, Blasi G. Digital evaluation of facial peri-implant mucosal thickness and its impact on dental implant aesthetics. *Clin Oral Investig*. 2023 Feb;27(2):581-590. doi: 10.1007/s00784-022-04753-x. Epub 2022 Oct 19. PMID: 36260169.
- [6] Szmukler-Moncler S, Savion A, Sperber R, Kolerman R, Beuer F. Novel digital way to measure the vertical and horizontal dimensions of the supracrestal peri-implant soft tissue. *Int J Comput Dent*. 2025 Sep 1;28(3):235-249. doi: 10.3290/j.jcd.b5638066. PMID: 39073119.
- [7] Mikulás K, Qian X, Tajti P, Agócs G, Gallucci GO, Pedrinaci I, Hermann P. Accuracy of Digital Impression Methods for Capturing the Peri-Implant Emergence Profile: A Systematic Review. *Clin Oral Implants Res*. 2025 Aug;36(8):930-943. doi: 10.1111/clr.14441. Epub 2025 Apr 12. PMID: 40219691; PMCID: PMC12319379.
- [8] Shomurodov K, Mirkhusanova R, Bekmurodov E, Idiev O. Intraoral Scanners for Three-Dimensional Assessment of Peri-Implant Soft Tissues: A Systematic Review of Clinical Studies. *J Clin Exp Dent*. 2026 May 29;18(6):e833-e841. doi: 10.4317/jced.64074. PMID: 42434025; PMCID: PMC13353921.
- [9] Tavelli L, Sabri H, Barootchi E, et al. Protective factors and critical mucosal thickness for the stability of the peri-implant soft tissue margin over 5 years: A longitudinal cohort study. *J Periodontol*. 2026; 1-14. <https://doi.org/10.1002/jper.70159>
- [10] Monaco C, Evangelisti E, Scotti R, Mignani G, Zucchelli G. A fully digital approach to replicate peri-implant soft tissue contours and emergence profile in the esthetic zone. *Clin Oral Implants Res*. 2016 Dec;27(12):1511-1514. doi: 10.1111/clr.12599. Epub 2015 Apr 22. PMID: 25907030.
- [11] Liu X, Liu J, Mao H, Tan J. A digital technique for replicating peri-implant soft tissue contours and the emergence profile. *J Prosthet Dent*. 2017 Sep;118(3):264-267. doi: 10.1016/j.prosdent.2016.11.006. Epub 2017 Feb 17. PMID: 28222868.

- [12] Galibourg A, Dumoncel J, Cormary J, Maret D. Volume of unsupported peri-implant soft tissue over time: A cross-sectional observation study. *J Prosthet Dent.* 2021 Jun;125(6):883-889. doi: 10.1016/j.prosdent.2020.03.010. Epub 2020 Jun 2. PMID: 32507350.
- [13] Li J, Chen Z, Wang M, Wang HL, Yu H. Dynamic changes of peri-implant soft tissue after interim restoration removal during a digital intraoral scan. *J Prosthet Dent.* 2019 Sep;122(3):288-294. doi: 10.1016/j.prosdent.2018.07.020. Epub 2019 Mar 15. PMID: 30885583
- [14] Zimmermann D, Ferreira de Almeida DC, Velloso G, Moraschini V. Digital replication of the peri-implant soft tissue contour of implant-supported crowns: A dental technique. *J Prosthet Dent.* 2022 Jul;128(1):8-12. doi: 10.1016/j.prosdent.2020.12.025. Epub 2021 Feb 5. PMID: 33551141.
- [15] Ramadan RE, Mohamed FS, Abd-Ellah ME. Three-dimensional evaluation of soft tissue changes following placement of two different healing abutments with different emergence profile designs: A randomized controlled trial. *J Prosthodont.* 2026 Aug 7. doi: 10.1111/jopr.70212. Epub ahead of print. PMID: 42565479.