RESEARCH ARTICLE

Influence of Transmucosal Contour on Peri-Implant Soft Tissue Dimensions: A Cross-Sectional Study in Posterior Single-Tooth Implants

Seungwon Back[1] | Jae-Seung Chang[2] (ORCID) | Se-Wook Pyo[2] | Sunjai Kim[2] (ORCID)

[1]Yonsei University College of Dentistry, Seoul, South Korea | [2]Department of Prosthodontics, Gangnam Severance Hospital, Yonsei University College of Dentistry, Seoul, South Korea

Correspondence: Sunjai Kim (sunjai@yuhs.ac)

ABSTRACT

Purpose: This study aimed to evaluate how the transmucosal contour of posterior single-tooth implant crowns, fabricated with CAD-CAM abutments, influences peri-implant soft tissue dimensions using the profile angle and crown ratio concepts.

Materials and Methods: Digital scans of 58 posterior single-tooth implant crowns were analyzed to measure peri-implant soft tissue height, width, crown ratio, and profile angles. Pearson's correlation analysis and independent *t* tests were performed to assess relationships between morphological parameters and soft tissue dimensions, as well as differences by arch and implant position ($p < 0.05$).

Results: Significant negative correlations were found between both profile angle and crown ratio and the soft tissue height and width, particularly within the 1–2 mm region above the implant platform ($r = -0.873$ to -0.719, $p < 0.05$). Buccal tissue width was greater in the maxilla than in the mandible, while soft tissue height showed no arch-dependent differences. Similar patterns were observed on the lingual aspect.

Conclusion: The profile angle and crown ratio significantly associated with peri-implant soft tissue dimensions in posterior implant restorations. Larger profile angles and crown ratio, especially within the 1–2 mm coronal region, were closely associated with reductions in both soft tissue height and width. These findings demonstrate region-specific associations between crown contour morphology and peri-implant soft tissue dimensions.

1 | Introduction

Traditionally, the importance of transmucosal contour has been emphasized primarily in the anterior region, driven by esthetic demands and the need to maintain peri-implant mucosal margin stability [1, 2]. In recent years, clinical evidence has indicated that the transmucosal contour of implant restorations also influences peri-implant hard tissue outcomes in the posterior region, drawing attention to its functional relevance beyond esthetic considerations [3, 4].

While many previous investigations have focused primarily on mesial and distal marginal bone levels using periapical radiographs [5, 6], quantitative evaluations of buccal and lingual peri-implant soft tissue dimensions remain limited. Cone-beam computed tomography (CBCT) provides valuable information on buccal and lingual hard tissue morphology [7, 8]; however, its application for soft tissue assessment is constrained by limited spatial resolution and concerns regarding cumulative radiation exposure [9].

Peri-implant soft tissue dimensions are essential not only for esthetics but also for the biological stability and long-term health of implant restorations [10, 11]. Most clinical evaluations of buccal soft tissue have relied on qualitative assessments, examining relationships between soft tissue dimensions or emergence profile and

marginal gingival level using periodontal probes, digital photography, or digital scans [12–14]. Although these studies suggest that contour morphology influences soft tissue behavior, their assessments remain largely qualitative. Similarly, animal studies have reported that narrower transmucosal profiles may help preserve soft tissue height and connective tissue integrity; however, direct clinical translation of these findings remains limited [15–17].

More recently, quantitative analyses have been introduced to better characterize transmucosal geometry. The profile angle concept, defined as the contour angle of the restoration measured at 1-mm intervals from the implant platform or bone crest, was proposed to describe the distance-dependent influence of transmucosal contour on peri-implant tissues [18, 19]. Profile angles measured within approximately 2 mm from the bone crest have been shown to be significantly associated with marginal bone loss, whereas angles beyond this range appear to exert a less pronounced effect.

Region-specific analytical approaches have also been applied to the evaluation of peri-implant soft tissues, assessing how the transmucosal contour interacts with the implant supracrestal complex across different vertical zones. These studies suggest that peri-implant tissue responses may vary according to the vertical location of the contour in contact with the supracrestal complex [20, 21]. However, in contrast to peri-implant hard tissue evaluations, evidence related to peri-implant soft tissues remains largely observational. One clinical study compared soft tissue width and height at the implant platform level and at a level approximately 1.5 mm coronal to the platform, reporting reduced bleeding on probing at sites with greater soft tissue height [22]. Nevertheless, because customized abutments were not used in that study, the influence of transmucosal contour geometry could not be isolated or quantitatively assessed. Consequently, quantitative investigations of buccal soft tissue dimensions across different vertical levels using a distance-based profile angle approach remain lacking.

The purpose of this study was to evaluate the influence of profile angles, measured at 1-mm intervals from the implant platform, on buccal and lingual peri-implant soft tissue dimensions in posterior single-tooth implant restorations using digital scans and three-dimensional superimposition. In addition, this study assessed whether arch location (maxilla vs. mandible) and implant position (premolar vs. molar) affect peri-implant soft tissue dimensions. Based on existing evidence regarding the biological influence of transmucosal contour on peri-implant tissues, the following research hypotheses were formulated:

1. Profile angle and crown ratio (CR) are significantly associated with peri-implant soft tissue height and width at different vertical levels from the implant platform.

2. Peri-implant soft tissue dimensions differ according to arch location and implant position.

2 | Materials and Methods

This retrospective study was reviewed and approved by the Institutional Review Board of Gangnam Severance Hospital (IRB Number: 3-2024-0022). Between March 2024 and August 2024, patients with regular maintenance visits were invited to participate if they met the following inclusion criteria: (1) single-tooth implant restorations in the premolar or molar regions, (2) bone-level implants with an internal conical connection, (3) equicrestally placed implants, (4) restorations using CAD-CAM titanium customized abutments, (5) at least 1 year of postdelivery records, including periapical radiographs from regular follow-ups, and (6) implants placed using a surgical guide with a restoration-driven implant position. Upon written informed consent and fulfillment of the inclusion criteria, patients were enrolled in the study.

Exclusion criteria included: (1) implants placed in the anterior region, (2) use of prefabricated abutments, (3) cement-retained restoration without screw access channel, (4) follow-up period of less than 1 year after final restoration placement, (5) subcrestally or supracrestally placed implants, (6) crestal bone loss exceeding 1 mm, and (7) presence of peri-implantitis, peri-implant mucositis, or other significant soft tissue pathology.

2.1 | Sample Size Calculation

Sample size calculation was performed a priori using G*Power software (version 3.1.9.7; Universität Kiel, Germany) based on the primary research hypothesis that transmucosal contour parameters would be significantly associated with peri-implant soft tissue dimensions. Because the primary outcome of this study was the correlation between crown-related morphological parameters (profile angle and CR) and peri-implant soft tissue height and width, a Pearson correlation model was selected for sample size estimation. A medium-to-large effect size ($r = 0.4$) was assumed based on previously reported associations between prosthetic contour parameters and peri-implant tissue responses. With a two-tailed significance level set at $\alpha = 0.05$ and a statistical power of 0.80, the minimum required sample size was calculated to be 46 implant sites. To account for potential variability in soft tissue morphology and to ensure sufficient power for subgroup analyses according to arch location and implant position, a total of 58 posterior single-tooth implant restorations were included in the final analysis.

2.2 | Data Gathering and Measurements

Electronic medical and dental records were retrieved to obtain patient-specific and clinical data. The patient-specific data included patient age and sex. The clinical data comprised the arch location (maxilla or mandible), implant position (premolar or molar), implant type and abutment types, and follow-up period.

2.2.1 | Intraoral and Extraoral Digital Scan

A single clinician (J.H.L.) performed a complete-arch digital scan using an intraoral scanner (Trios 3; 3Shape, Copenhagen K, Denmark) (Figure 1A). After completing the intraoral scan, the screw access channel was opened, and the abutment screw
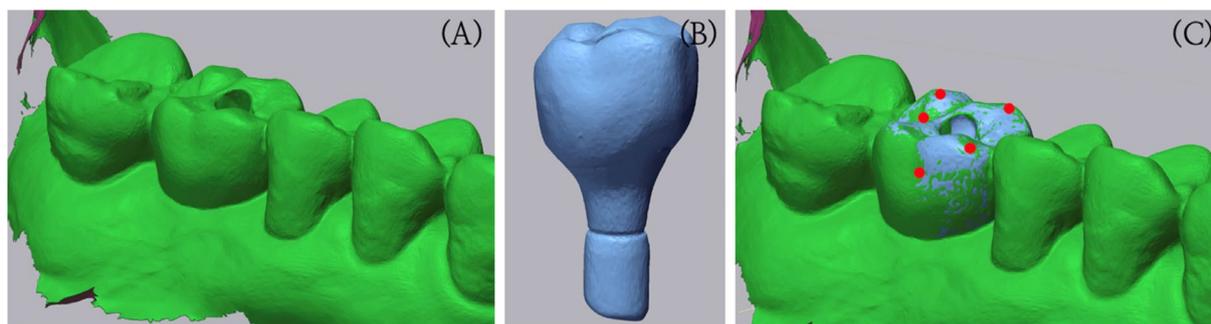
FIGURE 1 | (A) Intraoral digital scan file, (B) extraoral digital scan file of the implant crown connected to an implant replica, and (C) superimposition of extraoral and intraoral digital scan files.

was loosened and removed for retrieval. The retrieved implant crown was cleaned using an ultrasonic bath for 5 min in 83% ethyl alcohol (Green Pharmaceutical, Seoul, South Korea). Subsequently, the crown was connected to its corresponding implant replica, and the crown as well as the transmucosal part were scanned extraorally using the same intraoral scanner (Figure 1B). Figure 1C illustrates the superimposition of intraorally and extraorally scanned files.

2.2.2 | Preparation and Measuring the Dataset

Measurements and analyses were conducted using a CAD program (Geomagic Control X; 3D Systems, SC, USA) capable of three-dimensional analysis in Stereo Lithography (STL) file format. A graduate student (S.B.) performed all measurements and analyses. Intra-examiner reliability was tested with 10 randomly chosen intraoral digital scan data using the intraclass correlation coefficient (ICC) with a two-way mixed-effects model at a 1-week interval (ICC = 0.90), indicating high consistency.

2.2.3 | Superimposition of Scan Files

STL files of intraoral scan and extraorally scanned crowns were superimposed using a landmark-based method. Landmarks were selected at clearly distinguishable points, such as grooves, pits, or removing knots, and were evenly distributed across the buccal and lingual sides to avoid alignment error. After setting the landmarks, software-based alignment, matching, and optimization processes for superimposition were performed (Figure 1C).

2.2.4 | Establishing Reference Points, Lines, and Planes

The long axis of the implant was considered identical to that of the implant replica. A bucco-lingual reference plane (PL_{BL}) was then established by defining a plane including the long axis and perpendicular to the plane passing through the central fossae of the adjacent teeth. Cross-sectional images of the intraoral and extraoral crown scan files formed by PL_{BL} were defined as the crown contour (C_{Cr}) and soft tissue contour (C_{St}). A horizontal reference plane (PL_{H0}) was set at the implant platform level, with two additional horizontal planes (PL_{H1}, PL_{H2}) established

at 1 mm-intervals coronally along the implant's long axis. The slabs bounded by planes PL_{H0}–PL_{H1} and PL_{H1}–PL_{H2} were defined as R_1 (range 1) and R_2 (range 2), respectively (Figure 2A). The intersection points of C_{St} with each horizontal plane (PL_{H0}, PL_{H1}, PL_{H2}) were assigned as P_{St0}, P_{St1}, and P_{St2}, respectively. Similarly, the intersection points of C_{Cr} with each horizontal plane were assigned as P_{Cr0}, P_{Cr1}, and P_{Cr2}, respectively. P_{crest} was defined as the most coronal intersection point between C_{Cr} and C_{St}.

2.3 | Measurements

Based on the defined reference lines and points, crown width (W_{Cr}), soft tissue width (W_{St}), soft tissue height (H_{St}), and profile angle were measured for each dataset (Figures 3 and 4).

2.3.1 | Measurement of Height and Width

Figure 3 represented the height and width parameters.

2.3.2 | Measurement of Profile Angles

θ_1: Profile angle in R_1, the angle formed by the line connecting points pCr_0 and pCr_1 and the implant's long axis in 0–1 mm distance range.

θ_2: Profile angle in R_2, the angle formed by the line connecting points pCr_1 and pCr_2 and the implant's long axis in 1–2 mm distance range.

2.4 | Measurement of Soft Tissue Area and Crown Area

CAD software (AutoCAD 2025; Autodesk, CA, USA) was used to measure the crown areas (A_{Cr}) and soft tissue areas (A_{St}). Figure 5 represented crown area and soft tissue area at each distance range (R_1, R_2).

The CR within each distance range was calculated as follows (%):

CR_1: crown ratio in R_1, CR_2: crown ratio in R_2, CR_T: crown ratio in $R_1 + R_2$.
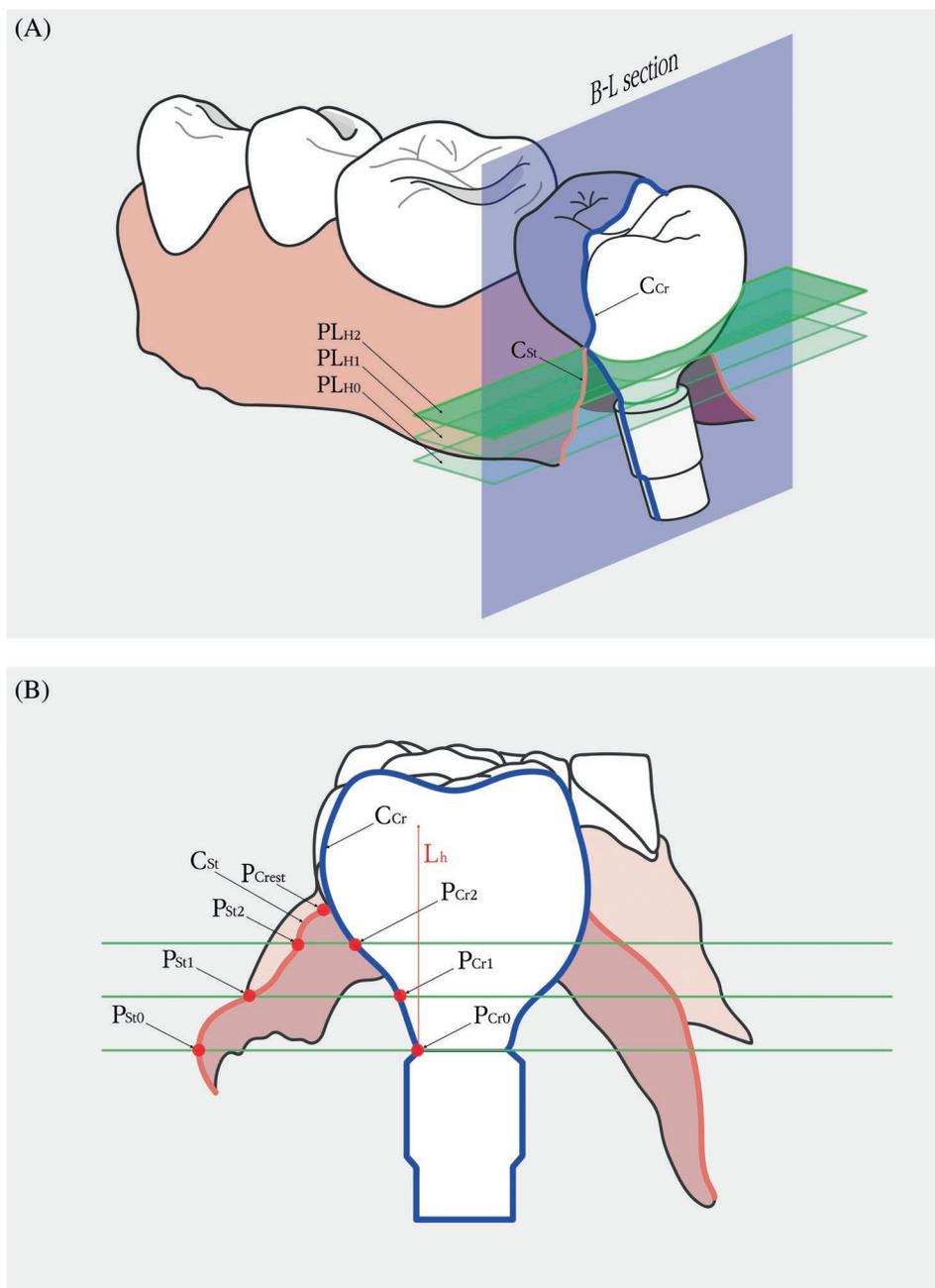
FIGURE 2 | (A) Horizontal reference planes (PL_{H0}, PL_{H1}, PL_{H2}) were presented as green planes, blue line represented crown contour (C_{Cr}) and outline of abutment and implant replica. Soft tissue contour (C_{St}) was presented as pale pink lines. (B) Reference points. P_{St0}, P_{St1}, and P_{St2} represented the intersections points of C_{St} with each horizontal reference plane (PL_{H0}, PL_{H1}, PL_{H2}). P_{Cr0}, P_{Cr1}, and P_{Cr2} represented the intersections points of C_{Cr} with each horizontal plane. P_{crest} was defined by the most coronal intersection point between C_{Cr} and C_{St}, L_h is the vertical reference line that passes through the most outer point of implant-abutment junction at the measurement aspect and is parallel to the implant long axis.

2.5 | Statistical Analysis

The measured values were summarized using spreadsheet (Excel; Microsoft, Washington, USA). Statistical tests were performed to analyze the relationships between soft tissue height (H), soft tissue width (W_0, W_1, W_2), and the width–height ratio (W_{St0}/H_{St}) with arch locations (maxilla/mandible), implant position (premolar/molar), and the CRs (CR_1, CR_2, CR_T).

Independent t tests were conducted to evaluate statistical differences in soft tissue parameters according to arch (maxilla/mandible) and implant position (premolar/molar). Pearson's correlation analysis was used to analyze the relationships between soft tissue width (W_0) and soft tissue height (H_{St}), as well as between CR (CR_T). Pearson's correlation analysis and a Z test were performed to evaluate the relationships between CR (CR_1, CR_2, CR_T) and soft tissue height and width, comparing the strength of these correlations.

For profile angle and CR, the cut-off values were calculated using Youden's index and the χ^2 test. All statistical analyses were conducted with a 95% confidence level using a statistical program (SAS version 9.4; SAS Institute, NC, USA).
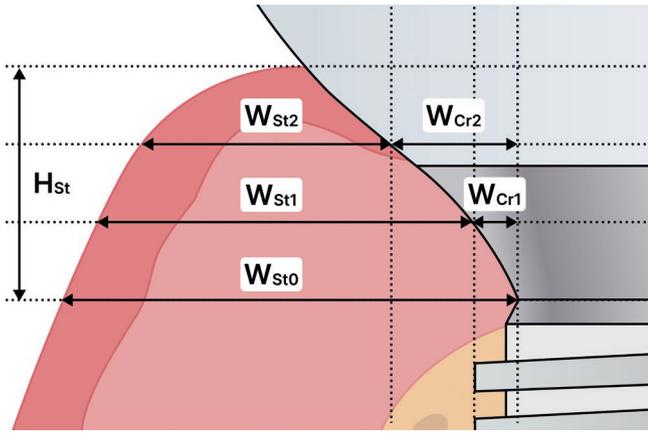
FIGURE 3 | Height and width parameters. W_{St0}: soft tissue width at the implant platform level, distance between points P_{Cr0} and P_{St0}, W_{St1}: soft tissue width at 1 mm coronal from the implant platform, distance between points P_{Cr1} and P_{St1}, W_{St2}: soft tissue width at 2 mm coronal from the implant platform, distance between points P_{Cr2} and P_{St2}, W_{Cr1}: crown width at 1 mm coroanl from the implant platform, distance from P_{Cr1} to L_h, W_{Cr2}: crown width at 2 mm coronal from the implant platform, distance from P_{Cr2} to L_h. H_{St}: soft tissue height, the shortest distance from P_{Crest} to PL_{H0}.
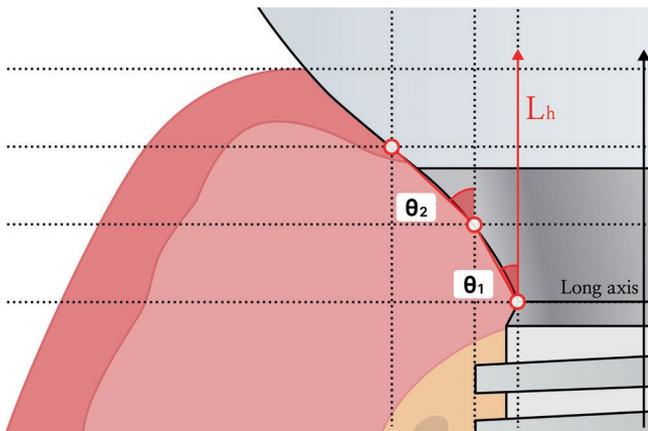
FIGURE 4 | Definition of profile angle. θ_1: profile angle in 0–1 mm distance range; θ_2: profile angle in 1–2 mm distance range.

3 | Results

3.1 | Implant Characteristics

A total of 58 posterior single tooth implant restorations met the inclusion criteria. Table 1 represents demographic data of included implant crowns.

The follow-up period after final restoration delivery ranged from 1 to 9 years, with an average of 5.19 ± 2.50 years.

3.2 | Influence of Arch Location, Implant Position on the Soft Tissue Dimension

At the buccal aspect, a statistically significant difference in soft tissue width (W_1, W_2) was observed based on the arch ($p < 0.05$). However, no statistically significant difference was noted for
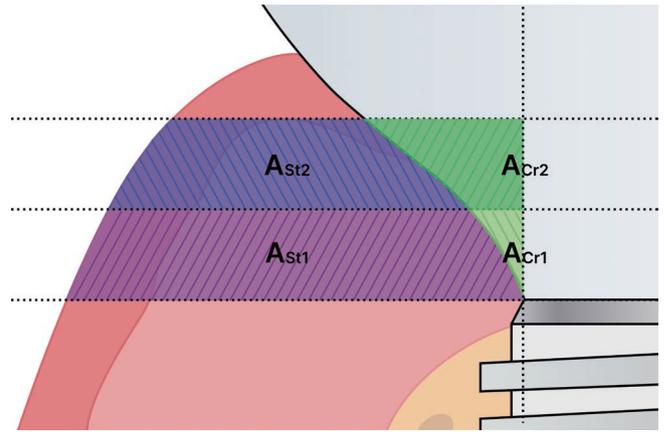
FIGURE 5 | Soft tissue area and crown area. A_{St1}: soft tissue area in R_1, A_{St2}: soft tissue area in interval R_2, A_{StT}: total soft tissue area in $R_1 + R_2$, A_{Cr1}: crown area in interval R_1, A_{Cr2}: crown area in interval R_2, and A_{CrT}: total crown area in $R_1 + R_2$.

soft tissue indices based on premolar/molar classification or follow-up period ($p > 0.05$) (Table 2A).

At the palatal/lingual aspect, statistically significant differences in W_1, W_2, and W/H ratio were found based on the arch ($p < 0.05$). No significant differences were observed based on premolar/molar classification or follow-up period ($p > 0.05$) (Table 2B).

3.3 | Relationship Between CR and the Soft Tissue Dimension

3.3.1 | CR and Soft Tissue Height (H)

At the buccal aspect, the CR (CR_T) and soft tissue height (H_{St}) showed a strong negative correlation coefficient ($r = -0.756$, $p < 0.05$) in 0–2 mm distance range. Strong ($r = -0.790$) negative correlation coefficient was noted in 1–2 mm distance range while moderate ($r = -0.654$) negative correlation coefficient was found in 0–1 mm distance range (Table 3A).

At the palatal/lingual aspect, CR_T and H demonstrated a moderate negative correlation ($r = -0.685$, $p < 0.05$). Similarly to buccal aspect, strong ($r = -0.731$) negative correlation coefficient was noted in 1–2 mm while moderate to low ($r = -0.426$) negative correlation coefficient was found in 0–1 mm distance range (Table 3B).

3.3.2 | CR and Soft Tissue Width (W)

Correlation analyses between CR and soft tissue width are summarized in Table 4A. At the buccal aspect, the strongest correlation was observed between CR_2 and W_{St2}, with a Pearson correlation coefficient of $r = -0.873$, indicating a very strong negative correlation coefficient. Similarly, W_{St1} also showed strong negative correlation coefficient with CR_2 ($r = -0.826$), suggesting a consistent and significant negative relationship between CR and soft tissue width in the more coronal region, which is R_2. In contrast, CR_1 demonstrated only

TABLE 1 | Characteristics of included implants.

Characteristics		Number	Characteristics		Number
Arch	Maxilla	25	Implant type (diameter in mm)	IT (4.3)	11
	Mandible	33		IU (4.5)	35
Implant position	Premolar	7		Implantium (4.5)	9
	Molar	51		Anyone (4.5)	3

TABLE 2A | Correlation of buccal soft tissue dimension with arch, tooth type, and follow-up period.

Variable	Total ($N=58$)	Tooth			Arch		
		Premolar ($N=7$)	Molar ($N=51$)	p	Mandible ($N=32$)	Maxillae ($N=26$)	p
H_{St}	3.129 ± 1.14	3.53 ± 1.14	3.08 ± 1.15	0.331	2.88 ± 1.03	3.43 ± 1.22	0.071
W_{St1}	3.572 ± 1.82	4.115 ± 1.346	3.49 ± 1.88	0.403	2.86 ± 1.60	4.40 ± 1.73	0.001
W_{St2}	2.505 ± 1.71	3.056 ± 1.361	2.41 ± 1.77	0.400	1.79 ± 1.44	3.12 ± 1.71	0.011
H/W	1.479 ± 0.37	1.35 ± 0.38	1.50 ± 0.374	0.332	1.45 ± 0.41	1.52 ± 0.32	0.500

Note: Independent t tests and Pearson's correlation analysis were used for statistical comparison ($p < 0.05$).
Abbreviations: H/W, height/width ratio; H_{St}, soft tissue height; W_{St1}, soft tissue width at 1 mm above implant platform; W_{St2}, soft tissue width at 2 mm above implant platform.

TABLE 2B | Correlation of lingual soft tissue dimension with arch, tooth type, and follow-up period.

Variable	Total ($N=58$)	Tooth			Arch		
		Premolar ($N=7$)	Molar ($N=51$)	p	Mandible ($N=32$)	Maxillae ($N=26$)	p
H_{St}	3.76 ± 1.04	3.91 ± 1.20	3.74 ± 1.02	0.682	3.59 ± 1.05	3.96 ± 1.01	0.198
W_1	4.49 ± 2.29	4.36 ± 1.65	4.52 ± 2.40	0.869	3.48 ± 1.21	5.63 ± 2.69	0.001
W_2	2.94 ± 2.09	2.99 ± 1.83	2.93 ± 2.16	0.945	2.14 ± 1.47	3.85 ± 2.35	0.004
W/H	1.34 ± 0.37	1.46 ± 0.41	1.32 ± 0.37	0.383	1.18 ± 0.23	1.54 ± 0.42	0.002

Note: Independent t tests and Pearson's correlation analysis were used for statistical comparison ($p < 0.05$).
Abbreviations: H/W, height/width ratio; H_{St}, soft tissue height; W_{St1}, soft tissue width at 1 mm above implant platform; W_{St2}, soft tissue width at 2 mm above implant platform.

TABLE 3A | Correlation analysis between crown ratio and soft tissue height at buccal aspect.

Data, variable	Buccal				
	Height		Correlation comparison		
	r (95% CI)	p	CR_1	CR_2	CRW
CR_1	−0.654 (−0.782 to −0.464)	<0.001			
CR_2	−0.790 (−0.871 to −0.658)	<0.001	<0.001		
CR_T	−0.756 (−0.850 to −0.608)	<0.001	<0.001	0.014	

Note: CR_1: crown ratio in 0–1 mm distance range, CR_2: crown ratio in 1–2 mm distance range, CR_T: crown ratio in 0–2 mm distance range, independent t tests, and Pearson's correlation analysis were used for statistical comparison ($p < 0.05$).

moderate correlations with W_{St1} and W_{St2}, with coefficients around −0.666, −0.653, respectively, indicating a comparatively weaker association.

Although all correlation analyses yielded statistically significant results on the palatal side, the strength of the correlation was generally weaker compared to the buccal side. Nonetheless, CR_2 demonstrated stronger correlations with soft tissue width than CR_1, even on the palatal aspect (Table 4B).

3.4 | Critical CR and Critical Profile Angle Based on Soft Tissue Height

At the buccal aspect, when the soft tissue heights were 2, 3, and 4 mm, the cutoff values for CR_T were calculated as 31%, 12%, and 8%, respectively. Similarly, the cutoff values for CR_1 were 8%, 4%, and 3%, and for CR_2 were 57%, 25%, and 14%. The corresponding profile angles θ_0 for achieving these heights were 66°, 41°, and 30°, respectively. For θ_1, the angles were 35°, 18°, and 14°, and for θ_2, the angles were 82°, 59°, and 36°.

TABLE 3B | Correlation analysis between crown ratio and soft tissue height at palatal/lingual aspect.

| Data, variable | Palatal/lingual | | | | |
| | Height | | Correlation comparison | | |
	r (95% CI)	p	CR$_1$	CR$_2$	CR$_T$
CR$_1$	−0.426 (−0.632 to −0.153)	0.003			
CR$_2$	−0.731 (−0.839 to −0.557)	<0.001	<0.001		
CR$_T$	−0.685 (−0.810 to −0.490)	<0.001	<0.001	0.002	

Note: CR$_1$: crown ratio in 0–1 mm distance range, CR$_2$: crown ratio in 1–2 mm distance range, CR$_T$: crown ratio in 0–2 mm distance range, independent *t* tests, and Pearson's correlation analysis were used for statistical comparison ($p < 0.005$).

TABLE 4A | Correlation between crown ratio (CR) and soft tissue width at buccal aspect.

| Data, variable | Buccal | | | |
| | W_{St1} | | W_{St2} | |
	r (95% CI)	p	r (95% CI)	p
CR$_1$	−0.666 (−0.790 to −0.480)	<0.001	−0.653 (−0.797 to −0.425)	<0.001
CR$_2$	−0.826 (−0.894 to −0.713)	<0.001	−0.873 (−0.929 to −0.769)	<0.001
CR$_T$	−0.785 (−0.868 to −0.651)	<0.001	−0.849 (−0.915 to −0.728)	<0.001

Note: CR$_1$: crown ratio in 0–1 mm distance range, CR$_2$: crown ratio in 1–2 mm distance range, CR$_T$: crown ratio in 0–2 mm distance range, W_{St1}: soft tissue width at 1 mm above the implant platform, W_{St2}: soft tissue width at 2 mm above the implant platform, independent *t* test, and Pearson's correlation analysis were used for statistical comparison ($p < 0.05$).

At the palatal/lingual aspect, when the soft tissue height were 3 and 4 mm, the cutoff values for CR$_T$ were 10.6% and 4.4%, respectively. Similarly, the cutoff values for CR$_1$ were 3.6% and 1.3%, and for CR$_2$ were 21% and 7.3%. The corresponding profile angles θ_0 were 37.9° and 17.9°, respectively. For θ_1, the angles were 16.6° and 6°, and for θ_2, the angles were 52.4° and 20.2°. No calculations were performed for soft tissue heights of 2 mm due to a lack of corresponding subject (Table 5).

Figure 6A,B represented the relationship between critical profile angle and soft tissue width at buccal and lingual aspects.

4 | Discussion

This study demonstrated that the transmucosal contour of posterior single-tooth implant crowns significantly influences

TABLE 4B | Correlation between crown ratio (CR) and soft tissue width at palatal aspect.

| Data, variable | Palatal/lingual | | | |
| | W_{St1} | | W_{St2} | |
	r (95% CI)	p	r (95% CI)	p
CR$_1$	−0.346 (−0.573 to −0.062)	0.017	−0.472 (−0.666 to −0.209)	<0.001
CR$_2$	−0.547 (−0.718 to −0.302)	<0.001	−0.719 (−0.832 to −0.539)	<0.001
CR$_T$	−0.508 (−0.691 to −0.253)	<0.001	−0.678 (−0.805 to −0.480)	<0.001

Note: CR$_1$: crown ratio in 0–1 mm distance range, CR$_2$: crown ratio in 1–2 mm distance range, W_{St1}: soft tissue width at 1 mm above the implant platform, W_{St2}: soft tissue width at 2 mm above the implant platform, independent *t* tests, and Pearson's correlation analysis were used for statistical comparison ($p < 0.05$).

peri-implant soft tissue dimensions. Both CR and profile angle showed strong negative correlation coefficient with soft tissue height and width, with the most pronounced effects occurring within the 1–2 mm region above the implant platform. These findings support the first research hypothesis. Additionally, soft tissue width was greater in the maxilla than in the mandible, while soft tissue height showed no arch-dependent differences, resulting in partial support of the second research hypothesis.

A key observation was that crown-related parameters closer to the free gingival margin (1–2 mm) exhibited stronger correlations with soft tissue height than those nearer the bone crest (0–1 mm). This differs from patterns described in previous studies evaluating hard tissue responses, in which profile angles within the apical 0–2 mm region were most strongly related to marginal bone loss in both equicrestal and subcrestal placements [18, 19]. These findings indicate that bone and soft tissue respond to different segments of the transmucosal contour: crestal bone is sensitive to apical contour changes, whereas mucosal height is predominantly influenced by the coronal emergent contour. These results are also consistent with the critical and subcritical contour concept, in which the coronal critical contour governs gingival level and soft tissue height, while the deeper subcritical contour influences supporting tissue architecture [21].

The critical-value analysis further clarified this relationship. Sites with greater soft tissue height consistently exhibited lower CRs, particularly within the 1–2 mm region. This suggests that vertical mucosal height can be maintained only when crown occupancy in this coronal zone remains below a certain volumetric threshold. Whereas soft tissue width decreases gradually as CR increases, soft tissue height appears to have a narrower biological tolerance, being reduced substantially once crown volume surpasses this threshold. These findings are consistent with observations in the earlier work reporting that convex emergence profiles are associated with greater soft tissue recession over time [1].

TABLE 5 | Critical crown ratio and critical profile angle for different soft tissue height.

Height	Buccal			Palatal/lingual		
	$cCR_T(c\theta_0)$	$cCR_1(c\theta_1)$	$cCR_2(c\theta_2)$	$cCR_T(c\theta_0)$	$cCR_1(c\theta_1)$	$cCR_2(c\theta_2)$
2 mm	31% (66.3°)	8% (34.8°)	57% (81.3°)			
3 mm	12% (41.4°)	4% (18.4°)	25% (59.0°)	11% (37.9°)	4% (16.6°)	21% (52.4°)
4 mm	8% (30.4°)	3% (13.9°)	14% (36.1°)	4% (17.9°)	1% (6.0°)	7% (20.2°)

Note: Height: soft tissue height, cCR_T: critical crown ratio in 0–2 mm distance range; cCR_1: critical crown ratio in 0–1 mm distance range; cCR_2: critical crown ratio in 1–2 mm distance range; $c\theta_T$: critical profile angle in 0–2 mm distance range; $c\theta_1$: critical profile angle in 0–1 mm distance range; $c\theta_2$: critical profile angle in 1–2 mm distance range. Cut-off value was calculated using Youden's index.
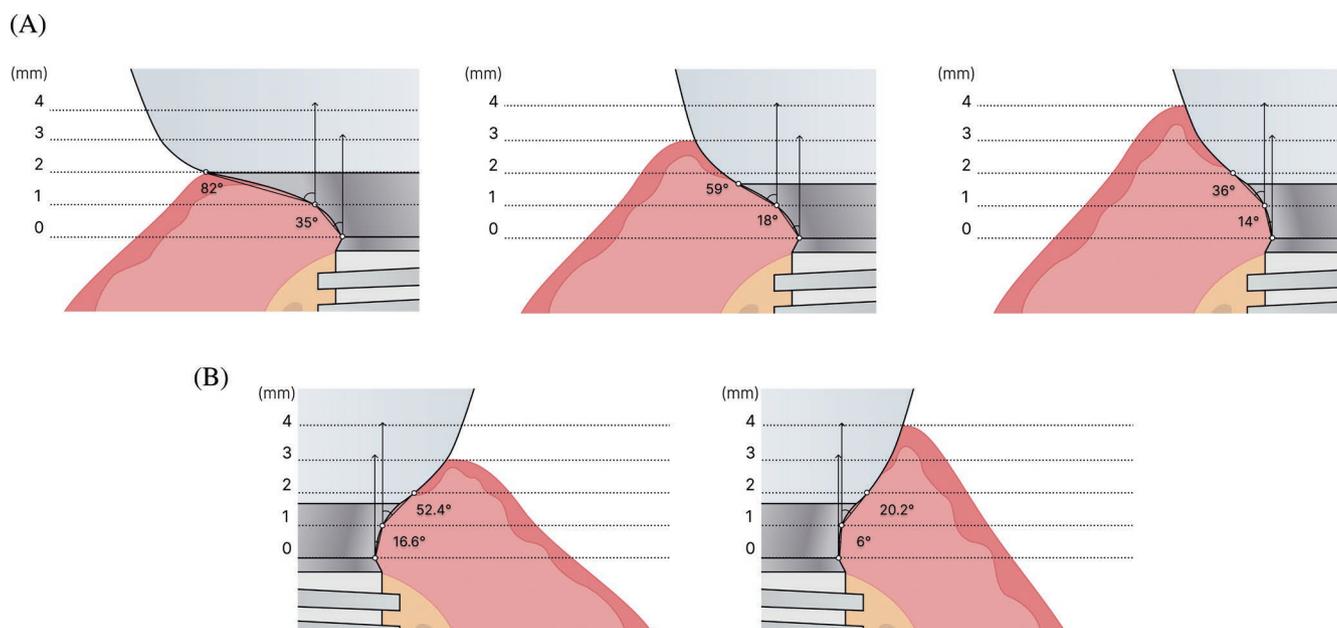
FIGURE 6 | (A) Critical crown ratio and critical profile angle as a function of soft tissue height in Buccal aspects. (B) Critical crown ratio and critical profile angle as a function of soft tissue height in Lingual aspects.

Previous observational studies have described region-dependent transmucosal contour zones in relation to peri-implant tissue behavior [20]. These concepts provide a framework for interpreting the region-specific associations observed in the present study.

This study has several limitations. First, all measurements were based on two-dimensional cross-sections derived from three-dimensional scans, which may not fully capture the geometric complexity of the transmucosal contour. Second, although reference intervals were defined from the implant platform, the results indicate that tissue dimensions are more strongly influenced by the region closer to the free gingival margin; therefore, future studies should consider analyses based on a gingival-margin reference. In addition, because this retrospective study evaluated tissues at a single follow-up time point, neither baseline soft tissue thickness nor temporal changes such as recession could be assessed, leaving the influence of initial mucosal thickness on the observed soft tissue dimensions uncertain.

Further histologic and volumetric studies are required to clarify the biological implications of transmucosal contour geometry. A more detailed understanding of how contour configuration relates to peri-implant soft tissue characteristics may support future evidence-based approaches for transmucosal contour design in posterior implant restorations. Improved understanding of the relationship between contour configuration and peri-implant soft tissue characteristics may contribute to the interpretation of transmucosal contour effects in posterior implant restorations.

5 | Conclusions

The following conclusions were drawn:

1. Profile angle and CR demonstrated significant negative correlations with buccal and lingual peri-implant soft tissue height and width.

2. The strength of these correlations was greatest within the 1–2 mm region coronal to the implant platform.

3. Peri-implant soft tissue width was significantly greater in the maxilla than in the mandible, whereas soft tissue height did not differ according to arch location.

4. No significant differences in peri-implant soft tissue dimensions were observed according to implant position (premolar vs. molar).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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