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Correlation analysis of periodontal tissue dimensions in the esthetic zone using a non-invasive digital method

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ABSTRACT

Purpose: Direct intraoral scanning and superimposing methods have recently been applied to measure the dimensions of periodontal tissues. The aim of this study was to analyze various correlations between labial gingival thickness and underlying alveolar bone thickness, as well as clinical parameters among 3 tooth types (central incisors, lateral incisors, and canines) using a digital method.
Methods: In 20 periodontally healthy subjects, cone-beam computed tomography images and intraoral scanned files were obtained. Measurements of labial alveolar bone and gingival thickness at the central incisors, lateral incisors, and canines were performed at points 0–5 mm from the alveolar crest on the superimposed images. Clinical parameters including the crown width/crown length ratio, keratinized gingival width, gingival scallop, and transparency of the periodontal probe through the gingival sulcus were examined.
Results: Gingival thickness at the alveolar crest level was positively correlated with the thickness of the alveolar bone plate ($P<0.05$). The central incisors revealed a strong correlation between labial alveolar bone thickness at 1 and 2 mm, respectively, inferior to the alveolar crest and the thickness of the gingiva at the alveolar crest line (G0), whereas G0 and labial bone thickness at every level were positively correlated in the lateral incisors and canines. No significant correlations were found between clinical parameters and hard or soft tissue thickness.
Conclusions: Gingival thickness at the alveolar crest level revealed a positive correlation with labial alveolar bone thickness, although this correlation at identical depth levels was not significant. Gingival thickness, at or under the alveolar crest level, was not associated with the clinical parameters of the gingival features, such as the crown form, gingival scallop, or keratinized gingival width.

Keywords: Cone-beam computed tomography; Gingiva; Maxilla; Computer-assisted radiographic image interpretation

INTRODUCTION

Variation in the clinical appearance of mucogingival tissues has been termed as the periodontal phenotype in the new classification, and it is accepted as a concept

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Conflict of Interest
No potential conflict of interest relevant to this article was reported.

encompassing the gingival biotype, bone morphotype, and tooth dimensions [1,2]. The gingival biotype, which includes gingival thickness and keratinized tissue width, has long been known to reflect the underlying alveolar bone architecture [3]. In 1977, Weisgold [4] introduced the terms "thick-flat" and "thin-scalloped" to describe gingival biotypes. The "thick-flat" biotype is described as a prognostic factor for esthetic implant outcomes [5], and the thickness of the gingiva has been reported to influence the results of root coverage surgery [6]. The so-called "thin-scalloped" gingiva is associated with a higher risk of gingival recession after immediate implant placement [7], and poorer healing of soft tissue after crown lengthening surgery [8]. These results may be explained by a few studies that reported a weak to moderate correlation between the thickness of the underlying bone and the thickness of gingiva that covers it [9,10]. However, relatively few studies have investigated this issue due to the lack of standardized techniques for measuring hard and soft tissue thickness.

Calipers [11] and cone-beam computed tomography (CBCT) [12,13] are common tools used to measure the thickness of alveolar bone. The simplest method to assess soft-tissue thickness in the clinical setting was to determine the degree of visibility of the periodontal probe outline through the soft tissue while probing the buccal gingival sulcus [14-16]. Another invasive probing method utilizing endodontic needles has been suggested [17-19]; alternatively, non-invasive ultrasonic devices have also been used [20]. However, the ability of these techniques to accurately determine the thickness of a specific site is limited, the results have been controversial, and the delineation between thick and thin biotypes remains imprecise.

Digital scanning and assessment methods have recently been applied to measure the dimensions of periodontal tissue. This approach has been successfully used in clinical studies to assess volumetric changes, in conjunction with linear measurements of soft and hard tissues [21]. Although studies have demonstrated the precision and reliability of this non-invasive method [22], the possibility of errors in the impression-model fabrication procedure is a fundamental limitation. Several studies have measured soft tissue dimensions as well as hard tissue thickness using CBCT images [9,23]; however, more accurate outlines could be detected by digitally scanning files with substantially higher resolutions.

In order to overcome the limitations of the aforementioned methods, such as invasiveness or inaccuracy, we measured the thickness of hard tissue and soft tissue by direct intraoral scanning and superimposition in a previous study [24]. In that previous study, we found that the gingiva and buccal bone of the maxillary anterior teeth were generally thin (<1 mm), and the gingival thickness increased and the bone thickness decreased toward the root apex. The correlation between buccal bone thickness and soft tissue thickness at the same level was generally not significant, but differences were found between teeth at some locations.

Several studies have also shown association of clinical parameters, such as tooth crown shape and the height of the gingival scallop, with gingival thickness [10,25,26]. However, these results were not consistent and the relationships should be verified. Hence, the objective of this study was to analyze various correlations between labial gingival thickness and underlying alveolar bone thickness, as well as clinical parameters, among 3 tooth types (central incisors, lateral incisors, and canines) as a follow-up to the previous study [24].

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MATERIALS AND METHODS

Patient selection

This study was performed at the Department of Periodontology, Seoul National University Gwanak Dental Hospital between October 2015 and June 2016. Twenty-one patients (20–65 years old) who visited the dental hospital for an annual dental examination with intact maxillary anterior teeth (#13, 12, 11, 21, 22, 23), without signs of marginal or periapical bone resorption, were included in this study. The following exclusion criteria were applied: pregnant patients; patients with fixed partial dentures or orthodontic appliances; patients with systemic disease or those who were taking medications that may have affected the thickness of the soft tissue, such as calcium channel blockers or immunosuppressive drugs; patients showing signs of either periodontal disease as defined by a periodontal probing depth >3 mm or gingival recession; and patients who refused to fill out the consent form.

Following the exclusion of 1 patient due to the poor quality of the radiographic images, 20 participants (10 male patients and 10 female patients) were included in this study. Ethical approval was obtained from the Ethics Committee of Seoul National University, and the investigation was carried out at the Department of Periodontology, Seoul National University Gwanak Dental Hospital (EC/ S-D20150029, registered 18 September 2015).

Image acquisition and analysis

Patients underwent scaling, after which 3 radiopaque cylindrical fiducial markers, measuring 2 mm in diameter by 2 mm in height, were attached to both maxillary second premolars and 1 incisor (Figure 1A). After a CBCT scan was performed (CS9300, Carestream, Rochester, NY, USA), the maxillary arch was directly scanned with an intraoral scanner (Trios2, 3Shape, Copenhagen, Denmark). The 3 cylindrical markers were used as a reference to match the scanned stereolithography files with the CBCT images precisely. Image reconstruction and superimposition were performed using Platon software (Ezplant, Seoul, Korea) with a series of mathematical algorithms (Figure 1B and C).

Measurements were taken in the same way as in the previous study [24]. One of the 2 corresponding teeth in the first and second quadrants was randomly selected. A longitudinal slice dividing the crown mesio-distally into 2 equal parts was then captured. A line coinciding with the axis of the tooth was subsequently drawn in the sections.

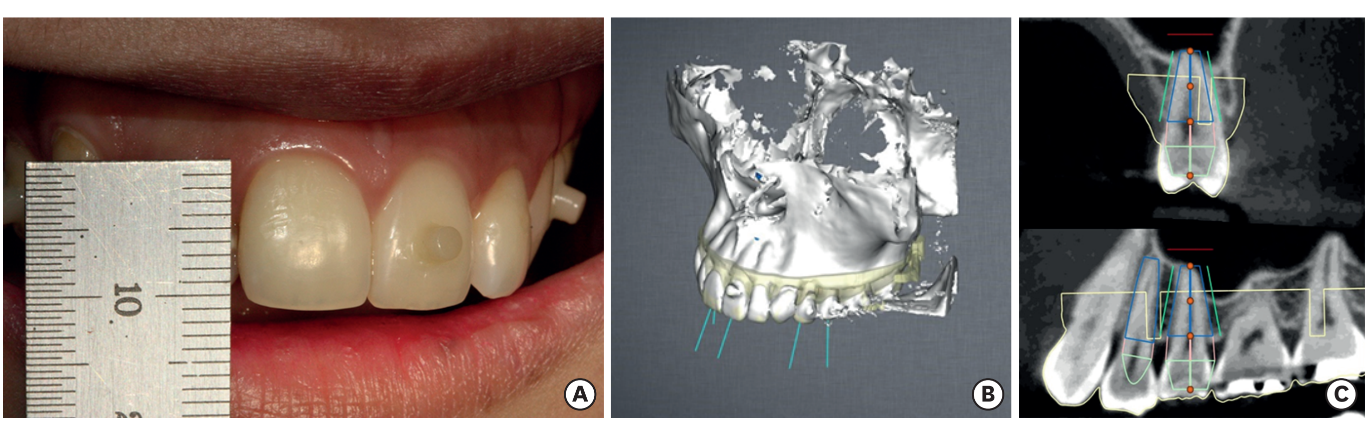

Figure 1. Three radiopaque, cylindrical fiducial markers, measuring 2 mm in diameter by 2 mm in height, were attached to both maxillary premolars and 1 incisor (A). Image reconstruction for visual analysis was performed using Platon software (Ezplant) to automatically superimpose the images (B, C).

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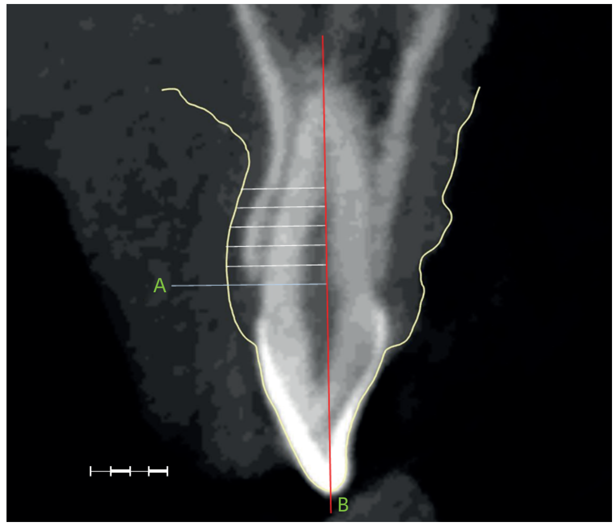

Figure 2. Para-axial slice at the mid-buccal aspect of the lateral incisor. The gingival outline obtained from a scanned file is marked as a yellow line. Thickness measurements at 1–5 mm from the alveolar crest (A), and perpendicular to the root axis (B).

The measurements of labial alveolar bone width and thickness of the gingiva were performed to the nearest 0.01 mm, at 1–5 mm from the alveolar crest at the mid-buccal aspect of each tooth and perpendicular to the axis of the tooth. The gingival thickness in the alveolar crest line (G0) was also determined (Figure 2). All of the values were measured by the same clinician. Duplicate registration was performed to assess intra-examiner reliability.

Clinical examination and photographic analysis

Intraoral examinations were performed on the randomly selected index tooth (central incisor, lateral incisor, and the canine), in addition to the direct measurement and analysis of the clinical photograph in the region of the index tooth. The measurement was carried out according to the method of Stein et al. [10]. All measurements were performed by 1 clinician. The following assessments were directly made using a periodontal probe (CPU 15 UNC, Hu-Friedy, Chicago, IL, USA):

- The width of the keratinized gingiva (GW) was measured from the mid-buccal point of the marginal gingiva to the mucogingival junction, to the nearest 0.5 mm.
- The transparency of the periodontal probe outline through the gingival sulcus (TRAN) was also determined after inserting the probe into the sulcus on the mid-buccal position. The visibility of the periodontal probe outline was recorded as a categorical variable (0=probe visible; 1=probe not visible).

On clinical photographs (Figure 3), the following parameters were recorded using image processing software (Image J 1.51f, Microsoft Java, Microsoft Corp., Redmond, WA, USA):

- The crown width/crown length ratio (CW/CL) was measured according to the method of Olsson and Lindhe [27]. The crown length was measured from the incisal edge to the margin of the labial gingiva. For the assessment of the width, the crown length was divided into 3 equal portions. The distance between the approximal crown surfaces at the border between the middle and the cervical portion was recorded.

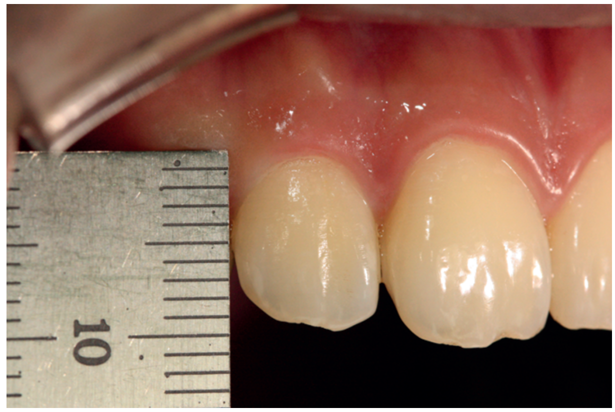

Figure 3. Clinical photograph of the index tooth.

- The height of the gingival scallop (SC) was recorded as the widest distance between the line connecting the peaks of the 2 adjacent inter-dental papillae and the most apical point of the buccal marginal gingiva.

Statistical analysis

Data were analyzed using the SPSS statistical software package (version 19.0, IBM Corp, Armonk, NY, USA). Clinical parameters were compared among the tooth types using the Friedman test, the *post hoc* Wilcoxon signed rank test, and the *post hoc* McNemar test. For the *post hoc* test, statistical significance was defined as a *P* value less than 0.017 according to the Bonferroni correction. The Spearman correlation coefficient was calculated to assess the correlation between labial alveolar bone thickness and gingival thickness according to the tooth type. With the corresponding 95% confidence intervals, the correlations of CW/CL, SC, and GW with the thickness of the gingiva at different apico-coronal levels (G0–G5), as well as the thickness of the labial alveolar bone plate at different apico-coronal levels (A1–A5), were calculated. The relationships between TRAN and thickness measurements were evaluated with the Mann-Whitney *U* test.

RESULTS

Mean values of clinical measurements

Table 1 shows the descriptive data of the clinical measurements. The specimens were described on the basis of their crown forms, which ranged from a tapered long form with a very low CW/CL to a squared short shape with the highest CW/CL. The average CW/CL values

Table 1. Descriptive data of the clinical measurements

Characteristics	Central incisors	Lateral incisors	Canines
CW/CL	0.76±0.07[a)]	0.71±0.08[a)]	0.71±0.08
SC (mm)	4.37±0.55	4.05±0.46[b)]	4.62±0.65[b)]
GW (mm)	5.15±0.90	4.95±0.79	4.90±0.90
TRAN (%)	40	70	75

Values are presented as mean±standard deviation or percentage.
CW/CL: crown width/crown length ratio, SC, height of the gingival scallop; GW, width of the keratinized gingiva; TRAM: transparency of the periodontal probe.
[a)]Statistically significant differences between central incisors and lateral incisors, $P<0.017$; [b)]Statistically significant differences between lateral incisors and canines, $P<0.017$.

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were 0.76, 0.71, and 0.71 at the central incisors, lateral incisors, and canines, respectively. The mean SC values for the central incisors, lateral incisors, and canines were 4.37, 4.05, and 4.62 mm, respectively, whereas the mean values for GW were 5.15, 4.95, and 4.90 mm, respectively. The insertion of the periodontal probe at the mid-buccal aspect of the sulcus was visible in 40% of subjects at the central incisors, 70% at the lateral incisors, and 75% at the canines.

Relationships between labial bone and gingival thickness

The results of the Spearman correlation tests are shown in Table 2. Gingival thickness at G0 was positively correlated with the thickness of the labial alveolar bone plate. The central incisors revealed a positive correlation between A1 and A2 (labial alveolar bone thickness at 1 and 2 mm, respectively, inferior to the alveolar crest) with the thickness of the gingiva at G0, whereas G0 and labial bone thickness at every level were positively correlated at the lateral incisors and canines.

Comparison of clinical parameters with respect to tooth type

Significant differences were found among the tooth types for CW/CL (P=0.022) and SC (P=0.004) according to the results of the Friedman test. The *post hoc* Wilcoxon test indicated a significant difference for CW/CL between the central incisors and lateral incisors (P=0.015). The SC values revealed significant differences between the lateral incisors and canines (P=0.000) (Table 1, Figure 4).

Correlations between clinical and radiographic measurements

No significant correlations were found between clinical parameters and hard and soft tissue thicknesses (Tables 3 and 4). GW and G0 were most closely correlated at the canines. A correlation between SC and G1 was found at the lateral incisors, and a correlation between G5 and CW/CL was also detected at the canines. The correlations between the remaining parameters were not statistically significant (P>0.05). For the TRAN data (marked 0 or 1), significant differences were found only for GO at the central incisors and the A1 measurements of the lateral incisors (Table 4).

Table 2. Spearman correlation coefficients between labial bone and soft tissue thickness

Characteristics	G0		G1		G2		G3		G4		G5	
	Correlation coefficients	*P* value	Correlation coefficients	*P* value	Correlation coefficients	*P* value	Correlation coefficients	*P* value	Correlation coefficients	*P* value	Correlation coefficients	*P* value
Central incisors												
A1	0.467[a)]	0.038	0.033	0.890	0.163	0.491	0.308	0.186	0.174	0.462	−0.069	0.773
A2	0.514[a)]	0.020	0.104	0.664	0.166	0.483	0.241	0.305	0.091	0.704	−0.142	0.549
A3	0.391	0.088	0.038	0.875	0.132	0.580	0.215	0.363	0.112	0.639	−0.088	0.713
A4	0.403	0.078	0.098	0.682	0.168	0.479	0.206	0.383	0.124	0.603	−0.037	0.876
A5	0.273	0.245	0.064	0.787	0.149	0.532	0.280	0.231	0.280	0.233	0.063	0.793
Lateral incisors												
A1	0.597[a)]	0.005	0.022	0.927	−0.155	0.514	−0.213	0.366	0.078	0.744	0.096	0.687
A2	0.534[a)]	0.015	−0.043	0.856	−0.266	0.257	−0.310	0.184	−0.031	0.896	−0.083	0.727
A3	0.508[a)]	0.022	0.099	0.677	−0.120	0.614	−0.162	0.494	0.006	0.980	−0.168	0.479
A4	0.483[a)]	0.031	0.096	0.687	−0.131	0.582	−0.231	0.327	−0.119	0.617	−0.308	0.187
A5	0.528[a)]	0.017	0.332	0.153	0.110	0.643	−0.022	0.927	−0.006	0.980	−0.224	0.341
Canines												
A1	0.658[a)]	0.002	−0.089	0.710	−0.198	0.402	−0.068	0.777	0.141	0.552	−0.147	0.536
A2	0.581[a)]	0.007	0.000	0.999	−0.115	0.628	−0.090	0.707	0.094	0.694	−0.155	0.513
A3	0.540[a)]	0.014	0.031	0.898	−0.141	0.552	−0.141	0.553	0.061	0.797	−0.189	0.425
A4	0.526[a)]	0.017	0.079	0.742	−0.100	0.676	−0.104	0.661	0.077	0.747	−0.183	0.440
A5	0.514[a)]	0.021	0.154	0.517	−0.050	0.835	−0.047	0.845	0.123	0.606	−0.160	0.500

G0: gingival thickness at the alveolar crest line, G1–G5: gingival thickness at 1–5 mm inferior to the alveolar crest, A1–A5: alveolar bone thickness at 1–5 mm inferior to the alveolar crest.
[a)]Statistically significant (P<0.05).

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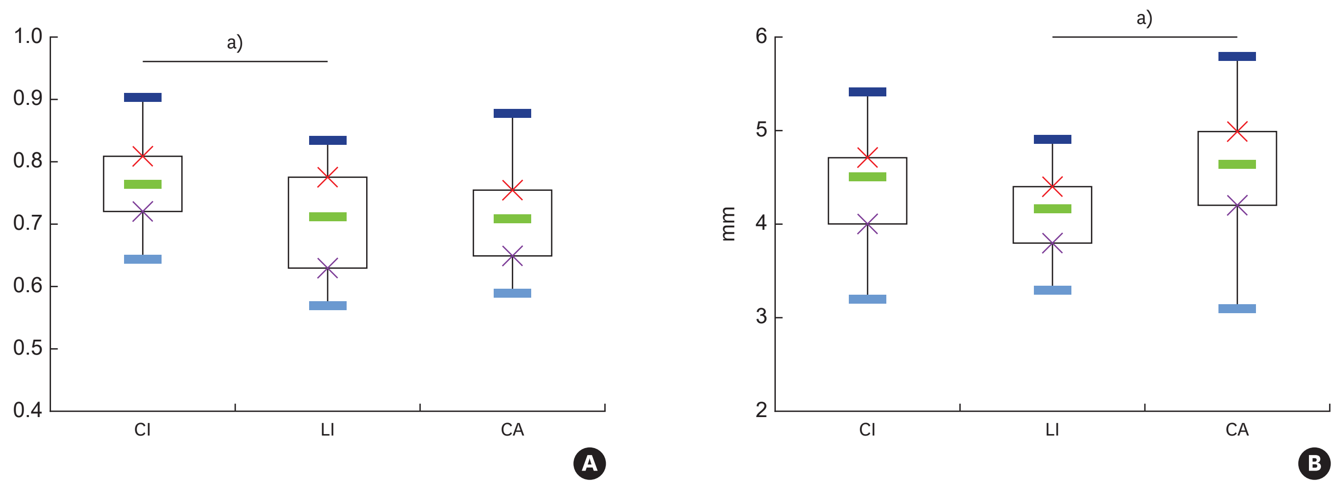

Figure 4. Comparison of clinical parameters with respect to tooth type. There was a significant difference between tooth types for (A) CW/CL and (B) SC.
CW/CL: crown width/crown length ratio, SC, height of the gingival scallop.
[a)]Statistically significant differences between groups, $P<0.017$.

DISCUSSION

The maxillary anterior region has been frequently investigated when discussing esthetic guidelines for critical cases with thin gingiva and/or alveolar bone [9,19,23,28]. Following our previous study [24], this paper overcame the possibility of errors during the impression procedure and the relatively low resolution of CBCT imaging by using a method of superimposing the CBCT images and the intraoral scanned data.

For periodontal treatment to be successful, it is important to analyze the correlation between soft and hard tissue thicknesses. In many studies reporting a positive correlation between labial bone and gingival thickness [10], gingival thickness was evaluated at the supracrestal level, while bone thickness was measured under the alveolar crest. In an *in vivo* study of 90 maxillary teeth in 15 patients, La Rocca et al. [19] observed no significant correlation between CBCT scan results and gingival probing results. Their study also did not perform comparisons at identical levels. Therefore, the correlation between the thickness of the gingiva and the thickness of the labial alveolar bone at each depth level was calculated to compare and contrast with previous studies. In our previous study [24], only the relationship between soft and hard tissues at the same level was examined, and no significant correlation was found. However, by expanding the range to compare tissue thickness at all levels, a significant relationship was found between gingival thickness at the alveolar crest level (G0) and bone thickness at all levels, particularly at the lateral incisors and the canines. This observation expands upon the results of previous studies reporting a moderate correlation between supracrestal gingival thickness and alveolar bone thickness. Nikiforidou et al. [23] also reported a strong positive correlation between gingival thickness at the level of the cementoenamel junction with labial bone thickness. The lack of accuracy of measurements of gingival thickness under the mucogingival junction due to the mobility of the gingiva may also contribute to this result.

Regarding clinical parameters, CW/CL and SC showed significant differences among tooth types. In a recent report that measured the crown shape and papilla height of the maxillary central incisor in young Koreans, the average CW/CL was 0.86 [29], which is slightly higher

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Table 3. Spearman correlation coefficients of CW/CL, SC, GW with gingival and alveolar bone thicknesses

Characteristics	G0		G1		A1		G2		A2		G3		A3		G4		A4		G5		A5	
	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value	Correlation coefficients	P value
Central incisors																						
CW/CL	−0.078	0.745	−0.349	0.132	0.191	0.419	−0.263	0.262	0.069	0.772	−0.169	0.476	0.097	0.683	−0.037	0.876	0.032	0.892	−0.165	0.487	0.010	0.966
SC	−0.019	0.936	0.156	0.511	0.141	0.552	0.186	0.433	0.158	0.506	0.389	0.090	0.140	0.556	0.296	0.206	0.125	0.598	0.176	0.458	0.310	0.184
GW	0.081	0.735	0.167	0.482	−0.189	0.424	0.221	0.350	−0.044	0.853	−0.203	0.391	0.046	0.846	−0.316	0.175	0.089	0.708	−0.309	0.185	0.042	0.862
Lateral incisors																						
CW/CL	0.029	0.902	0.068	0.774	0.226	0.338	0.184	0.438	0.170	0.474	0.083	0.728	0.211	0.371	0.105	0.658	0.245	0.297	0.022	0.927	0.145	0.541
SC	0.229	0.332	0.473[a)]	0.035	−0.031	0.895	0.397	0.083	−0.114	0.632	0.338	0.145	−0.025	0.915	0.157	0.508	0.150	0.527	0.085	0.721	0.316	0.175
GW	0.399	0.081	0.199	0.399	0.051	0.831	0.126	0.597	0.015	0.949	0.058	0.808	0.061	0.798	−0.043	0.857	0.021	0.930	−0.007	0.976	0.043	0.858
Canine																						
CW/CL	−0.023	0.925	−0.239	0.309	0.069	0.772	−0.062	0.796	0.046	0.847	−0.243	0.303	0.054	0.823	−0.225	0.340	0.027	0.910	−0.456[a)]	0.043	−0.084	0.724
SC	−0.128	0.589	−0.116	0.627	0.210	0.374	0.032	0.894	0.070	0.769	0.325	0.163	0.092	0.699	0.385	0.093	0.044	0.854	0.420	0.066	0.051	0.832
GW	0.563[a)]	0.010	0.392	0.088	0.212	0.369	−0.101	0.672	0.249	0.289	−0.247	0.294	0.292	0.212	−0.270	0.250	0.309	0.185	−0.418	0.067	0.332	0.153

CW/CL: crown width/crown length ratio, SC: height of the gingival scallop; GW: width of the keratinized gingiva, G0: gingival thickness at the alveolar crest line, G1–G5: gingival thickness at 1–5 mm inferior to the alveolar crest, A1A5: alveolar bone thickness at 1–5 mm inferior to the alveolar crest.
[a)]Statistically significant ($P<0.05$).

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Table 4. Analysis of the differences between gingival and labial bone thickness according to probe transparency (by the Mann-Whitney *U* test)

Characteristics	TRAN 0	TRAN 1	*P* value
Central incisors			
G0	1.38±0.32	1.72±0.25	0.028[a)]
G1	0.70±0.15	0.80±0.16	0.165
A1	0.84±0.11	0.92±0.23	0.536
G2	0.71±0.15	0.74±0.11	0.246
A2	0.86±0.14	0.99±0.23	0.315
G3	0.78±0.23	0.72±0.09	0.643
A3	0.86±0.18	0.91±0.19	0.563
G4	0.86±0.29	0.78±0.15	0.216
A4	0.80±0.19	0.84±0.17	0.417
G5	0.96±0.36	0.88±0.17	0.396
A5	0.79±0.20	0.77±0.17	0.908
Lateral incisors			
G0	1.24±0.22	1.42±0.26	0.137
G1	0.60±0.21	0.64±0.15	0.804
A1	0.84±0.18	1.04±0.22	0.047[a)]
G2	0.62±0.21	0.65±0.14	0.836
A2	0.89±0.30	1.13±0.29	0.187
G3	0.69±0.22	0.72±0.19	0.901
A3	0.84±0.36	0.96±0.28	0.216
G4	0.75±0.27	0.92±0.26	0.302
A4	0.75±0.37	0.80±0.24	0.620
G5	0.88±0.29	1.07±0.28	0.127
A5	0.66±0.36	0.65±0.19	0.563
Canines			
G0	1.30±0.30	1.40±0.13	0.275
G1	0.61±0.16	0.74±0.06	0.066
A1	0.94±0.23	0.90±0.29	1.000
G2	0.70±0.30	0.65±0.14	0.965
A2	0.97±0.26	1.01±0.35	0.662
G3	0.69±0.21	0.65±0.19	0.793
A3	0.93±0.27	0.96±0.33	0.694
G4	0.75±0.25	0.66±0.22	0.383
A4	0.86±0.26	0.89±0.28	0.694
G5	0.85±0.22	0.80±0.27	0.965
A5	0.80±0.25	0.82±0.28	0.727

TRAN: transparency of the periodontal probe, G0: gingival thickness at the alveolar crest line, G1–G5: gingival thickness at 1–5 mm inferior to the alveolar crest, A1A5: alveolar bone thickness at 1–5 mm inferior to the alveolar crest.
[a)]Statistically significant (P<0.05).

than the average value in this study. Differences in clinical parameters between tooth types may be influenced by differences in gingival thickness near the alveolar crest. Several reports have found differences in tooth shape and gingival morphology among maxillary central incisors, lateral incisors, and canines. According to a Korean report in 2005 [30], the CW/CL ratio was associated with papilla height or keratinized gingiva width, but there was no clear correlation with gingival thickness, and the correlations differed between teeth. In another Korean study published in the same year, no statistically significant relationship was found between tooth shape and gingival thickness, but there was a significant relationship between keratinized gingival width and gingival thickness in all central incisors, lateral incisors, and canines [31]. Unlike previously mentioned papers, the results of this investigation, which measured thickness via a non-invasive direct oral scan, did not find any significant correlations between clinical parameters and tissue thickness.

De Rouck et al. [16] observed that the gingival biotypes were not necessarily associated with the height of the scallop. Therefore, the gingival scallop cannot be an indicator of periodontal

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phenotype. The visibility of the periodontal probe outline has not always correlated with gingival thickness measurements [9,32]. Studies that have shown evidence of this correlation indicated that the visibility of the probe was related to the thickness of the gingiva at the supracrestal level [16,33], specifically 2 mm apical from the free gingival margin [14] or 1 mm coronal to the gingival pocket within free and keratinized gingiva [34]. This study also showed significant results for the relationship of gingival thickness at the crestal level (G0) of the central incisors with TRAN. For G0, a correlation was also detected with GW at the canines. Several previous studies have found positive associations between labial bone thickness and keratinized tissue [19,25,26]. However, only partial data for the correlation between labial gingival thickness and the width of keratinized tissue were reported [16,25]. Cook et al. [25] showed no relationship between biotype and the tooth height-to-width ratio. This study observed differences in CW/CL between central and lateral incisors, but no significant correlations between crown shape and gingival thickness were found.

Overall, clinical parameters were inadequate for the evaluation of gingival thickness in this study. The potential limitations of this study include a small sample size and lack of measurements at the gingival margin level. Measurements of gingival thickness below the alveolar crest level could not be correlated with the clinical parameters of CW/CL, SC, and TRAN, which were acquired from gingival features around the gingival margin above the alveolar crest level. In addition, the buccolingual tooth position and the axis of anterior teeth could influence labial gingival features, despite the exclusion of subjects with gross misalignment of the dentition. As the age range of the subjects was wide, failure to consider changes in CW/CL due to the attrition of anterior teeth may also have had an effect.

Therefore, the classification of the periodontal phenotype on the basis of measurements such as crown form and the gingival scallop should be made with caution. Digital measurements of labial gingival thickness may be a superior indicator for evaluating the periodontal phenotype, which determines the outcomes of mucogingival surgery. In future studies, reliable measurement methods for supracrestal gingival areas should be developed, and it is necessary to reconsider the predictability of clinical parameters for soft tissue thickness.

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