Received: 20 July 2022 | Accepted: 15 January 2023

DOI: 10.1002/JPER.22-0434

JOURNAL OF Periodontology

ORIGINAL ARTICLE

Relationship between supracrestal soft tissue dimensions and other periodontal phenotypic features: A cross-sectional study

Emilio Couso-Queiruga[1] | **Eliane Porto Barboza**[2] | **Gustavo Avila-Ortiz**[3,4] | **Oscar Gonzalez-Martin**[3,4,5] | **Leandro Chambrone**[6,7] | **Diogo Moreira Rodrigues**[8]

[1]Department of Oral Surgery and Stomatology, School of Dental Medicine, University of Bern, Bern, Switzerland

[2]Department of Dental Clinic, Federal Fluminense University, Niterói, Rio de Janeiro, Brazil

[3]Private Practice, Atelier Dental Madrid, Madrid, Spain

[4]Department of Oral Medicine, Infection, and Immunity, Harvard School of Dental Medicine, Harvard University, Boston, Massachusetts, USA

[5]Department of Periodontology, Complutense University of Madrid, Madrid, Spain

[6]Evidence-Based Hub, Interdisciplinary Research Center Egas Moniz (CiiEM), Egas Moniz-Cooperative of Higher Education, Caparica, Almada, Portugal

[7]Unit of Basic Oral Investigation (UIBO), School of Dentistry, Universidad El Bosque, Bogotá, Colombia

[8]Department of Periodontology, National Institute of Dental Sciences (INCO 25), Niterói, Rio de Janeiro, Brazil

Correspondence
Diogo Moreira Rodrigues, Department of Periodontology INCO 25, Rua Lemos Cunha 420, Niteirói, Rio de Janeiro 24230-136, Brazil.
Email: diogomrcd@gmail.com

Abstract

Background: The purpose of this study was to determine the association between periodontal supracrestal soft tissue dimensions (PSSTDs) and other phenotypic features in non-molar maxillary teeth.

Materials and Methods: Adult subjects in need of comprehensive dental treatment were recruited. Periodontal phenotypic variables (i.e., facial and palatal gingival thickness [GT], alveolar bone thickness [BT], and PSSTDs, namely distance from the gingival margin to the bone crest defined as periodontal supracrestal tissue height [PSTH] and distance from the cementoenamel junction to the bone crest [CEJ-BC]) were recorded using cone-beam computed tomography scans. Standardized intraoral photographs were obtained to assess facial keratinized tissue width (KTW) and other anatomical parameters (i.e., tooth type, gingival architecture, and interproximal papilla height).

Results: The study sample was constituted of 87 participants that contributed with a total of 522 maxillary anterior teeth. Differences in mean values of PSSTDs, KTW, GT, and BT were observed between tooth types and gender. Males exhibited a thicker GT and BT, and taller PSTH and KTW compared to females. Shorter CEJ-BC was associated with shorter PSTH, wider KTW, and thicker GT and BT. Shorter PSTH was associated with thicker facial BT. Notably, BT and GT were positively correlated at both facial and palatal sites, meaning that the thicker the gingival phenotype, the thicker the bone morphotype. Facial BT and facial GT were positively correlated with KTW. A flat gingival architecture was associated

with the thick periodontal phenotype. Square teeth had shorter CEJ-BC, wider KTW, and thicker GT.

Conclusions: Periodontal phenotypic features vary across and within subjects, between facial and palatal sites at different apico-coronal levels, and as a function of gender and tooth type. The shorter the PSSTDs, the wider the KTW and the thicker the GT and BT. PSSTDs, particularly PSTH, should be considered an integral component of the periodontal phenotype.

KEYWORDS

3-D imaging, cone beam computed tomography, dental digital radiography, gingiva, phenotype

1 | INTRODUCTION

The characteristics of the periodontal and peri-implant phenotype are critically relevant in contemporary clinical practice and research.[1,2] According to the consensus reached in the 2017 World Workshop on the classification of periodontal and peri-implant diseases and conditions, the periodontal phenotype[3] is determined by the gingival phenotype, which is constituted by the gingival thickness (GT) and the keratinized tissue width (KTW), and the bone morphotype, which is solely characterized by the thickness of the alveolar bone plate (BT).[4] The components and dimensions of both compartments are site-specific and may change over time depending on a variety of environmental factors (e.g., inflammation, trauma, therapy). The gingival phenotype has been identified as a predictor for the outcomes of root coverage procedures[5,6] and the long-term stability of the mucosal margin after gingival augmentation interventions.[7,8] The bone phenotype has been recognized as a key prognostic factor in periodontics and implant dentistry, particularly in the context of tooth replacement therapy after tooth extraction.[9–14] However, other periodontal phenotypic features related to the vertical dimension of the supracrestal soft tissue deserve specific attention.

The supracrestal tissue attachment (STA), also known as the "biologic width," is a histological concept originally described by Dr Walter Cohen,[15] that comprises the apico-coronal height of the junctional epithelium and the supracrestal connective tissue attachment.[4] Several studies have shown that the most consistent element is the vertical dimension of the connective tissue attachment, while the junctional epithelium exhibits more variability.[16,17] However, differences in STA dimensions have been observed in different intraoral locations within the same individual in correlation with tooth crown type.[18] Clinical and preclinical studies have reported that infringement of the STA as a consequence of restorative therapy can cause local irritation that typically results in an inflammatory response with or without subsequent apical migration of the gingival margin and bone loss.[4] Therefore, it seems evident that the supracrestal soft tissue dimension holds substantial clinical relevance as a phenotypic variable of the periodontal tissues.

Historically, the PP has been classified into two types: "thick flat" and "thin scalloped."[19] The "thin scalloped" type has been related to thin gingiva and bone, and shorter KTW. Conversely, the "thick flat" type has been related to a thick gingiva and bone, and wider keratinized tissue. Clinical studies have also reported a direct relationship between the gingival phenotype and the bone morphotype,[20,21] and between the PP and tooth crown shape. Long tapered teeth are usually associated with a thin PP, while short and wide crowns with long proximal contacts are associated with a thick PP.[22,23] Among available clinical studies on the topic of characterization of the PP, there is limited information on the relationship between the supracrestal soft tissue dimensions and other anatomical variables (i.e., facial and palatal GT, facial and palatal BT, and KTW), as well as the clinical significance of the supracrestal soft tissue dimensions in the clinical decision-making process. Therefore, the aim of this study was to determine the association between periodontal supracrestal soft tissue dimensions (PSSTDs) with respect to other periodontal and tooth-related phenotypic features.

2 | MATERIALS AND METHODS

2.1 | Experimental design and center

This trial was designed as a cross-sectional study and was conducted in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cross-sectional studies.[24] The clinical component of this study was conducted in the Department of Periodontics at Fluminense Federal University (Brazil) between January 2016 and January 2020.

2.2 | Ethical approval and registration

Ethical approval for the experimental protocol was obtained from Fluminense Federal University (CEP/HUAP/UFF#506.300).

2.3 | Eligibility criteria and recruitment

Adult patients that required comprehensive dental treatment were eligible to participate in the study. The inclusion criteria were as follows: (1) ≥18 years of age; (2) ASA status I or II; (3) presence of at least one maxillary non-molar tooth bound by periodontally healthy teeth and with no history of restorative therapy; (4) a cone-beam computed tomography (CBCT) scan capturing the region of interest was obtained as a part of the comprehensive diagnostic and treatment planning process. The exclusion criteria were as follows: (1) mandibular teeth; (2) maxillary premolars and molars; (3) history of orthodontic treatment or surgical therapy in the anterior maxilla; (4) presence of clinical attachment loss; (5) gingival excess (i.e., pseudopockets, inconsistent gingival margin, excessive gingival display, gingival enlargement) or abnormal color[25]; (6) malpositioned teeth or tooth crowding; (7) history of trauma; (8) teeth presenting with a diastema, carious lesions, fractures, resorption, or restorations; (9) uncontrolled diabetes mellitus, defined as HbA1c > 7.0; (10) current smokers; (11) any active local or systemic acute infections; (12) any diseases or medications that may influence bone or soft tissue metabolism; (13) currently receiving chemo- or radiotherapy or a history of radiotherapy in the head and neck area; (14) severe hematologic disorders; (15) pregnant or nursing mother; (16) any disabilities or barriers that may interfere with understanding, reading, and signing the informed consent.

2.4 | Clinical and digital data acquisition

One week prior to obtaining the clinical measurements, radiographs, and intraoral photographs, all participants received professional mechanical plaque removal and hygiene instructions, including tooth brushing, flossing, and rinsing with 0.12% chlorhexidine gluconate* twice a day for dental biofilm control. A CBCT scan was acquired following the principle of as low as diagnostically acceptable (ALADA) according to the patient's needs.[26] The field of view was approximately 5 cm at 0.11 mm voxel size and the exposure factor settings were fixed at 90 kVp and 4 mAs for all scans.† Participants were seated with their chin and head stabilized using a plastic lip retractor as described elsewhere.[27] One calibrated examiner (D.M.R.) obtained the mid-facial KTW using a UNC-15 dental probe‡ in each tooth of interest as shown in Figure 1. To ensure data quality, the same examiner previously assessed KTW in 150 maxillary anterior teeth, in 25 random participants in an interval of 15 days for calibration purposes. Standardized intraoral clinical photographs were obtained using a constant room light, the same camera body,§ a tripod, a 90 mm macro lens, with a ratio of 1.5:1, aperture size f/32, shutter speed 1/15, and a working distance of 20 cm. Image files had a resolution of 18 megapixels and were saved in JPEG compression format. Participants had the Frankfort plane and the pupillary line parallel to the long axis of the camera lens and the focal point was centered at the midline.

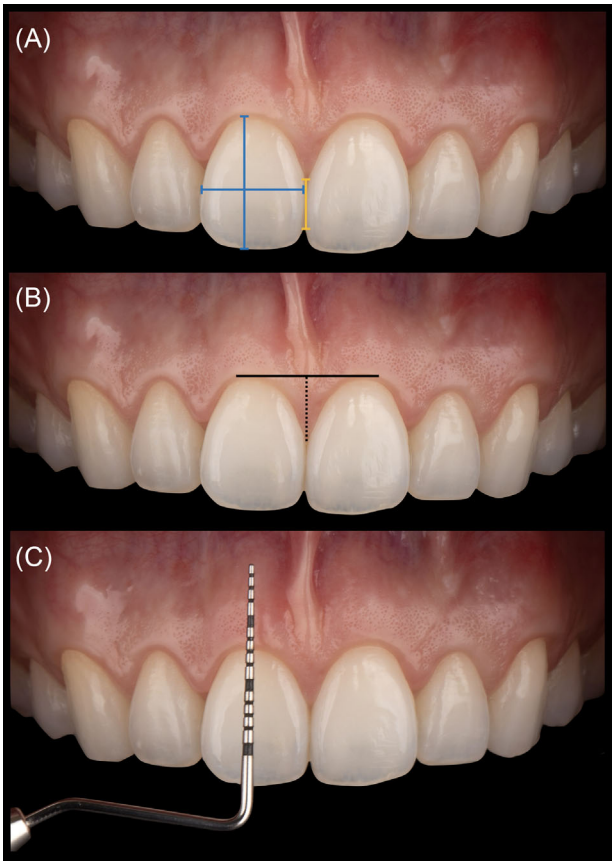

FIGURE 1 Visual depiction of the methodology followed to determine crown length (vertical blue line), crown width (horizontal blue line), and contact surface (vertical yellow line) (A). Papilla height (B). Keratinized tissue width (C).

* Periogard, Colgate-Palmovile Inc., New York, USA

† Prexion 3D Elite, Prexion Inc., San Mateo, CA, USA
‡ UNC-15 periodontal probe, Hu-Friedy, Chicago, IL, USA
§ Canon 30D SLR camera, Canon Inc., Tokyo, Japan

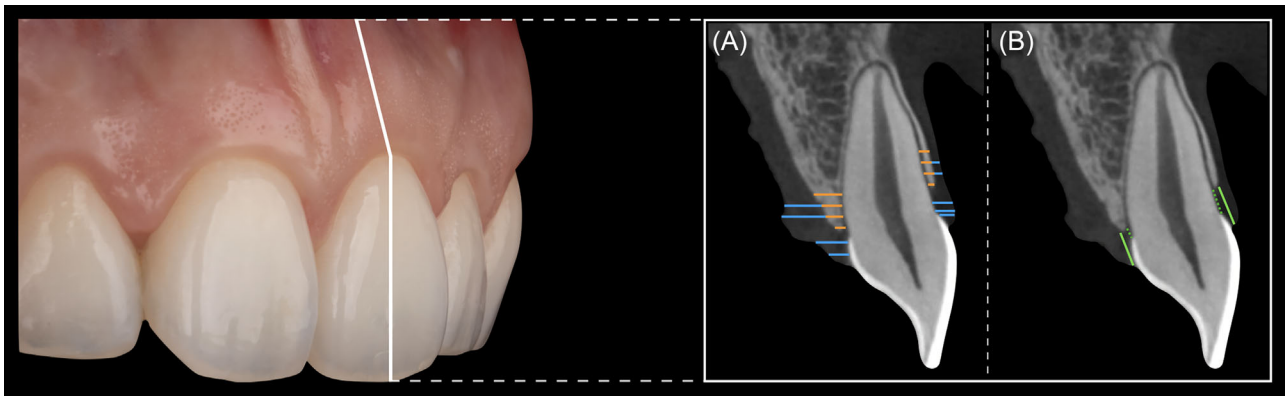

FIGURE 2 Sagittal radiographic section demonstrating the method followed to make measurements of the facial and palatal gingival (blue line) and bone (orange line) thickness at different apico-coronal levels (A), as well as the periodontal supracrestal soft tissue height (green line) and the distance from the cementoenamel junction to the bone crest (green dotted line) (B).

2.5 | Digital imaging assessments and variables of interest

Digital Imaging and Communication in Medicine (DICOM) files obtained from the CBCT scans were analyzed by one independent examiner (D.M.R.) utilizing a specialized software package.[**] To standardize the linear measurements (in mm) of the GT, BT, and PSSTDs, a sagittal section at the middle of each maxillary tooth was obtained, as described in previous publications.[14,28,29] Images were displayed with the largest possible zoom without affecting the quality, utilizing a standardized contrast and brightness on a 32′ flat panel screen with a resolution of 1920 × 1080 pixels. For the assessment of the facial and palatal GT, a horizontal line was made at 1 and 2 mm apical to the zenith of the gingival margin and 1 and 2 mm apical to the bone crest at an angle perpendicular to the long axis of the tooth.[20,30] On the facial, the GT was also obtained at the level of the CEJ as displayed in Figure 2A. For the assessment of the BT, a horizontal line perpendicular to the long axis of the axial root plane was drawn to intersect the facial and palatal most point of the facial and palatal bone and the tooth surface at the level of the bone crest and at 1, 2, and 3 mm apical to the alveolar bone crest as shown in Figure 2A. For the assessment of the PSSTDs on the mid-facial and mid-palatal, a vertical line was drawn from the zenith of the gingival margin to the bone crest to measure the periodontal supracrestal soft tissue height (PSTH), and another line to determine the distance from the CEJ to the bone crest (CEJ-BC), as illustrated in Figure 2B. To ensure data quality, the same independent examiner (D.M.R.) previously performed linear measurements in 150 maxillary anterior teeth, in 25 random participants twice with an interval of 15 days for calibration purposes.

Standardized intraoral clinical photographs were analyzed by a single independent examiner (E.P.B.) utilizing a software package[††] to make the following measurements twice in an interval of 15 days. Contact surface (CS) and crown length (CL) was measured as described previously.[31] Visible crown shape was classified as "triangular" (CS/CL ratio < 43%), "square/tapered" (CS/CL 43 to 57%), and square (CS/CL ratio > 57%). Crown width (CW) was measured, and tooth crown shape was also categorized as a function of the CW/CL ratio.[23] Teeth with a CW/CL ratio ≥80% and <80% were classified as "square" and "triangular," respectively.[32] Papilla height was defined as the distance from the tip of the most coronal point of the papilla to a line joining the zenith of the two adjacent teeth, as shown in Figure 1. Finally, the gingival architecture (GA) was categorized as "flat" (including thick flat and thick scalloped) or "pronounced scalloped" (thin scalloped), as displayed in Figure 3.

2.6 | Data analyses

All data analyses were performed using a software package.[‡‡] Variables were tested for normal distribution using the Shapiro-Wilk test. Mean values and standard deviations (SD) were calculated for all variables. Frequencies and percentages were expressed as categorical data. The association between categorical data was tested using the chi-squared test. Analysis of variance (ANOVA), Student's *t*-test, and post-hoc analysis (Tukey's test) was used for comparisons between continuous variables. Pearson

[**] Prexion 3D Viewer Software, Prexion Inc., San Mateo, CA, USA

[††] Image J, National Institutes of Health, USA

[‡‡] SPPS 22.0, IBM, Chicago, IL, USA

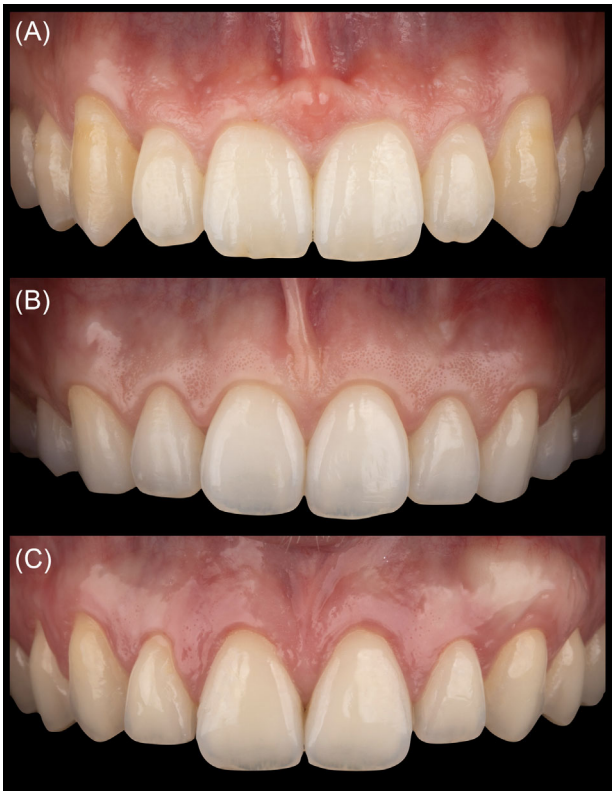

FIGURE 3 Representative examples of three distinct types of gingival architecture: thick flat (A); thick scalloped (B); and thin scalloped (C).

correlation test was used to determine the correlations between PSSTDs and other PP variables. The "*r*" score was adopted ($r = 0.1$-0.3, weak correlation; $r = 0.4$–0.6, moderate correlation; $r > 0.7$, strong correlation). Statistical significance was set at $p = 0.05$.

2.7 | Sample size calculation

The tooth was set as the unit of analysis. Samples were compared considering the smallest difference between mean values. The sampling error was $\alpha = 0.05$ and the power of study 0.8. The highest sample size to test the correlations between PSSTDs and PP was found between the distance from the CEJ-BC and KTW outcome for a total of 520 maxillary teeth.

3 | RESULTS

3.1 | Population

A total of 221 participants were initially screened. Seventy-three were not eligible upon initial screening due to being a smoker, history of or active orthodontic treatment, systemic diseases, or medication intake that may influence bone and/or soft tissue metabolism. Forty-three subjects were not eligible upon comprehensive clinical examination due to presence of periodontitis, dental restorations, tooth malpositioning, or gingival recession defects. Eighteen participants were excluded due to the existence of excessive scattering in the CBCT images. Therefore, the final population was constituted by 39 males (44.8%) and 48 females (55.2%) between 18 and 45 years of age, with a mean age of 25.8 ± 6.4 (females:25.6 ± 7/males:26 ± 5.52). Regarding race distribution, 18 patients were black, and 69 patients were white.

3.2 | Sample characteristics

A total of 522 permanent maxillary anterior teeth (174 central incisors, 174 lateral incisors, and 174 canines) were included in this study. All teeth presented an intact periodontium with minimal or no signs of inflammation. All facial sites showed an adequate dimension of mid-facial KTW with a mean value of 4.55 ± 1.31 mm. Mean CEJ-BC values showed statistically significant differences at the facial sites compared with the palatal (1.76 ± 0.64 mm and 1.38 ± 0.63 mm, respectively ($p < 0.001$)). Mean PSTH was similar at the facial and palatal sites (3.26 ± 0.69 mm and 3.27 ± 0.65 mm, respectively ($p = 0.820$)). Mean facial GT and BT were statistically significantly lower than at the palatal sites at any apico-coronal level ($p < 0.001$). Mean values for facial and palatal periodontal phenotypic variables are displayed in Table 1. Differences in mean GT, BT, PSTH, CEJ-BC, and KTW were observed between tooth types and gender as shown in Tables S1 and S2 in online Journal of Periodontology. Compared to females, males exhibited thicker mean GT and BT at all apico-coronal levels evaluated, as well as greater dimensions of facial PSTH and KTW.

3.3 | Intra-examiner reliability

Measurements using intraoral clinical photographs showed an intra-examiner kappa value of 0.96 for GA, and an intra-class correlation higher than 0.90 for PH, CW, CL, and CS. Intra-class correlation for the clinical assessment of KTW was 0.948. Measurements using DICOM files revealed an intra-class correlation > 0.895.

3.4 | Outcomes of interest

A positive correlation was observed between CEJ-BC and PSTH on the facial (Pearson $r = 0.457$, $p < 0.001$) and

TABLE 1 Periodontal phenotypic variables on facial and palatal sites

Baseline Parameters	Facial (522 teeth) Mean (SD)	Palatal (522 teeth) Mean (SD)	*p* Value
CEJ-BC	1.76 (0.64)	1.38 (0.63)	<0.001*
PSTH	3.26 (0.69)	3.27 (0.65)	0.820
GT1-GM	0.95 (0.23)	2.99 (0.73)	<0.001*
GT2-GM	1.19 (0.28)	2.99 (0.74)	<0.001*
GT-CEJ	1.23 (0.35)	N/A	N/A
GT1-BC	0.70 (0.24)	1.29 (0.28)	<0.001*
GT2-BC	0.64 (0.22)	1.81 (0.41)	<0.001*
KTW	4.55 (1.31)	N/A	N/A
BT-BC	0.47 (0.20)	0.67 (0.22)	<0.001*
BT1-BC	0.67 (0.29)	0.89 (0.33)	<0.001*
BT2-BC	0.72 (0.37)	1.12 (0.50)	<0.001*
BT3-BC	0.71 (0.42)	1.40 (0.66)	<0.001*

Note: CEJ-BC (distance from the cementoenamel junction to the bone crest); PSTH (periodontal supracrestal tissue height; distance from the gingival margin to the bone crest); GT1-GM (gingival thickness 1 mm apical to the gingival margin); GT2-GM (gingival thickness 2 mm apical to the gingival margin); GT-CEJ (gingival thickness at the level of the CEJ); GT1-BC (gingival thickness 1 mm apical to the bone crest); GT2-BC (gingival thickness 2 mm apical to the bone crest); KTW (mid-facial keratinized tissue width); BT-BC (bone thickness at the level of the bone crest); BT1-BC (bone thickness 1 mm apical to the bone crest); BT2-BC (bone thickness 2 mm apical to the bone crest); BT3-BC (bone thickness 3 mm apical to the bone crest). Student *t*-test.
*Statistical significance, $p < 0.05$.

palatal (Pearson $r = 0.436$, $p < 0.001$). On the facial, CEJ-BC showed a negative correlation with KTW (Pearson $r = -0.190$, $p = 0.000$), GT at the level of the CEJ (Pearson $r = -0.306$, $p < 0.001$) and 2 mm apical to the gingival margin (Pearson $r = -0.190$, $p = 0.013$), and BT at all apico-coronal levels evaluated.

Also, on the facial, PSTH showed a negative correlation with BT at the level of the alveolar bone crest (Pearson $r = -0.086$, $p = 0.014$), and 1 mm apical (Pearson $r = -0.108$, $p = 0.014$), as shown in Table 2. However, no correlation was found between PSTH and BT on the palatal side. Interestingly, a negative correlation was observed between CEJ-BC and GT at the level of the CEJ (Pearson $r = -0.190$, $p = 0.038$) and 3 mm apical (Pearson $r = -0.107$, $p = 0.015$). A positive correlation was also detected between CEJ-BC and crown length in central incisors (Pearson $r = 0.241$, $p < 0.001$), as displayed in Table 3.

The proportion of flat and pronounced scalloped GA in central incisors was 56.3% and 43.7%, respectively. Shorter dimensions of CL ($p < 0.001$), CS ($p = 0.011$), and PH ($p < 0.001$) were observed on teeth presenting a flat GA compared with the pronounced scalloped. The comparison of GA with PP showed that sites presenting a flat architecture exhibited wider KTW ($p < 0.001$), and thicker GT and BT at any apico-coronal level, as shown in Table S3 in online Journal of Periodontology.

When the crown shape was defined as CS/CL, a square-tapered shape was observed in 69% of the central incisors followed by the square (20.7%) and triangular (10.3%) shapes. When CW/CL was used to determine crown shape, triangular, and square shape was observed in 61% and 39% of the central incisors, respectively. Mean values of CL, CS, and PH were higher in triangular teeth as compared with square teeth ($p < 0.001$). Conversely, CW was wider in the square shape group ($p = 0.014$). Square teeth also had shorter CEJ-BC ($p = 0.030$), wider KTW ($p = 0.004$), and thicker GT at all levels, while BT was similar between groups, as shown in Table S4 in online Journal of Periodontology. When the tooth shape was determined by CS/CL ratio, triangular tooth shape group was associated with higher CL and PH values, but smaller values for CW and CS. In addition, differences between groups in terms of the PP were observed only for GT at the level of the CEJ, where triangular tooth shape showed thicker gingiva ($p = 0.038$), as shown in Table S5. in online Journal of Periodontology

3.5 | Stratification according to the gingival and bone phenotype

Sites were stratified as a function of the facial gingival and bone phenotype according to the findings of previous studies.[6,9] At 1 and 2 mm apical to the gingival margin, 64.4% and 26.8% of the teeth presented a thin gingival phenotype (≤1 mm), respectively. At the level of the facial bone crest, and at 1, 2, and 3 mm apically, 97.7%, 79.5%, 87%, and 80.8% of the maxillary teeth presented a thin bone phenotype (≤1 mm), respectively, as displayed in Table S6 in online Journal of Periodontology.

JOURNAL OF Periodontology

TABLE 2 Correlation between the periodontal supracrestal soft tissue dimensions and other periodontal phenotypic features

Site	Periodontal supracrestal soft tissue dimensions	GT1-GM Pearson R (*p*-value)	GT2-GM Pearson R (*p*-value)	GT-CEJ Pearson R (*p*-value	GT1-BC Pearson R (*p*-value)	GT2-BC Pearson R (*p*-value)	KTW Pearson R (*p*-value)	PH Pearson R (*p*-value)	BT-BC Pearson R (*p*-value)	BT1-BC Pearson R (*p*-value)	BT2-BC Pearson R (*p*-value)	BT3-BC Pearson R (*p*-value)
Facial	**CEJ-BC**	0.041 (0.352)	−0.109* (0.013)	−0.306* (<0.001)	−0.035 (0.421)	0.032 (0.472)	−0.190* (0.000)	0.169* (0.026)	−0.114* (0.009)	−0.200* (0.000)	−0.164* (0.000)	−0.102* (0.020)
	PSTH	−0.040 (0.356)	−0.077 (0.079)	0.218* (<0.001)	0.145* (0.001)	0.137* (0.002)	0.112* (0.010)	−0.048 (0.541)	−0.086* (0.014)	−0.108* (0.014)	−0.054 (0.222)	−0.010 (0.829)
Palatal	**CEJ-BC**	0.112* (0.010)	0.155* (0.000)	N/A	0.213* (0.000)	0.102* (0.020)	N/A	N/A	−0.091* (0.038)	−0.069 (0.118)	−0.046 (0.291)	−0.107* (0.015)
	PSTH	0.125* (0.004)	0.202* (0.000)	N/A	0.229* (0.000)	0.171* (0.000)	N/A	N/A	0.043 (0.332)	0.021 (0.603)	−0.010 (0.823)	−0.018 (0.684)

Note: CEJ-BC (distance from the cementoenamel junction to the bone crest); PSTH (periodontal supracrestal tissue height; distance from the gingival margin to the bone crest); GT1-GM (gingival thickness 1 mm apical to the gingival margin); GT2-GM (gingival thickness 2 mm apical to the gingival margin); GT-CEJ (gingival thickness at the level of the CEJ); GT1-BC (gingival thickness 1 mm apical to the bone crest); GT2-BC (gingival thickness 2 mm apical to the bone crest); KTW (mid-facial keratinized tissue width); PH (papilla height); BT-BC (bone thickness at the level of the bone crest); BT1-BC (bone thickness 1 mm apical to the bone crest); BT2-BC (bone thickness 2 mm apical to the bone crest); BT3-BC (bone thickness 3 mm apical to the bone crest). Student *t*-test.

*Statistical significance, $p < 0.05$.

When the sites were stratified according to the gingival phenotype at 1 and 2 mm apical to the gingival margin, no differences were observed in the mean values of the CEJ-BC or PSTH ($p = 0.856$, and $p = 0.467$, respectively). However, a statistically significant difference was observed when the gingival phenotype was stratified at the level of the CEJ ($p < 0.001$). Thicker facial GT and BT were observed in the thick gingival phenotype group at any apico-coronal level ($p < 0.001$). Nevertheless, a statistically significant difference was only observed in the thick gingival phenotype group in terms of KTW when the gingival phenotype was evaluated at the level of the CEJ and at 2 mm apical to the gingival margin ($p < 0.001$). Mean PH values were higher in the thin gingival phenotype group at the level of the CEJ ($p = 0.030$), as displayed in Table S7 in online Journal of Periodontology.

When the sites were stratified according to the bone phenotype at 1 mm apical to the facial bone crest, no differences were observed between thin (≤1 mm) and thick (>1 mm) bone phenotypes respective to the mean values of CEJ-BC ($p = 0.253$) and PSTH ($p = 0.404$). However, the thick bone phenotype group showed statistically higher mean values of GT at 1 and 2 mm apical to the gingival margin ($p < 0.001$), at the level of the CEJ ($p < 0.001$), and at 1 mm apical to the facial bone crest ($p = 0.002$), as well as wider KTW ($p = 0.033$), compared with the thin bone phenotype group. Statistically significant thicker facial BT was observed at all apico-coronal levels in the thick bone phenotype group ($p < 0.001$), as shown in Table S8 in online Journal of Periodontology.

4 | DISCUSSION

To the authors' knowledge, this cross-sectional study represents the most comprehensive analysis to date evaluating the relationship between the PSSTDs with other phenotypic features.

Digital assessment of PP characteristics demonstrated higher mean GT, and BT values at palatal sites compared with facial locations, whereas higher mean CEJ-BC distance was observed on facial compared to palatal sites. However, no significant differences were observed between facial and palatal PSTH. Interestingly, PSSTDs varied as a function of tooth crown shape. Also, males showed thicker GT and BT, and greater PSTH and KTW dimensions compared with females. These findings are in agreement with previous studies on this topic, which reported variations in PSSTDs between different teeth and surfaces,[20,33,34] and also between other periodontal phenotypic variables (KTW, GT, and BT) and gender.[35,36] Our study also revealed a negative relationship between facial CEJ-BC and KTW, GT, and BT, and between facial

TABLE 3 Correlation between features of the gingival and bone phenotype

Site	Soft tissue phenotype	GT1-GM Pearson R (*p*-value)	GT2-GM Pearson R (*p*-value)	GT1-BC Pearson R (*p*-value)	GT2-BC Pearson R (*p*-value)	KTW Pearson R (*p*-value)	BT-BC Pearson R (*p*-value)	BT1-BC Pearson R (*p*-value)	BT2-BC Pearson R (*p*-value)	BT3-BC Pearson R (*p*-value)
Facial	**GT1-GM**	1	0.611* (<0.001)	0.470* (<0.001)	0.401* (<0.001)	−0.024 (0.577)	0.356 * (<0.001)	0.329* (<0.001)	0.306* (<0.001)	0.345* (<0.001)
	GT2-GM	0.611* (<0.001)	1	0.473* (<0.001)	0.369* (<0.001)	0.160* (<0.001)	0.453* (<0.001)	0.460* (<0.001)	0.434* (<0.001)	0.430* (<0.001)
	GT1-BC	0.470 * (<0.001)	0.473* (<0.001)	1	0.845* (<0.001)	0.108* (0.013)	0.233* (<0.001)	0.200* (<0.001)	0.229* (<0.001)	0.331* (<0.001)
	GT2-BC	0.470 * (<0.001)	0.401* (<0.001)	0.369* (<0.001)	1	0.028* (<0.001)	0.181* (<0.001)	0.059 (0.152)	0.027 (0.535)	0.131* (0.003)
	KTW	−0.024 (0.577)	0.160* (<0.001)	0.108* (0.013)	0.028* (<0.001)	1	0.083 (0.059)	0.181* (<0.001)	0.202* (<0.001)	0.165* (<0.001)
Palatal	**GT1-GM**	1	0.772* (>0.001)	0.108* (0.014)	0.265* (>0.001)	N/A	0.187* (>0.001)	0.198* (>0.001)	0.221* (>0.001)	0.227* (>0.001)
	GT2-GM	0.772* (>0.001)	1	0.205* (>0.001)	0.337* (>0.001)	N/A	0.182* (>0.001)	0.214* (>0.001)	0.230* (>0.001)	0.248* (>0.001)
	GT1-BC	0.108* (0.014)	0.205* (>0.001)	1	0.584* (>0.001)	N/A	−0.012 (0.784)	0.066 (0.131)	0.073 (0.098)	0.115* (0.009)
	GT2-BC	0.265* (>0.001)	0.337* (>0.001)	0.584* (>0.001)	1	N/A	−0.036 (0.408)	0.000 (0.995)	−0.022 (0.618)	−0.005 (0.914)

Note: GT1-GM (gingival thickness 1 mm apical to the gingival margin); GT2-GM (gingival thickness 2 mm apical to the gingival margin); GT1-BC (gingival thickness 1 mm apical to the bone crest); GT2-BC (gingival thickness 2 mm apical to the bone crest); KTW (mid-facial keratinized tissue width); BT-BC (bone thickness at the level of the bone crest); BT1-BC (bone thickness 1 mm apical to the bone crest); BT2-BC (bone thickness 2 mm apical to the bone crest); BT3-BC (bone thickness 3 mm apical to the bone crest). Student *t*-test.

*Statistical significance, $p < 0.05$.

PSTH and facial bone plate thickness. In summary, the shorter the CEJ-BC, the wider the KTW, and the thicker the facial GT and BT. Also, the shorter the PSTH, the thicker the facial bone plate. These findings are in accordance with a classic study by Cook and collaborators, who observed taller CEJ-BC in patients with a thin PP compared with patients exhibiting a thick PP,[12] and with a cross-sectional study including 53 adult subjects that reported shorter PSTH in the thick phenotype group.[37] Conversely, a study by Arora and colleagues reported taller PSTH in patients with a thick phenotype.[34] The discrepancies between studies could be explained by the differences in the methodology used to measure the gingival and alveolar bone phenotypes, the sample size, the landmark, or the cutting points used to classify and determine thin and thick phenotypes.[38]

A positive association between the gingival and bone phenotype both at facial and palatal sites was noticed. Additionally, facial GT and BT were positively correlated with KTW. These associations indicate that the thicker the gingival tissue, the thicker the alveolar bone, and vice versa. They also suggest that the thicker the facial GT/BT, the wider the KTW. These findings are in accordance with those reported in previous studies.[20,21] To the best of the author's knowledge, this is the first study that showed a positive relationship between the gingival and bone phenotypes on the palatal aspect. Our findings provide a valuable perspective and highlight the importance of considering the effect of periodontal phenotypic characteristics at palatal sites in a variety of non-surgical and surgical therapies. Additionally, we observed that flat GA was associated with shorter CEJ-BC, wider KTW, and thicker GT and BT at all apico-coronal levels evaluated. These findings are in contrast with those reported by Cook et al., who observed no statistically significant differences in KTW between different GA types.[12] However, our findings are in alignment with two classic studies that showed that long and narrow teeth are associated with a thin PP, while wide crowns are associated with a thick phenotype.[22,23] Another interesting finding in our study is that square teeth exhibit shorter CEJ-BC, wider KTW, and thicker GT at the level of the CEJ. However, no differences in facial BT were observed among different tooth crown shapes. Similarly, Stellini et al. observed that teeth with a triangular crown shape exhibited greater PH, less KTW, and thinner gingiva, but no differences in the bone morphotype were found with square teeth.[13] Another study reported that CW/CL ratio and KTW could be used to characterize the GT at the level of the CEJ and also that CW/CL ratio could be used as an indicator of the alveolar bone crest thickness.[39] Nonetheless, our findings differ from the outcomes reported by Fischer et al. who found no differences neither for the correlation between PSTH and other phenotypic variables, nor for the association between PP and CW/CL ratio.[40] The differences between studies could be explained by the eligibility criteria, the number and type of teeth evaluated, and landmark levels used to measure phenotypic variables.

Following stratification according to the gingival phenotype, defined as thin (facial GT $\leq$ 1 mm) or thick (facial GT > 1 mm), the thick group showed thicker facial alveolar bone at all apico-coronal levels evaluated compared with the thin gingival phenotype group. However, no differences in PSSTDs values between gingival phenotypes were observed. Interestingly, as reported in a recent study by Moreira and collaborators, the determination of thin and thick gingival phenotypes is related to the apico-coronal level of assessment and the threshold used to differentiate between a thin and a thick phenotype.[38] Indeed, as observed in this study, depending on apico-coronal evaluated, the frequency distribution of thin and thick gingival phenotype and the direction of the association with KTW and PH varied. However, regardless of the vertical level of assessment, it was consistently observed that the thicker the GT, the thicker the facial BT. Taking into consideration the apico-coronal levels respective to specific landmarks (e.g., gingival margin or bone crest) most frequently used in the literature, it can be generally concluded that the thicker the facial GT, the thicker the facial BT, the wider the KTW, and the shorter the PH.

Following stratification according to the bone phenotype, defined as thin (facial BT $\leq$ 1 mm) and thick (facial BT > 1 mm), the thick bone group exhibited wider KTW and thicker GT at any apico-coronal level evaluated compared with the thin bone phenotype group. Interestingly, although taller CEJ-BC and PSTH values were observed in the thin bone group, the differences between bone phenotypes were not statistically significantly different. This finding could be explained by the fact that the only level used to measure the facial bone thickness was established at 1 mm apical to the facial bone crest. These clinically relevant findings should be taken into consideration to make clinical decisions in the treatment and replacement of anterior maxillary teeth. Due to the vast methodological diversity to assess the GT and BT present in the literature,[9,20,28,30,41–46] a standardized definition of thin and thick gingival and bone phenotypes and standardized anatomical landmarks should be established to provide an adequate and reliable direct comparison across studies.

The relationship of periodontal phenotypic features (i.e., KTW, GT, PSTH, and BT) with GA and tooth-related characteristics (e.g., crown shape) reported in this study should also be taken into consideration in restorative dentistry. As reported in classic studies, inadequate prosthetic management such as the placement of subgingival restorations with overhanging margins, inadequate embrasures, deficient marginal fit, poor selection of the restorative material

or unfavorable restoration contours could lead to local irritation and disruption of the homeostatic biological interface and/or plaque accumulation and microbial dysbiosis with the subsequent initiation and progression of inflammatory disease (e.g., periodontitis).[4,19,47,48] This is particularly crucial in anterior areas, where the goal is to achieve a satisfactory esthetic outcome compatible with long-term function, comfort, and periodontal health. In order to avoid the infringement of the STA as a consequence of restorative therapy, specific therapies such as biologic reshaping[49] or biologically oriented preparation technique (BOPT)[50] have been proposed. Future well-designed clinical trials should be conducted to properly evaluate the effect of different phenotypic variables on the outcomes of non-surgical and surgical periodontal and implant-related therapy, as well as in restorative therapy.

Despite having adhered to the highest methodology standard, this study is not exempt of limitations. First, only anterior maxillary teeth (canine to canine) were included. Moreover, finding from this study should not be extrapolated to other intraoral locations (i.e., mandibular teeth, maxillary premolar, or molar teeth). Second, different approaches have been described to measure and classify the PP. These include visual assessment of the soft tissue characteristics,[51] visual assessment of periodontal probe transparency inserted into the gingival sulcus,[41,52] transmucosal bone sounding,[43,45] ultrasonography,[53] measurement with a caliper after flap reflection or tooth extraction,[41] and the use of digital technologies such as CBCT with or without the superimposition of stereolithography files[20,28,30]; but each method has inherent limitations. However, previously published studies have concluded that digital assessment using CBCT imaging is an effective way to characterize the phenotypic features of the periodontium compared with clinical methods and histologic assessments.[28,54,55] Third, teeth with a previous history of attachment loss and periodontal therapy that may have modified the phenotypic features of interest were not included. This decision was made to homogenize the sample and avoid possible confounding variables. Fourth, the stratification and classification of the gingival and bone phenotype (thin vs. thick) was established with a cutoff point of 1 mm and measured at specific apico-coronal locations. This was a deliberate decision considering the significant effect that these variables have on the outcomes of therapy (e.g., periodontal plastic surgery and post-extraction alveolar ridge dimensional changes), as reported in previous studies.[6,9,43] Fifth, patients of only two racial backgrounds were included in this study. Therefore, the findings observed in this cohort of patients should be taken with caution when making extrapolations to populations with other characteristics.[56–58]

5 | CONCLUSIONS

Within the limitations of this cross-sectional study, it can be concluded that:

- Variations in the phenotypic features of the periodontium exist between facial and palatal sites, at different apico-coronal levels, and as a function of tooth crown type.
- Males typically exhibit thicker GT, BT, taller PSTH, and wider KTW compared to females.
- The shorter the facial PSTH, the thicker the facial alveolar bone plate.
- The shorter the facial CEJ-BC, the wider the KTW, and the thicker the facial GT and BT.
- Flat GA group is associated with shorter CEJ-BC, wider KTW, thicker facial GT, and facial BT than the pronounced scalloped group.
- Teeth with a square crown shape typically exhibit shorter CEJ-BC, wider KTW, and thicker GT.
- The thicker the BT, the thicker the GT and the wider the KTW.

AUTHOR CONTRIBUTIONS

Emilio Couso-Queiruga, Eliane Porto Barboza, and Diogo Moreira Rodrigues conceived and design the idea. Emilio Couso-Queiruga and Diogo Moreira Rodrigues contributed to data acquisition and analysis. Emilio Couso-Queiruga and Diogo Moreira Rodrigues led the writing. Eliane Porto Barboza, Gustavo Avila-Ortiz, Oscar Gonzalez-Martin, and Leandro Chambrone contributed to data analysis and critically revised the manuscript. All authors gave final approval and agreed to be accountable for all aspects of the scientific work.

ACKNOWLEDGMENTS

No financial support or sponsorship was received.

CONFLICTS OF INTEREST STATEMENT

The authors have no conflicts of interest to report pertaining to the conduction of this study.

ORCID

Emilio Couso-Queiruga https://orcid.org/0000-0002-9989-4483
Gustavo Avila-Ortiz https://orcid.org/0000-0002-5763-0201
Oscar Gonzalez-Martin https://orcid.org/0000-0003-3957-4872
Leandro Chambrone https://orcid.org/0000-0002-2838-1015

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SUPPORTING INFORMATION

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How to cite this article: Couso-Queiruga E, Barboza EP, Avila-Ortiz G, Gonzalez-Martin O, Chambrone L, Rodrigues DM. Relationship between supracrestal soft tissue dimensions and other periodontal phenotypic features: A cross-sectional study. *J Periodontol*. 2023;1-12. https://doi.org/10.1002/JPER.22-0434