**A novel cone-beam CT scanning technique for measuring periodontal soft tissues in the esthetic area**

Jia-wei Lu1), Xiong Shi2), Shi-hui Huang1), Xiang-zhen Yan3), Cong-jiao Hu1), Ming-yan Shi1), and Li-jun Luo1)

1) Department of Periodontics, School & Hospital of Stomatology, Tongji University, Shanghai Engineering Research Center of Tooth Restoration and Regeneration, Shanghai, P. R. China
2) Department of Radiology, School & Hospital of Stomatology, Tongji University, Shanghai Engineering Research Center of Tooth Restoration and Regeneration, Shanghai, P. R. China

**Abstract**

**Purpose:** This study investigated and tested a novel cone-beam computed tomography (CBCT) scanning technique capable of obtaining clear contours of soft tissues in the esthetic area.

**Methods:** Twenty-three periodontally healthy participants underwent this novel CBCT scanning technique. Soft tissue morphological parameters were measured on the CBCT images obtained. Intraoral clinical data were also collected at the same locations, and the accuracy of the CBCT method was tested.

**Results:** The median (interquartile range [IQR]) of the supercrestal gingival tissue thickness was 0.91 (0.73-1.13) mm, and the thickness of the central incisors was significantly greater than that of the canines (P < 0.05). The median (IQR) of keratinized tissue thickness was 0.73 (0.55-0.91) mm, which also showed a significantly greater thickness in the central incisors than in the canines (P < 0.05). Bland-Altman analysis suggested that CBCT could be accurate for measuring soft tissues in the esthetic area.

**Conclusion:** The novel CBCT technique described yields clear contours of soft tissues in the esthetic area without the need for auxiliary tools. Moreover, measurements of soft tissue morphological parameters on CBCT appear to be accurate.

**Keywords:** CBCT, esthetic area, keratinized tissue, periodontal phenotype, periodontal surgery, supercrestal gingival tissue

**Introduction**

The teeth and periodontal tissues that are visible when people smile have been described as the aesthetic area [1]. When complex cases oral issues arise in the aesthetic area, the main challenge is how to properly treat periodontal soft and hard tissues, which requires adequate acquisition of morphological parameters in this area [2].

Periodontal phenotype is a combination of both the gingival phenotype and bone morphotype [3]. It has been reported that patients with thin gingiva are at risk of gingival recession after implant placement and lower root coverage after periodontal surgery [4,5]. In contrast, thick gingiva is associated with positive prognostic factors for the esthetic success of periodontal treatments and a lower risk of flap perforation during surgery, thus being prognostically favorable in terms of esthetics [6].

Many different methods for measurement of gingival thickness have been proposed, including direct visual inspection [2], dental probe transparency [7], transgingival probing [8], the use of an ultrasonic transducer [9], and cone-beam computed tomography (CBCT) [10,11]. Among these methods, direct visual inspection and dental probe transparency are qualitative methods for determining whether the gingiva is “thin” or “thick”. Transgingival probing is a widely used quantitative method for measuring the thickness of soft tissues. However, its invasiveness limits its applicability [12]. Use of an ultrasonic transducer is a noninvasive approach for soft tissue measurement, but it requires additional equipment and therefore has limited applications in clinical practice [12]. CBCT has been widely used to assess hard tissues such as alveolar bone and teeth, and recently it has also been suggested to be a noninvasive method for measuring periodontal soft tissues [10,13-16]. However, because the gingiva always overlaps with the lips, and the two tissues show similar CT values, soft tissues on the labial side of the esthetic area cannot be independently displayed by the traditional CBCT scanning. In the current situation, a noninvasive, quantitative, and accurate soft tissue measurement method is necessary. Moreover, although some studies [17] consider CBCT to be a more accurate method for measuring the thickness of soft tissues, its role is still controversial [18]. The accuracy of CBCT for soft tissue measurement remains unclear.

Preoperative assessment of gingival width is also an important prerequisite for achieving good esthetic outcomes and periodontal health [19]. A wider gingiva has better resistance to microbial infection [20]. The width of the keratinized tissue and supracrestal gingival tissues are two important parameters for evaluation of periodontal soft tissues. Keratinized tissue consists of the attached gingiva and free gingiva, and its width has been defined as the vertical distance from the gingival margin (GM) to the mucogingival junction. Usually, the width of keratinized tissue has been measured by intraoral direct visual inspection, and few reports have mentioned the application of CBCT as a measurement method. The supracrestal gingival tissue consists of the attached tissues from the bottom of the gingival sulcus to the alveolar bone crest and the free gingiva [21], and the width of the supracrestal gingival tissue refers to the distance from the gingival margin to the alveolar ridge crest. Transgingival probing [8] is the primary method for measuring this width. As mentioned above, CBCT may also have potential for measurement of supracrestal gingival tissue. So far, however, few studies have investigated this issue.

Against this background, the present study aimed to develop a soft tissue CBCT scanning technique that does not require auxiliary tools, and to use it to determine the morphological parameters of periodontal soft tissues in the esthetic area. A transgingival probe was also applied to test the accuracy of the CBCT measurement method.

**Materials and Methods**

**Inclusion and exclusion criteria**

Patients who visited Affiliated Stomatolgy Hospital of Tongji University between 2018 and 2020 were enrolled in the study. All subjects underwent supragingival scaling one week before scans. If the subjects had periodontitis (probe depth >3 mm, or attachments loss) or met one of the following criteria, they were excluded: (i) systemic disease with oral manifestations, (ii) pregnancy or breastfeeding, (iii) ingestion of drugs known to cause gingival enlargement; (iv) wedge-shaped defects in the upper front teeth that would make the cementoenamel junction (CEJ) unclear on CBCT images; (v) history of orthodontic treatment that had changed the morphology of the gingiva and alveolar bone; (vi) incorrect tooth position, severely crowded teeth, abnormal tooth shape; (vii) smoking more than 5 cigarettes per day. Initially, 23 participating subjects underwent CBCT examination. After excluding two subjects due to insufficient radiographic image quality, a total of 21 participants (8 male and 13 female) aged between 19 and 40 years were finally enrolled.

With the approval of the Ethics Committee of the Affiliated Stomatol-
ogy Hospital of Tongji University, Shanghai, China in June 2018 (No: [2018]-36) and in full accordance with the Declaration of Helsinki, subjects were provided with information about the purpose of the study and gave their written consent.

CBCT scans and measurements
The CBCT examinations were obtained using radiology equipment (Morita 3D Accuitomo, Morita, Suita, Japan). Exposure was performed at 90 kV and 4.0-6.0 mA for 17.5 s (voxel size, 0.16 mm; field of view, 80 × 80 mm) as recommended by the manufacturer. The size of the FOV included the teeth and soft tissues to be measured. A previous study investigating the effect of field of view and angle of rotation showed that the effective radiation dose for dental CBCT [22] was approximately 211 µSv. The patients were seated with their chins and heads stabilized. Before the scanning began, patients were required to actively close their lips, inflate their vestibule, and retract the tongue toward the bottom of the mouth (Fig. 1). The lips were pushed away from the teeth and gingiva by the retained air (Fig. 2A). CBCT images were generated and analyzed using software (One Volume Viewer, Morita). Subsequently, a senior radiologist analyzed and measured the six maxillary anterior teeth on a CBCT sagittal section, including the distance from the GM to the CEJ (D) (Fig. 2B). If the GM was above the CEJ, the data were recorded as a positive value; otherwise, they were recorded as a negative value, followed by the width (STW) and thickness (STT) of the supracrestal gingival tissue (Fig. 2C, D), and the width (KTW) and thickness (KTT) of keratinized tissue (Fig. 2E, F). The width measurements were taken at the mesial-distal midpoint of each tooth. Gingival thicknesses referred to the vertical distance from the gingival surface to the bone surface, and was measured at the vertical midpoint of the supracrestal gingival tissue and keratinized tissue. After the soft lip tissues had been retracted, the labial gingival soft tissues in the esthetic area exhibited an S-shape, which was thicker at the free gingiva and became gradually thinner in the direction of the root. The soft tissue of the alveolar mucosa is thicker than the soft tissue of the gingiva because submucosa lay under the oral mucosa while the attached gingiva did not. Therefore, there is an area of thickness transition at the mucogingival junction. Dynamic observation of soft tissue contours on sagittal images is required to detect this soft tissue morphological transition (Fig. 3). The mucogingival junction location on CBCT was selected according to this morphological transition. The width of the keratinized tissue was taken as the vertical apico-coronal distance from the mucogingival junction to the GM. All radiographic data were accurate to 0.01 mm. All data were measured three times to reduce error.

Clinical examinations
Clinical examinations included general examinations and invasive examinations. General examinations included probing of periodontal pockets and determination of the distance from the GM to CEJ (cD), keratinized tissue width (cKTW), and bleeding on probing. A periodontal probe (Hu-Friedy, Chicago, IL, USA) was used to measure cD and cKTW (Fig. 3A). The measurement sites were selected to be consistent with the CBCT measurement sites. All measurements were rounded to the nearest 0.5 mm. The invasive examination used K-files (Mani, Utsunomiya, Japan) or periodontal probes with a rubber stop (Fig. 4) and Vernier calipers (Shanghai Menette Industrial, Shanghai, China) (Fig. 5), including the distance from the GM to the alveolar crest (cSTW) (Fig. 3B), and the thicknesses of the supracrestal gingival tissue (cSTT) and keratinized tissue (cKTT) (Fig. 3C) [11]. The measurement sites were also consistent with the sites of CBCT measurement. These measurements were rounded to the nearest 0.01 mm, and all data were measured three times to reduce error.

Statistical analysis and sample size determination
All data are presented as median (IQR) mm. After the data had been tested for normality (using the Shapiro-Wilk normality test), the Kruskal-Wallis H test was used to compare the five morphological parameters among three teeth, and a further pairwise Mann-Whitney U test with Bonferroni

Fig. 1 Patients were required to actively close the lips and inflate their vestibule.

Fig. 2 Morphological parameters of the esthetic area can be measured on CBCT images. Red line, D, GM to CEJ; yellow line, STW, Supracrestal attached tissue width; light blue line, STT, Supracrestal attached tissue thickness; green line, KTW, keratinized tissue width; dark blue line, KTT, Keratinized tissue thickness; red arrow, mucogingival junction determined by dynamic detection

Fig. 3 Dynamic detection of the mucogingival junction. The yellow curves are the labial contours of the soft tissues at the mesial-distal midpoint of the teeth, and a thickness transition can be observed at the mucogingival junction. The red arrows indicate the mucogingival junction determined by dynamic detection.
correction was used for multiple comparison of differences between teeth. The above statistical analysis was performed using SPSS version 21 (IBM, Chicago, IL, USA). Bland-Altman analysis (plotting) [23] using MedCalc version 19 (MedCalc Software, Ostend, Belgium) was performed to compare the results of the two methods. Statistical significance was set at \( P < 0.05 \).

A priori power analysis was used for determination of the minimum required sample size. A sample size of 42 teeth was found to have 0.90 power at a significance level of \( \alpha = 0.05 \). Power analysis was performed using the PASS 11 software package (NCSS, Kaysville, UT, USA).

**Examiner reliability**

Twenty percent of the measurements (26 teeth) were remeasured one week after completing the first recordings to evaluate intra-examiner reliability. A second examiner measured 20% of the measurements in order to evaluate inter-examiner reliability. The measurement methodology was discussed by the examiners and standardized in a one-hour session before the measurements were taken; both examiners measured the same scans at the same magnification. The lowest degree of intra-examiner and inter-examiner reliability was 0.89 and 0.88, respectively (using Spearman’s rank correlation, \( r = 0.89 \) and \( r = 0.88 \)). No statistically significant differences were detected in the mean values of the measurements for intra-examiner and inter-examiner reliability (\( P > 0.05 \) in all statistical comparisons with the Wilcoxon test).

**Results**

The radiographic and clinical results for the esthetic area are shown in Table 1. The results of the statistical analysis are shown in Table 2.

**Supracrestal gingival tissue**

The median (IQR) of D for the six teeth in the esthetic area was 0.97 (0.79-1.11) mm. The median of gingival margin coverage of the central incisors was 1.07 (0.97-1.19) mm, while the lateral incisors and canines were narrower at 0.96 (0.83-1.04) mm and 0.81 (0.54-1.02) mm. The D for central incisors was significantly higher than that for lateral incisors and canines (\( P < 0.05 \)). The median (IQR) STW of the six teeth in the esthetic area was 3.27 (3.06-3.50) mm, with no significant difference between the central incisors, lateral incisors, and canines; the median (IQR) STT for the six teeth was 0.91 (0.73-1.13) mm, being 1.03 (0.87-1.14) mm for the central incisors and 0.81 (0.61-1.10) mm for the canines, and the thickness of the central incisors was significantly greater than that of the canines (\( P < 0.05 \)).

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**Table 1** Parameters of gingival soft tissues (median [IQR]) (mm).

| Tooth          | n  | D     | STW   | STT   | KTW   | KTT   |
|----------------|----|-------|-------|-------|-------|-------|
| **Radiographic results** |    |       |       |       |       |       |
| Central incisor | 42 | 1.07 (0.97-1.19) | 3.20 (2.98-3.39) | 1.03 (0.87-1.14) | 5.04 (4.23-5.51) | 0.82 (0.62-1.07) |
| Lateral incisor | 42 | 0.96 (0.83-1.04) | 3.25 (2.82-3.40) | 0.83 (0.68-1.11) | 4.72 (3.19-5.82) | 0.70 (0.55-0.85) |
| Canine          | 42 | 0.81 (0.54-1.02) | 3.37 (2.92-3.73) | 0.81 (0.61-1.10) | 4.17 (3.44-5.84) | 0.67 (0.47-0.88) |
| Three teeth     | 126| 0.97 (0.79-1.11) | 3.27 (2.96-3.50) | 0.91 (0.73-1.13) | 4.72 (3.62-5.72) | 0.73 (0.55-0.91) |
| **Clinical results** |    |       |       |       |       |       |
| Central incisor | 42 | 1.00 (0.96-1.04) | 3.22 (3.10-3.49) | 1.00 (0.84-1.19) | 5.17 (3.50-6.00) | 0.79 (0.64-0.96) |
| Lateral incisor | 42 | 1.00 (0.83-1.00) | 3.30 (2.84-3.63) | 0.77 (1.05-0.67) | 4.33 (3.67-5.67) | 0.65 (0.49-0.87) |
| Canine          | 42 | 0.67 (0.53-1.00) | 3.60 (3.30-3.89) | 0.83 (1.20-0.63) | 4.33 (3.10-5.58) | 0.59 (0.43-0.78) |
| Three teeth     | 126| 1.00 (0.67-1.00) | 3.38 (3.03-3.73) | 0.91 (0.69-1.13) | 4.67 (3.50-5.67) | 0.69 (0.50-0.89) |

n, sample size; IQR, interquartile range

**Table 2** P values of Kruskal-Wallis H test and pairwise Mann-Whitney U tests with Bonferroni correction for multiple comparisons.

| Tooth          | n  | D     | STW   | STT   | KTW   | KTT   |
|----------------|----|-------|-------|-------|-------|-------|
| **Kruskal-Wallis H test** |    |       |       |       |       |       |
| Central incisor-lateral incisor | 42 | 0.037* | NA    | 0.053 | NA    | 0.143 |
| Lateral incisor-canine          | 42 | 0.068 | NA    | 1.000 | NA    | 1.000 |
| Central incisor-canine         | 42 | <0.001* | NA    | 0.008* | NA    | 0.017* |

* sample size; *Adj. \( P < 0.05 \); Adj. \( P \), \( P \) value has been multiplied by 3 according to the Bonferroni correction for multiple comparison. NA, not applicable
There were no significant differences between the central incisors and lateral incisors, or between the lateral incisors and canines.

Keratinized tissue
The median (IQR) KTW was 4.72 (3.62-5.72) mm, with no significant difference between the three teeth; the median (IQR) KTT was 0.73 (0.55-0.91) mm, with 0.82 (0.62-1.07) mm for the central incisors and 0.67 (0.47-0.88) mm for the canines. The keratinized tissue of central incisors had a significantly greater thickness than that of the canines (P < 0.05). There were no significant differences between central incisors and lateral incisors, or between the lateral incisors and canines.

Discussion
Studies of CBCT measurements of gingival soft tissues in the esthetic area have been limited because it is difficult to obtain CBCT images of labial gingival soft tissues without interference from the oral mucosa. Although some auxiliary tools have been used to push the lips away from the gingiva in some studies to distinguish the lip and the gingiva, these methods have shown certain limitations [17]. For example, retractors [10] sometimes cannot fully retract the lips, resulting in incomplete display of the gingiva. Moreover, lip retractors cannot be fixed during scanning, which may cause movement artifacts during scanning. Obstructions in the vestibule such as cotton rolls [24-26] may apply pressure to the soft tissues, leading to dimensional alterations. In this study, it was possible to obtain clear contours of soft tissues in the esthetic area using the novel CBCT scanning technique without auxiliary tools. Morphological parameters including the width and thickness of the supracrestal gingival tissue and keratinized tissue were measured on the obtained CBCT images. In addition to the radiographic results, corresponding intraoral clinical results were collected to test the accuracy of the CBCT method. This scanning technique is simple to learn.
and requires no auxiliary tools, making it more comfortable for patients, more acceptable for practitioners and, as a result, more promotable in clinical practice. Other than that, there is a similar scanning technique called the “puffed cheek” scan method, which has been shown in several studies to be sensitive for diagnosis of buccal tumors [27]. In 2010, Dvorak et al. [28] used this method to measure mucosal thickness but found it to be less reliable. This may have been because the studies were done using spiral CT with a slice thickness of 1.0 mm, whereas in the present study CBCT with a higher resolution was used, allowing a higher quality of soft tissue imaging and more accurate measurement of radiographic parameters.

Distinguishing the bottom of the gingival sulcus on CBCT is difficult. Likewise, the histological depth of the gingival sulcus differs from the clinical probing depth, as the probe penetrates the junction epithelium [29]. Therefore, Kois et al. [30] have proposed that all gingival soft tissues above the crest should be considered continuous gingival connective tissue. Previous research has shown that supracrestal gingival tissue is composed of supracrestal tissue attachment and free gingiva [31]. Transgingival probing has been used to measure the width and thickness of this tissue [8]. However, its use is limited and there have been few relevant studies due to the invasiveness of the measurement method [29-32].

The present results (Tables 1, 2) obtained using CBCT showed that among teeth in the esthetic area, for D, the central incisors had more than 1 mm gingival coverage, and were significantly higher than the canines and lateral incisors (P < 0.05). The median STW in the esthetic area was 3.27 mm with an interquartile range of 2.96-3.50 mm, with no significant differences between the central incisors, lateral incisors, and canines. Tristão et al. [32] obtained a result of 2.75 ± 0.59 mm in histological sections of extracted teeth, and this inconsistency may have been attributable to the different measurement methods. Arora et al. [33] measured a STW of approximately 3.5 mm in the maxillary anterior teeth using the transgingival probing method, while Amid et al. [26] obtained an STW range of 3.06-3.60 mm for the three teeth in the esthetic area using the CBCT method, being similar to the present results.

Regarding the results for thickness (Table 1), the central incisors showed a thicker STT of 1.03 (0.87-1.14) mm, while the lateral incisors and canines were thinner (<1 mm). Statistical analysis (Table 2) showed that the STT was significantly thicker in the central incisors than in the canines, perhaps indicating weaker attachment tissue in the canines. Among the CBCT methods reported, Amid et al. [26], using measurement positions similar to the present study, found that the gingival thickness of individuals with a thin gingival biopsy was <1 mm for the central incisors, lateral incisors, and canines, whereas the gingival thickness of individuals with a thick gingival biopsy was >1 mm, although there were no significant differences between the teeth. Kim et al. [15] measured the gingival soft tissue thickness above the alveolar crest at different levels, and the thickness obtained at the crest level was 1.58 ± 0.32 mm for the central incisors, 1.30 ± 0.24 mm for the lateral incisors, and 1.32 ± 0.26 mm for the canines. These results were slightly greater than those obtained in the present study, probably due to the differences in measurement sites. In addition, Kim et al. [15] found that the soft tissue thickness of the central incisors was significantly greater than that of the lateral incisors and canines, again being similar to the findings of the present study.

The width and thickness of keratinized tissue were also measured in the present study (Table 1), revealing that the keratinized tissue width (KTW) was generally >2 mm in the esthetic area, 2.22-6.94 mm in the central incisors, 2.61-7.03 mm in the lateral incisors, and 2.01-8.25 mm in the canines. Since the keratinized gingival width can be obtained intraorally easily and noninvasively with a periodontal probe, the CBCT method has no significant advantages. In addition, the location of the mucogingival junction has been traditionally localized by direct visual inspection of the color and removability of the soft tissues, while the method for localizing the mucogingival junction by morphological changes in CBCT images needs to be further studied. Therefore, although this method of determining the location of the mucogingival junction appears to be accurate from the results of this study, the CBCT measurement method may not have any significant advantage over the traditional method. In the present study, the keratinized tissue thickness (KTT) in the esthetic area was generally thin, 69.1% and 85.7% being <1 mm in the central and lateral incisors, and in the canines, respectively. These results agree with studies that have also used CBCT, in terms of both width [34,35] and thickness [18,19]. The present statistical analysis (Table 2) showed that the thickness of keratinized tissue was significantly greater in the central incisors than in the canines, whereas there was no significant difference between the central and lateral incisors, nor between the lateral incisors and canines. This may have been due to the fact that the canines are located at the corner of the dental arch, where there is a higher chance of gingival recession. In addition, canines usually have a thin underlying alveolar plate, making the soft tissue attachment in this area relatively weak. Combining the above D and STT results for the canines, it was found that the gingival soft tissue in the esthetic area showed gradual thinning from the central incisor to the canines, suggesting that the soft tissue is weaker in the canine area and thus extra care should be taken when performing surgical maneuvers in this area.

Since transgingival probing needs to be performed under local anesthesia, the accompanying pain, bleeding, and injections may put more stress on the patients. In addition, it is sometimes difficult to locate the alveolar crest because there is a certain amount of resistance when the probe pierces the attached gingival tissues, and this may cause measurement errors. However, as a noninvasive imaging method, CBCT is more acceptable for patients. In the present study, clinical data were collected and compared with radiographic data to test the accuracy of this method. Bland-Altman plots have been used extensively to evaluate the degree of agreement between two different instruments or two measurements techniques [23]. The present study applied this analysis to compare differences between the radiographic method and the clinical method (Fig. 6). When measuring D, the limits of agreement indicated that the radiographic method may be at most 0.63 mm below or 0.76 mm above the clinical method, which may less acceptable for clinical purposes. When measuring STW and KTW, there may be at most 0.99/1.15 mm below or 0.63/1.3 mm above the clinical method, which seem to be reasonable for clinical practices. When measuring STT and KTT, there may be at most 0.32/0.30 mm below or 0.49/0.37 mm above the clinical method, which may be acceptable for thickness measurements [28]. These results suggest that CBCT could be considered an accurate method for measuring soft tissues in the esthetic area.

Before dental surgery, the morphological parameters of the gingival soft tissues can be obtained by the above scanning technique, which can help the practitioner to identify patients at high esthetic risk, as well as to use these parameters to guide the surgery and perform accurate prognostication. Furthermore, the soft tissue parameters can be combined with those of the underlying bone tissue to study in greater depth the morphological characteristics of the periodontal tissue in the esthetic area. The same approach can also be used to assess the outcome after soft tissue augmentation, since any invasive examination of the soft tissues after surgery would be unacceptable. With the present improved CBCT scanning technique, the soft tissues in the esthetic area can be visualized without the need for auxiliary tools. However, because the soft tissues of the lip are inflated, the facial soft tissue morphology is altered. Therefore, for orthodontics cases involving craniomaxillofacial soft tissue parameters, this method is not applicable. Moreover, despite the relatively low radiation dose of CBCT, radiation damage should still be considered. The American Dental Association [16] recommends that CBCT should be used only if it leads to better clinical results. Therefore, considering the minimal amount of radiation, pre-treatment CBCT has clear diagnostic benefits and meets the above guidelines. For example, soft tissue augmentation may be considered before surgery for patients who require implant surgery in the esthetic area. In addition, during orthodontic tooth movement, teeth may be repositioned beyond the border of the alveolar bone and cause dehiscence and fenestration [36,37]. Pretreatment CBCT can be used to confirm the boundaries of tooth movement and associated soft tissue problems. Since patients already require CBCT for treatment planning, they are not exposed to additional radiation.

Acknowledgments
This work was supported by the Science and Technology Commission of Shanghai Municipality (project 20YJ11904200).

Conflict of interest
The authors do not have any financial interest in the companies whose materials were included in this study.
References

1. Zucchelli G, Sharma P, Mounsif I (2018) Esthetics in periodontics and implantology. Periodontology 2000 77, 7-18.
2. Frank MS, Vincent GC, David PM (2006) Interdisciplinary management of anterior dental esthetics. J Am Dent Assoc 137, 160-169.
3. Jepsen S, Caton JG, Albandar JM, Bissada NF, Bouchard P, Cortellini P et al. (2018) Periodontal manifestations of systemic diseases and developmental and acquired conditions: consensus report of workgroup 3 of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. J Clin Periodontol 45, 219-229.
4. Muller HP, Eger T (2002) Masticatory mucosa and periodontal phenotype: a review. Int J Periodontics Restorative Dent 22, 172-183.
5. Evans CD, Chen ST (2008) Esthetic outcomes of immediate implant placements. Clin Oral Implants Res 19, 73-80.
6. Hwang D, Wang HL (2006) Flap thickness as a predictor of root coverage: a systematic review. J Periodontol 77, 1625-1634.
7. De Rouck T, Eghbali R, Collys K, De Bruyne H, Cosyn J (2009) The gingival biotype revisited: transparency of the periodontal probe through the gingival margin as a method to discriminate thin from thick gingiva. J Clin Periodontol 36, 428-433.
8. Greenberg J, Laster L, Listgarten MA (1976) Transgingival probing as a potential estimator of alveolar bone level. J Periodontol 47, 514-517.
9. Daly CH, Wheeler JB 3rd (1971) The use of ultra-sonic thickness measurement in the clinical evaluation of the oral soft tissues. Int Dent J 21, 418-429.
10. Janairo AL, Barriviera M, Duarte WR (2008) Soft tissue cone-beam computed tomography: a novel method for the measurement of gingival tissue and the dimensions of the dentogingival unit. J Esthet Restor Dent 20, 366-374.
11. Fu JH, Yeh CY, Chan HL, Tatarkis N, Leong DJ, Wang HL (2010) Tissue biotype and its relation to the underlying bone morphology. J Periodontol 81, 569-574.
12. Ronay V, Sahrmann P, Bindl A, Attin T, Schmidlin PR (2011) Current status and perspective of mucogingival soft tissue measurement methods. J Esthet Restor Dent 23, 146-156.
13. Barriviera M, Duarte WR, Janairo AL, Faber J, Rezera AC (2009) A new method to assess and measure palatal masticatory mucosa by cone-beam computerized tomography. J Clin Periodontol 36, 564-568.
14. La Rosca AP, Alemany AS, Levi P Jr, Juan MV, Molina JN, Weigold AS (2012) Anterior maxillary and mandibular biotype: relationship between gingival thickness and width with respect to underlying bone thickness. Implant Dent 21, 507-515.
15. Kim YJ, Park JM, Kim S, Koo KT, Seol YJ, Lee YM et al. (2016) New method of assessing the relationship between buccal bone thickness and gingival phenotype. J Periodontol Implant Sci 46, 372-381.
16. Kim DM, Basiir SH (2017) When is cone-beam computed tomography imaging appropriate for diagnostic inquiry in the management of inflammatory periodontitis? An American Academy of Periodontology best evidence review. J Periodontol 88, 978-998.
17. Gürlek Ö, Sönmez Ş, Güneri P, Nizam N (2018) A novel soft tissue thickness measuring method using cone beam computed tomography. J Esthet Restor Dent 30, 516-522.
18. Ogawa M, Katagiri S, Koyanagi T, Maekawa S, Shibahara T, Ohsugi Y et al. (2020) Accuracy of cone beam computed tomography in evaluation of palatal mucosa thickness. J Clin Periodontol 47, 479-488.
19. Schmidt JC, Sahrmann P, Weiger R, Schmidlin PR, Walter C (2013) Biologic width dimensions—a systematic review. J Clin Periodontol 40, 493-504.
20. Lang NP, Löe H (1972) The relationship between the width of keratinized gingiva and gingival health. J Periodontol 43, 623-627.
21. Smukler H, Chaht M (1997) Periodontal and dental considerations in clinical crown extension: a rational basis for treatment. Int J Periodontics Restorative Dent 17, 464-477.
22. Pauwels R, Zhang G, Theodorou C, Walker A, Bosmans H, Jacobs R et al. (2014) Effective radiation dose and eye lens dose in dental cone beam CT: effect of field of view and angle of rotation. Br J Radiol 87, 20130654.
23. Band J, Alman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 8, 307-310.
24. Kamakina A, Nakano T, Ono S, Kato T, Tyanai H (2015) Cone-beam computed tomography evaluation of horizontal and vertical dimensional changes in buccal peri-implant alveolar bone and soft tissue: a 1-year prospective clinical study. Clin Implant Dent Relat Res 17, 576-585.
25. Nikiforidou M, Tsalikis L, Angelopoulou C, Menexes G, Yousro I, Kontstantinides A (2016) Classification of periodontal biotypes with the use of CBCT. A cross-sectional study. Clin Oral Investig 20, 2061-2071.
26. Amri R, Mirakhorli M, Sahij Y, Kadkhodazadeh M, Namadi M (2017) Assessment of gingival biotype and facial hard/soft tissue dimensions in the maxillary anterior teeth region using cone beam computed tomography. Arch Oral Biol 79, 1-6.
27. Erdogan N, Bulbul E, Songu M, Uluc E, Oral K, Apaydin M et al. (2012) Puffed-cheek computed tomography: a dynamic maneuver for imaging oral cavity tumors. Ear Nose Throat J 91, 383-386.
28. Dvorak G, Arnhart C, Schön P, Heuberger S, Watzek G, Gahlheimer A (2013) The “puffed cheek method” to evaluate mucosal thickness: case series. Clin Oral Implants Res 24, 719-724.
29. Arora R, Narula SC, Sharma RK, Tewari S (2013) Supracrestal gingival tissue: assessing relation with periodontal biotypes in a healthy periodontium. Int J Periodontics Restorative Dent 33, 763-771.
30. Kosi JC (1994) Altering gingival levels: the restorative connection part I: biologic variables. J Esthet Dent Rest 6, 3-7.
31. Barboza EP, Monte Alto RF, Ferreira VE, Carvalho WR (2008) Supracrestal gingival tissue measurements in healthy human periodontium. Int J Periodontics Restorative Dent 28, 55-61.
32. Trindão GC, Barboza CA Jr, Rodrigues DM, Barboza EP (2014) Supracrestal gingival tissue measurement in normal periodontium: a human histometric study. Int J Periodontics Restorative Dent 34, 97-102.
33. Arora R, Narula SC, Sharma RK, Tewari S (2013) Evaluation of supracrestal gingival tissue after surgical crown lengthening: a 6-month clinical study. J Periodontol 84, 934-940.
34. Egge RA, Kahn S, Barcelo M, Bittencourt D (2012) Relationship between the width of the zone of keratinized tissue and thickness of gingival tissue in the anterior maxilla. Int J Periodontics Restorative Dent 32, 573-579.
35. Stellini E, Comuzzi L, Mazzocco F, Parente N, Gobato L (2013) Relationships between different tooth shapes and patient’s periodontal phenotype. J Periodontol Res 48, 657-662.
36. Morris JW, Campbell PM, Tadlock LP, Boley J, Buschang PH (2017) Prevalence of ginglyval recession after orthodontic tooth movements. Am J Orthod Dentofacial Orthop 151, 851-859.
37. Chiu S, Lee SM, Zhang C, Tan Z, Zhao Q (2021) Correlation between gingival phenotype in the aesthetic zone and craniofacial profile—a CBCT-based study. Clin Oral Investig 25, 1363-1374.