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Original Article

Accuracy of assessing gingival thickness in the esthetic maxillary region by periodontal probing, cone-beam computed tomography and digital scanning

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Abstract: To evaluate the accuracy of four noninvasive methods for measuring gingival thickness (GT) and to examine correlations among the four methods, this study analyzed 180 maxillary anterior teeth from 30 volunteers. The gingival biotype (GB) was assessed by M1-transparency probing (TP). M2-cone-beam computed tomography (CBCT) images with radiopaque material were scanned. M3-intraoral digital scanning (IDS) and M4-extraoral DS (EDS) of a gypsum cast were assessed using a three-dimensional scanner. Measurements of GT at the central incisors (CI), lateral incisors (LI), and canines (CA) were performed at the cementoenamel junction (CEJ) and alveolar ridge crest (ARC) on superimposed DS and CBCT images. The results showed that the GB determined by M1 showed no significant differences in CI, LI, or CA but differed significantly between males and females. At the CEJ position, significant differences were measured by M2, M3, and M4 in most teeth, with the exception of CI in M3 and M4. At the ARC position, the GT of most teeth measured by M2, M3, and M4 showed no significant difference. There were positive correlations among these four methods. It can be concluded that measurements of GT by superimposing IDS or EDS and CBCT images are not reliable.

Keywords: Gingival biotype, gingival thickness, transparency probing, cone-beam computed tomography, digital scanning

Introduction

Gingival biotype (GB) influences the esthetic outcomes of implant placement, restorative treatments, periodontal therapy, and root coverage procedures in the esthetic region of the anterior maxilla [1]. A thick flat GB has been reported to be a prognostic factor for successful esthetic outcomes of periodontal treatment [2]. However, patients with thin scalloped gingiva were at higher risk of gingival recession after the placement of immediate implants [3] and less root coverage after periodontal surgery [2]. Thus, it is crucial to determine the GB before treatment, and caution is required when treating patients with a thin GB.

The GB is a result of several factors, such as the width of keratinized tissue, the crown length:width ratio, labial or buccal bone thickness, gingival papilla height, and gingival thickness (GT) [4]. Various methods have been proposed for assessing GT, including direct visual inspection [5], transparency probing (TP) [6], ultrasonic devices [7], and cone-beam computed tomography (CBCT) [8]. TP has been an adequately reliable, objective, and simple method of evaluating GT [9], whereas direct visual inspection has been less reliable than direct measurement [5]. The direct measurement of GT by transgingival probing using endodontic needles has been suggested, but this method is invasive and requires anesthesia. Ultrasonic devices are noninvasive and reproducible but are limited by difficulties in maintaining transducer directionality, availability, and cost [10]. CBCT facilitates the measurement of GT and has been an objective method for determining the thickness of soft and hard tissues, but its low resolution of density and contrast limits the utility of CBCT for the visualization of soft tissue [11, 12]. Soft tissue CBCT scans have report-

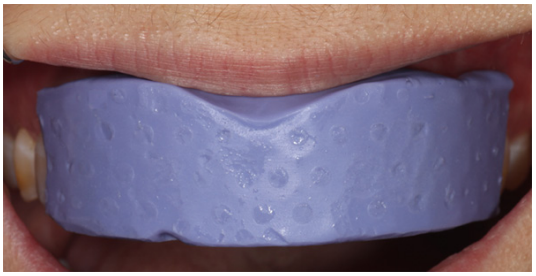

Figure 1. Silicone matrix with radiopaque impression material was fabricated on the maxillary anterior dentition.

edly enabled the visualization of soft tissue but require a high dose of radiation and are costly [13]. To overcome this problem, Cao et al. [14] used a radiopaque impression material for CBCT to visualize the outline of soft tissue. Alternatively, digital scanning (DS) information can be combined with CBCT data [15]. DS images with more accurate outlines and greater resolution can be obtained by intraoral scanning or extraoral scanning of a gypsum cast, thereby improving the reproducibility and reducing the variance in measurements between investigators [16]. However, no consensus on the accuracy of DS for soft tissue has been reached [17].

The limitations of the above methods for measuring GT warrant further studies in this area. Thus, the aim of this study was to assess the accuracy of several methods of measuring GT on superimposed CBCT scans and intraoral or extraoral DS images and to evaluate correlations between these methods and the GB assessed by TP. The null hypothesis was that there was no significant difference among these methods.

Materials and methods

Selection of volunteers

Thirty medical students (18 males and 12 females) aged 20 to 26 years in Zhejiang Provincial People's Hospital were enrolled in this study. Informed consent was obtained from the subjects, and this study was approved by the Ethics Committee of Zhejiang Provincial People's Hospital (2018KY015). All subjects had a healthy periodontal condition with a periodontal probing depth of no more than 3 mm, a bleeding index of < 2, and no gingival recession on maxillary anterior teeth. The following exclusion criteria were adopted: pregnant or lactating females; fillings or crowns in the maxillary anterior dentition; tooth malocclusion; use of any medication affecting the soft tissue; cigarette smoking; and a history of orthodontic therapy. Each subject was given instructions on maintaining oral hygiene and had their teeth cleaned one week before the test.

Method 1 (M1): GB assessment by TP

GB was categorized as thin, moderate, or thick based on the transparency of periodontal probe KPC15 (Kangqiao, Shanghai, China) as described by Kan et al. [18]. The probe was gently inserted by three experienced clinicians into the central gingival groove until reaching the bone sounding on the labial side of the maxillary anterior teeth and paralleling the long axis of the crown. The GB was categorized as thick if the probe tip was not visible through the tissue and as thin if the probe was visible. If the thick end of the probe was visible through the sulcus but the thin end was not, then the GB was classified as moderate.

Method 2 (M2): GT assessment by CBCT

GT was assessed by CBCT according to Cao's method [14]. A silicone matrix (Dentsply, Konstanz, Germany) was fabricated on a gypsum cast of the maxillary arch, and the inner surface was trimmed evenly with a scraper to create approximately 1 mm of relief space. Then, the final impression was made by using a mixture of barium sulfate powder (Reagent grade, Qingdao Dongfeng Chemical, Qingdao, China) and alginate material (Heraues Kulzer, Hanau, Germany) at a ratio of 1:2 by weight, and the mixture was subsequently loaded into the prepared matrix to capture the detail of the mucogingival tissue contour (**Figure 1**). With the silicon matrix in place, a scan of the maxillary arch and dentition was obtained with the CBCT machine (ProMax 3D; Planmeca, Helsinki, Finland) at a setting of 80 kV, 6.0 mA, 15 s, 0.15-mm voxel size, and 0.50-mm slice thickness. Reconstructed images were generated with Planmeca Romexis software (3.5.1R; Planmeca). The outline of the soft tissue on the labial side was visible as a white line on the CBCT image, and the GT was measured perpendicularly along the long axis of the tooth at the

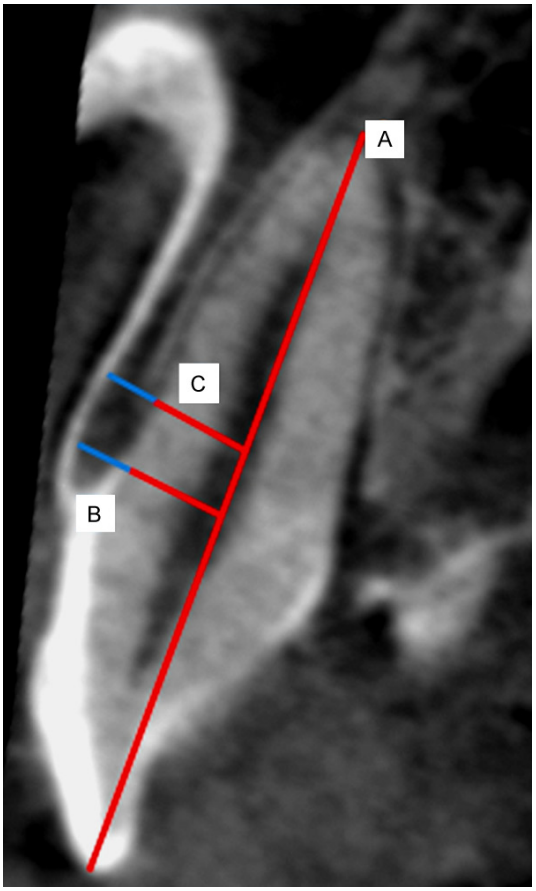

Figure 2. Reconstructed CBCT image showing a sagittal section of the upper left central incisor. The gingival outline obtained from CBCT is marked by a white line. GT (blue line) was measured at the CEJ position (B) and at the ARC position (C), which is perpendicular to the root axis (A).

cementoenamel junction (CEJ) and alveolar ridge crest (ARC) (**Figure 2**). All measurements were performed in triplicate by three experienced clinicians.

Method 3 (M3): GT assessment by CBCT and intraoral digital scanning (IDS)

In method 3 (M3), GT was assessed by CBCT combined with IDS [15]. The soft tissue of the anterior maxilla was scanned using a three-dimensional intraoral scanner (TRIOS; 3Shape, Copenhagen, Denmark). A CBCT image was acquired under the same conditions as in M2. The IDS data were exported into stereolithography (STL) format and matched with the CBCT data (**Figure 3**). Three highly radiopaque and relatively stable positions in the teeth were chosen as fiducial markers and were used as references to match the STL files with the CBCT images according to a best-fit algorithm using TRIOS software (3Shape). The outline of the soft tissue on the labial side was visible as a yellow line, and the GT was measured at the CEJ and ARC positions in triplicate by three clinicians (**Figure 4**).

Method 4 (M4): GT assessment by CBCT and extraoral digital scanning (EDS)

In method 4 (M4), GT was assessed by superimposing the image obtained from CBCT and the EDS of a gypsum cast of the maxillary teeth. A conventional alginate impression of the maxillary arch was made and cast with dental stone (Heraeus Kulzer, Hanau, Germany). The gypsum cast was scanned using a three-dimensional scanner, and the STL data were matched with the CBCT image according to a best-fit algorithm as in M3. The outline of the soft tissue on the labial side was visible as a yellow line, and the GT was measured at the CEJ and ARC positions in triplicate by three clinicians.

Statistical analysis

Statistical analysis was carried out using SPSS software version 23.0 (IBM Corp., Armonk, NY, USA). The significance level was set at $P < 0.05$. Quantitative data are presented as the means and standard deviations (SDs), and the normality of the data distribution was assessed by one-way variance analysis. The least significant difference (LSD) test was then used to compare within the groups. Qualitative data are presented as case numbers and were analyzed by the Kruskal-Wallis test. Spearman's correlation analysis and 95% confidence intervals were used to evaluate the correlations between the values determined by M1, M2, M3 and M4. The strength of the correlations was assessed based on the absolute value of r (0.00-0.39, mild; 0.40-0.69, moderate; and 0.70-1.00, strong).

Results

Classification of GB by M1

The GB classification by M1 is shown in **Table 1**. Moderate GB comprised 51.11% central incisors (CI), 48.33% lateral incisors (LI), and 53.33% canines (CA). A thick GB comprised 31.67% CI and 18.33% LI. A thin GB accounted for 16.67% CI and 33.33% LI, while the GB of

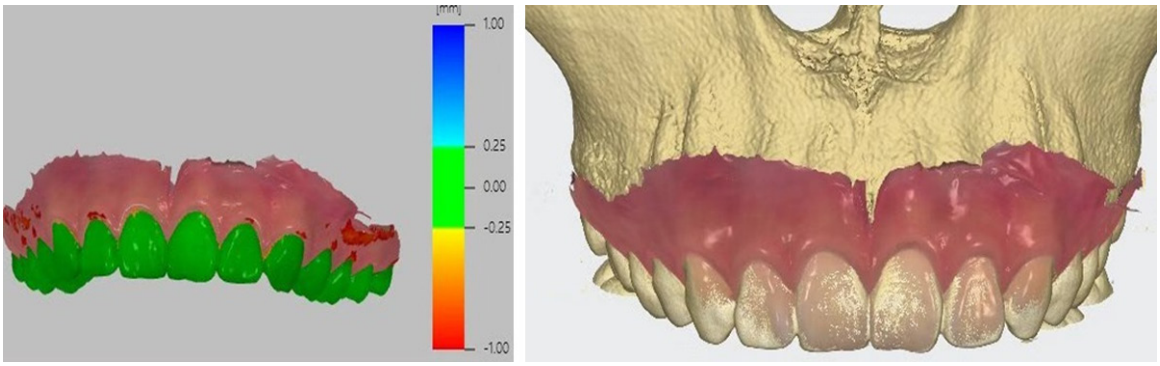

Figure 3. The IDS data were exported into stereolithography (STL) format and matched with the CBCT data.

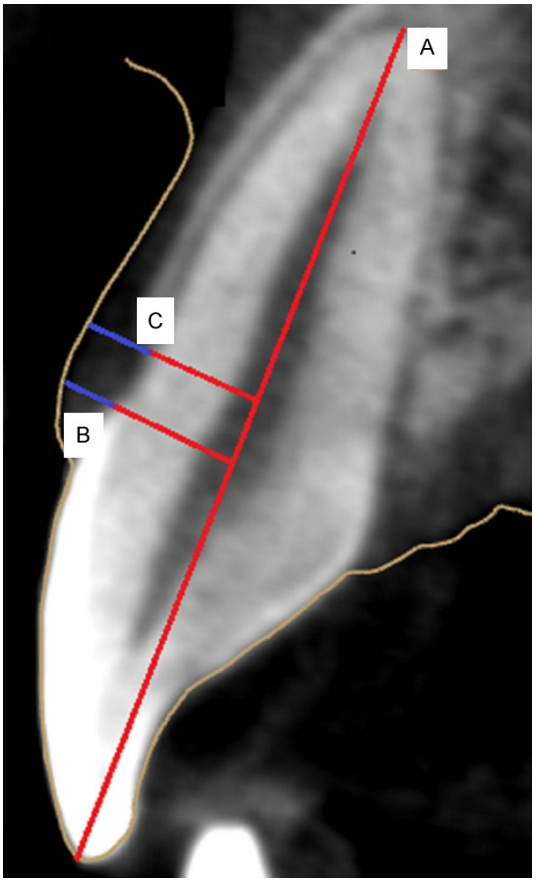

Figure 4. Reconstructed superimposed images from the STL and CBCT data showing a sagittal section of the upper left central incisor. The gingival outline is marked by a yellow line. GT (blue line) was measured at the CEJ position (B) and at the ARC position (C), which is perpendicular to the root axis (A).

CA was similar to that of all teeth. There was no significant difference in the GB between different teeth ($P > 0.05$). However, males had a significantly greater frequency of a thick GB than females ($P < 0.05$) (**Table 2**).

GT measured by M2-M4 at the CEJ position

The GTs at the CEJ position evaluated by M2, M3, and M4 are shown in **Table 3**. The values yielded by M2, M3, and M4 differed significantly in all teeth except for CI between M3 and M4, and the M3 values were significantly lower than those of M2 and M4 ($P < 0.05$).

GT measured by M2-M4 at the ARC position

The GTs at the ARC position evaluated by M2, M3, and M4 are shown in **Table 4**. The GTs measured by M2, M3, and M4 did not differ significantly, except that for LI; the GT measured by M3 was lower than those by M2 and M4.

Correlations among the four methods

As determined by M1, 44 (24.44%) teeth had a thick GB, while 92 (48.88%) had a moderate GB, and 44 (24.44%) had a thin GB in all volunteers. The GTs of each GB type measured using the three digital methods are shown in **Table 5**. At the CEJ position, the GB was defined by M1 as thick, moderate, and thin. There was a significant difference between M2, M3, and M4, where the GT of the thin GB group was smaller than that of the moderate GB group, while the GT of the thick GB group was larger than that of the moderate GB group. The GT data for all teeth measured by M3 were lower than those measured by M2, and the values measured by M4 were intermediate between those measured by M2 and M3. The values at the ARC position mirrored those at the CEJ position. The GT of the thick GB group was significantly larger than that of the moderate GB group, and the GT of the thin GB group was smaller than that of the moderate GB group. The GT measured by M3 was smaller than that measured by M2 and

Table 1. Frequencies of the thick, moderate, and thin GBs in CI, LI, and CA

Tooth type	Thick (%)	Moderate (%)	Thin (%)	χ^2	P
CI	19 (31.67)	31 (51.67)	10 (16.67)	5.832	5.832
LI	11 (18.33)	29 (48.33)	20 (33.33)		
CA	14 (23.33)	32 (53.33)	14 (23.33)		
Total	44 (24.44)	92 (51.11)	44 (24.44)		

Table 2. Frequencies of the thick, moderate, and thin GBs in males and females

Sex	Thick	Moderate	Thin	χ^2	P
Male	33	53	22	6.178	0.046
Female	11	39	22		

Table 3. GTs of CI, LI, and CA at the CEJ position (means ± SD)

Tooth	M1 (mm)	M2 (mm)	M3 (mm)	F	P
CI	1.23 ± 0.13	1.15 ± 0.13[a]	1.18 ± 0.13[a]	17.136	0.000
LI	0.98 ± 0.12	0.87 ± 0.11[a]	0.90 ± 0.13[a,b]	17.662	0.000
CA	1.02 ± 0.15	0.88 ± 0.14[a]	0.93 ± 0.14[a,b]	7.745	0.002

Letters (a and b) indicate significant differences within the same row ($P < 0.05$).

Table 4. GTs of CI, LI, and CA at the ARC position (means ± SD)

Tooth	M1 (mm)	M2 (mm)	M3 (mm)	F	P
CI	1.17 ± 0.16	1.12 ± 0.14	1.16 ± 0.15	1.495	0.242
LI	0.95 ± 0.14	0.89 ± 0.12[a]	0.95 ± 0.14[b]	10.552	0.000
CA	1.00 ± 0.15	0.96 ± 0.11	0.98 ± 0.11	2.738	0.073

Letters (a and b) indicate significant differences within the same row ($P < 0.05$).

M4, while there was no difference between the values yielded by M2 and M4. The values determined by the four methods were positively correlated. The correlations among M2, M3, and M4 were stronger ($r > 0.70$) than those between TP and M2, M3, and M4 ($r < 0.40$) (**Tables 6** and **7**).

Discussion

A precise diagnostic classification of GB is essential for establishing a treatment plan in implant surgery, periodontal therapy, orthodontic treatment, and restorative procedures, especially in the anterior zone, and the accurate evaluation of GT is important for classifying GB [1, 4, 19].

In a previous study, the GT of a thin GB was defined as < 1.5 mm, and that of a thick GB was defined as > 2.0 mm [20]. In another study in which GT was directly measured using a periodontal probe, the threshold between thick and thin GB was 1.5 mm [21]. However, > 1.0 mm was considered the threshold between thick and thin GB [9]. There was no consensus on the GT threshold to define GB, and use of 1.5 mm as the threshold for a thick GB may reduce the risk of an unsuccessful esthetic outcome of implant placement [3]. In this study, the mean GTs of a thick GB in the anterior maxilla measured by M2, M3, and M4 at the CEJ position were 1.17, 1.05, and 1.09 mm, respectively, while those at the ARC position were 1.14, 1.09, and 1.15 mm, respectively. The GTs of thick GB varied from 1.0 to 1.2 mm, and males had significantly greater GTs than females. Furthermore, the GTs of CI were greater than those of LI and CA, while the LI had the smallest GTs at the CEJ and ARC positions, irrespective of which of the three methods was used. These values were comparable to those reported previously [22, 23] and may be useful in clinical practice, as the soft tissue biotype is important for the esthetics of implant restoration, the success of implantation, and the prevention of mucosal recession [19, 24].

An intact > 1.0-mm-thick facial bone wall and a thick GB are indications for immediate implant therapy [25]. Only 4.6% of patients had a labial bone wall thickness of > 1.0 mm in the CI of the anterior maxilla [26]. There was a correlation between the phenotype of the labial bone wall and the GB [27]; a thin labial bone in the anterior maxilla is linked to a thin soft tissue biotype [28]. The mean GTs of CI, LI, and CA at the CEJ and ARC positions measured by M2, M3, and M4 were all < 1.5 mm, the threshold for a thick GB. Thus, most patients have a thin GB and are at high risk of an unsuccessful esthetic outcome in clinical practice. Immediate implantation in the esthetic zone of the anterior maxilla is recommended due to the high risk of

Table 5. GTs at the CEJ and ARC positions (means ± SD)

Position	GB	M2 (mm)	M3 (mm)	M4 (mm)	F	P
CEJ	Thick (44)	1.17 ± 0.21	1.05 ± 0.19[a]	1.09 ± 0.23[b]	7.799	0.005
	Moderate (92)	1.07 ± 0.19	0.98 ± 0.18[a]	1.01 ± 0.18[a,b]	22.654	0.000[A]
	Thin (44)	0.98 ± 0.13	0.88 ± 0.17[a]	0.92 ± 0.15[a]	20.807	0.000[A,B]
ARC	Thick (44)	1.14 ± 0.24	1.09 ± 0.15[a]	1.15 ± 0.19[b]	3.467	0.047
	Moderate (92)	1.01 ± 0.17	0.97 ± 0.16[a]	1.01 ± 0.15[b]	3.334	0.040[A]
	Thin (44)	1.00 ± 0.16	0.93 ± 0.16[a]	0.96 ± 0.17[b]	5.906	0.011[A,B]

Lowercase letters (a and b) indicate significant differences within the same row ($P < 0.05$). Capital letters (A and B) indicate significant differences between rows ($P < 0.05$).

Table 6. Correlations among M2, M3, M4, and TP at the CEJ position

Method		M2	M3	M4
M2	r	0.784***		
	P	0.000		
M3	r	0.794***	0.898***	
	P	0.000	0.000	
TP	r	0.345***	0.366***	0.388***
	P	0.001	0.000	0.000

***P < 0.001.

Table 7. Correlations among M2, M3, M4, and TP at the ARC position

Method		M2	M3	M4
M2	r	0.734***		
	P	0.000		
M3	r	0.751***	0.825***	
	P	0.000	0.000	
TP	r	0.210*	0.275**	0.264*
	P	0.047	0.009	0.012

*P < 0.05, **P < 0.01, ***P < 0.001.

an adverse esthetic outcome with a GT < 1.5 mm.

The GT measured by TP differed significantly according to the GB in this study ($P < 0.05$). At the CEJ and ARC positions, the GTs of the thick, moderate, and thin GB groups differed significantly, and the GTs determined by TP were correlated with those yielded by M2, M3, and M4. This result was consistent with that of a previous report [29]. Therefore, TP is a reliable, simple, and convenient method of assessing the GB. Indeed, TP was considered as the gold standard method for evaluating the GB [27].

The null hypothesis was rejected, as there were significant differences among these three methods. The GTs determined by M3 and M4, particularly M3, were lower than those determined by M2. At the CEJ and ARC positions, the GTs determined by M3 were significantly smaller than those determined by M2. No consensus has been reached regarding the accuracy of DS; therefore, further studies of the accuracy of this method and its suitability for clinical application are needed [17]. The GTs measured by M3 and M4 differed significantly in the LI and CA groups at the CEJ position and LI groups at the ARC position. Digital impressions reportedly have greater errors than conventional implant impressions, which may be due to the lack of fixed anatomical landmarks, errors of the superimposition of the STL and CBCT data, various intraoral situations, the use of different brand scanners, and the level of skill of the clinician [30-32]. Lin et al. [31] examined the accuracy of models fabricated from conventional and iTero digital impressions; the digital pathway was significantly less accurate (mean error, 158-328 μm). Intraoral digital impressions may be restricted under clinical conditions and result in less accuracy for complete-arch casts than those obtained from an extraoral scanner, while extraoral optical scanning was reportedly rapid and yields high-resolution data with an accuracy of 5-10 μm, compared to 50 μm for intraoral scanning [33].

However, most prior studies focused on accuracy for hard tissue or implants, and few studies have addressed soft tissue. Obtaining intraoral digital impressions of soft tissue was hampered by the flexibility of the oral mucosa and the smooth saliva-covered surface [34, 35]. In addition, single-unit scans have excellent accuracy, while the accuracy of intraoral scanners in multiple units or the full arch is controversial [36]. The precision was clinically acceptable when scanning less than half of the arch, while

the precision of extraoral scanning was acceptable in any arch region [37]. However, compared with direct intraoral scanning, extraoral scanning can lead to shrinkage of the dental stone and deviations in the impressions [38]. Therefore, the large scanning region, errors in the superimposition of the STL and CBCT data, the characteristics of soft tissue, and deviations in the impressions may explain the differences among the GTs determined by M2, M3, and M4.

Three quantitative and one qualitative method for assessing GT are discussed in this study and further improvements in the accuracy of DS, higher resolution CBCT and further software applications may facilitate to get more precise results and develop better treatment strategies especially in the esthetic zone. Further, it is very important to obtain repeatable reference points in the oral cavity for superimposition of the DS image and CBCT data.

Conclusions

Within the limitations of this study, it can be concluded that GB differs significantly between males and females. GB assessed by TP was correlated with that assessed by CBCT and the intraoral and extraoral DS of a gypsum cast. TP was a relatively reliable, objective, and reproducible method for evaluating GB. The GT measured by intraoral DS was significantly lower than that measured by CBCT alone. Neither intraoral nor extraoral scanning of a gypsum cast were reliable methods for evaluating GT.

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Disclosure of conflict of interest

None.

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