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Original Article

Evaluation of the accuracy of cone-beam computed tomography for measuring intraoral soft tissue thickness

Xue-Yu Wang[1,2], Yan-Wei Shi[3], Song Zhou[4], Yu-Hui Chen[2], Shu Yan[1,2]

[1]PLA 306 Clinical Hospital of Anhui Medical University, Beijing, China; [2]Department of Stomatology, PLA Strategic Support Force Medical Center, Beijing, China; [3]Dongba Community Health Service Center of Chaoyang District, Beijing, China; [4]Army 73Rd Group Military Hospital, Xiamen, China

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Abstract: Objectives: We evaluated the accuracy of directly measuring mucogingival tissue thickness using cone-beam computed tomography (CBCT). Methods: Twenty patients (10 men and 10 women, age 19-45 years) were enrolled. CBCT was first performed for each patient with a periodontal pack around the mucosal boundaries (control group), and the findings were compared with those of direct CBCT scan (experimental group). Using position registration, two scanned images were aligned along 3D coordinates. The soft tissue thickness at 56 sites was measured using both experimental and control scans for each patient. Differences and correlations between the groups and intra- and interobserver reliability were determined. Results: No significant differences in maxillary palatal soft tissue thickness measurements were observed ($P>0.05$). The values of the experimental group were higher than those of the control group with regard to the mandible and buccal side of the maxilla ($P<0.05$). All intraobserver and interobserver correlations exceeded 0.95, indicating high reliability. Conclusions: The application of position registration provides a new method for CBCT image measurements that enables comparison of initial and subsequent values. Direct thickness measurements of the palatal mucosa using CBCT images can be accurate; however, the values for soft tissue measurements in other locations might be slightly exaggerated.

Keywords: Cone-beam computed tomography, mucogingival tissue, palate

Introduction

The quality of the gingiva and mucosa around the teeth and dental implants affects the success of implantation as well as the esthetics [1]. Regarding the stability and esthetics of soft and hard tissues, keratinization of the peri-implant mucosa with appropriate width may improve prognosis [2]. Therefore, soft tissue grafting should be considered when dental implants are placed [3]. The accuracy of soft tissue thickness measurements is crucial during optimal planning for implant placements, in terms of both preventive and therapeutic management.

There are various methods for assessing the thickness of oral soft tissues, including transgingival probing [4], ultrasonic devices [5-7], computed tomography (CT), and cone-beam CT (CBCT) [1]. However, the accuracy of these methods is unclear. As an invasive method of measurement, transgingival probing might result in high measurement errors because it is performed under local anesthesia; the level of error is estimated to be up to 0.5 mm [8]. Nguyen et al. reported that ultrasonography has great potential for measuring soft tissue thickness, but access to the posterior maxillary area is limited. Furthermore, attempts to distinguish the characteristics of soft and hard dental tissues require the use of different wavelengths [9].

The application of CBCT in dental imaging to accurately reproduce linear dental and hard tissue measurements has attracted extensive attention in recent years [10]. One of the disadvantages of CBCT is that it is not suitable for the evaluation of soft tissues because of its low resolution and contrast as well as difficulties in distinguishing the margins on CBCT owing to the small density difference between the oral mucosa and the air [10]. Some studies have evaluated the accuracy of CBCT in measuring soft tissue thickness. Gürlek et al., Ogawa et al., and Borges et al. used a novel CBCT method along with radiopaque materials [11-13]. Comparison of the results of CBCT with the results of gingival probing showed that CBCT is an effective diagnostic method for visualizing and measuring the thickness of soft tissues. However, it has also been suggested that dental CBCT does not provide ideal images of soft tissues and that alternative examinations should be performed, such as medical grade CT or magnetic resonance imaging (MRI) [14-16].

The aim of this study was to evaluate the role of CBCT in measuring oral soft tissue thickness. Using a new position-registration technique and opaque agent, we assessed the accuracy, reliability, and effectiveness of CBCT in measuring soft tissue thickness in order to improve treatment plans and predict outcomes.

Materials and methods

Study population

Twenty patients (10 men and 10 women), aged 19-45 years (mean age: 32 years), who required CBCT for impacted third molar extraction were included in this study. The inclusion criteria were as follows: healthy periodontal and mucosal tissue, with no obvious loss of attachment, and probing depths of <4 mm; no use of prosthetic or orthodontic appliances, such as removable partial dentures, fixed partial dentures, or orthodontic plate retainers; no history of smoking or alcohol abuse; no medication that may affect the health of the periodontal tissue and mucosa, such as a calcium channel blockers; and no ectopically positioned or morphologically altered teeth. The exclusion criteria were a history of periodontal pathology or a history of surgery involving soft tissue removal in the region analyzed or the presence of bone or mucosal pathological lesions on CBCT.

This study was approved by the ethical committee of 306th Hospital of the People's Liberation Army in Beijing, China and was conducted in compliance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants, after providing them with information on the project and protocol, including the anticipated degree of discomfort that may occur and the need for two exposures to CBCT. The registration number of registered trial is ChiCTR1900024845.

Preparation of the CBCT images

During CBCT scanning, the patients remained standing, with their chins and heads stabilized, and their tongues remained low in the oral cavity. A periodontal plug (Pulpdent Corp, Brookline, MA) was applied to the surface of the gum during CBCT for control images to serve as a gingival photographic developer. CBCT (Smart-3D, LargeV Instruments Corp, Beijing, China) was used to scan the patients' upper and lower jaws with the following settings: volume, 15 cm × 9 cm; settings, 6 mA, 100 kV; scanning time, 12.5 s; axial slice thickness, 0.25 mm; voxel size, 0.25 mm.

After extraction of the third molar, a second CBCT was performed under the same settings for all patients but this time without the use of a gingival photographic developer. These images were designated as the experimental group. Patients wore a plastic mouth gag to help push away the soft tissues of the lips and cheeks from the gingival tissue [17, 18]. **Figure 1** shows a representative patient wearing the plastic mouth gag and the position for CBCT scanning. The two groups of images were saved in DICOM format and were analyzed using Smart V software (Smart V2 2.0.9.3897, Large V Instruments Corp).

Comparison of measurements through DICOM image registration

To eliminate any differences in positioning of the two CBCT scans for each subject, the control and experimental images were registered along two-dimensional coordinates using a new position-registration technique by means of a Smart V software. The image registration was based on grayscale information, and the measurement index was based on mutual image information. The registration mode adopted local registration using the following settings: metric, Maximum Mutual Information; iterations, 1000; sampling frequency, 0.02; interpolation method, linear interpolation; optimiza-

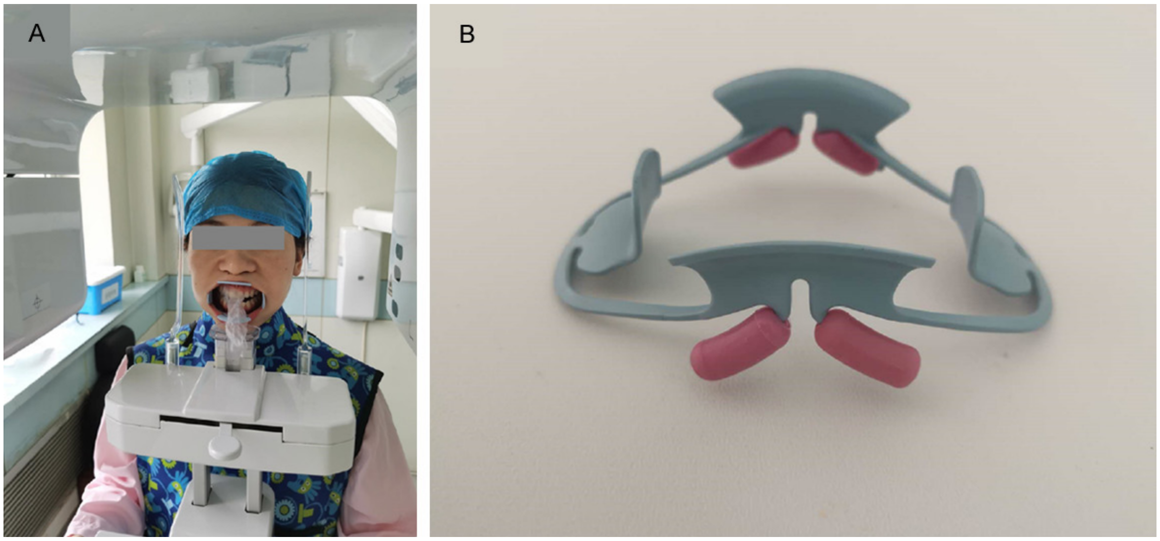

Figure 1. A. Patients wore a plastic mouth gag to help push away the soft tissues of the lips and cheeks from the gingival tissue. Informed consent to use of this image was obtained from the patient. B. The plastic lip retractor.

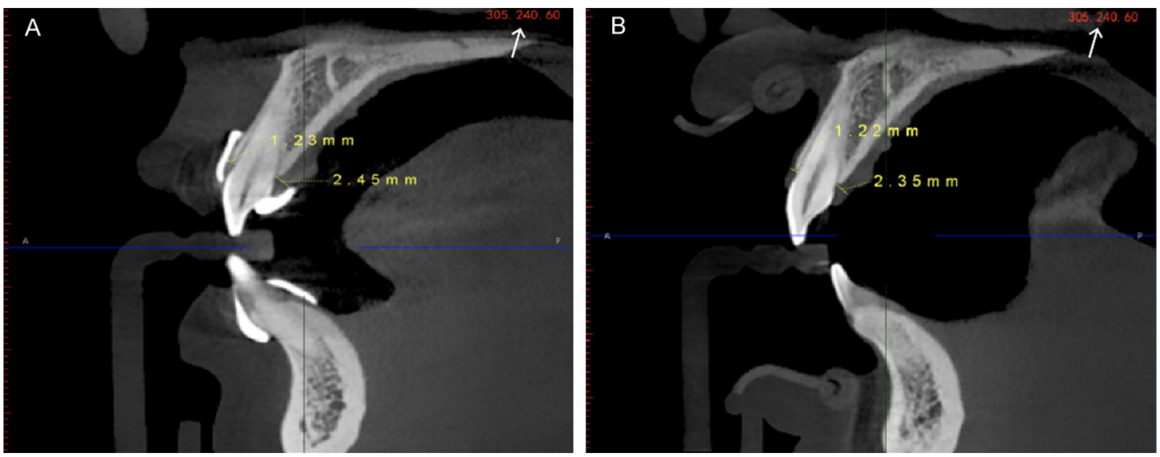

Figure 2. Comparison of two methods for measuring the thickness of masticatory mucosa. A cone-beam computed tomography (CBCT) image shows the gingival sagittal plane of the upper right central incisor. A. Mucogingival tissue thickness of central incisor in the control group. Three-dimensional coordinates are recorded as 305.240.60 (Arrow). B. Mucogingival tissue thickness of central incisor in the experimental group. The corresponding three-dimensional coordinates were the same as before (Arrow).

tion method, gradient descent; tolerance: 0.001.

The thickness of the mucosa was measured at the middle crest of the alveolar ridge of the teeth in sagittal sections. For each tooth, we used two measurement sites, including the labial, buccal and palatal, and lingual mucosa. The corresponding tooth position for measurement was selected, and the clear axial cross sections of multiple sites in the selected interval were obtained. The length between the alveolar crest and the gingival surface determined the thickness of the gingiva. Axial sections that corresponded to the labial median site of the corresponding tooth's position ware selected. We then drew a vertical line from the alveolar crest point to the gingival edge contour line on the image and measured this distance. After the gingival thickness of a tooth's position was measured in the control image, the coordinate values of the three planes involved (sagittal plane, coronal plane, and vertical plane) were recorded, and the corresponding planes

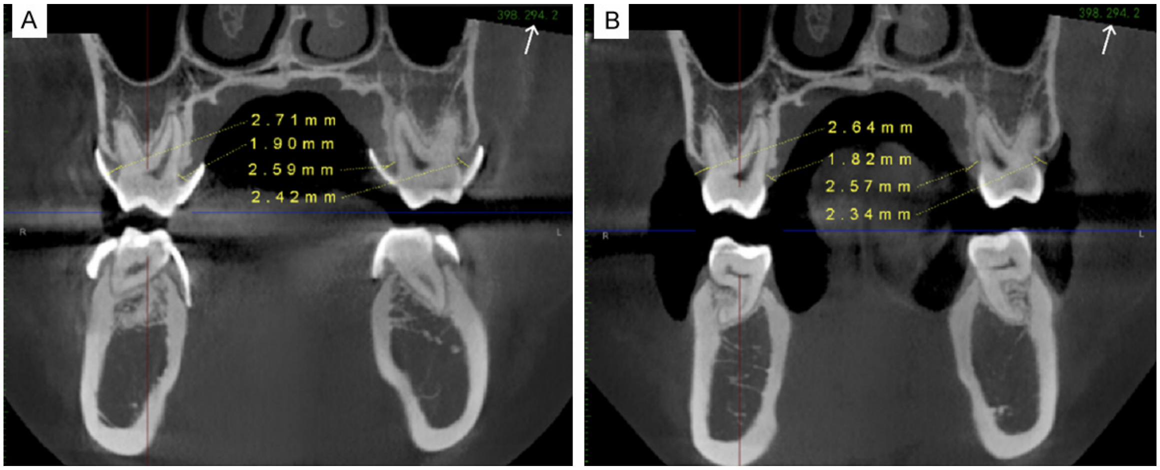

Figure 3. A cone-beam computed tomography (CBCT) image shows the gingival sagittal plane of maxillary first molar. A. Mucogingival tissue thickness of the maxillary first molar in the control group. Three-dimensional coordinates are recorded as 398.294.2 (Arrow). B. Mucogingival tissue thickness of the maxillary first molar in the experimental group. The corresponding three-dimensional coordinates were the same as before (Arrow).

Table 1. Mean and standard deviation (SD) of mucosal thickness measurements obtained by the two observers at the various regions in the control and experimental images

		Labial/Buccal		Palatal/Lingual	
		Mean (mm)	SD	Mean (mm)	SD
Control group	Maxilla	1.50	0.49	2.33	0.79
	Mandible	1.25	0.49	1.59	0.53
Experimental group	Maxilla	1.53	0.50	2.35	0.78
	Mandible	1.29	0.53	1.64	0.59

of the tooth's position were found in the experimental image, based on the three-dimensional coordinates recorded before measurement. The measurements were then performed as described above (**Figures 2** and **3**).

For each participant, 56 sites were measured in each of the control and experimental images. Two medical radiologists (Wu J and Yan YY), who were board-certified with >3 years of experience, performed all the measurements. Measurements were repeated after 2 weeks to assess intraobserver reliability.

Statistical analyses

Data were analyzed using the statistical software package SPSS version 16.0 (IBM SPSS, Chicago, IL, USA). Intraobserver agreement between the two measurements and interobserver agreement between the radiologists were analyzed using the interclass correlation coefficient. The Wilcoxon rank-sum test was used to compare the statistical difference in the thickness measurements between the two groups. A P-value of <0.05 was considered statistically significant.

Results

For the 20 patients enrolled in this study, 1076 paired positional measurements were made. **Table 1** shows the mean and standard deviation of gingival thickness measurements obtained by the two observers for the maxilla and mandible in the control and experimental images. The differences in the measurement of soft tissue thickness between the experimental and control images are summarized in **Table 2**. No significant difference was observed in the results of measurement of palatal mucosal thickness of the maxilla between the control and experimental images (P>0.05). However, measurements in the experimental images were significantly larger than those in the control images for the mandible and for the buccal side of the maxilla (P<0.01). The maximum difference was 1.94 mm.

Intraobserver and interobserver correlations exceeded 0.95 for all measurements, showing high reliability (**Tables 3** and **4**).

Discussion

This study used a new position-registration technique and opaque agent (periodontal plug)

Table 2. Summary of the difference in mucosal thickness between the control and experimental images

Measurement	Labial/Buccal				Palatal/Lingual			
	Mean (mm)	SD (mm)	Z	*P*-value	Mean (mm)	SD (mm)	Z	*P*-value
Maxilla	0.027	0.206	-2.159	0.031	0.021	0.297	-0.149	0.882
Mandible	0.035	0.245	-2.491	0.013	0.041	0.267	-2.683	0.007

Table 3. Assessment of reliability of measurements based on intra-observer agreement, using the interclass correlation coefficient

Interclass correlation coefficient	Observer 1	Observer 2
Control group	0.983	0.987
Experimental group	0.980	0.984

Table 4. Assessment of reliability of measurements based on inter-observer agreement, using the interclass correlation coefficient

Interclass correlation coefficient	First time	Second time
Control group	0.974	0.980
Experimental group	0.959	0.968

to evaluate the accuracy of CBCT in measuring soft tissue thickness. The new position-registration method helped match experimental images as close as possible to three-dimensional coordinates of control images. Moreover, during the first CBCT, mucogingival tissues were covered with a thin layer of opaque agent, and the labial or buccal mucogingival tissue surfaces were accurately developed. This quantitative, rather than qualitative method, addressed the greatest limitation of CBCT (that it cannot distinguish between soft tissues).

In CBCT images, inflamed gingivae appear similar to healthy gingivae. Previous studies have noted the importance of soft tissue thickness in many disciplines, particularly in periodontology, implantology, prosthodontics, oral surgery, and orthodontics. The gingival biotype is one of the key factors that determine the outcomes of implant restorations, with a thick gingival biotype being more favorable and resulting in lower-risk peri-implant esthetics than thin biotypes [19]. During periodontal plastic surgery, the palatal masticatory tissue is the main donor site for soft tissue transplantation. Therefore, appropriate soft tissue measurement before surgery is important for assessing the prognosis and for treatment planning.

To measure intraoral mucosal thickness, several methods have been used. Visual evaluation is often used in some measurements, although with low accuracy, as it is easy to perform and is less invasive. However, this method is based on subjective judgment and the findings are not reproducible; thus, it is not suitable for patients with high esthetic risks and patients undergoing periodontal plastic surgery [20]. Bone probing or transgingival probing has also been widely used to measure mucosal thickness and has been used as a control measurement in many reports. However, it is an invasive method that requires local anesthesia and may result in overestimation of the thickness of soft tissues and inconvenience patients preoperatively. Furthermore, the location of some structures, such as the bone crest and cemento-enamel junction, may prevent accurate measurement.

Ultrasonography is a non-invasive, non-destructive, non-ionizing radiation imaging technology. Medical ultrasonography has mainly been used for soft tissue imaging. Eger and Müller reported the effectiveness of ultrasonic measurement of masticatory mucosal thickness, but the reliability of the measurement needs to be improved using highly reproducible measurements or an average of multiple measurements [5-7].

With technological advances, high-resolution dental MRI has been used to achieve good visualization of soft tissues [21]. Alexander et al. used dental MRI to measure the thickness of the palatal masticatory mucosa and were able to prove that dental MRI has high geometric accuracy. However, dental MRI requires the use of contrast media and is more expensive than CBCT. It is also affected by artifacts caused by metal dental materials [22].

CBCT is an imaging technique that is commonly used in dental implant planning and other preoperative examinations. In recent years, numerous attempts have been made to determine the accuracy of CBCT measurements of soft and hard tissues. CBCT is accurate in taking linear measurement of hard tissues, such as the mandible [10], and in assessing periodontal defects [23]. Ganguly et al. evaluated the accuracy of CBCT in measuring the thickness of hard tissues in the presence of soft tissues and compared the results with physical measurements obtained using digital calipers. They showed that CBCT can be used for linear measurements of the anatomical structure of the mandible in the presence of soft tissues [24]. Qualitative evaluation of soft tissues has been limited because of the low-density resolution and contrast on CBCT; however, CBCT has been proven to be beneficial for quantitative linear measurements.

Most previous studies compared the measurement accuracy of CBCT with that of other methods, but there have been few studies on the accuracy of soft tissue measurement using CBCT. Januario et al. exposed the buccal gingiva using soft tissue using retraction; this overcame the interference that occurs when the lips, tongue, and cheeks collapse on the facial gingiva during CBCT scanning, and the soft and hard tissues were clearly shown [17]. Fourie et al. described the accuracy of CBCT measurements of facial soft tissue by measuring benchmarks on cadaveric heads. They considered that it is clinically meaningful if the mean absolute error exceeded 1.5 mm, and this is not suitable for oral mucosal measurement [25, 26]. Patcas et al. compared the accuracy of CBCT and multidetector CT in the measurement of hard tissues and verified the effectiveness of CBCT in measuring oral soft tissues. They showed that CBCT was less affected by metal artifacts and that the accuracy of intraoral soft tissue measurements using CBCT was similar to that of hard tissue measurements [27]. The combination of CBCT and digital 3D reconstruction technology can also obtain high measurement accuracy [28].

In our study, the developer adhered closely to the surface of the gingival and mucosal tissue to produce high-resolution images of the measured site. Gürlek et al. used a developer dot map on the gingiva, without any pressure or chemical polymerization, and proposed that the material can be applied to a larger area [11]. Owing to the scanning characteristics of CBCT, images of the same area can be obtained at different time points, with the same aspect ratio, which makes it possible to repeat the measurement. We found that the measurements on the maxillary buccal side, mandibular buccal side, and lingual side were larger in the experimental images than in the control images (maximum difference: 1.94 mm), indicating that linear measurement of soft tissues in certain areas using CBCT may not be accurate.

Interestingly, there was no significant difference in the measurements of the palatal side of the maxilla in our study, probably owing to the following reasons. First, some experiments showed that the use of a retractor or cotton roll may exert pressure on soft tissues, thereby changing their size [29]. Second, the pulling distance of the palate was large, and the error was small during measurements, while the pulling distance of the rest of the soft tissue was small; this may have led to a larger error due to changes in the pulling force each time. Finally, Barriviera et al. reported the possibility of using soft tissue CBCT to measure the size of the palatal mucosa without using a developer [18]. However, owing to the main shortcoming of radiation caused by CBCT, this technique is mainly used in dental operations that require high measurement accuracy.

Though the newly introduced method appears to be an alternative to transgingival probing, its main disadvantage is radiation caused by CBCT. The results of this study need to be optimized by collecting more samples and obtaining more measurements.

In conclusion, the use of position registration provides a new approach for comparing CBCT measurements. CBCT can display the intraoral soft tissue and measure the thickness of the palatal mucosa accurately, though measurements of soft tissues in other locations could be slightly higher than the actual dimensions. Owing to the noninvasiveness and reliability of the method provided, direct CBCT measurement can be widely used for soft tissue evaluation during dental procedures.

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Disclosure of conflict of interest

None.

Address correspondence to: Shu Yan, Department of Stomatology, PLA Strategic Support Force Medical Center, 9 Anxiang North Road, Chaoyang District, Beijing 100101, China. Tel: +86-1381133-9808; Fax: +86-1064876056; E-mail: 49239302@qq.com

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