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ACCURACY AND RELIABILITY OF CONE BEAM COMPUTED TOMOGRAPHY FOR MEASURING BUCCAL AND LINGUAL PERIODONTAL ALVEOLAR BONE LEVELS

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ABSTRACT

Introduction: The aim of this study was to evaluate the accuracy and reliability of cone beam computed tomography (CBCT) volumetrically rendered (VR) and multiplanar reconstructed (MPR) images from for measuring buccal and lingual periodontal alveolar bone levels.

Methods: Three dry human skulls with 215 sites were scanned with CBCT unit. Measurements were made on each tooth using VR and MPR images, from the cusp tip or incisal edge to the cementoenamel junction (CEJ) and from the CEJ to the alveolar bone margin along the long axis of the tooth. The accuracy of the CBCT measurements were determined by comparing the means, standard deviations (SDs), mean differences, and SD differences of the VR and MPR measurements with those of direct measurements made on the dry skulls as the gold standard (GS).

Results: The means ± SDs of the GS, MPR, and VR measurements were 4.64 ± 1.94 mm, 4.21 ± 1.86 mm, and 4.1 ± 1.86 mm, respectively. There were significance differences between the GS measurements and both MPR and VR measurements ($P < 0.05$). Results of a GS-MPR paired-samples test showed a mean difference of 0.43 mm and a SD difference of 0.77 mm, whereas those of a GS-VR paired-samples test showed a mean difference of 0.540 mm and a SD difference of 0.98 mm.

Conclusions: Although there were significance differences between the GS measurements and both MPR and VR measurements, MPR is more accurate and reliable than VR for measuring the levels of buccal and lingual periodontal alveolar bone. However, the difference detected is not clinically significant. Thus, CBCT can accurately and reliably assess the buccal and lingual periodontal alveolar bone levels.

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INTRODUCTION

Loss of alveolar bone support is one of the characteristic signs of destructive periodontal disease and is generally considered to represent an anatomical sequela to the apical spread of periodontitis. [1] Diagnosis of periodontal disease depends on the probing of gingival tissues and on traditional two dimensional (2D) radiographic assessments to evaluate osseous support. However, this radiographic method is severely limited by the inherent overlay of anatomic structures and the difficulty in reproducing x-ray beam projection angles over time. Ample research demonstrates that lingually located defects cannot be detected and that destruction of the buccal plate can be undiagnosed or undistinguished from lingual defects.[1] Further studies comparing radiographs to pre-surgical measurements concluded that bone loss can be underestimated by 1.5 mm, with large variations between examiners.[2,3]

Previous studies have shown that computed tomography (CT) assessment of alveolar bone height and bony pockets is reasonable, accurate, and precise. However, the clinical use of CT in dentistry has been limited because of machine costs, the complexity of the procedure, high radiation doses, and relatively low resolution.[3]

In recent years, a new technology for acquiring 3D images of oral structures has become available, cone beam computed tomography (CBCT) (also called cone beam volumetric tomography), which was introduced in European and USA markets in 1998 and 2001, respectively. CBCT is cheaper and less bulky, with a lower radiation dose to the patient compared with CT.[4,5] During a CBCT scan, the scanner (X-ray source and a rigidly coupled sensor) rotates, usually 360 degrees, around the head to obtain multiple images. The scanning software collects the raw image data, and the resultant image set or raw data are subjected to a reconstruction process, producing a digital volume (voxels) of anatomical data that can be visualized with specialized software. A voxel is the smallest subunit of a digital volume. CBCT voxels generally are isotropic (that is, X, Y, and Z dimensions are equal) and range from approximately 0.07 to 0.40 mm per side. Each voxel is assigned a gray-scale value (instead of the Hounsfield scale used for medical CT) that approximates the attenuation value of the represented tissue or space. [6,7] CBCT has become an important diagnostic aid in dentistry, especially in oral surgery, implantology, periodontology, and orthodontics. [8,9]

Many studies have evaluated the accuracy and reliability of CBCT as a diagnostic tool in different periodontal diagnosis tasks. [10,11,12] However, we were able to find only few studies in recent years that evaluated the accuracy and reliability of CBCT for measuring the marginal levels of periodontal alveolar bone. Misch et al. [2] for example, compared CBCT measurements of periodontal defects to traditional methods by creating artificial osseous defects on mandibles of dry skulls. CBCT scanning, periapical radiography, and direct measurements with a periodontal probe were compared with electronic caliper measurements as the standard reference. Linear measurements for all defects revealed no statistical differences between bone sounding, radiography, and CBCT. There was a significant difference between isolated interproximal measurements using a probe versus using the caliper ($P < 0.001$), but no significant difference for CBCT or radiography. All bony defects were identifiable and measurable directly or with CBCT. In comparison, buccal and lingual defects could not be measured with periapical radiographs, leading the researchers to conclude that CBCT offers a significant advantage because all defects can be detected and quantified. [2]

Vandenberghe et al. [13] reported 100% detectability for both crater and furcation involvements by using CBCT. In addition, they measured values closer to

the gold standard with cross-sections of a certain thickness.[13] The same authors reported in a different study that they found no significant difference between CBCT and intraoral radiography when measuring mesial, central, and distal bone levels on the oral and vestibular sides of each selected tooth, but bone craters and furcation involvements were better depicted on CBCT than on intraoral radiography.[14]

Using human dry skulls, Leung et al.[15] compared direct measurements of the levels of buccal periodontal alveolar bone as a gold standard with measurements on 2D slices obtained from 3D volumes. The authors found that CBCT alveolar bone height can be measured to an accuracy of about 0.6 mm.[15]

Timock et al.[16] found that CBCT buccal alveolar bone height and thickness CBCT measurements did not differ significantly from direct measurements made on human cadaver heads, and there was no pattern of underestimation or overestimation.[16]

Grimard et al.[17] found CBCT measurements correlated strongly with surgical measurements of bone level changes following regenerative periodontal therapy, whereas intraoral radiographs correlated less favorably. Intraoral radiographic measurements were significantly less accurate compared with CBCT measurements.[17] In another study, Mol and Balasundaram[18] reported that the accuracy of new CBCT scanners was higher than that of intraoral radiographs in quantifying bone height.

Wood et al.[19] found out that buccal alveolar bone height measurement accuracy from the maxillary molar region in pigs was improved by using 0.2-mm voxel-size CBCT scans when the overlying facial and gingival tissues are kept intact.[19]

Sun et al.[20] found that alveolar bone-height measurements made from 0.4 mm voxel size CBCT images of pigs' maxillary specimens might overestimate alveolar bone-height loss associated with rapid palatal expansion.[20]

The authors of these studies recommended more researches to verify the accuracy of CBCT as a diagnostic tool to assess marginal periodontal alveolar bone levels. Additionally, most of the studies used only one method of image reconstruction and did not compare the accuracy of different 3D reconstruction modalities, such as multiplanar reconstruction (MPR) and volume rendering (VR).

The aim of the current study was to evaluate the accuracy and reliability of CBCT for measuring buccal and lingual marginal periodontal alveolar bone levels by using the MPR and VR modalities of CBCT data. The null hypothesis was that there is no difference in the measurement of these levels with CBCT compared with naked-eye measurements on dry human skulls as a gold standard (GS). The alternative hypothesis was that there is a difference in the measurement of alveolar bone height with CBCT on dry human skulls.

MATERIALS AND METHODS

The initial sample consisted of 3 dry human skulls obtained from the Oral and Maxillofacial Radiology Division, College of Dentistry, King Saud University. No demographic data were available, and they were not identified by age, sex, or ethnicity. Inclusion criteria were as follows: (1) skulls have permanent dentition only; (2) maxilla and mandible occlude in a reproducible position ; (3) no obvious jawbone pathology (cysts or tumors); (4) no gross mechanical damage to the jawbones (chips, cracks, or breaks in the alveolar process); (5) the cementoenamel junction (CEJ) outline should be clear without chipping and should not be obscured by calculus; and (6) cusp tips or incisal edges should be free of attrition or mechanical damage. These skulls were scanned by a CBCT device (Iluma, IMTEK, 3M, USA) that had a flat panel detector composed of 127-mm amorphous

silicon. The scanning parameters were 110 kVp, 2 mA, 9.6 seconds per revolution, and a 19 x 24 cm field of view. These settings produced a voxel size of 0.38 mm. The skulls were placed within a 20 x 20 x 20 cm glass box filled with water in a reproducible position to compensate for soft tissues. The anterior maxillary and mandibular teeth were disoccluded with a cotton roll (Fig 1).

Multiple sites were measured on each tooth buccally and lingually from the cusp tip or incisal edge to the CEJ and from the CEJ to the alveolar bone level, an incisor having 4 sites and a molar 8 sites (Fig 2). After excluded sites were eliminated, the sample size was 215 sites (Table

I). GS measurements were made directly on the skulls with a digital caliper calibrated to the nearest 0.01 mm (CD 6-inch CX, Mitutoyo America, Plymouth, MI, USA) (Fig 3).

The GS measurements were compared with the measurements made on volume rendered images processed with reformatting software (IlumaVision 3-D, IMTEK, 3M, version 1.0.2.5) using MPR and VR modalities. The software was used to produce buccolingual sections of the teeth and jawbones at the specified measurement sites (Fig 4). The window and level of the VR image histogram was adjusted in each CBCT image to best display the teeth and periodontal bone and to allow minimal interference of the adjacent structures for the 2 examiners. The best view was then saved in the software to be measured later.

To eliminate examiner bias, an X-ray technician scanned and coded each skull, and the GS measurements were taken by one reliable examiner. Reliability of the measurements was examined in 20% of the sites selected randomly with random number generator software. Two examiners were calibrated and trained to measure the same sites on the VR and MPR modalities; the same sites were then measured again after 1 week to evaluate intra- and interexaminer reliability. The codes of the skulls were obscured from the examiners, and different examiners registered the measurements with the codes of the related sites. All sites were later measured by the same process. After intra- and interexaminer reliability tests were performed on the random sample, all measurements were taken by the reliable examiner or divided randomly between two examiners if interexaminer reliability was achieved.

Statistical analyses were performed by using SPSS 16.0 and a paired-samples *t* test to compare the GS measurements with the measurements of MPR and VR.

Fig (1) Scanning of the skull with a cone beam tomography device (Iluma, IMTEK, 3M, USA).

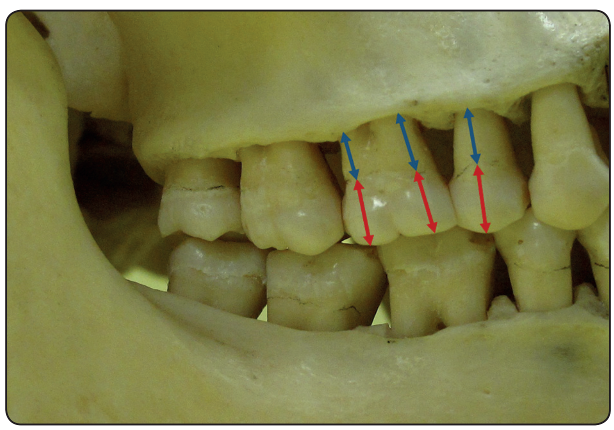

Fig (2) Buccal measurement sites in molars (4 sites) and premolars (2 sites).

Fig (3) Gold standard measurements using a digital caliper.

Fig (4) Measurements by multiplanar reconstruction (left) and volume rendering (right).

RESULTS

The means ± standard deviations (SDs) of the GS, MPR, and VR measurements were 4.64 ± 1.94 mm, 4.20 ± 1.86 mm, and 4.10 ± 1.86 mm, respectively. Results of a paired-samples t test showed that there was a significance difference between the GS measurements and both MPR and VR measurements ($P > 0.05$) (Table II). The GS-MPR paired-samples t test showed a mean difference of 0.43 mm and a SD difference of 0.77 mm, whereas the GS-VR paired-samples t test showed a mean difference of 0.54 mm and a SD difference of 0.98 mm.

The data were then divided into groups by site of measurement (from cusp tip to CEJ [49%] and from CEJ to periodontal bone margin [51%]) to compare the measurement accuracy of these sites using MPR and VR. In both modalities, there were significant differences compared with GS measurements of these sites ($P < 0.05$) (Table III). In the measurements from cusp tips to CEJ, the GS-MPR mean difference was the same as the GS-MPR mean difference for the measurements from CEJ to alveolar bone margin; however, the GS-VR mean difference of measurements from cusp tips to CEJ was less than the mean difference of the measurements from CEJ to alveolar bone margin. The SD differences in GS-MPR and GS-VR for the measurements from cusp tips to CEJ were less than the SD differences in GS-MPR and GS-VR for the measurements from CEJ to alveolar bone margin (Table III).

In addition, the data were divided into groups by site of measurement (buccal [53%] and lingual [47%]). In both buccal and lingual MPR and VR measurements, there were significance differences compared with buccal and lingual GS measurements ($P < 0.05$). The buccal GS-MPR mean difference and SD difference were comparable to the lingual GS-MPR mean difference and SD difference. In VR, the buccal GS-VR mean difference and SD difference were greater than the lingual GS-VR mean difference and SD difference (Table IV).

The intra- and interexaminer reliability in this study was evaluated by paired sample *t* test for the measurements of the same examiner at different times. There was no significant difference between the measurements of each examiner at different times for MPR, but there was a significant difference in the measurements of one examiner for VR. The intraexaminer interclass correlation coefficient ranged from 0.84 to 0.85 for both examiners for VR. For MPR, the intraexaminer interclass correlation coefficient ranged from 0.92 to 0.96 for both examiners. The interexaminer interclass correlation coefficient ranged from 0.99 to 0.96 for MPR (Table V).

TABLE (I) Distribution of sites examined by tooth type

Tooth	Maxilla	Mandible	Total
Third molar	14	0	14
Second molar	22	36	58
First molar	22	32	54
Second premolar	11	24	35
First premolar	14	14	28
Canine	4	0	4
Lateral incisor	4	4	8
Central incisor	8	6	14
Total	99	116	215

TABLE (II) Measurement accuracy of the whole sample by means, standard deviations, mean differences, and correlations (N = 215)

GS mean ± SD (mm)	Modality	Mean ± SD (mm)	Mean difference ± SD (GS-MPR or VR)	Correlation	Significance (2-tailed)
4.64 ± 1.94	MPR	4.20 ± 1.86	0.43 ± 0.77	0.92	0.000
	VR	4.10 ± 1.86	0.54 ± 0.98	0.87	0.000

GS, gold standard; SD, standard deviation; MPR, multiplanar reconstruction; VR, volume rendering.

TABLE (III) Measurement accuracy from cusp tip or incisal edge to CEJ and from CEJ to alveolar bone level by means, standard deviations, mean differences, and correlations

Variable	GS mean ± SD (mm)	Modality	Mean ± SD (mm)	Mean difference ± SD (GS-MPR or VR)	Correlation	Significance (2-tailed)
From cusp tip or incisal edge to CEJ	6.13 ± 1.35	MPR	5.70 ± 1.24	0.43 ± 0.66	0.88	0.000
		VR	5.72 ± 1.09	0.41 ± 0.81	0.80	0.000
From CEJ to alveolar bone level	3.19 ± 1.16	MPR	2.75 ± 1.03	0.43 ± 0.86	0.70	0.000
		VR	2.51 ± 0.76	0.67 ± 1.11	0.39	0.000

CEJ, cementoenamel junction; GS, gold standard; SD, standard deviation; MPR, multiplanar reconstruction; VR, volume rendering.

TABLE (IV) Measurement accuracy of buccal and lingual sites by means, standard deviations, mean differences, and correlations

Variable	GS mean ± SD (mm)	Modality	Mean ± SD (mm)	Mean differences ± SD (GS-MPR or VR)	Correlation	Significance (2-tailed)
Buccal	4.84 ± 2.03	MPR	4.41 ± 1.89	0.43 ± 0.79	0.92	0.00
		VR	4.15 ± 1.97	0.86 ± 1.08	0.85	0.00
Lingual	4.41 ± 1.81	MPR	3.98 ± 1.81	0.44 ± 0.74	0.92	0.00
		VR	4.03 ± 1.73	0.67 ± 0.84	0.89	0.00

GS, gold standard; SD, standard deviation; MPR, multiplanar reconstruction; VR, volume rendering.

TABLE (V) Intraexaminer reliability for MPR and VR modality measurements at 2 different times by means, standard deviations, and ICC

	MPR			VR		
Examiner	1st time (mean ± SD)	2nd time (mean ± SD)	ICC	1st time (mean ± SD)	2nd time (mean ± SD)	ICC
1st examiner	4.21 ± 1.80	4.24 ± 1.69	0.96	3.73 ± 1.60	3.87 ± 1.60	0.85
2nd examiner	4.20 ±1.85	4.29 ± 1.63	0.92	3.70 ± 1.65*	3.96 ± 1.48*	0.84

There was a significant difference between the 1st and 2nd measurements ($P < 0.05$). MPR, multiplanar reconstruction; VR, volume rendering; SD, standard deviation; ICC, interclass correlation coefficient.

DISCUSSION

The aim of this study was to evaluate the accuracy and reliability of CBCT for measuring the buccal and lingual marginal periodontal alveolar bone levels by using the MPR and VR modalities of CBCT data. This aim was divided into 2 parts: first, to evaluate the accuracy of CBCT in measuring buccal and lingual marginal periodontal alveolar bone levels in different modalities, and second, to evaluate the reliability of these modalities. Generally, CBCT measurements of the levels of buccal and lingual marginal periodontal alveolar bone in both modalities were comparable to GS measurements. This accuracy was augmented by the ability to distinguish between buccal and lingual levels.

To measure these levels, it is necessary to locate the bone margin and the CEJ. We were able to locate the CEJ with greater accuracy than we were for the bone margin in VR. This may be due to the varying hydroxyapatite content of enamel, cementum, and bone, leading to corresponding differences in the resulting contrast resolution of the image. CEJ is the junction where enamel meets cementum; thus it represents 2 substances with different hydroxyapatite content (97% vs 50%, respectively). On the other hand, bone contains hydroxyapatite content (65%) that is closer to cementum than to enamel. Thus, the higher difference in hydroxyapatite content between enamel and cementum makes it easier to accurately locate the CEJ in the VR modality.

Mischkowski et al.[21] and Kobayashi et al.[22] used gutta percha to mark different anatomical

landmarks in the mandibles of human dry skulls in order to examine the accuracy of CBCT in linear measurements. They reported a higher accuracy than shown in our study. This higher accuracy was attributed to improvement in the visualization of these landmarks during their measurement. [21,22] In addition, Leung et al[15] concluded that bone with thickness less than 0.6 mm cannot be seen in the VR modality. However, they did not use soft tissue compensation and measured only buccal bone rather than buccal and lingual bone levels. Nevertheless, the lingual measurements in our study showed better accuracy when compared with the buccal measurements. From this comparison, the best sites to be measured by VR are lingual CEJs. Two possibilities may explain this: The examiner may have located bone margin more apically if its thickness was less than 0.6 mm, or the examiner may have located bone margin more coronal if the bone margin and the cementum could not be distinguished.

In contrast to VR, MPR showed almost the same accuracy in locating both CEJ and bone margin bucally and lingually. The superiority of MPR in locating these landmarks may be explained by many factors, but is mainly due to the modality variable. The image contrast in enamel, cementum, and bone in MPR is higher than that in VR. The second factor is that the manipulation of the site and section orientation in MPR led to a better ability to locate these anatomical landmarks. The third factor is the ability to reduce the thickness of the section in MPR to a minimum to eliminate any superimpositions.

The linear measurements of the alveolar bone levels were comparable to intraoral digital X-rays using a parallel technique, but MPR showed better identification of crater and furcation involvement. [14] Additionally, MPR can determine buccal and lingual bone levels reliably. These advantages suggest that MPR can be used when buccal or lingual alveolar bone levels need to be assessed. The intraexaminer interclass correlation coefficient was high for both examiners in MPR, but decreased in VR. When we compared the intraexaminer reliability results in our study with those in the study by Leung et al. [15] our study showed a decreased intraexaminer interclass correlation coefficient in VR. This decrease may be related to the difference in study designs.

There were some limitations of this study. First, for ethical reasons, it was conducted on human dry skulls with soft tissue compensation, which differs from the clinical situation. Second, to eliminate viewing variables, the two examiners measured the same section in both modalities. Third, jawbones used in this study were free of metallic restorations, prostheses, dental implants, or fixed orthodontic appliances. The presence of such metallic objects would result in image artifacts that would likely affect the accuracy of measurements. The extent of this effect needs further investigation. Finally, the effect of different software and hardware used to process, display, and measure marginal bone levels also needs to be investigated.

CONCLUSION

Although there was a significance difference between the GS measurements and both MPR and VR measurements, MPR is more accurate and reliable than VR in measuring the levels of buccal and lingual periodontal alveolar bone. However, this difference is not significant clinically. CBCT can accurately and reliably assess the buccal and lingual periodontal alveolar bone levels. Further research and randomized clinical trials are indicated to evaluate the accuracy and reliability of different CBCT modalities for measuring periodontal alveolar bone height.

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