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RESEARCH ARTICLE

Comparison of CBCT with different voxel sizes and intraoral scanner for detection of periodontal defects: an in vitro study

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Objectives: This study aimed to compare the diagnostic accuracy of cone beam CT (CBCT) units with different voxel sizes with the digital intraoral scanning technique in terms of the detection of periodontal defects.
Methods and materials: The study material comprised of 12 dry skulls with maxilla and mandible. Artificial defects were created on teeth separately using burs randomly on dry skulls. In total 46 dehiscences, 10 fenestrations, 17 furcations, 12 wall defects and 13 without periodontal defect were used in the study. Each tooth with and without defects was imaged at various vertical angles using each of the following modalities: a Veraviewepocs 3D R100 CBCT device and a 3D Shape TRIOS® Color P13 Shade Intraoral Scanner.
Results: The κ values for interobserver agreement between observers ranged between 0.29 and 0.86 for the CBCT 10 × 8 cm field of view (FOV) with 0,160 mm^3 voxel size; 0.35 and 1 for the CBCT 8 × 8 cm FOV with 0,125 mm3 voxel size; and 0.30 and 1 of intraoral scans. The κ values for detecting defects on anterior teeth were the least, following premolar and molar teeth both CBCT and intraoral scanning.
Conclusions: Smaller voxel sizes and smaller CBCT FOV has the highest sensitivity and diagnostic accuracy for detecting various periodontal defects among the scanner modalities examined.
Advances in knowledge: Adequate evaluation of the condition of the alveolar bone and periodontal tissues is important for the diagnosis, treatment, and prognosis of periodontal disease. Limited examination methods, such as palpation, inspection, and periodontal probe examination, may provide insufficient information for the diagnosis of periodontal diseases.
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Keywords: Cone Beam CT; Alveolar Bone Loss; Furcation Defects

Introduction

Current approaches to the diagnosis of periodontal disease include probing gingival tissues and evaluating radiographs to characterize osseous support. In combination with diagnostic imaging, information derived from the probing of gingival tissues guides assessing alveolar bone height and evaluating potential bone defects.[1,2] Many intra- and extraoral imaging modalities can be used to examine patients with periodontal disease. Commonly used two-dimensional (2D) modalities include bitewing, periapical, and panoramic radiography; notably, these modalities are easily acquired

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Figure 1 (a, b) The photograph of the dry skull. Artificial defects were created as an anterior, premolar, and molar region.

and inexpensive while providing high-resolution images. Although all available 2D imaging modalities provide important diagnostic information, they also exhibit inherent limitations.[3] These include overlapping anatomical structures,[4,5] difficulties concerning standardization,[1–5] and underestimation of the size and occurrence of bone defects.[6] Importantly, 2D images typically show less severe bone destruction than is present within the patient. Early (*i.e.* incipient) mild destructive lesions in bone do not cause sufficient changes in density to enable detection. Moreover, 2D images do not demonstrate soft tissue-to-hard tissue relationships; thus, they provide no information regarding the depth of soft tissue pockets.[7]

Figure 2 The scanned image produced with Software of 3D Shape TRIOS® Color.

Intraoral (IO) radiography has been shown to underestimate alveolar bone loss due to projection errors or observer errors.[8–10] Funnel-shaped or lingually located defects cannot be detected; furthermore, destruction of the buccal plate can be undiagnosed or undistinguished from lingual defects.[5] Therefore, three-dimensional (3D) modalities, such as cone beam CT (CBCT) images of periodontal bone level, have been employed and have been highly informative.[11] The use of CBCT in clinical practice offers several potential advantages over conventional tomography, including easier image acquisition, higher imaging accuracy, reduction in the number of artifacts, and lower effective radiation doses.[12] IO scanning technology is a fast-growing field in dentistry, as it is responsive to the need for accurate 3D mapping of the mouth, which is required in a large number of procedures, such as restorative dentistry and orthodontics. Currently, more than 10 IO scanning devices are available worldwide for restorative dentistry.[13]

Optical scanners can be used to capture both *in vivo* images of the dentition and *in vitro* images of the physical models to create a 3D digital representation. IO scanner devices have numerous applications in orthodontics, such as digital storage of study models and advanced software for cast analysis, landmark identification, arch width and length measurements, tooth segmentation, and occlusal evaluation.[14] It was also used to evaluate gingival recessions.[15] In another study, Windisch et al used optic scanners in an *in vitro* study of localized alveolar ridge defects.[16] These platforms allow clinicians to obtain a digital diagnostic set-up, perform indirect bonding, and export the digital scans into open-source file formats. The electronic files can then be shared with third-party providers and imported into a variety of digital workflows for advanced treatment planning for surgical cases and implants and superimposition with CBCT data.

Purpose

This study aimed to compare the observers' agreement and diagnostic accuracy for different imaging techniques, in terms of the detection of periodontal defects by CBCT units with different voxel sizes and the digital IO scanning technique.

Methods and materials

The study material comprised of 12 dry human skulls with maxilla and mandible. Artificial defects (dehiscence, furcation, fenestration, and wall defects) were created separately on the anterior, premolar, and molar teeth of the dry skulls using burs. (Figure 1a) These defects were randomly created by an experienced dentomaxillofacial radiologist and periodontal surgeon in a manner consistent with the approach used by Mengel et al. (Figure 1b).[17] In the teeth in the present study, 46 dehiscences, 10 fenestrations, 17 furcations, and 12

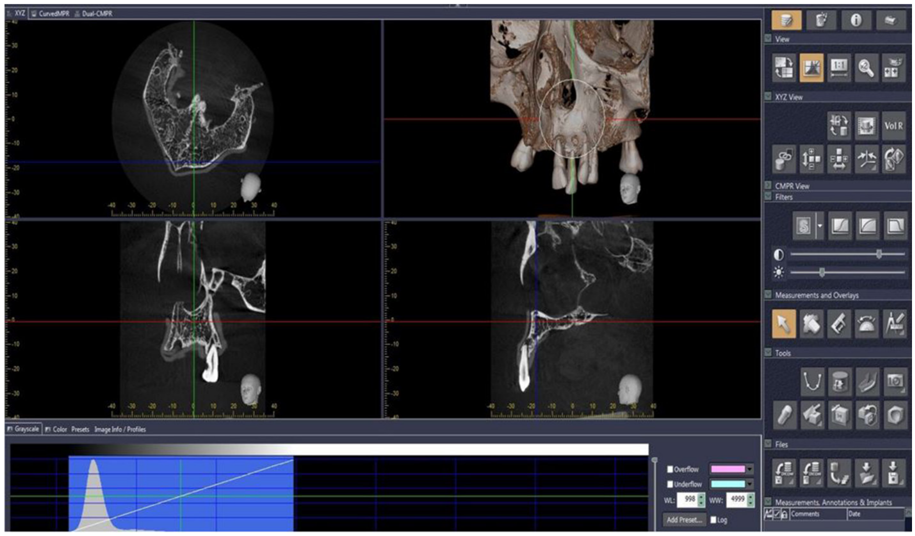

Figure 3 For CBCT evaluations, software i-Dixel 2.0 was used. CBCT, cone beam CT.

wall defects were created; additionally, 13 teeth without periodontal defects were used in the study. The skulls were scanned by 3D Shape TRIOS® Color before and after wax addition. However, observers only reviewed waxed-up skulls . Because the defect area couldn't be determined below the wax.

Each tooth with and without defects was imaged at various vertical angles by using each of the following modalities with a Veraviewepocs 3D R100/F40 (J Morita Mfg. Corp., Kyoto, Japan) CBCT device; CBCT exposures were made at 90 kVp and 3 mA, with 0.160 mm^3 and 0.125 mm^3 voxel size. The respective fields of view (FOVs) were 10 cm in diameter and 8 cm in height and 8 cm in diameter and 8 cm in height. Axial, sagittal, and cross-sectional images were reconstructed for all skulls; 3D reconstructions were used as necessary. IO scans were performed by an orthodontics resident with 3D Shape TRIOS® Color P13 Shade Intraoral Scanner (Biolase, Irvine, CA, USA).

Image evaluation

All digital scan images were saved in the STL file format. All images were displayed on a 23-inch flat-panel screen (EIZO RadiForce MS 230 W 23-inch Class Color LCD monitor, Eizo Nanao Corporation, Ishikawa, Japan). Digital scan images were displayed using the dedicated software of 3D Shape TRIOS® Color; (Figure 2) CBCT images were evaluated using i-Dixel 2.0 software (J. Morita Corporation, Osaka, Japan) (Figure 3). Observation conditions were optimized by using the same computer monitor for the display of all images. Viewing distance was maintained at approximately 50 cm for observers, and the lights were subdued during examinations.

A dentomaxillofacial radiologist, an orthodontist, and a periodontist—all of whom had experience with CBCT—examined the CBCT images and IO scans in different sessions for the presence of periodontal defects. The observers were aware that some teeth had no periodontal defects. The observers performed the study twice, with an interval of 1 month after the initial viewing. All teeth were evaluated randomly for the presence or absence of periodontal defects, then scored using the following 5-point scale: 5 = defect definitely present; 4 = defect probably present; 3 = uncertain/unable to tell; 2 = defect probably not present; and 1 = defect definitely not present. All observers performed the assessment simultaneously in three different workstations and had access to the multiple scans. The time allocated for observation was not restricted. Adjustment

Table 1 κ values for interobserver agreement ranged from 0.43 to 0.78 for IO scans; from 0.38 to 0.92 for CBCT 10 × 8 cm FOV with 0.160 mm voxel size; and from 0.53 to 0.82 for CBCT 8 × 8 cm FOV with 0.125 mm voxel size for molar teeth

	MOLAR					
		1.READING			**2.READING**	
	Observer 1–2	**Observer 2–3**	**Observer 1–3**	**Observer 1–2**	**Observer 2–3**	**Observer 1–3**
IO Scan	0.77	0.751	0.706	0.479	0.434	0.542
CBCT 10 × 8 0.160	0.522	0.923	0.482	0.382	0.762	0.406
CBCT 8 × 8 0.125	0.490	0.743	0.503	0.477	0.819	0.525

CBCT, cone beam CT; FOV, field of view; IO, intraoral.
$p < 0.05$

Table 2 κ values for interobserver agreement ranged from 0.43 to 0.63 for IO scans; from 0.29 to 0.71 for CBCT 10 × 8 cm FOV with 0.160 mm voxel size; and from 0.30 to 0.45 for CBCT 8 × 8 cm FOV with 0.125 mm voxel size for premolar teeth

	PREMOLAR					
		1.READING			2.READING	
	Observer 1–2	**Observer 2–3**	**Observer 1–3**	**Observer 1–2**	**Observer 2–3**	**Observer 1–3**
IO Scan	0.634	0.497	0.424	0.177	0.368	0.535
CBCT 10 × 8 0.160	0.462	0.711	0.287	0.220	0.858	0.223
CBCT 8 × 8 0.125	0.120	0.686	0.302	0.365	0.448	0.130

CBCT, cone beam CT; FOV, field of view; IO, intraoral.
$p < 0.05$

of contrast and brightness could be performed using the built-in image display tools when the observers considered such adjustment to be necessary.

The observers' responses were tabulated and platted for receiver operating characteristic (ROC) curves. The ROC analysis was performed with observer responses, and values of the regions tested were calculated. The areas under the ROC curves in the regions were compared with the one way variance analysis (ANOVA), assuming a significance level of % 5 (p = 0,05)

Statistical analysis

All inter- and intraobserver evaluations were compared based on a gold-standard, which was created and annotated by a periodontal consultant. Statistical analysis was performed with SPSS 19.0 software (SPSS Inc., Chicago, IL). Descriptive statistics were expressed as frequencies and percentages. κ statistics were used to determine the inter- and intraobserver agreement. A p-value of less than 0.05 was considered to be statistically significant for all tests.

Results

The κ values for interobserver agreement ranged from 0.29 to 0.86 for CBCT 10 × 8 cm FOV with 0.160 mm voxel size; from 0.35 to 1 for CBCT 8 × 8 cm FOV with 0.125 mm voxel size; and from 0.30 to 1 for IO scans (Tables 1–4).

The area under the ROC curve values for the observers and test locations are showed in Table 5. There was no statistically significant difference between anterior and premolar test regions. For molar region IO scaning protocol had lower values that were statistically different from anterior and premolar regions.

Table 6 summarized the sensitivity, specificity, accuracy, positive predictive and negative predictive value (PPV, NPV) for the regions and observers. For all regions, these values were highest in CBCT 8 × 10 and 8 × 8 FOV area.

Discussion

Adequate evaluation of the condition of the alveolar bone and periodontal tissues is important for the diagnosis, treatment, and prognosis of periodontal disease. Limited examination methods, such as palpation, inspection, and periodontal probe examination, may provide insufficient information for the diagnosis of periodontal diseases. Despite the numerous studies that have been conducted regarding the accuracy of the imaging modalities used for the assessment of alveolar bone resorption, this has become a problem.[1,18]

Notably, IO scanners can be used to scan soft tissue; they constitute valuable tools concerning the ease of application and facilitation of 3D image creation for mouth and tooth structures. Images can also be generated to evaluate the clinical outcomes of surgical and non-surgical treatment in the head and neck regions.[19] Lehmann et al showed that IO scanners can produce highly reproducible measurements of volume changes in the gingival recession.[20] However, there have been no publications regarding the effectiveness of IO scanners for assessing periodontal defects. In this study, periodontal defects could not be displayed after double wax application. Therefore, only, the images non-waxed-up

Table 3 κ values for interobserver agreement ranged from 0.32 to 0.91 for IO scans; from 0.40 to 0.79 for CBCT 10 × 8 cm FOV with 0.160 mm voxel size; and from 0.35 to 1 for CBCT 8 × 8 cm FOV with 0.125 mm voxel size for anterior teeth

	ANTERIOR					
		1.READING			2.READING	
	Observer 1–2	**Observer 2–3**	**Observer 1–3**	**Observer 1–2**	**Observer 2–3**	**Observer 1–3**
IO Scan	0.912	0.592	0.672	0.340	0.317	0.468
CBCT 10 × 8 0.160	0.540	0.789	0.397	0.447	0.550	0.404
CBCT 8 × 8 0.125	0.351	1	0.351	0.388	0.805	0.409

CBCT, cone beam CT; FOV, field of view; IO, intraoral.
$p < 0.05$

Table 4 κ values for intraobserver agreement between the first and second readings are shown. κ values had the highest sensitivity and diagnostic accuracy in the 0.125 mm voxel size CBCT and the lowest for the IO scan

	MOLAR			*PREMOLAR*			*ANTERIOR*		
	Obs 1	**Obs 2**	**Obs 3**	**Obs 1**	**Obs 2**	**Obs 3**	**Obs 1**	**Obs 2**	**Obs 3**
IO Scan	0.440	0.480	0.909	0.226	0.246	0.686	0.569	0.564	0.656
CBCT 10 × 8 0.160	0.826	0.923	0.841	0.852	0.575	0.765	0.688	0.873	0.820
CBCT 8 × 8 0.125	0.877	0.828	1	0.882	0.860	0.841	0.912	0.905	0.722

CBCT, cone beam CT; IO, intraoral.
$p < 0.05$

images were included in the observer readings. The efficacy of IO scanners was not comparable to that of CBCT for the identification of periodontal defects. The IO scanner magnifies the changes that may be overlooked in the 3D inspection and improves imaging. It can be used as an auxiliary method for IO examination.

In vitro studies have shown that CBCT comprises a reliable option for the diagnosis of periodontal diseases. However, resolution may vary among CBCT machines, such that the accuracy involved in the identification of periodontal defects may change. Voxel size is directly related to the spatial resolution of an image: as voxel size decreases, resolution and detail increase.[1,18,20] Images with reduced FOV size will exhibit less scatter and fewer artifacts, thus resulting in higher contrast and images with less noise, as well as in qualitative improvements in image quality for specific diagnostic tasks. More importantly, the reduction in FOV size is typically associated with a reduction in patient radiation dose.[21]

As a result of our study, we determined that smaller voxel and FOV sizes were more effective for the detection of the periodontal bone defect. But contrary to these results, Dong et al, used different voxel dimensions for the detection of alveolar bone defects and studied the accuracy of CBCT and the optimal voxel size for clinical use. For CBCT imaging, the kaVo 3D eXam scanner (KaVo Dental GmbH, Biberach, Germany) used three different voxel sizes: 0.125 mm^3, 0.2 mm and 0.4 mm^3, but they used a viewing angle (FOV, 8.5 × 8.5 cm). They declared that a 0.2 mm voxel size could be a good choice for the detection of bone defects.[22] In another study, de-Azevedo-Vaz et al created fenestration and dissociation around the implants that they artificially placed on ribs. They used two different voxel sizes and scanning modes with the i-CAT device. Although there was no significant difference in fenestration, 0.2 mm^3 voxel size and full scan mode (360) were more significant for dehiscence imaging.[23]

On the other hand, similar to the results of our study, using two different CBCT devices (Eagle 3D V-Beam, I-CAT), Yamamoto-Silva et al compared the efficacy of four different voxel sizes (0.1 mm, 0.16 mm, 0.125 mm, and 0.2 mm) for the detection of vertical root fractures in the presence of an intracanal metallic post. They found that more accurate results were obtained using a smaller voxel size and FOV area.[24] Safi et al found that lower amperage (4 mA) protocols combined with a smaller FOV size (7.5 cm) were more accurate for the detection of vertical root fractures in teeth with an intracanal post.[25] Wenzel et al used an I-CAT scanner with voxel sizes of 0.125 and 0.25 mm to evaluate the diagnostic accuracy of CBCT and phosphor plate systems with regard to the detection of vertical root fractures; they reported higher accuracy with smaller voxel sizes, such that a voxel size of 0.125 mm demonstrated 98% specificity and 87% sensitivity.[26] In an investigation of the effect of FOV and voxel size on the volumetric measurement of internal root resorption lesions that were simulated using CBCT, Da Silveira et al reported no significant difference between 0.2 mm voxel images of limited protocols and those of large FOV protocols; however, low resolution and small voxel dimensional imaging protocols may have hidden the true dimensions of the internal root resorption.[27]

Table 5 The area under the receiver operating characteristics values

		Observer 1	*Observer 2*	*Observer 3*	p-*value*
Anterior	CBCT 8 × 8 FOV 0.125 mm^3	0,91	0,93	0,96	$p > 0,05$
	CBCT 8 × 10 FOV 0.160 mm^3	0,96	0,90	0,97	
	IO Scanner	0,85	0,88	0,90	
Premolar	CBCT 8 × 8 FOV 0.125 mm^3	0,90	0,91	0,94	
	CBCT 8 × 10 FOV 0.160 mm^3	0,94	0,93	0,96	
	IO Scanner	0,86	0,87	0,88	
Molar	CBCT 8 × 8 FOV 0.125 mm^3	0,88	0,89	0,92	$p < 0,05$
	CBCT 8 × 10 FOV 0.160 mm^3	0,92	0,88	0,91	
	IO Scanner	0,75	0,71	0,67	

CBCT, cone beam CT; IO, intraoral.

Table 6 Diagnostic values for tested regions

		Sensitivity	*Specificity*	*Diagnostic accuracy*	*PPV*	*NPV*
Anterior	CBCT 8 × 8 FOV 0.125 mm^3	0,87	0,86	0,85	0,83	0,86
	CBCT 8 × 10 FOV 0.160 mm^3	0,91	0,96	0,94	0,96	0,91
	IO Scanner	0,88	0,93	0,90	0,92	0,87
Premolar	CBCT 8 × 8 FOV 0.125 mm^3	0,88	0,83	0,86	0,84	0,87
	CBCT 8 × 10 FOV 0.160 mm^3	0,90	0,96	0,91	0,94	0,92
	IO Scanner	0,85	0,91	0,90	0,93	0,83
Molar	CBCT 8 × 8 FOV 0.125 mm^3	0,86	0,85	0,84	0,82	0,83
	CBCT 8 × 10 FOV 0.160 mm^3	0,89	0,92	0,90	0,90	0,80
	IO Scanner	0,75	0,66	0,55	0,63	0,58

CBCT, cone beam CT; FOV, field of view; IO, intraoral; NPV, negative predictive value; PPV, positive predictive value.

In another study, Liedke et al evaluated the *in vitro* diagnostic capability of CBCT scans with different voxel resolutions for the detection of simulated external root resorption; they reported that three different voxel sizes (0.4, 0.3, and 0.2 mm) produced the same results for the diagnosis of cavities that simulated external root resorption.[28] Cheng et al compared phosphor plate systems with different resolution CBCT images for the detection of proximal caries and found no significant differences among CBCT images of 0.16-, 0.32-, 0.2-, and 0.3 mm voxel resolution for both the CBCT and phosphor plate images. However, phosphor plate images were advantageous for the imaging of dentin caries.[29] Similarly, Kamburoğlu et al reported that different voxel resolutions were ineffective for the diagnosis of occlusal caries.**30** Bauman et al used four different isotropic voxel sizes for the detection of mesiobuccal root canals in maxillary molars and did not find a significant difference between 0.2 and 0.125 mm voxel sizes; however, the detectability of the mesiobuccal root canal was 60.1% for a voxel size of 0.4 mm, and this ratio increased to 93.3% for a voxel size of 0.125 mm.[31] Sun et al studied the effect of bone thickness on alveolar bone height measurements and showed that measurements of a 0.25 mm voxel size image were more accurate than those of a 0.4 mm voxel size image.[32]

In the present study, the κ values for the detection of periodontal defects had maximum sensitivity and diagnostic accuracy in a 0.125 mm voxel size CBCT; these values were lower for IO scanners. Choosing a variety of voxel sizes without compromising image quality can help reduce the radiation doses administered to patients. However, in our study, no measurements were made regarding the doses received by patients. Additionally, artificial defects created *ex vivo* to produce CBCT images were known, and their visibility was increased. To increase the accuracy of our study, we performed two measurements at 1 month intervals. Parameters that interfere with making a diagnosis based on CBCT images can thus affect both image quality and diagnostic accuracy. The patient movement was not an influential factor in our study. Another limitation of our study was that the FOV dimensions varied among voxel resolutions. In future studies, different voxel resolutions should be evaluated with a fixed FOV size.

Conclusions

Among the scanner modalities examined in the present study, those with smaller voxel sizes and a smaller CBCT FOV had the highest sensitivity and diagnostic accuracy for the detection of various periodontal defects. Greater accuracy in the measurement of periodontal defects could be achieved by matching images obtained using IO scanners to those obtained using CBCT. The limitation of this study is that the IO scanners are inadequate for imaging periodontal defects in waxed-up dry skulls.

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