RESEARCH ARTICLE

Detection of simulated periodontal defects using cone-beam CT and digital intraoral radiography

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Objectives: This study sought to assess the diagnostic value of CBCT and digital intraoral radiography for the detection of periodontal defects in the sheep mandible.

Methods: In this *in vitro* study, 80 periodontal defects including Grades I, II and III furcation involvements, one-, two-, three-wall and trough-like infrabony defects, fenestration and dehiscence were artificially created in the sheep mandible by burr. Intraoral digital radiographs using photostimulable phosphor plates and CBCT scans were obtained. Three periodontists evaluated the images for the presence and type of defects. The results were compared with the gold standard (photographs of the created defects).

Results: CBCT scans were significantly superior to digital radiographs for the detection of Grade I furcation involvements, three-wall defects, fenestrations and dehiscence ($p < 0.05$). No significant difference was noted between CBCT and digital radiography for the detection of Grades II and III furcation involvements, one-wall, two-wall and trough-like defects (p -value > 0.05).

Conclusions: CBCT was superior to digital intraoral radiography for the detection of Grade I furcation involvements, three-wall defects, dehiscence and fenestrations.

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Introduction

Accurate diagnosis of periodontal bone defects, such as vertical bone defects or furcation involvements, is a challenge for dental clinicians.¹ Periodontal defects are among the main oral and dental problems with a prevalence rate as high as 15% worldwide.² Periodontal diagnosis is generally made based on medical and periodontal history, inflammatory indices, probing pocket depth, probing attachment level, furcation entrance probing and dental radiographs.³ Standard radiographic techniques used for this purpose include periapical, bitewing and panoramic radiography.⁴ Diagnosis of advanced defects by the use of periodontal

probe has limitations such as variable sizes and shapes of periodontal probe tips, probing force, gingival inflammation and anatomical conditions of the probing site.⁵ Conventional radiography provides two-dimensional (2D) image of three-dimensional (3D) structures. As a result, overlapping and superimposition of anatomical structures occur, which lead to loss of some diagnostic data. Also, conventional radiographs are not sufficient for the assessment of fine bone structures owing to image distortion and blurring of anatomical structures.⁶ They underestimate the size and prevalence of bone defects.⁷ In general, accurate diagnosis of bone defects is possible only by direct observation during a surgical procedure.⁸ Underestimation of defects can lead to inadequate treatment, which enhances the progression of periodontal bone loss and results in eventual tooth loss.

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The correlation of periodontal disease and several systemic conditions such as premature birth, cardiovascular diseases and cancer has been confirmed.⁹ Overestimation of defects can lead to improper treatment planning for further treatment or unnecessary periodontal surgery.¹⁰

Thus, one of the most important factors for the success of periodontal therapy is to have an accurate image of the morphology of periodontal bone destruction for the proper treatment planning and determination of prognosis.¹¹ Several studies are available on the diagnostic accuracy of CBCT. However, only a few studies have discussed the application of CBCT in periodontology. Not many studies have documented the benefits of CBCT.^{12,13} Some previous studies have used CBCT as a new modality for periodontal diagnoses and have compared its efficacy with that of 2D radiography.^{10,11,14} Several studies have reported the higher diagnostic sensitivity of CBCT than that of intraoral radiography, while the latter has a higher resolution and lower effective radiation dose.¹⁰ Perception of the images obtained with the use of CBCT in the assessment of periodontal bone defects could lead to a novel approach in evaluating patients with periodontal disease and could demonstrate to be a great resource for selecting the most appropriate treatment. Our hypothesis is that CBCT could be superior to digital intraoral radiography for the detection of some periodontal lesions, while in some other defects, it could not add further information.

To our knowledge, there is no study evaluating all types of periodontal defects including trough-like defects; therefore, this study aimed to compare the diagnostic value of CBCT and periapical radiography for the detection of the type of simulated periodontal defects (infrabony defects, furcation involvements, fenestration and dehiscence) in the sheep mandible.

Materials and methods

Simulation of bone defects

This *in vitro* study was approved by the Research Committee of the Dental Branch of Islamic Azad University, Tehran, Iran. Seven fresh sheep mandibles with six posterior teeth at each quadrant were prepared from a butcher shop. Using a scalpel, a sulcular flap was elevated from the distal surface of the last molar tooth to the mesial surface of the first premolar tooth. 7 Grade I furcation involvements, 14 Grade II furcation involvements and 10 Grade III furcation involvements were created at the furcation area. Three one-wall defects, eight two-wall defects and six three-wall defects were created at the mesial or distal of the teeth. 11 fenestrations and 13 dehiscences were created on the buccal roots of the teeth. Defects were artificially created (Figure 1a) using one-half and one-quarter round diamond burs mounted on a high-speed handpiece. Eight teeth already had trough-like lesions and were

considered as specimens. A total number of 80 defects were evaluated. 80 intact areas were considered as control. The teeth were coded to blind the observers. The presence or absence of defects and type of defects were recorded in a datasheet. The teeth and their defects were then photographed for later use as the gold standard. The flap was then returned and sutured in its original position (Figure 1b).

Radiographic examination

Periapical radiographs were obtained as the standard diagnostic method of all the mandibular posterior teeth. Intraoral digital radiographs were captured using a DC dental X-ray unit (MINRAY®, Soredex, Tuusula, Finland) with exposure settings of 70 kV, 7 mA and 0.2 s. A film holder (XCP®, Dentsply Rinn, Elgin, IL) was fixed to the X-ray tube head. Size 2 photostimulable phosphor plates (DIGORA® Optime; Soredex, Tuusula, Finland) with 30-μm pixel size and 17-lp mm⁻¹ resolution were placed in the lingual surfaces of the teeth in relation to the similar oral clinical situation and were located at 30-cm distance from the focal spot. Since the roots were long, sensors were used in the vertical position. The Scanora 4.3.1.1 radiographic analysis software (Soredex, Tuusula, Finland) was used to capture the images and for archiving and export of images. The radiographs were saved in joint photographic experts group (JPEG) format. To obtain CBCT images, the NewTom VGi® CBCT system (Quantitative Radiology, Verona, Italy) with an amorphous silicon flat plate detector measuring 25 × 20 cm was used. The mandibles were placed on the horizontal plate of the device and a 12 × 8-cm field of view (FOV) was used to capture an image of the posterior teeth on both sides. The midline and mandibular position were adjusted using the laser guide. The X-ray source is attached opposite to the detector unit arrangement and both rotate around the centre of rotation (sheep mandible in this study) at 360°. One 2D projection image is produced per each 1° of rotation. High-resolution images were captured with exposure settings of 110 kV, 5.8 mAs and 5.4-s exposure time. 3D data were calculated from 2D projections. The reconstructed volume included isotropic voxels 0.125 mm³ in size. Using NNT Viewer software v. 3.10 (Quantitative Radiology, Verona, Italy), sections with 1-mm intervals were made in axial, sagittal, coronal and panoramic reformatted views.

Assessment of radiographic images

Three periodontists (two faculty members of the Islamic Azad University and one faculty member of Tehran University of Medical Sciences) randomly observed and evaluated the images. The radiographic images were displayed on a laptop computer (MacBook Core Duo; Apple, Cupertino, CA) with a 13.1-inch monitor and 2.26-GHz Intel processor (Intel, Santa Clara, CA), 256 graphic card NVIDIA GeForce 9400M (NVIDIA Corporation, Santa Clara, CA) and with a resolution of 1280 × 800 pixels, placed in a room with subdued light.

Prior to the study, the observers were briefed about the classification and type of periodontal defects to ensure that they all used the same classification. Also, some explanations were given about the anatomy of the sheep mandible and sheep teeth, localization of bone defects and how to fill out the datasheet. Next, 2D and 3D radiographs of one quadrant were shown to the observers for the purpose of instruction. Moreover, the observers were trained on how to use the NNT Viewer software for the assessment of CBCT images. They practised working with the software by observing the above-mentioned images of one mandibular quadrant and detecting bone defects. The results of the tutorial were not included in the data collection and statistical analysis.

First, periapical radiographs were shown to the observers in the form of a PowerPoint presentation (Microsoft Office 2010; Microsoft Corporation, Iselin, NJ). The images were randomly shown against a black background. The teeth had been numbered on the images and their mesial and distal surfaces had been designated (Figure 2). The observers were requested to express their opinion regarding the presence or absence of periodontal defects and their type on the images and record it in the datasheet. The CBCT scans were viewed using the NNT Viewer software. The observers were allowed to use all the enhancement features provided by the software and viewed the images in all three spatial planes (Figures 3–5). No time limitation was set for the observation of images. Detection and diagnosis of lesions were carried out and the datasheet was filled out accordingly. The presence or absence of defects was recorded as yes/no. The type of defect was determined by choosing the correct answer choice among Grades I, II and III furcation involvements, one-, two-, three-wall and trough-like defects, fenestration and dehiscence. Finally, the data recorded in the datasheets were compared with the gold standard data (photographs). In this study, the detection of the periodontal defect (its presence) was reported as total diagnostic sensitivity. Correct diagnosis of the type of defect was reported as exact diagnostic sensitivity. Paired *t*-test was applied to compare the mean diagnostic sensitivity of CBCT and digital radiography. In order to assess the diagnosis reproducibility, 26 defects and 26 intact areas of 2 mandibles were evaluated again after 2 weeks and kappa coefficient was calculated. The level of statistical significance was $p\text{-value} < 0.05$. All statistical analyses were carried out using SPSS® v. 22.0 statistical software (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL).

Results

Tables 1 and 2 display the mean total and exact diagnostic sensitivity of both modalities and show that these sensitivities of CBCT for Grade I furcation involvement, three-wall defects and dehiscence were significantly higher than those of digital radiography ($p\text{-value} < 0.05$). The mean exact diagnostic sensitivity

of CBCT was significantly higher than that of digital radiography for the detection of fenestration ($p\text{-value} < 0.05$), but the difference between CBCT and digital radiography for the total diagnostic sensitivity was not significant. The mean total diagnostic sensitivity of CBCT and digital radiography was equal for the detection of Grade III furcation involvements and one-wall defects ($p\text{-value} = 1$). For other defects, the mean total and exact diagnostic sensitivity values of CBCT were higher than those of digital radiography, but the differences did not reach a statistical significance ($p\text{-value} > 0.05$).

Table 3 displays that CBCT had a significantly higher mean total diagnostic sensitivity for furcation involvements, fenestration and dehiscence than digital radiography ($p\text{-value} < 0.05$), but no statistically significant difference was noted in the mean total diagnostic sensitivity of CBCT and digital radiography for infrabony defects ($p\text{-value} > 0.05$). In general, the mean total diagnostic sensitivity of CBCT was significantly higher than that of digital radiography for all periodontal defects ($p\text{-value} < 0.05$).

The total and exact diagnostic specificity for all observers was 1, and there was no difference between the two modalities ($p\text{-value} = 1$).

To assess the reproducibility of diagnoses, the kappa coefficient was used as a measure of reproducibility, which was calculated to be 0.943 ± 0.015 for CBCT and 0.880 ± 0.045 for digital radiography, and it revealed that no difference existed in the reproducibility of the two imaging modalities ($p\text{-value} = 0.083$).

Discussion

The results of this study showed that in general, CBCT was superior to digital periapical radiography for the diagnosis of the type of periodontal defects. Of all defects evaluated in the present study, CBCT was significantly superior to digital radiography for the detection of Grade I furcation involvement, fenestration, dehiscence and three-wall defects. This finding indicated that CBCT could play an important role in the diagnosis of primary stages of periodontal defects. On the other hand, early correct diagnosis plays a critical role in accurate treatment planning and favourable prognosis of periodontal disease; this highlights the importance of using CBCT for suspected periodontal defects. Similar to the present study, Noujeim *et al*¹⁴ stated that the difference of CBCT and periapical radiography for the detection of small bone defects was greater than that for the detection of large-size defects; thus, CBCT is a promising modality for the assessment and diagnosis of early periodontal lesions.

Based on the results of the present study, CBCT can also be used for the assessment of suspected three-wall angular lesions. In such cases, the use of CBCT is recommended, since knowledge about the number of remaining walls affects periodontal treatment planning and prognosis.¹⁵ In the present study, all infrabony

Figure 1 Simulated defects in the sheep mandible (a) and sutured flap (b).

defects were created in interproximal surfaces. The detection of defects located in the buccal or lingual surfaces is difficult, if not impossible, on 2D radiographs owing to the superimposition of the root image. In such cases, CBCT is significantly superior to digital intraoral radiography, as noted by Misch *et al.*¹⁶

Mol *et al.*¹⁷ showed that CBCT was superior to intraoral digital radiography for the detection of periodontal bone loss in a dry human skull. Noujeim *et al.*¹⁴ artificially created interradicular bone defects in a dry human mandible and reported that high-resolution CBCT was more accurate than conventional radiography for the detection of such defects.

With regard to vertical bone defects, two previous studies showed a high accuracy of CBCT for the detection of intrabony defects compared with periapical radiography.^{18,19} Faria Vasconcelos *et al.*¹⁹ recommended the use of CBCT for severe periodontal diseases such as aggressive periodontitis and particularly prior to regenerative or mucogingival surgical planning, since these treatment procedures are expensive and difficult to plan.

Three clinical studies on candidates of periodontal surgery for maxillary molar furcation involvements unanimously reported that pre-surgical estimation of

the Grade of furcation involvement in these teeth by the use of high-resolution CBCT had a high degree of agreement with intrasurgical findings; CBCT showed a high accuracy for the morphological analysis of maxillary molars and the surrounding periodontal tissues.^{20–22} In the present study, CBCT had a high accuracy for the detection of furcation involvements; however, the accuracy of CBCT only for the detection of Grade I furcation involvement was significantly higher than that of intraoral digital radiography. Several explanations can be offered for this finding: in this study, furcation defects were created in the bifurcation areas and detection of a radiolucency in this area might be easier than a radiolucency in trifurcation areas in maxillary molars owing to no superimposition of the root images. On the other hand, the cortical bone covering the roots in the sheep mandible is much thicker than that in humans; therefore, to create a furcation defect, relatively high amounts of bone had to be removed, which created a clear radiolucency on the radiographs and enhanced the diagnosis.

The emphasis of the present study was placed on the diagnostic value of CBCT for the detection of periodontal lesions. If emphasis had been placed on treatment planning, despite the equal diagnostic accuracy of

Figure 2 Digital intraoral radiographs illustrating a trough-like defect on tooth 2, a Grade II furcation involvement on tooth 3, a Grade III furcation involvement on tooth 4, a fenestration on tooth 5 and a three-wall defect at distal of tooth 6. D, distal; M, mesial.

Figure 3 Sagittal (a, b) and axial (c–e) CBCT slices indicating a three-wall defect (long arrows), a two-wall defect (short arrows) and a trough-like defect (arrowhead).

CBCT and digital intraoral radiography, CBCT could have been introduced as the preferred modality because CBCT not only helps in the detection and diagnosis of lesions, but also provides valuable information about the morphology of the roots such as root proximity or fusion; such information is helpful for proper treatment planning.²³ Similarly, Walter *et al*²⁰ in their study on decision-making for maxillary molar furcation surgery showed a significant difference in treatment planning based on clinical examination and periapical radiographs compared with CBCT. They explained that CBCT facilitated more detailed surgical treatment planning with a clear decision about resective interventions with a specification of the roots that were planned to be kept. Walter *et al*²³ in a preliminary study reported the possible reduction of treatment time and costs (based on Switzerland dental tariffs) for periodontally diseased maxillary molars when CBCT scans were used.

Braun *et al*¹¹ in their study on simulated periodontal lesions in a pig mandible reported that CBCT was more accurate for the detection of one-, two- and three-wall infrabony defects, fenestration and dehiscence than intraoral radiography. Also, CBCT was significantly superior to intraoral radiography for the detection of Grade II furcation involvements.¹¹ The authors did not mention the type of digital sensor used in their study for intraoral radiography. The number of periodontal lesions simulated in their study was half the number of defects created in the present study.

Faria Vasconcelos *et al*¹⁹ compared intraoral radiography and CBCT and concluded that the two modalities were not significantly different for the diagnosis

of the pattern of bone loss. They evaluated radiographs obtained by using both parallel and bisect techniques. It is known that the bisect technique is not standard for the evaluation of periodontal lesions. However, they reported that CBCT enabled the analysis of buccal, lingual and palatal surfaces and enhanced the identification of combined bony defects by enabling the 3D assessment of the alveolar bone crest.¹⁹

In a study by Misch *et al*¹⁶ on determining the accuracy of CBCT for the measurement of buccal, lingual and interproximal intrabony defects simulated in a dry human mandible, they found no significant difference in linear measurements among periapical radiography, CBCT and bone sounding, although buccal and lingual lesions were not measurable on periapical radiographs and CBCT was superior to periapical radiography for this purpose. In their study, the number of evaluated periodontal defects was not mentioned. The lack of a significant difference in linear measurements of the bone level by periapical radiography and CBCT was also reported in another *in vitro* study by Vandenberghe *et al*.¹⁰ The two afore-mentioned studies used a larger voxel size than ours. They reported the significant superiority of CBCT for the assessment of crater defects and furcation involvements, but intraoral radiography was preferred for the assessment of bone quality and delineation of the lamina dura, since it had a higher resolution.¹⁰ However, they had a small sample size. Vandenberghe *et al*²⁴ in an *in vitro* study on a larger sample size showed that the accuracy of measurements made on CBCT scans was significantly higher than that of intraoral radiographs when cross-sectional images were evaluated; however, by the use of CBCT

Figure 4 Sagittal (a), axial (b, c) and coronal (d, e) CBCT slices illustrating Grade III (long arrows), Grade II (short arrows) and Grade I (arrowhead) furcation involvements.

panoramic reconstruction views, no significant difference was noted in bone level measurements. They also emphasized that CBCT was superior to intraoral radiography for the imaging of crater defects and furcation involvements, and significant differences existed in the classification of

defects by the use of CBCT and intraoral radiography.²⁴ Another study revealed that axial slices made parallel to the occlusal plane allowed better visualization of the morphology of periodontal defects.²⁵ Another study reported that observers preferred sagittal images for the

Figure 5 Axial (a–c) and coronal (d–f) CBCT slices showing fenestration (arrows) and dehiscence (arrowheads). In the apical section (a), both defects are obvious. In more coronal sections (b, c), the fenestration gradually fades, but the dehiscence extends up to the most coronal section.

evaluation of interradicular defects.¹⁴ In the present study, observers had access to CBCT scans at all planes and were not limited to a specific plane, in order to better simulate the clinical setting.

In some previous studies, simulated periodontal defects in a dry human skull¹⁶ or mandible were evaluated¹⁴ and in some others, actual defects in a dry human skull¹⁷ were

evaluated. In two studies conducted by Vandenberghe *et al*,^{10,24} periodontal defects in a cadaver and a dry skull were assessed. Several clinical studies evaluated maxillary molar furcation involvements.^{20–22} Braun *et al*¹¹ simulated periodontal defects in a fresh pig mandible. In the present study, a fresh sheep mandible was used. Al-Qareer *et al*²⁶ stated that sheep mandible

Table 1 Total diagnostic sensitivity of CBCT and digital radiography for periodontal defects for the three observers

Periodontal defects	Observer 1		Observer 2		Observer 3		Mean $\pm$ SD		p-value
	PSP	CBCT	PSP	CBCT	PSP	CBCT	PSP	CBCT	
Grade I FI	0.00	0.86	0.29	0.57	0.29	0.71	0.19 $\pm$ 0.16	0.71 $\pm$ 0.14	0.015
Grade II FI	0.86	1.00	1.00	1.00	1.00	1.00	0.95 $\pm$ 0.82	1.00 $\pm$ 0.00	0.374
Grade III FI	1.00	1.00	1.00	1.00	0.90	0.90	0.93 $\pm$ 0.06	0.93 $\pm$ 0.06	1.000
Three wall	0.17	0.83	0.33	0.67	0.33	0.67	0.27 $\pm$ 0.09	0.72 $\pm$ 0.02	0.005
Two wall	0.63	0.88	1.00	0.88	0.75	1.00	0.79 $\pm$ 0.19	0.91 $\pm$ 0.07	0.349
One wall	0.67	1.00	1.00	0.67	1.00	1.00	0.89 $\pm$ 0.20	0.89 $\pm$ 0.20	1.000
Trough like	0.38	0.88	0.50	0.63	0.63	1.00	0.54 $\pm$ 0.72	0.83 $\pm$ 0.19	0.069
Fenestration	0.36	0.82	0.82	0.82	0.36	0.91	0.51 $\pm$ 0.26	0.84 $\pm$ 0.52	0.097
Dehiscence	0.00	0.69	0.08	0.69	0.46	0.92	0.17 $\pm$ 0.24	0.76 $\pm$ 0.13	0.022

FI, furcation involvement; PSP, photostimulable phosphor; SD, standard deviation.

was a suitable model for periodontal procedures owing to optimal dimensions, special anatomical features and easy accessibility.²⁶

In *in vitro* studies using dry skulls, the soft-tissue attenuation and scattering of X-ray should be simulated. This is often performed by placing the samples in water^{14,18} or covering them with specific substances such as Mix D^{10,24} or a tissue-equivalent plastic.¹⁴ However, this was neglected in some studies.²⁶ For this reason, in the present study and in the study by Braun *et al*,¹¹ a fresh mandible was used instead of a dry mandible.

The quality of CBCT images depends on image acquisition parameters such as milliamperage, kilovoltage and voxel size.²⁷ The smaller the voxel size, the higher the image resolution. In a recently published study, the effect of voxel resolution on periodontal diagnoses was evaluated and a voxel size of 0.150 mm³ was identified as the cut-off point for the detection of periodontal defects.²⁸ The afore-mentioned study highlighted the role of voxel size in the detection of periodontal defects and showed that voxel size affected the findings. Some previous studies used larger voxel sizes (more than the cut-off).^{16,18,19,24} In a few other studies, voxel size was not mentioned.²⁰ In the present study, a 0.125-mm³ voxel size was used, which had an even higher resolution than the recommended cut-off point.

According to the European Commission guidelines in 2012,²⁹ limited-volume, high-resolution CBCT may be indicated in selected cases of periodontal defects. In the present study, high-resolution CBCT scans were obtained. However, some previous studies used lower

resolutions¹⁶ and some others did not mention anything about the resolution of the scans.¹⁰ Regarding the FOV, Ludlow *et al*²⁷ reported radiation dose reduction when using smaller FOVs. In the present study, since teeth with periodontal defects were evaluated along with adjacent sound teeth as controls, a medium FOV was used. Moreover, since it was an *in vitro* study, we did not have any concern regarding the radiation dose. But, in the clinical setting, imaging of suspected periodontal defects should be preferably carried out using a small FOV. This issue was also taken into account in clinical studies conducted by Walter *et al*.^{20,21}

In cases where 3D analysis of periodontal defects is required, the application of CBCT can be justified, as described by Kasaj *et al*.³⁰ They showed the superiority of CBCT to conventional CT for the detection of furcation involvement, intrabony defects, fenestration and dehiscence. Moreover, the radiation dose of CBCT is up to 15 times lower than that of conventional CT.³¹ The effective radiation dose of dental CT is variable, depending on the brand of the device and technical exposure settings (FOV, exposure time, kilovoltage and milliamperage).²⁷ When compared with conventional radiography, the radiation dose of CBCT is 4–15 times the dose of panoramic radiography.²⁷ However, CBCT has the potential to provide higher diagnostic information.¹⁹

The comprehensiveness of the present study was a major strength, since it evaluated the different types of periodontal defects. Obtaining high-resolution CBCT scans with a small voxel size was another advantage of this study. Also, the observers were allowed to view

Table 2 Exact diagnostic sensitivity of CBCT and digital radiography for periodontal defects for the three observers

Periodontal defects	Observer 1		Observer 2		Observer 3		Mean $\pm$ SD		p-value
	PSP	CBCT	PSP	CBCT	PSP	CBCT	PSP	CBCT	
Grade I FI	0.00	0.86	0.00	0.57	0.29	0.71	0.09 $\pm$ 0.16	0.71 $\pm$ 0.14	0.008
Grade II FI	0.71	0.93	0.93	0.79	0.71	0.71	0.78 $\pm$ 0.12	0.80 $\pm$ 0.10	0.815
Grade III FI	0.90	0.90	0.70	1.00	0.70	0.80	0.76 $\pm$ 0.11	0.90 $\pm$ 0.10	0.205
Three wall	0.17	0.67	0.17	0.67	0.33	0.67	0.22 $\pm$ 0.09	0.66 $\pm$ 0.00	0.001
Two wall	0.50	0.63	0.75	0.75	0.63	0.88	0.62 $\pm$ 0.12	0.75 $\pm$ 0.12	0.288
One wall	0.67	1.00	1.00	0.67	0.67	1.00	0.78 $\pm$ 0.20	0.89 $\pm$ 0.20	0.519
Trough like	0.38	0.88	0.25	0.63	0.63	1.00	0.41 $\pm$ 0.19	0.83 $\pm$ 0.19	0.056
Fenestration	0.36	0.73	0.46	0.73	0.36	0.91	0.45 $\pm$ 0.15	0.78 $\pm$ 0.10	0.038
Dehiscence	0.00	0.62	0.08	0.69	0.46	0.92	0.17 $\pm$ 0.24	0.74 $\pm$ 0.16	0.029

FI, furcation involvement; PSP, photostimulable phosphor; SD, standard deviation.

Table 3 Total diagnostic sensitivity of CBCT and digital radiography for all periodontal defects for the three observers

Periodontal defects	Observer 1		Observer 2		Observer 3		Mean $\pm$ SD		p-value
	PSP	CBCT	PSP	CBCT	PSP	CBCT	PSP	CBCT	
Furcation involvements	0.55	0.87	0.71	0.81	0.71	0.87	0.65 $\pm$ 0.09	0.84 $\pm$ 0.03	0.029
Infrabony defects	0.47	0.88	0.76	0.78	0.65	0.88	0.62 $\pm$ 0.14	0.84 $\pm$ 0.06	0.084
Fenestration and dehiscence	0.17	0.75	0.42	0.75	0.42	0.92	0.33 $\pm$ 0.14	0.80 $\pm$ 0.09	0.009
All defects	0.48	0.88	0.66	0.80	0.46	0.91	0.59 $\pm$ 0.10	0.86 $\pm$ 0.05	0.016

PSP, photostimulable phosphor; SD, standard deviation.

images in all planes and use the software instead of viewing printed images. A fresh mandible along with the soft tissue was used instead of a dry mandible, which further added to the value of the present study.

In general, studies on the use of CBCT for periodontal imaging are scarce and the available ones mostly have an *in vitro* design. Moreover, only a limited number of CBCT systems have been evaluated. It should be noted that *in vitro* studies (such as the present study) have limitations in simulating the clinical setting. For the diagnosis of periodontal bone loss, *in vitro* studies do not allow the comparison of CBCT with clinical diagnosis based on pocket probing.²⁹ Moreover, many CBCT scans of patients have metal artefacts owing to the presence of metallic restorations or other devices, which affect the image quality,¹⁹ but, they are often non-existent *in vitro*. Another limitation of the present study was the presence of anatomical differences in the morphology of tooth crowns and roots as well as the thickness and density of the alveolar bone in sheep and human mandibles, which might have affected the detection of periodontal defects. Although the limitations of *in vitro* studies have been well acknowledged, further *in vitro* studies are still required prior to generalization of results to the clinical setting, because the ethical issues regarding taking CBCT scans of patients with periodontal disease are still a matter of debate.

An overall estimate of the findings of relevant studies revealed that CBCT must be selectively used for specific cases with periodontal defects taking into account the as low as diagnostically acceptable principle³² and in cases where clinical and conventional radiographic examinations cannot provide sufficient information to reach a diagnosis or offer a treatment plan. The additional radiation risks associated with CBCT are justifiable only for limited cases, and indications and contraindications must be separately evaluated for each individual case.²³

From the results of this study, it was concluded that CBCT was superior to digital intraoral radiography for the detection of simulated Grade I furcation involvements, three-wall defects, fenestration and dehiscence in the sheep mandibles because this 3D imaging modality visualized well the initial periodontal defects, since it prevented the superimposition of opaque structures on the defects.

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