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ORIGINAL ARTICLE

Cone-beam computed tomography in assessment of periodontal ligament space: in vitro study on artificial tooth model

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Abstract The aim of this in vitro study was to compare cone-beam computed tomography (CBCT) to conventional radiography (RG) in the assessment of the periodontal ligament space. A phantom with a variable "artificial" periodontal ligament space (0, 100, 200, 300, and 400 µm) was used as a model. The examinations were performed simultaneously with RG and NewTom® 9000 digital volume tomograph. Assorted after increasing widths, 15 RGs and 15 CBCT images were presented for judgment to 20 dentists (DD), 20 dental assistants, and 20 dental students. Several weeks later, the same images were randomly mixed and presented to the same 20 DD again. The trial shows that RG gaps wider than 200 µm could be correctly identified by all participants with an accuracy of nearly 100%. A significant difference was observed between the modalities ($p<0.05$ and $p<0.001$) where conventional RGs performed better than CBCT for assessment of periodontal ligament space. Interobserver variation in relation to each technique was evaluated and no significant difference was found ($p>0.05$). In subjective evaluations of image quality with CBCT, the results were basically inferior for images of artificial periodontal ligament space, regardless of the experience of the observers.

Keywords Periodontal ligament · Diagnosis · Radiograph · Cone-beam computed tomography

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Introduction

Periodontal disease has been seen at an increased rate in many countries throughout the world. Studies have shown that early diagnosis of periodontal diseases is important in preventing the tooth loss associated with this high prevalence [21, 24]. The use of clinical and radiographic methods as an aid in the diagnosis and treatment of periodontal disease is widely accepted. Radiographs (RG) are necessary for showing the extent of alveolar bone loss, periodontal ligament space, and periapical pathologies. The earliest signs of periodontal disease in RGs are fuzziness, a break in the continuity of lamina dura, and a wedge-shaped radiolucent area at the mesial or distal aspect of the periodontal ligament space [2]. In addition to this, the proper observation of periodontal ligament space may indeed offer some potentials regarding detection of occlusal trauma and the effects of systemic diseases on the periodontium [3].

Under suitable circumstances, loss of bony support has been shown to be the only reliable parameter for the radiographic diagnosis of early periodontitis, yet it is clear that this does not occur until some time after the loss of soft tissue attachment [7]. As a consequence, there is a need for an imaging technique of greater sensitivity to detect the earliest changes in the periodontal ligament space. While conventional film-based RGs have been a great benefit to periodontal diagnosis, they still have some significant limitations including overlap of anatomical structures. This limits the assessment due to possible projection errors caused by sensor or X-ray tube positioning in the mouth. In addition, conventional RGs may cause some problems related with chemical processing and errors in patient positioning [17]. There is now a wider appreciation for the need of devices which inherently show no projection overlap and eliminate the projection errors in the periodontium and the adjacent tissue. Therefore, there are now new possibilities, such as computed tomography (CT) that provides three-dimensional information and better visualization of dental and craniofacial anatomical structures. However, there have only been few studies addressing the potential of CT images versus RGs in the diagnosis and treatment planning of periodontal diseases with particular reference to visualization of the periodontal ligament space [8, 19, 20, 26]. Traditional computed tomographic examination can deliver a significantly higher effective dose of radiation. In the late 1990s, cone-beam computed tomography (CBCT) which uses the cone-beam technique instead of fan-beam technique, with significantly reduced radiation exposure to the patient, was developed for dentomaxillofacial imaging [4–6, 9–16, 18, 22, 25, 27–29]. CBCT performs a single rotation around the patient, simultaneously acquiring all necessary data for a reconstruction, unlike traditional CT, which reconstructs images using a series of axial slices. Moreover, it permits intrinsically the manufacture of less expensive CT images [18]. Several studies have investigated the accuracy and the application of CBCT in implant planning and placement [4, 27] and impacted third molars [22], but limited research evaluating the use of CBCT for periodontal diagnosis has been published [9, 15, 16, 25, 28]. In a recent study, Vandenberghe et al. [28] compared intraoral digital radiography with CBCT in the determination of the periodontal bone loss and defects. While intraoral radiography has been found better for contrast, bone quality, and recognition of lamina dura, CBCT has been more accurate for periodontal craters and furcation involvements.

There have been as yet no published data on application of CBCT for periodontal ligament space and comparing the conventional RGs with CBCT in the visibility of periodontal ligament space. Hence, the aim of this in vitro study was to compare CBCT to conventional radiography in the assessment of the periodontal ligament space. The null hypothesis was that there is no difference between these two imaging modalities.

Materials and methods

An in vitro model was developed to simulate the tooth, periodontal ligament space, and the surrounding tissues. Three artificial teeth made by a composite (Adaptic®, Dentsply DeTrey GmbH, Konstanz, Germany), similar to dentin in its radiopacity, were placed in a plastic cylinder filled with a heavy body impression material, with a radiopacity similar to bone (President® microSystem, heavy body, Coltène, Whaledent Ltd, West Sussex, UK). Schematic presentation of the phantom was shown in Fig. 1a and b. Figure 1a is the cross section of Fig. 1b. We pulled the inner cone (artificial composite tooth) in an outward direction from the plastic cylinder. We knew the trials from our previous study that 100-μm outward movement from the impression material leads to a 13.7-μm gap difference in the artificial periodontal ligament according to mathematical calculations (Fig. 2). Based on that fact, five different “artificial” periodontal ligament spaces (0, 100, 200, 300, and 400 μm) were prepared for the conventional and tomographic imaging (Table 1).

The measurements were made between the bottom of the plastic cylinder and the conical-shaped root part of the artificial tooth. The location of the measurements was indicated as a white line in Fig. 1. The phantoms were radiographed with a Gendex Oralix DC (60 kV, 7 mA; Gendex Dental Systems, IL, USA) using a Kodak Ektaspeed Plus size 3×4 film (Eastman-Kodak, Rochester NY, USA).

All RGs were processed using the same standard recommended processing conditions. Radiographs were developed in an automatic film processor (Velopex, Extra-

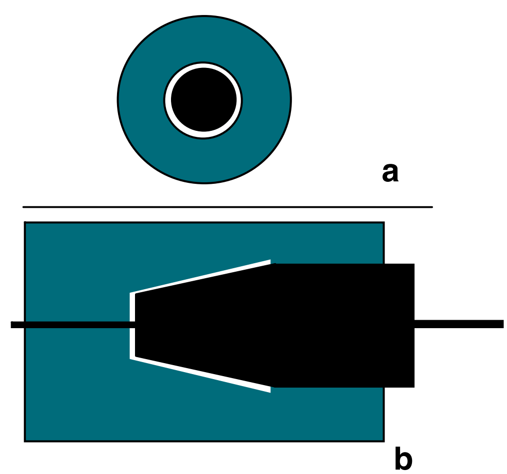

Fig. 1 Schematic presentation of phantom with a variable “periodontal gap”. This figure demonstrates the artificial tooth made by a composite and placed in a plastic cylinder filled with a heavy body impression material. **a** is the cross section of (**b**). The measurements were made between the bottom of the plastic cylinder and the conical-shaped root part of the artificial tooth. The location of the measurements is indicated by *white boundaries* in (**b**)

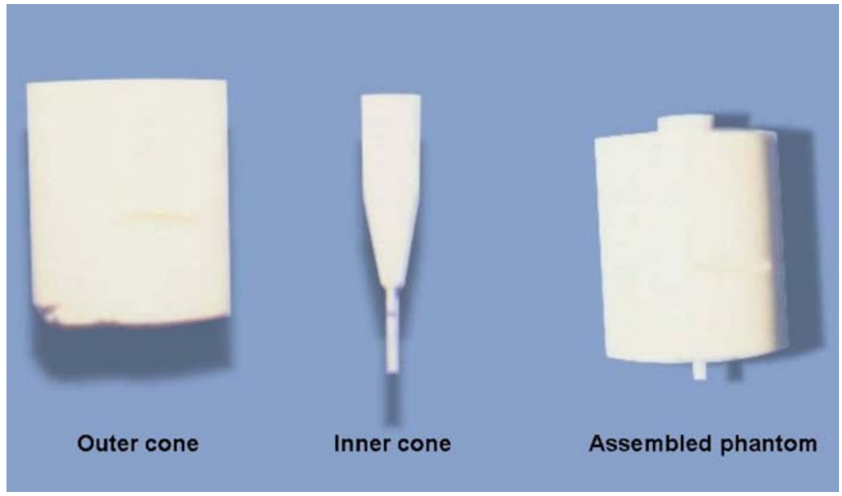

Fig. 2 An in vitro model developed to simulate the tooth, periodontal ligament space, and the surrounding tissues

X, Medivance Instruments Ltd., UK, and NW107A). The phantoms were then placed on the table of the Digital Volume NewTom®-Tomograph (110 kV, 10 mA, 0.7 mm A1-equivalent filtration and a constant 14° cone beam angle; NewTom 9000 QR s.r.l., Verona, Italy) with longitudinal axis parallel to the direction of the table feeding. CBCT uses a cone-shaped X-ray beam centered on an X-ray area detector. The detector consists of an image intensifier with an 8×8-in. input window with an intensification factor of 22:1 [29]. The tube detector system performs a complete 360° rotation around the container, during which a series of exposures is achieved which provides, as digital images, the raw data used for the reconstruction of the examined volume. The image has a slice thickness of 1 mm, and the resolution of images is 512×512 pixels. Primary reconstructed data of phantom examinations were transferred for three-dimensional image reconstruction and a software package was used for CT scanning and image reconstruction (NewTom 9000 Dental QR s.r.l., Verona, Italy). After the three-dimensional images were obtained, the region of interest was extracted. All RGs were imported into the computer with a scanner (Astra 1220S, UMAX Systems GmbH, Willich, Germany). The resolution for the scans of the radiographs was 72 dpi and the size of the presented images was 18.06×18.06 cm. CBCT images have the same dimensions on the computer screen.

Scanned radiographic images and CBCT images were saved under JPG format and displayed by means of Powerpoint software (Microsoft Office XP, Microsoft Corporation, 1290 Avenue of the Americas, Sixth Floor New York, NY 10104, USA) for convenience in observation. In the present study, the images were presented to the participants through a computer.

Fifteen RGs and 15 CBCT images, assorted after increasing widths, were presented for judgment to 20 dentists (DD), 20 dental assistants (DA), and 20 dental students (DS). A mask was placed over the images, so that only the middle third of the artificial root could be evaluated by the examiner. Observers were calibrated in a training session to evaluate the RG and CBCT images. The purpose of the study and the parameters for rating images were explained to all observers. The observers were then asked to judge the images of the conventional RGs and the corresponding CBCT images concentrating on factors related to the visibility of the periodontal gap with different sizes. Both RGs and CBCT images were examined simultaneously on a 15-in. super VGA computer monitor operating at 1,024×768×16 bit in a darkened room to minimize glare. No time limit was set for viewing. The observers were not allowed to manipulate any image characteristics. A 3-point rating scale was used to score the visibility of the periodontal ligament space where, 1 = gap can be seen, 2 = uncertain, and 3 = gap cannot be seen. Several weeks later, the sequence of images was randomized for presentation to the same 20 dentists again. Representative images are shown in Fig. 3. The results are reported in percentages that indicate the percentage of the

Table 1 A change of 100 µm in an outward direction from the cylinder shown in Fig. 1 leads to a 13.7-µm gap difference in the artificial periodontal ligament space

Space (mm)	Change (mm)	Gap width (mm)
0	0	0
100	680	93
200	1,350	185
300	2,250	308
400	3,050	418

A change of 100 µm=13.7-µm change in “gap width”
Five different gap widths were evaluated with both radiographs and CBCT images.

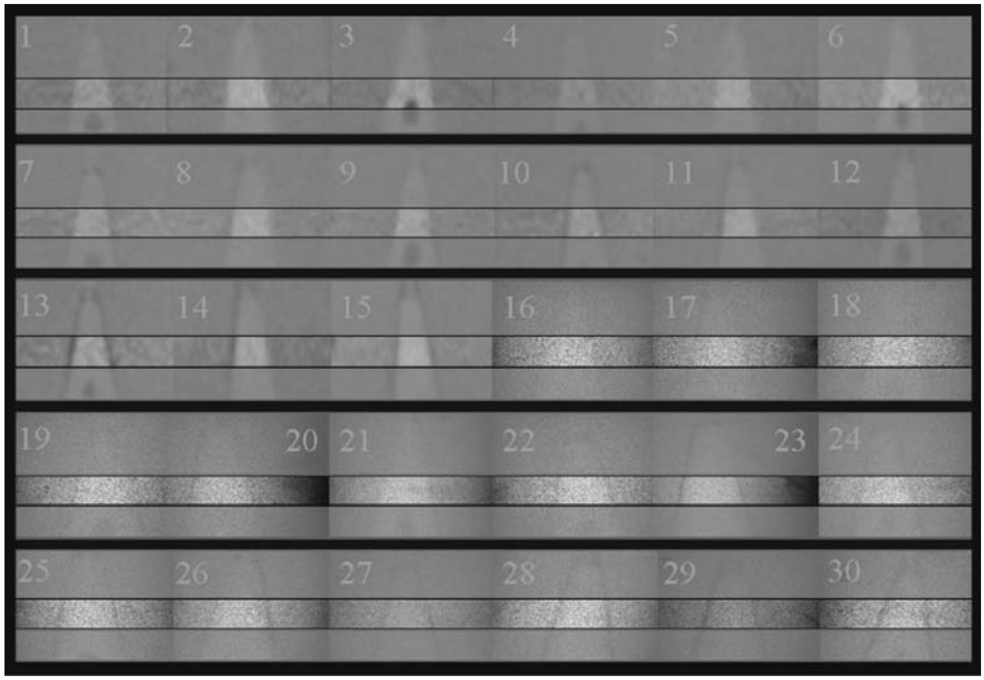

Fig. 3 Representative images of the periodontal gap. The region of interest is middle third of the artificial root, space between the lines. Images *1–15* are radiographic images of 0-, 100-, 200-, 300-, and 400-μm periodontal gaps. Images *16–30* are CBCT slices of 0-, 100-, 200-, 300-, and 400-μm periodontal gaps

observers divided into three groups having different clinical experiences.

Statistical analysis

Data analysis was performed with statistical software (SPSS 12 for Windows; SPSS, Chicago, IL, USA). Chi-square test was used for evaluation of interobserver agreement between dentists, dental assistants, and dental students groups. After obtaining a statistically significant difference between groups, post hoc Duncan test was done to observe which groups were particularly different from each other. Paired samples test was used to analyze which imaging modalities were better for each gap sizes.

Results

All observer groups (DD, DA, and DS) evaluated the visibility of simulated periodontal ligament space and recognized spaces wider than 200-μm gap both in CBCT images and RGs (Tables 2 and 3). CBCT images were found inferior to the conventional RGs concerning clarity of the periodontal gap narrower than 200 μm. Detection of the 100-μm gap was observed to a lesser degree compared with the detection of a 0-μm gap on CBCTs for all observer groups.

Tables 2 and 3 give the percentages of all observers who recognized the artificial periodontal ligament spaces 0–400 μm with conventional RGs and CBCT images. It has

Table 2 Percentage of observers who recognized the periodontal gaps correctly with conventional radiographs and interobserver reliability in relation to each technique

Space (mm)	RG DD sort	RG DD mix	RG DA	RG DS	*p* value
0	33	58	46	37	0.940
100	75	47	67	78	0.336
200	98	98	97	100	0.197
300	98	100	98	98	0.558
400	98	100	100	100	0.366

Significance of differences between the observers for each technique was tested using chi-square test.
RG Radiograph, *DD* dentists, *DA* dental assistants, *DS* dental students, *sort* assorted images, after widths
$p>0.05$, non-significant

Table 3 Percentage of observers who recognized the periodontal gaps correctly with digital volume tomographs and interobserver reliability in relation to each technique

Space (μm)	CBCT DD sort	CBCT DD mix	CBCT DA	CBCT DS	*p* value
0	53	62	56	45	0.753
100	17	0	22	15	0.137
200	92	53	83	93	0.014*
300	98	84	97	100	0.552
400	98	93	100	100	0.366

Significance of differences between the observers for each technique was tested using chi-square test.
CBCT Cone-beam computed tomography, *DD* dentists, *DA* dental assistants, *DS* dental students, *sort* assorted images, after widths
*$p<0.05$, significant

been shown that 200-μm gap sizes could be correctly identified by 98% of DD, 97% of DA, and 100% of DS on RGs and 92% of DD, 83% of DA, and 93% of DS on CBCT images. RG was perceived to improve clarity in the evaluation of the periodontal gap with 100 μm compared with CBCT for all groups ($p<0.001$; Table 3). While on the RGs, DD recognized the 100-μm gaps in 75%, DA in 67%, and DS in 78% of the cases, only 17% of DD, 22% of DA, 15% of DS could detect on CBCT images. Thirty-three percent of DD, 46% of DA, and 37% of DS could determine the 0-μm periodontal ligament space on RGs and 53% of DD, 56% of DA, and 45% of DS on CBCT images (Table 3). CBCT showed 0-μm gap with slightly higher percentages than RG ($p<0.05$), and it was less accurate to detect small gaps.

Table 4 shows all the results of judgments made by DD, DA, and DS. In 100-μm gap sizes evaluated, RGs were significantly superior to CBCT images ($p<0.001$), and CBCT was more accurate in 0-μm gaps ($p<0.05$). While DA and DS judged the 200-μm gap in RGs to be significantly superior in terms of clarity of periodontal ligament space to the CBCT ($p<0.05$), there is no difference in DD group between both modalities for the assessment of 200-μm gap ($p>0.05$).

Similar results were found when the CBCT images were mixed and presented to the dentists (Tables 2 and 3). None of the DD could recognize the 100-μm gap width on mixed CBCT images. On the CBCT, more difficulties in identifying the 200-μm gaps occurred when the images were mixed. Only 53% were correctly recognized in contrast to a correct identification of 98% of the mixed RG. There were no comparable differences in recognizing all radiographic and CBCT images of periodontal gaps between DD, DA, and DS, except DA who differs from the other groups in recognizing 200 μm in CBCT images ($p<0.05$; Table 3).

Discussion

Periodontal disease is a factor influencing 87.8% of the dentists to take RGs [23]. However, the poor image quality related to the overlap of contact points observing crestal bone, anatomical superimposition, geometric distortion, and reduced sharpness were considered to be the major disadvantages of RGs in periodontology [1].

With the use of CT, those disadvantages of the RGs could be excluded and it has enabled dentists to evaluate the structural and biological changes in periodontium for diagnosis and prognosis of diseases [14, 19, 26, 28, 29]. Since conventional CT scans cannot be used to image small structures like periodontal ligament space with sufficient accuracy, high resolution CT has a specific back-projection algorithm that permits much better resolution. In a previous study of our group, an in vitro model was developed to determine if the periodontal ligament space could be visualized as well as recognized with high resolution CT. The examinations were performed with a Tomoscan 350 HS (Philips). A phantom with a variable “periodontal gap”

Table 4 Comparison of detectability of various gap sizes in cone-beam computed tomographic (CBCT) and conventional radiographic images for all groups

Group	Variable	Mean	SD	95% Confidence interval of the difference		t	p (2-tailed)
				Lower	Upper		
DD	CBCT 0–RG 0	0.367	1.314	0.027	0.706	2.161	0.035*
	CBCT 100–RG 100	0.950	0.928	0.710	1.190	7.926	0.000**
	CBCT 200–RG 200	0.067	0.312	-0.014	1.147	1.657	0.103
	CBCT 300–RG 300	0.000	0.184	−0.048	0.048	0.000	1.000
	CBCT 400–RG 400	0.000	0.184	−0.048	0.048	0.000	1.000
DA	CBCT 0–RG 0	0.400	1.196	0.091	0.709	2.591	0.012*
	CBCT 100–RG 100	0.867	1.096	0.583	1.150	6.122	0.000**
	CBCT 200–RG 200	0.200	0.755	0.005	0.395	2.053	0.045*
	CBCT 300–RG 300	0.017	0.390	−0.084	0.117	0.331	0.792
	CBCT 400–RG 400	–[a]					
DS	CBCT 0–RG 0	0.300	1.430	−0.069	0.669	1.625	0.109
	CBCT 100–RG 100	1.233	1.064	0.959	1.508	8.983	0.000**
	CBCT 200–RG 200	0.067	0.252	0.002	1.132	2.053	0.045*
	CBCT 300–RG 300	−0.017	0.129	−0.050	0.017	−1.000	0.321
	CBCT 400–RG 400	–[a]					

DD Dentists, *DA* dental assistants, *DS* dental students ($n=20$)
*$p<0.05$, **$p<0.001$, significant
[a] The correlation and t cannot be computed because the standard error of the difference is 0.

(0–400 μm) served as a model. High resolution CT images from this model were presented to 21 dentists for judgment. A periodontal gap wider than 110 μm could be recognized with an accuracy of 85% (unpublished data).

The use of conventional CT in general dentistry has been limited, because of two critical issues, a low vertical resolution and the high radiation dose. CBCT has several advantages compared with conventional CT: a shorter scan time, better vertical resolution, and lower exposure dose. The NewTom 9000 is a computerized volumetric tomograph dedicated to the dentomaxillofacial imaging. The volume acquired with the CBCT includes image formation for other views such as panoramic and occlusal. This volume can be viewed from numerous perspectives by using the accompanying software [4, 6, 9, 10, 13, 15, 16, 18, 22, 25, 27–29].

We designed this in vitro study to evaluate the usefulness of the CBCT in visualizing the periodontal ligament space compared to the conventional RGs since no reports have yet described the use of CBCT in the assessment of periodontal ligament space. The present study involved subjective visual evaluations of image quality. According to the results, dentists, dental assistants, and dental students mostly failed to identify the periodontal ligament space narrower than 200 μm. Within the limits of the present study, we conclude that using this CBCT technology for assessment of the periodontal ligament space, the resolution of the resulting images is inferior compared to conventional dental RGs. CBCT may not be the modality of choice for assessing periodontal ligament space. However the incidence of "not visible" periodontal ligament space was higher for CBCT, leading to the conclusion that those imaging processes may not be the alternative to the conventional RGs with regard to the visualization of small changes in periodontal ligament space. Similar to these results, Vandenberghe et al. [28] analyzed both bone loss, defects/furcations, and also small details like lamina dura, contrast, and bone quality which scored better on intraoral RGs.

In a previous study, a CBCT machine for dental use (3DX, marketed as 3D Accuitomo in Europe and United States) were compared with the multidetector CT (MDCT) for image quality of a maxillary incisor and mandibular first molar in an anthromorphic phantom and the observers evaluated how well the periodontal ligament space and lamina dura were portrayed [5]. According to that study, CBCT far surpassed the MDCT in terms of evaluation of periodontal ligament space and lamina dura. In 2006, the same group used dried specimen of the maxillary bone and investigated 3DX and MDCT images with respect to bone structure image quality. 3DX images were scored highly for the periodontal ligament space and lamina dura [6]. Lofthag-Hansen et al. [9] evaluated 3D Accuitomo for the diagnosis of apical periodontal disease. They found more affected roots with the 3D Accuitomo than with conventional intraoral radiography. In a recent study, Stavropoulos and Wenzel [25] evaluated the accuracy of CBCT scanning (NewTom 3G) with intraoral periapical radiography (Dixi2, Planmeca CCD sensor and Insight film) for the detection of periapical bone defects. They stated that a statistically significant difference in sensitivity was observed between NewTom 3G and intraoral radiography, but no difference in specificity was found. Thus, if a defect does not exist, all diagnostic modalities as well as NewTom fail to show the non-existence of the defect. In our study, CBCT showed 0-μm gap with slightly higher percentages than RGs although it was less accurate to detect 100-μm gap.

Intraoral radiography, panoramic radiography, CT, and CBCT techniques were compared for detection of intrabony defects, dehiscence, fenestration, and furcation involvements [15]. All the defects were reported to be exactly presented in three dimensions both with CT and CBCT. In terms of image quality, the CBCT scans were found to be superior to the CT scans with particular reference to the periodontal ligament space [15]. Moreover, buccal and lingual bone defects could be diagnosed correctly with CBCT [16]. Contrary to those results, in our study, RGs were found significantly superior to CBCT images and this was thought to be partly a result of inexperience on the part of the observers in viewing CBCT images.

From the point of view of radiation risk, the difference between intraoral RGs and a multilayer tomogram is not great enough to justify the use of tomography in cases where a diagnostic problem of clinical importance cannot be solved using conventional techniques [26]. In a previous study, the effective dose (the effective dose is used to estimate the damage from radiation to an exposed population) associated with a new generation maxillofacial CBCT was found to be many times lower than with the other CT devices and within the range of traditional dental imaging modalities [13]. The absorbed dose profiles of this CBCT were compared with a conventional CT (Somatom Plus 4, Siemens, Erlangen, Germany) regarding the maximum value of the central profile, and the dose provided by CBCT was approximately one sixth of the conventional CT [18]. In addition to this, skin doses from the 3DX were observed to be extremely low, approximately 1/400 of those from the MDCT. Although there are several advantages of CBCT and reduced radiation dose compared to CT, the radiation risk for patients does not still justify the use of CBCT in routine periodontal diagnosis.

According to our results, there may have been a bias toward conventional radiography, and we thought that the examiners in the present study were well acquainted with this routine imaging method. We did not find any comparable differences in recognizing all radiographic images of periodontal gaps between dentists, dental assistants, and dental students who are all familiar with identifying the RGs.

As indicated in the present study, CBCT was perceived to be inferior to conventional RGs in terms of the clarity of the artificial periodontal ligament space. However, within the limits of this in vitro study, it was concluded that further research is necessary for observing smaller slice thickness and window/level techniques to optimize the image for periodontal ligament space assessment. In addition to this, the CBCT imaging technique should be evaluated in the in vivo conditions, i.e., periodontal diseases, to see whether this technique will be the method used in the initial phase of periodontal diagnosis since in vitro conditions do not always reflect the clinical situations.

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