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Diagnostic accuracy of periapical radiolucency using periapical radiography and cone-beam computed tomography

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ABSTRACT

Objectives: This research is aimed to compare the accuracy of periapical radiography in detecting periapical radiolucency with that of Cone-beam Computed Tomography (CBCT) and to assess the additional information that CBCT provides.

Materials and Methods: 96 patients with a primary diagnosis of endodontic problem had been studied retrospectively. Each root was examined for the presence or absence of periapical lesions according to the Periapical Index (PAI) Score. Roots and root canals identified through perapical radiography and CBCT were recorded. Additional information from CBCT regarding effects of lesions in cortical bone and maxillary sinus was also noted. Sensitivity, specificity, positive predictive value, and negative predictive value were analyzed.

Results: The result showed that accuracy of periapical radiography as expressed by its sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) was 0.65, 0.90, 0.86, 0.75, respectively.

Conclusion: Periapical radiography has a low sensitivity in detecting periapical lesions compared to CBCT. CBCT also provides more detailed information that is useful in endodontic treatment.

Keywords: *Detection, periapical lesion, periapical radiography, CBCT*

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INTRODUCTION

Radiographic examination has a very important role in endodontic treatment from the pre-operative phase through treatment and into post-operative review. Radiographic images should provide the clinician with accurate information regarding tooth morphological variations, number of roots and root canals, and the presence or absence of periapical lesions.[1,2] This information aids the clinician in establishing a proper diagnosis and a better treatment plan, and increases the success rate of endodontic procedures.[3]

Currently, intraoral periapical radiography is commonly used during endodontic treatment. The technique used to obtain the image is quite simple compare to panoramic or CBCT. A study comparing conventional and digital periapical film stated that the diagnostic accuracy between two modalities is equal in detecting periapical lesion. Regarding image quality, conventional periapical film has good contrast and resolution rather than digital film.[4] However, its diagnostic performance is limited by its visualization of three-dimensional anatomical structures in the form of two-dimensional images. Thus, many normal anatomical structures are seen superimposed. Under these circumstances it is very difficult to detect small lesions, especially those confined within cancellous bone and those that have not reached the cortical bone plate.[5,6] It is widely accepted that, for a bone lesion to be visible in radiographic examination, it must have reached a state of 30%-50% mineral loss.[7] The location of a lesion relative to the surrounding normal anatomical structures such as the maxillary sinuses and zygomatic processes will also affect its visibility in periapical radiographs.[8]

CBCT, in contrast, provides the clinician with three-dimensional images, thereby overcoming the limitations of conventional radiographs. In recent years, it has been successfully used for a variety of endodontics-related purposes, such as differentiating pathosis from normal anatomy, determining a lesion's relationship with important anatomical structures, identifying the accessory canal, and aiding in the management of dens invaginatus and pulp anatomy variations, external and internal root resorption, the surgical management of fractured instruments and surgical endodontic planning.[9,10,11]

A periapical lesion is the result of a bacterial infection which has spread through a root canal into the periapical region. One consequence of increased bacterial presence in the apical area is

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the destruction of bone structure. Several changes visible on radiographs are commonly associated with periapical lesions; one sign of chronic periapical lesion, the widening of the periodontal ligament space, is usually related to initial or residual inflammation. Changes in lamina dura integrity may indicate the early stages of a periapical lesion. The destruction of cancellous bone in the apical area or extending into the furcation area and root resorption are also consequences of increased bacterial presence.[8,12]

The purpose of this study is to compare the accuracy of periapical radiography in detecting periapical radiolucency with that of CBCT and to assess the additional information that CBCT provides.

MATERIALS AND METHODS

In this study, 96 patients with a primary diagnosis of endodontic problems were selected. All patients had undergone periapical radiographic examinations for diagnostic or treatment-planning purposes, but their endodontists had referred them for CBCT examinations due to some problem that arose during or after treatment. They had specifically requested detailed information regarding anatomy and pathology including the causative tooth and expansion of lesions, the possibility of additional root canals and/or roots, suspected vertical root fractures, and preoperative examinations before periapical surgery. CBCT images and periapical radiographs were collected from the patient database of the Dentomaxillofacial Radiology Department, Showa University Dental Hospital and retrospectively studied. This study was approved by the Ethical Committee of Showa University.

CBCT images were obtained on a 3D Accuitomo machine (J. Morita, Kyoto, Japan) whose field of view (FOV) is a cylinder with a height of 40 mm, a diameter of 40 mm, and a voxel size of 80 µm. Exposure parameters were 80 kV tube voltage, 4 mA tube current and 18 s exposure time. Under these conditions, the dose-area product (DAP) measured by Dose Area Product Meter (PTW Diamentor M4, PTWFreiburg, Germany) was 236 mGycm^2. After scanning in three orientations and recording sagittal, coronal and axial sections with slice widths of 0, 24 mm and/or 0, 56 mm, the volume data were constructed using dedicated CBCT software. Intraoral periapical radiographs were obtained using the parallel technique, and exposure time varied depending on tooth type. F-Speed film was used and processed in an automatic processing machine. Periapical radiographs were observed in a film viewer with the aid of a magnifying glass. CBCT images were observed on a computer screen using One Data Viewer® Software (J. Morita, Kyoto, Japan). All images were analyzed by four maxillofacial radiologists independently. When there was a disagreement, a consensus was reached after discussion.

Each root was assessed by each observer regarding the presence or absence of periapical lesions according to the Periapical Index (PAI) Score established by Ørstavik et al.[12] Each root was classified as: (1) normal periapical structure; (2) small changes in bone structure; (3) changes in bone structure with some mineral loss; (4) periodontitis with well-defined radiolucent area; (5) severe periodontitis with exacerbating feature. Roots with PAI scores of 1 and 2 were categorized as normal while those with scores of 3 to 5 were considered to have periapical lesions. All observers were given the following instructions for each scoring: (1) find the reference radiograph where the periapical area most closely resembles the periapical area you are studying and assign the corresponding score to the observed root; (2) when in doubt, assign the higher score; (3) for multi-rooted teeth, each root must be given its own score.

The numbers of roots and root canals visible on periapical radiographs and CBCT images were recorded. On CBCT, additional information regarding cortical bone expansion caused by periapical lesions on the mandible and maxilla was also recorded. The abbreviation T (thinning) was used to indicate the thinning of cortical bones, and E (expansion) to indicate the expansion of cortical bones that were still surrounded by a thin outer shell of bone. The effect of periapical lesions on the maxillary sinus was also noted with the abbreviation E (expansion) if the periapical lesion invaginated into the maxillary anthrum and with P (perforation) if there was communication between the lesion and the maxillary sinus.

The results of our assessment of periapical lesions in CBCT and periapical radiographs are presented in frequency tables, assuming CBCT as the gold standard. Sensitivity, specificity, positive predictive value, and negative predictive value were analyzed.

RESULTS

Periapical radiographs and CBCT images from 96 patients were observed retrospectively. The patients consisted of 21 males with an age range of 27-84 years and 75 females with an age range of 11 -76 years. The overall mean age of patients was 49 years. In total, 110 teeth were observed on periapical radiographs and CBCT images. The distribution of involved teeth and number of roots assessed in this study is presented in Table 1.

The results of our periapical lesion assessment according to PAI Score are shown in Table 2. The present of periapical lesions are defined as roots with PAI score 3 to 5 and absent are defined as roots with PAI score 1 and 2. A total of 205 roots were assessed for the presence or absence of periapical lesions. In periapical radiographs, periapical lesions appeared to be present in 74 (36%) roots and absent in 131 (64%) roots. In CBCT, however, the number of apparent periapical lesions in the same set of roots rose to 97 (47%) while only 108 (53%) roots appeared to be free of such lesions.

Table 1. The distribution of teeth and number of roots assessed in this study

Periapical radiograph	Molar				Premolar			Canine	Incisor	Total
Number of root	**4**	**3**	**2**	**1**	**3**	**2**	**1**	**1**	**1**	
Maxilla		31	1	1		6	8	6	26	79
Mandible		1	24				4	1	1	31
										110

CBCT	Molar				Premolar			Canine	Incisor	Total
Number of root	**4**	**3**	**2**	**1**	**3**	**2**	**1**	**1**	**1**	
Maxilla		31	1	1	1	6	7	6	26	79
Mandible	1	5	19				4	1	1	31
										110

Table 2. The results of periapical lesion assessment according to PAI Score

		CBCT					
	PAI Score	**1**	**2**	**3**	**4**	**5**	**Total**
Periapical Radiograph	**1**	32	32	3	2		59
	2	13	30	15	11	3	72
	3	2	9	15	15	1	42
	4			2	16	3	21
	5				7	4	11
		47	61	35	51	11	205

Note: CBCT (Cone Beam Computed Tomography); PAI Score (Periapical Index Score)

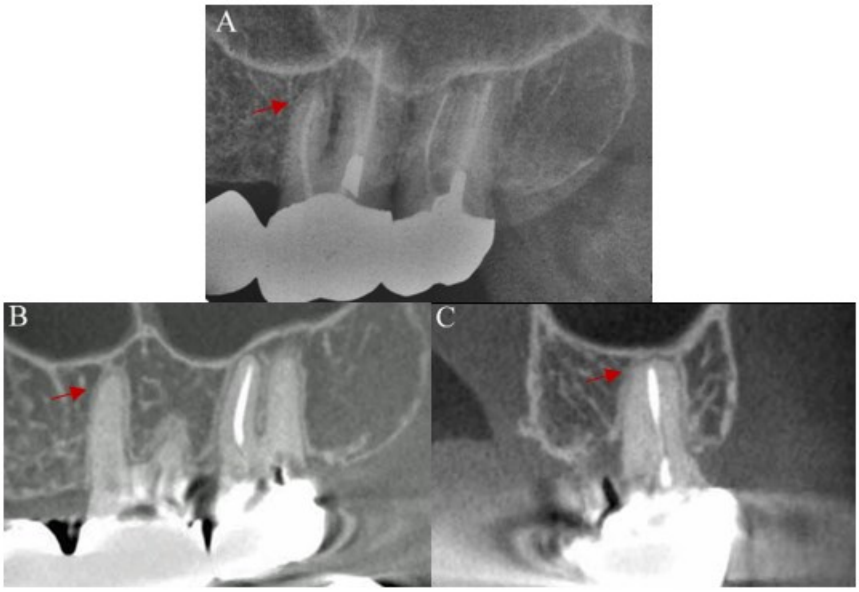

Figure 1. Comparison of PAI score between periapical radiograph and CBCT of tooth 27. Periapical radiograph of tooth 27 (A) shows small radiolucent area at apical region of mesial root, widening of periodontal ligament space, and loss of lamina dura integrity (PAI score 3). CBCT image of tooth 27 shows on sagittal (B) and coronal (C) view of tooth 27 there are no sign of periapical lesion on mesial root (PAI score 1).

Lesion severity was overestimated in 33 (16%) roots (Fig. 1) and underestimated in 79 (38%) roots (Fig. 2) when the roots were assessed by periapical radiograph alone.

Ten additional roots that were visible on CBCT but not on periapical radiograph were located in the mandibular molars (n = 5), maxillary molars (n = 2), and maxillary premolars (n = 2). Those roots were not included in this study. With regard to variations in tooth anatomy, distolingual roots were found in mandibular first molars (n = 4), and a mandibular second molar (n = 1). One maxillary first premolar was observed to have three roots (Figure 3).

The accuracy of periapical radiography in detecting periapical lesions is presented in Table 3. Sensitivity was 0.65 and specificity 0.90 for periapical radiographs, while PPV and NPV for periapical radiographs were 0.86 and 0.75 respectively.

Additional findings pertaining to the effects of lesions on the cortical bone plate and maxillary sinus were visible in the CBCT images; the data distribution for these is presented in Table 4. A total of 43 (39%) teeth showed lesion-related changes in the cortical bone and maxillary sinus. All cases of expansion and perforation in the maxillary sinus caused by periapical lesions were due to lesions in the maxillary molars and premolars; none were due to lesions in the canine teeth or incisors. Thinning, expansion, and destruction of buccal and/or palatal or lingual cortical bone plate were seen more often in CBCT images (Figure 4 and 5).

Figure 2. Comparison of PAI score between periapical radiograph and CBCT of tooth 26. Periapical radiograph (A) shows no sign of lesion at mesial, distal, or palatal root (PAI score 2 for mesial, distal, and palatal roots). CBCT image of tooth 26 shows on coronal (B) and sagittal (C) view of mesial root there are radiolucent area at the apical region, well defined and corticated (PAI score 4).

Figure 3. Three-rooted first maxillary premolar cannot be identified on periapical radiograph (A) because of superimposition; there is also no sign of periapical radiolucency. Axial views on CBCT image (B) show that the tooth has three roots. Sagittal view of mesial and distal roots (C) shows the presence of large periapical radiolucencies involving both roots, well defined, and corticated, while the palatal root (D) features only a widening of periodontal ligament space.

Table 3. Sensitivity, Specificity, PPV, NPV of Periapical Radiography using CBCT as Gold Standard

		CBCT		
		Positive	**Negative**	**Total**
Periapical radiograph	**Positive**	63	11	74
	Negative	34	97	131
	Total	97	108	205

Sensitivity 0.65; Specificity 0.90; Positive predictive value 0.65; Negative predictive value 0.75

Table 4. Distribution of teeth and periapical lesions affecting cortical bone plate or maxillary sinus

		Maxilla				**Mandibula**				
		M	**P**	**C**	**I**	**M**	**P**	**C**	**I**	**Total**
Cortical bone	**Thinning**	8	5	2	6	1		1		
	Expansion	2	1		6	3				
Maxillary sinus	**Expansion**	6	1							
	Perforation	1								
	Total	17	7	2	12	4		1		43

Note: M (molar); P (premolar); C (caninus); I (incisor)

Figure 4. Periapical lesion cannot be detected on periapical radiograph (A); no sign of mucosal thickening on the sinus floor. Coronal (B) and sagittal (C) view of CBCT image shows an expansion and some mucosal thickening in the sinus floor.

DISCUSSION

The results of this study suggest that periapical radiography has a low accuracy in detecting periapical radiolucency. The sensitivity and specificity of these scans were 0.65 and 0.90 respectively. This means that periapical radiography was only able to detect the presence of periapical lesions in 65% of cases. The results of this study are in agreement with those of Estrela et al.[14] In their study, which had a larger sample size, they compared the accuracy of periapical and panoramic radiographs using CBCT as a gold standard. A total of 1508 teeth from 888 patients were observed; the overall values for the sensitivity and specificity of periapical radiography were 0.55 and 0.98 respectively. Several other studies using artificial periapical lesions have also verified that the accuracy of periapical radiography is inferior to that of CBCT. Patel et al.[15] generated small and large artificial periapical lesions in the distal roots of six molar teeth in human mandibles and reported that the overall sensitivity of periapical radiography was 0.24 while the specificity was 1.0, compared to 1.0 and 1.0, respectively, for CBCT images. This shows that periapical radiography has a low accuracy in

Figure 5. Periapical radiograph of tooth 26 (A) does not reveal perforation of the maxillary sinus. Sagittal (B), coronal (C), and axial (D) view on CBCT image shows perforation of the maxillary sinus floor caused by odontogenic infection.

detecting both small and large periapical lesions. In another study, Kanagasigam et al.[16] compared the accuracy of periapical radiography and CBCT at diagnosing periapical lesions to that of histopathological findings as a gold standard on jaw section containing 67 teeth (86 roots). Their results yielded sensitivity and specificity values for periapical radiographs of 0.27 and 0,99, while the same values for CBCT were 0.89 and 1, respectively. This shows that periapical radiography is not sensitive at detecting periapical lesions, though it is able to confirm when periapical lesions are absent, in this case with 100% accuracy (specificity 1.0). Sogur et al.[17] reported lower sensitivity and specificity values in chemically induced lesions: after 1 hour of chemical treatment, the sensitivity and specificity values of periapical radiography were 0.68 and 0.52, while those for CBCT were 0.83 and 0.71 respectively. After 1.5 hours, the sensitivity and specificity of periapical radiography increased to 0.90 and 0.52, while those of CBCT were 0.92 and 0.71. After 2 hours, the values were 0.95 and 0.52 for periapical radiography and 0.97 and 0.70 for CBCT. The lower specificity values in this study might have been caused by an increased number of false-positive results in both periapical radiographs and CBCT.

The limitations of periapical radiography in detecting periapical lesions are clearly shown in the present study. Viewing periapical radiographs alone, the observer underestimated lesion severity in 79 (38%) roots. In the lower mandibular molars, small lesions are particularly difficult to detect on periapical radiographs. It is also sometimes difficult to distinguish the boundaries of a lesion and to determine whether it is corticated and the extent to which it invades the cortical bone or maxillary sinus. There are several reasons for this: first, lesions located inside cancellous bone with little or no cortical plate erosion can be difficult to diagnose before they reach the cortical bone, because cortices have a masking effect on such lesions.[6,18] Bender and Seltzer[5,6] concluded that bone lesions could be detected in periapical radiographs only in cases of perforation, extensive destruction of the bone cortex on the outer surface or erosion of the cortical bone from the inner surface. Radiographic visualization of a lesion is also influenced by the lesion's location and the type of bone it is in, particularly the composition of the mineralized tissue and the mineral content per unit volume of bone.[7] In the maxillary molar area, projection geometry is not optimal due to the low palatal vault and the complex anatomical structures nearby such as the maxillary sinus and zygomatic process as well as the characteristics of the surrounding bone structure. In this region, X-ray beam angulation errors will result in superimposition of the zygomatic process and bone to the roots.[8,14] In contrast, CBCT devices and their sophisticated software allow the clinician to select the optimal image from three orthogonal planes, thus eliminating interference from adjacent anatomical structures. The image can be displayed in axial, sagittal, and coronal planes simultaneously.[17,18] For example, the root of a maxillary molar and its periapical tissue can be visualized separately in all three orthogonal planes without superimposition of the overlying anatomical structure. The roots of multi-rooted teeth can be visualized individually and their spatial relationship seen clearly.[17,20]

Given that the essential goal of root canal therapy is to clean, shape, and seal all of the root canals in each treated tooth, awareness of each patient's tooth and root morphology is important in endodontic treatment. Some studies have reported that distolingual roots can often be found in mandibular molars. A study conducted by Zhang et al.[21] using CBCT reported that 30% of mandibular first molars have distolingual roots. Huang et al.[22] reported distolingual roots in 22% of molars and 24% of examined subjects. Three-rooted maxillary premolars, on the other hand, are very rare. Tian et al.[23] have reported that, in 300 CBCT images showing maxillary premolars, only two of these teeth have three roots. Likewise, Iqbal[24] has reported that only three (1.2%) out of 246 extracted first premolars had three roots. In the present study, five distolingual roots were seen in CBCT images, located in the mandibular first molar (n = 4) or the mandibular second molar (n = 1); there was also one three-rooted first maxillary premolar. These roots were difficult to see on periapical radiographs, even though the images were taken using parallel technique, perhaps because of root overlap making several roots look like one. Failure to identify a root will lead to root canal treatment failure due to the persistence of bacteria in the periapical region and the resulting development of secondary infection in the periradicular area. It is important to identify any distolingual roots before and during root canal treatment in order to avoid complications and treatment failure.[25,26] CBCT can aid the clinician in determining the locations of all extant root canals before treatment begins, thus reducing the time that must be spent exploring the pulp chamber in search of orifices.[4]

The additional information yielded by CBCT regarding the effects of periapical lesions on the cortical bone plate and maxillary sinus was recorded. In the present study, 43 (39%) teeth had lesions affecting the cortical bone plate and maxillary sinus. Lofthag-Hansen et al.[14] and Hu et al.[27] have reported that CBCT is better than periapical radiography at detecting the effect of periapical lesions on the cortical bone plate and maxillary sinus. This information provided by CBCT is valuable in treatment planning for apical surgery. Al Mheiri et al.[28] have reported that analysis of CBCT images makes it possible not only to evaluate interposition of the maxillary sinus between the roots but also to detect any other pathological condition caused by the lesion to the sinus itself. During apical surgery such information can facilitate vestibular access to the palatine roots of the maxillary molars. Chanani et al.[29] stated that CBCT images may provide a better, more accurate, and faster method for differential diagnosis of a solid lesion from a fluid-filled lesion or cavity. This allows the clinician to determine whether surgery is required without waiting through the recall period to see if healing has occurred.

The effective radiation dose required for a CBCT scan can be as low as that for a panoramic dental X-ray and less than that for a medical CT scan. Koivisto et al.[30] and Weiss and Reid-Fuller[31] stated that the effective dose for CBCT varies depending on the device but is typically less than the doses reported for medical CT scans. It should be noted, however, that the presence of artefacts on CBCT sometimes makes interpretation of the images difficult. Artefacts are common in modern CBCT and are caused by discrepancies between mathematical modeling and the actual physics of the imaging process.[32]

In this study, we used conventional periapical film rather than digital periapical radiography because several studies have stated that the diagnostic accuracies of the two techniques are equal. In a study comparing conventional and digital film in terms of diagnostic accuracy at detecting periapical bone lesions, Campello et al.[33] found that the digital system was inferior when high-contrast resolution was used, but comparable to E-speed film when low-contrast resolution was used. No significant differences in diagnostic accuracy were seen between the areas under the receiver operating characteristic curves. Ramis-Alario *et al.*[4] also reported that digital film and conventional film are comparable in detecting lesions, and that digital imaging did not enhance the ability to detect lesions.

CONCLUSION

Periapical radiography has a low sensitivity in detecting periapical lesions compared to CBCT. CBCT also provides more detailed information that is useful in endodontic treatment, especially in root canal therapy of the maxillary or mandibular molars. Even though CBCT is very useful in dentistry, we should not discount its limitations. When indicated, three-dimensional CBCT scans should supplement conventional two-dimensional radiographic techniques; in this way we will gain the benefit of both systems. As a final note, we should always consider the ALARA (As Low As Reasonably Achievable) principle in prescribing radiographic examination.

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FOOTNOTES

All authors have no potential conflict of interest to declare for this article. This study was approved by the Ethical Committee of Showa University. All procedures conducted were in accordance with the ethical standards.

REFERENCES

1. Patel S, Dawood A, Whaites E, Pitt Ford T. New dimensions in endodontic imaging: part 1. Conventional and alternative radiographic systems. Int Endod J. 2009;42:447-62.
2. Patel S, Dawood A, Ford TP, Whaites E. The potential applications of cone beam computed tomography in the management of endodontic problems. Int Endod J. 2007;40:818-30.
3. Patel S, Wilson R, Dawood A, Mannocci F. The detection of periapical pathosis using periapical radiography and cone beam computed tomography - part 1: pre-operative status. Int Endod J. 2012;45:702-10.
4. Ramis-Alario A, Tarazona-Alvarez B, Cervera-Ballester J, Soto-

Peñaloza D, Peñarrocha-Diago M, Peñarrocha-Oltra D, Peñarrocha-Diago M. Comparison of diagnostic accuracy between periapical and panoramic radiographs and cone beam computed tomography in measuring the periapical area of teeth scheduled for periapical surgery. A cross-sectional study. J Clin Exp Dent. 2019 Aug 1;11(8):e732-e8.
5. Bender IB, Seltzer S. Roentgenographic and direct observation of experimental lesions in bone: I. 1961. J Endod. 1961;29:702-6.
6. Tsai P, Torabinejad M, Rice D, Azevedo B. Accuracy of cone-beam computed tomography and periapical radiography in detecting small periapical lesions. Journal of Endodontics. 2012;38(7):965–70.
7. Bender IB. Factors influencing the radiographic appearance of bony lesions. J Endod. 1982;23:5-14.
8. Huumonen S, Ørstavik D. Radiological aspects of apical periodontitis. Endod Top. 2002;I:3-25.
9. Tyndall DA, Rathore S. Cone-beam CT diagnostic applications: caries, periodontal bone assessment, and endodontic applications. Dent Clin North Am. 2008;52:825-41.
10. European Commission, Radiation Protection 136: European guidelines on radiation protections in dental radiology. 2004;28-9.
11. Sedentext CT, Radiation Protection: Cone Beam CT for Dental and Maxillofacial Radiology. 2011;57-8.
12. Estrela C, Bueno MR, Leles CR, Azevedo B, Azevedo JR. Accuracy of cone beam computed tomography and panoramic and periapical radiography for detection of apical periodontitis. J Endod. 2008;34:273-9.
13. Orstavik D, Kerekes K, Eriksen HM. The periapical index: a scoring system for radiographic assessment of apical periodontitis. Endod Dent Traumatol. 1986;2:20-34.
14. Lofthag-Hansen S, Huumonen S, Gröndahl K, Gröndahl HG. Limited cone-beam CT and intraoral radiography for the diagnosis of periapical pathology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;103:114-9.
15. Patel S, Dawood A, Mannocci F, Wilson R, Pitt Ford T. Detection of periapical bone defects in human jaws using cone beam computed tomography and intraoral radiography. Int Endod J. 2009;42:507-15.
16. Kanagasingam, S, Lim, CX, Yong, CP, Mannocci, F, Patel, S. Diagnostic accuracy of periapical radiography and cone beam computed tomography in detecting apical periodontitis using histopathological findings as a reference standard. International Endodontic Journal. 2017;50:417–26.
17. Sogur E, Baksi BG, Gröndahl HG, Lomcali G, Sen BH. Detectability of chemically induced periapical lesions by limited cone beam computed tomography, intra-oral digital and conventional film radiography. Dentomaxillofac Radiol. 2009;38:458-64.
18. Patel, S, Brown, J, Pimentel, T, Kelly, RD, Abella, F, Durack, C. Cone beam computed tomography in Endodontics – a review of the literature. International Endodontic Journal. 2019;52:1138–52.
19. Patel S. New dimensions in endodontic imaging: Part 2. Cone beam computed tomography. Int Endod J. 2009;42:463-75.
20. Song D, Zhang L, Zhou W, Zheng Q, Duan X, Zhou X, Huang D. Comparing cone-beam computed tomography with periapical radiography for assessing root canal obturation in vivo using microsurgical findings as validation. Dentomaxillofac Radiol. 2017 Jul;46(5):20160463.
21. Zhang R, Wang H, Tian YY, Yu X, Hu T, Dummer PM. Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular molars in Chinese individuals. Int Endod J. 2011;44:990-9.
22. Huang RY, Cheng WC, Chen CJ, Lin CD, Lai TM, Shen EC, Chiang CY, Chiu HC, Fu E. Three-dimensional analysis of the root morphology of mandibular first molars with distolingual roots. Int Endod J. 2010;43:478-84.
23. Tian YY, Guo B, Zhang R, Yu X, Wang H, Hu T, Dummer PM. Root and canal morphology of maxillary first premolars in a Chinese subpopulation evaluated using cone-beam computed tomography. Int Endod J. 2012;45:996-1003.
24. Iqbal A, Karobari MI, Alam MK, Khattak O, Alshammari SM, Adil AH, Noorani TY, Algarani HA, Alonazi MA, Sirivastava KC, Issrani R. Evaluation of root canal morphology in permanent maxillary and mandibular anterior teeth in Saudi subpopulation using two classification systems: a CBCT study. BMC Oral Health. 2022 May 10;22(1):171.
25. Abella F, Patel S, Duran-Sindreu F, Mercadé M, Bueno R, Roig M. Evaluating the periapical status of teeth with irreversible pulpitis by using cone-beam computed tomography scanning and periapical radiographs. J Endod. 2012;38:1588-91.
26. Narayanan LL, Vaishnavi C. Endodontic microbiology. J Conserv Dent. 2010 Oct;13(4):233-9.
27. Hu X, Lei L, Cui M, Huang Z, Zhang X. Anatomical analysis of periapical bone of maxillary posterior teeth: a cone beam computed tomography study. J Int Med Res. 2019 Oct;47(10):4701-10.
28. Al Mheiri E, Chaudhry J, Abdo S, El Abed R, Khamis AH, Jamal M. Evaluation of root and canal morphology of maxillary permanent first molars in an Emirati population; a cone-beam computed tomography study. BMC Oral Health. 2020 Oct 7;20(1):274.
29. Chanani A, Adhikari HD. Reliability of cone beam computed tomography as a biopsy-independent tool in differential diagnosis of periapical cysts and granulomas: An In vivo Study. J Conserv Dent. 2017 Sep-Oct;20(5):326-31.
30. Koivisto J, van Eijnatten M, Ludlow J, Kiljunen T, Shi XQ, Wolff J. Comparative dosimetry of radiography device, MSCT device and two CBCT devices in the elbow region. J Appl Clin Med Phys. 2021 May;22(5):128-38.
31. Weiss R, Read-Fuller A. Cone Beam Computed Tomography in Oral and Maxillofacial Surgery: An Evidence-Based Review. Dent J (Basel). 2019 May 2;7(2):52.
32. Smeets R, Schöllchen M, Gauer T, Aarabi G, Assaf AT, Rendenbach C, Beck-Broichsitter B, Semmusch J, Sedlacik J, Heiland M, Fiehler J, Siemonsen S. Artefacts in multimodal imaging of titanium, zirconium and binary titanium-zirconium alloy dental implants: an in vitro study. Dentomaxillofac Radiol. 2017 Feb;46(2):20160267.
33. Campello AF, Gonçalves LS, Guedes FR, Marques FV. Cone-beam computed tomography versus digital periapical radiography in the detection of artificially created periapical lesions: A pilot study of the diagnostic accuracy of endodontists using both techniques. Imaging Sci Dent. 2017 Mar;47(1):25-31.