

Comparison of diagnostic accuracy of root perforation, external resorption and fractures using cone-beam computed tomography, panoramic radiography and conventional & digital periapical radiography

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ABSTRACT

Context: Some radicular changes are challenging for clinicians to diagnose, such as of root perforations, external root resorption (ERR), and vertical root fractures (VRFs). This study aims to facilitate it by comparing the diagnostic accuracy of cone-beam computed tomography (CBCT), orthopantomography, and conventional and digital periapical radiography (DPR) in the diagnosis of such problems. Is it worth doing CBCT despite the radiation dose?

Aims: To evaluate and compare the diagnostic accuracy of CBCT, panoramic radiography, and conventional and DPR in the diagnosis of root perforation (RP), ERR, and VRF.

Materials and Methods: The sample consisted of 40 extracted human teeth and 10 macerated human mandibles. RPs were performed using diamond burs, ERRs using spherical carbide burs, and RPs using a universal machine EMIC-DL 1000. The images were evaluated by 6 dentomaxillofacial radiologists.

Results: Receiver operating characteristic (ROC) revealed that CBCT showed the highest area under the ROC curve (Az) values for RP, ERR, and VRF (0.903, 0.950, and 0.849, respectively). The worst Az values for RP, ERR, and VRF (0.718, 0.494, and 0.611, respectively) were for panoramic radiography.

Conclusions: CBCT showed the best results in the diagnosis of ERR and VRF. The diagnosis of ERR was the least accurate, panoramic radiography being not appropriate for its diagnosis. CBCT and conventional periapical radiography obtained similar results for the evaluation of RP. So for, RP indicate the conventional periapical radiography because CBCT has a higher radiation dose.

Key words: Cone-beam computed tomography, diagnosis, digital radiography, orthopantomography, root resorption, tooth fractures

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The diagnosis of radicular changes is a challenge in dentistry, one that requires imaging techniques that allow observation not only of the tooth in question but also of the adjacent bone structures.^[1,2]

Dental radiology offers several imaging methods to examine anatomical and pathological details during

treatment planning. However, despite the advancements in the area, the diagnosis of some radicular changes, such as root perforation, external root resorption (ERR) and vertical root fractures (VRFs), can still be a difficult task for dentists.^[3]

Root perforation (RP) is a communication between the root canal system and the external root surface.^[4] Usually an iatrogenic and undesirable incident, RP may occur at

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any stage of endodontic treatment and represent 10% of endodontic failures.^[5,6]

ERR has a complex etiology and its classification depends on the location and stimuli that induce its development. ERR in the permanent dentition usually results of trauma, orthodontic movements, tumors, and eruption of teeth.^[7] Early imaging diagnosis is essential since the stimulus that causes resorption must be removed as soon as changes are observed.

VRF are caused by impact of great strength. Compression on lingual and/or buccal aspect leads to separation of the root into two or more fragments.^[8,9] The diagnosis of VRF is difficult and imposes a challenge for the treatment planning.^[10] Clinical signs and symptoms of VRF are not pathognomonic of the condition and its prognosis is poor.^[11-13]

Conventional and digital periapical radiography (DPR) and panoramic radiography are typically used to diagnose radicular changes. Although they offer acceptable images in the mesiodistal aspects, they are unsatisfactory in the buccolingual aspect;^[14] a problem minimized with the advent of three-dimensional (3D) images of cone-beam computed tomography (CBCT).^[15-19]

Thus, the aim of the present study was to compare CBCT diagnostic accuracy with that of panoramic radiography and conventional and DPR in the diagnosis of RP, ERR, and VRF in the middle third of the root.

MATERIALS AND METHODS

Ethics

The study was approved by the Standing Committee on Ethics in Human Research of the State University of Maringá-PR, Brazil (Protocol CAAE: 03731012.9.0000.0104). This research was conducted in accordance with the Declaration of Helsinki.

Methodology

The sample consisted of 40 premolars teeth extracted from the Human Teeth Bank of the Department of Dentistry, State University of Maringá. The teeth were mounted in alveolar sockets of 10 macerated human mandibles using pink wax 7 (Polidental, Cotia, São Paulo, Brazil); hence, they were kept in place but could also be removed to create the artificial defects.

Artificial ERR were performed by the same operator using spherical carbide burs ($\frac{1}{4}$ diameter, KG Sorensen, Cotia, SP, Brazil), on the middle third of the three in the distal, three in the mesial, two in the lingual, and two in the buccal aspects of the roots, perpendicularly positioned to the surface, in high-speed rotation and constant cooling.^[7,20] The size of the wear was 0.25 mm diameter/0.25 mm depth

holes correspond to the size of the carbide burs. Only one size was used. The small size of resorption was determined based on literature, including being smaller than reported in literature.^[7,20] For minor defects, the greater the difficulty of diagnosis.^[7,20]

RPs were produced by single operator using diamond drills (FG 1011HL, kG Sorensen, Cotia, SP, Brazil), in a water-cooled high-speed handpiece at 45° angle to the long axis of each tooth, until perforations were observed on the two in the lingual, two in the buccal, three in the mesial, and three in the distal aspects of the root.^[6] The size of the perforations was 0.5 mm diameter. Only one size was used. The size was based on the literature and is equivalent to the size of the drill used in coronary opening, a major cause of RPs.^[7]

For the creation of VRFs, first, all teeth were examined using a stereomicroscope (Olympus SZX7, São Paulo, SP, Brazil). The crowns were sectioned 2 mm above the dentin-enamel junction.^[21-23] The teeth were placed into perforated polyvinyl chloride pipes to give the assembling material some retention and were fixed in place with acrylic resin (Classic, São Paulo, SP, Brazil).

A universal testing machine (EMIC-DL 1000, EMIC, São José dos Pinhais, PR, Brazil) created the VRFs using adequate strength for static tensile and compression tests. The strength was applied vertically to the center of the teeth, which were slightly worn to adapt the machine's strength applicator tip. Root fractures were generated in the vertical plane and the fracture line inclined orientation (buccolingual or mesiodistal) was also recorded. According to a protocol reported in literature,^[7,21,22] tooth roots broke into more than three fragments and were excluded from the study.

The same control group was used for comparison of RP-group and ERR-group. To compare with the VRF-group, the control group used was previously sectioned crown 2 mm above the dentin-enamel junction.^[21-23] The teeth were divided into four groups with 10 teeth each: Control Group, RP-Group, ERR-Group, and VRF-Group. Sample size determination specified the sample size used in the present study^[24] as well as a pilot study [Table 1].

The teeth mounted in the jaws were radiographed with conventional periapical radiographs (CPR) using RINN

Table 1: Sample size determination based on literature and a pilot study

Sample size determination	
SD	0.081
Probability to detect differences	0.140
Significance level (%)	5
Power (%)	95
Sample size required for each group	7
SD=Standard deviation	

film holder (Dentsply®, York, PA, USA). Three radiographs were taken with different beam angulations: An orthogonal projection and two projections with 20° horizontal shifts to mesial and distal of the central X-ray.^[23,25]

DPR were taken using RINN film holder (Dentsply®, York, PA, USA) coupled to complementary metal-oxide semiconductor sensor (CMOS, Schick®, Long Island City, New York, USA), again with different beam angulations: An orthogonal projection and two projections with 20° horizontal shifts to mesial and distal of the central X-ray.^[6,23,25]

Radiographs were taken using a dental X-ray machine 70X (Dabi Atlante®, São Paulo, Brazil) at 70 kVp, 8 mA, cylindrical locator with 40 cm focal length, exposure time of 0.4 s. Exposure parameters had been previously piloted according to the as low as reasonably achievable principle (as low as reasonably achievable).

Panoramic radiographs were obtained with Orthoralix 9200 GENDEX (Dentsply®, York, PA, USA) using T-Mat G/RA Kodak film (15 cm × 30 cm, Carestream Health®, Rochester, New York, USA) with their metallic cassette and intensifying screen (Kodak Lanex Medium Extraoral Imaging Screens X-Omat). The midsagittal plane of the jaws was positioned perpendicularly to the ground and the occlusal plane parallel to the ground. Periapical and panoramic films were processed in an automatic processor (Revell X-TEC, São Paulo, Brazil).

CBCT images were obtained with an i-CAT scanner (Imaging Sciences International, Hatfield, PA, USA), using 14-bit grayscale, field of view of 6 cm, voxel of 0.125 mm, 120 kVp, and 36.2 mAs exposure time, with the midsagittal plane of the jaws positioned perpendicularly to the ground and the occlusal plane parallel to the ground.

The CBCT images and DPR images were observed in an Intel Core I7 computer (6-GHz RAM, 500 GB hard drive) with a 20 inch LCD monitor (AOC, Top Victory Electronics, Taiwan), with the software CDR Dicom for Windows V4.5 (Schick Technologies, Long Island City, New York, USA) and the software Xoran CAT (Xoran CAT V.2.0.21, Xoran Technologies, Ann Arbor, MI, USA). The observers, according to necessity, adjusted the images' brightness and contrast, utilized the zoom tool, same room and evaluated the images from all available plans and reconstructions (axial, sagittal, and coronal planes; panoramic and parasagittal reconstructions). Conventional radiographs were examined on a light viewing box, in a dark room, using a × 4 magnifying glass. All the images were evaluated by six experts in Dental Radiology, and root changes were classified using a five-point scale: (1) Change definitely present, (2) change probably present, (3) uncertain, (4) change probably absent, and (5) change definitely absent. Random images

were evaluated the 2nd time 15 days later (Takeshita *et al.*,^[14] Takeshita *et al.*^[23]).

Data analysis

Statistical analysis used receiver operator characteristic (ROC) curves to evaluate the accuracy of the imaging methods. The values obtained for areas under the ROC curve were compared in pairs, with a significance level of 0.05 (MedCalc 12.3.0 Software, Ostend, Belgium). Kappa test^[26] was used to verify intra-examiner reliability, which revealed very good intra-examiner agreement, except for good intra-examiner agreement for panoramic radiography [Table 2].

RESULTS

Root perforation

CBCT obtained the highest values of sensitivity and specificity of the area under the ROC curve (Az) whereas the lowest were for panoramic radiography [Table 3 and Figure 1]. The mean Az values of CBCT differed significantly from DPR and from panoramic radiography [Table 4].

Table 2: Mean ratings of inter- and intra-examiner (Kappa test)

Imaging methods	Intra-examiner
CPR	0.813
DPR	0.809
Panoramic radiography	0.728
CBCT	0.878

CPR=Conventional periapical radiograph, DPR=Digital periapical radiograph, CBCT=Cone-beam computed tomography

Table 3: Area under the receiver operating characteristic curve and standard deviation of root perforation for each imaging method

Imaging method	Az	SD
CPR	0.820	0.048
DPR	0.788	0.052
Panoramic radiography	0.718	0.059
CBCT	0.903	0.034

CPR=Conventional periapical radiograph, DPR=Digital periapical radiograph, CBCT=Cone-beam computed tomography, SD=Standard deviation, Az=Area under the receiver operating characteristic curve

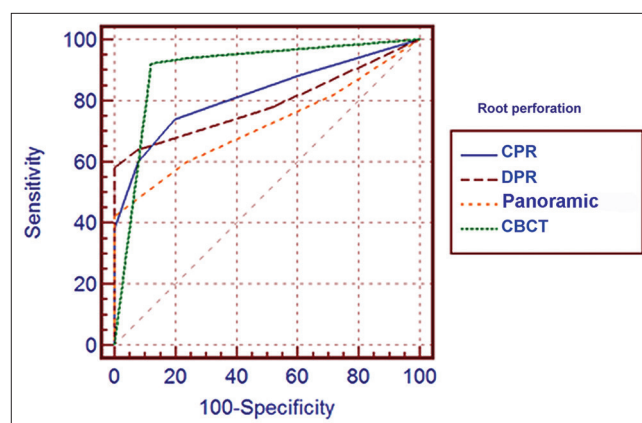


Figure 1: The receiver operator characteristic curve for the different imaging methods that analyzed root perforation

External root resorption

Again, sensitivity and specificity of the area under the ROC curve (Az) were high for CBCT and low for panoramic radiography [Table 5 and Figure 2]. The mean Az values of CBCT differed significantly from CPR, DPR, and panoramic radiography [Table 6].

Vertical root fracture

Once again, CBCT showed the highest values of sensitivity and specificity of the area under the ROC curve (Az), and panoramic radiography the lowest ones [Table 7 and Figure 3]. The mean Az values of CBCT differed significantly from CPR, DPR, and panoramic radiography [Table 8]. In addition, CPR differed from DPR.

DISCUSSION

A careful treatment planning uses several imaging methods to evaluate anatomical and pathological details the oral and maxillofacial complex. However, despite the current improvement in imaging techniques, diagnosis of some radicular changes, such as RP, ERR, and VRF, is still challenging.^[3]

Several instruments and techniques are suggested for clinical diagnosis of RP such as electronic apex locator, surgical microscopy, endoscopy, and radiographic methods.^[27-29] The present study evaluated RP using imaging methods recommended in literature: CPR, DPR, panoramic radiography, and CBCT. The RP was performed in different positions with the purpose of simulating the different possible failures in endodontic treatment.^[6] Similarly to the previous research,^[6,30,31] the present study found that CBCT was the most accurate imaging method.

CBCT was the most accurate in the diagnosis of RP in the present study, showing a higher value than that found by Shemesh *et al.*^[6] The present study used teeth without endodontic treatment as it is believed that once RP is found,

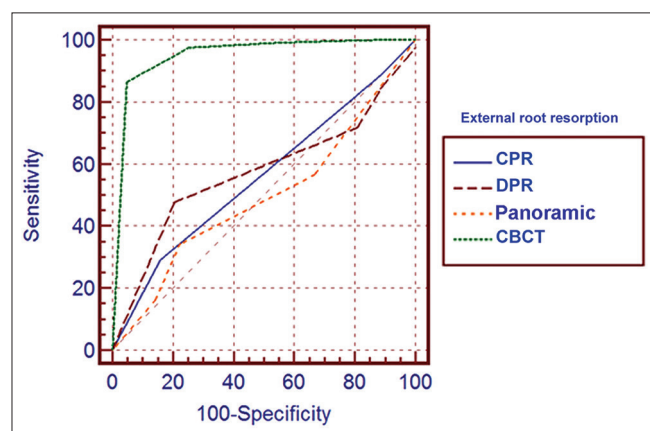


Figure 2: The receiver operator characteristic curve for the different imaging methods that analyzed external root resorption

Table 4: Comparison of the area under the receiver operating characteristic curve among the imaging methods for root perforation

Imaging methods	P	SD
CPR × DPR	0.393	0.037
CPR × panoramic radiography	0.099	0.062
CPR × CBCT	0.112	0.052
DPR × panoramic radiography	0.208	0.056
DPR × CBCT	0.039*	0.055
Panoramic radiography × CBCT	0.003*	0.063

*P<0.05 statistical significance. CPR=Conventional periapical radiograph, DPR=Digital periapical radiograph, CBCT=Cone-beam computed tomography, SD=Standard deviation

Table 5: Area under the receiver operating characteristic curve and standard deviation of external root resorption for each imaging method

Imaging method	Az	SD
CPR	0.558	0.045
DPR	0.573	0.045
Panoramic radiography	0.494	0.045
CBCT	0.950	0.015

CPR=Conventional periapical radiograph, DPR=Digital periapical radiographs, CBCT=Cone-beam computed tomography, SD=Standard deviation, Az=Area under the receiver operating characteristic curve

Table 6: Comparison of the area under the receiver operating characteristic curve among the imaging methods for external root resorption

Imaging methods	P	SD
CPR × DPR	0.793	0.058
CPR × panoramic radiography	0.206	0.051
CPR × CBCT	<0.001*	0.047
DPR × panoramic radiography	0.161	0.057
DPR × CBCT	<0.001*	0.046
Panoramic radiography × CBCT	<0.001*	0.047

*P<0.05 statistical significance. CPR=Conventional periapical radiograph, DPR=Digital periapical radiograph, CBCT=Cone-beam computed tomography, SD=Standard deviation

Table 7: Area under the receiver operating characteristic curve and standard deviation of vertical root fracture for each imaging method

Imaging method	Az	SD
CPR	0.528	0.065
DPR	0.674	0.060
Panoramic radiography	0.611	0.063
CBCT	0.849	0.044

CPR=Conventional periapical radiograph, DPR=Digital periapical radiograph, CBCT=Cone-beam computed tomography, SD=Standard deviation, Az=Area under the receiver operating characteristic curve

Table 8: Comparison of the area under the receiver operating characteristic curve among the imaging methods for vertical root fracture

Imaging methods	P	SD
CPR × DPR	0.034*	0.069
CPR × panoramic radiography	0.250	0.072
CPR × CBCT	<0.001*	0.069
DPR × Panoramic radiography	0.340	0.067
DPR × CBCT	0.009*	0.067
Panoramic radiography × CBCT	<0.001*	0.062

*P<0.05 statistical significance. CPR=Conventional periapical radiograph, DPR=Digital periapical radiograph, CBCT=Cone-beam computed tomography, SD=Standard deviation

imaging examinations should be performed to evaluate the alteration and to avoid endodontic treatment—a questionable treatment for this problem. In contrast, the result of present result is similar to that found by D'Addazio *et al.*^[30] probably because the authors also examined RP using teeth without endodontic treatment [Figure 4].

The etiology of ERR is complex and its classification depends on the location and stimulus that can cause its development. Hence, the EER was held in different positions with the purpose of proving the difficulty of EER view, especially in two-dimension (2D) techniques. However, does this difficulty compensate the radiation dose received in 3D exams? Orthodontic treatment is one of the etiologies of ERR, which causes rounding of the root apex.^[32,33] This

type of resorption occurs between 39% and 99% of patients under orthodontic treatment^[34,35] as a result of a complex combination of individual biological characteristics and mechanical forces employed during treatment.

The most accurate imaging method in the diagnosis of ERR was again CBCT, with an Az value similar to those obtained by other studies,^[7,30,36] and statistically different from all the other imaging methods examined in the present study. Panoramic radiography had the lowest Az value, being thus the worst method to investigate resorption the middle third of the root, whereas CBCT is the method of choice to detect ERR, particularly on the buccal and lingual aspects of the root. Although there was no statistical difference between CPR and DPR in the diagnosis of ERR, it seems that DPR leans toward a more accurate result.

Among all radicular alterations, ERR was the most difficult to detect with 2D imaging methods, as shown by the low Az values of DPR, CPR, and panoramic radiography, given that alterations in the buccal and lingual aspects of the root are more difficult to visualize with such methods.^[7]

A single defect size was produced because the aim was to evaluate the different imaging methods [Figure 5].

Accurate diagnosis of VRF depends on a careful clinical examination, meticulous evaluation of the case, and imaging examination that allows the assessment of both bone and tooth structures. On one hand, periapical radiographs may not be useful in the diagnosis of VRF, particularly when the X-ray beam is perpendicular to the

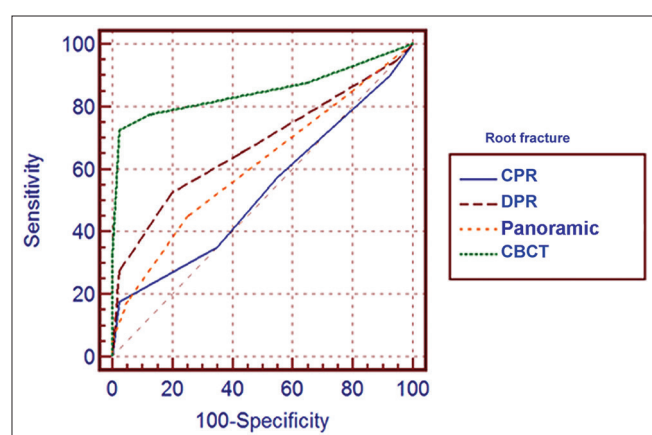


Figure 3: The receiver operator characteristic curve for the different imaging methods that analyzed vertical root fracture

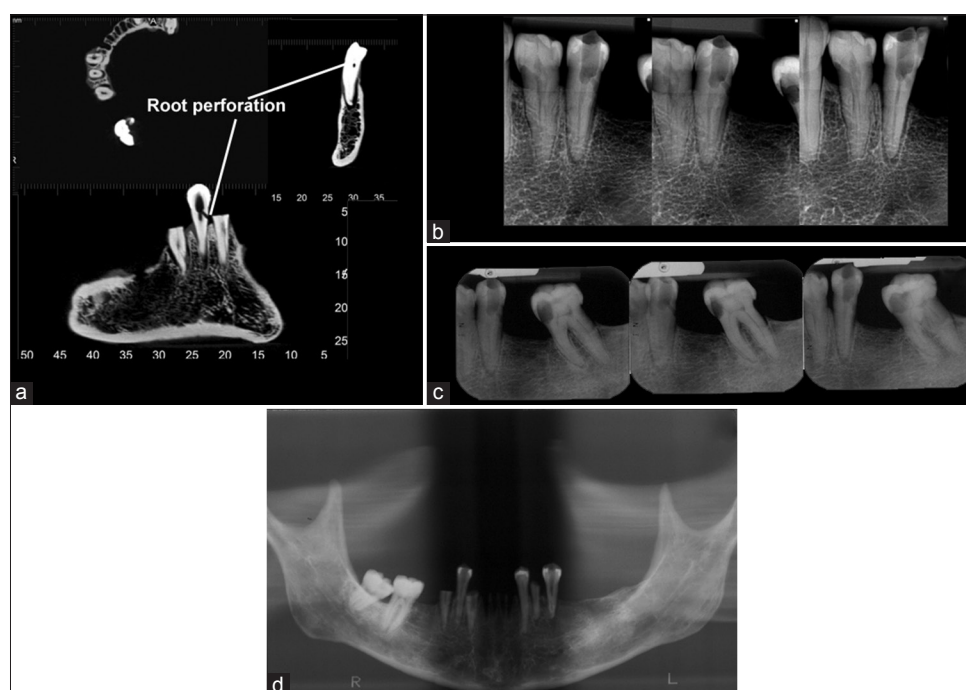


Figure 4: Root perforation images. (a) Cone-beam computed tomography. (b) Digital periapical radiography using parallax principle. (c) Conventional periapical radiograph using parallax principle. (d) Panoramic radiography

line of fracture.^[37] On the other hand, CBCT allows the assessment not only of the fracture but also of the bone loss due to inflammation.^[38]

Some studies indicate that CBCT is the most accurate imaging method to detect VRF for teeth either with endodontic treatment^[38,39] or without it.^[40] Case reports with two^[38] and four cases^[41] demonstrated that CBCT was more accurate than CPR to diagnose VRF, showing the fracture lines clearly, and a study with a series of clinical cases^[42] demonstrated that CBCT provided additional information about the lesion, which can aid diagnosis of VRF and help to prevent unnecessary treatment.

Some studies, however, show conflicting results regarding the accuracy of CBCT. On one hand, Edlund *et al.*,^[10] who examined 32 teeth suspected of VRF from 29 patients, found that CBCT shows high accuracy and specificity in the diagnosis of VRF. Bernardes *et al.*^[2] examined suspicion of VRT in 20 patients and found that CBCT was an excellent diagnostic method, superior to CPR. An *in vitro* study Mora *et al.*^[43] also revealed that CBCT was more accurate to detect VRT than CPR. Comparing multidetector computed tomography (MCT), CBCT, and DPR to detect VRF, Khedmat *et al.*^[44] found that MCT was better than CBCT as the presence of Gutta-percha reduced accuracy, sensitivity, and specificity of the latter but not of the former. However, the use of MCT is restricted due to its higher radiation dose compared to CBCT.

The results of the present study corroborate those of Bernardes *et al.*,^[2] Bernardes *et al.*,^[7] Bornstein *et al.*,^[9] Edlund *et al.*,^[10] Tang *et al.*,^[38] and Takeshita *et al.*^[23] given that CBCT was more accurate to detect VRF than CPR.

Conversely, the results contrast with those of Kambungton *et al.*^[25] and da Silveira *et al.*^[39] maybe because da Silveira *et al.*^[39] examined endodontically treated teeth and Kambungton *et al.*^[25] used X-ray equipment very different from those used in the present study. Furthermore, in the present study, CBCT showed significant differences compared to the other imaging methods while DPR was statistically different from CPR, CBCT being more efficient in the detection of VRF [Figure 6].

Although different imaging methods are important in the diagnosis of VRF, a systematic review^[45] on the matter asserts that the studies carried out so far lack precision and that the existing data, with their clinical and radiographic indices, are still insufficient to detect VRF accurately. The authors^[44] argue that despite the advent of CBCT, the diagnosis of VRF is still challenging, even for experienced professionals.

CONCLUSION

The present study found that:

- CBCT images were more accurate than DPR, CPR, and panoramic radiography to detect RP, ERR, and VRF
- Panoramic radiography was the least accurate imaging method to detect radicular changes
- ERR was to most difficult radicular change to diagnose
- Panoramic radiography was not a suitable method to detect ERR in the middle third of the root
- CBCT and conventional periapical radiography obtained similar results for the evaluation of RP.

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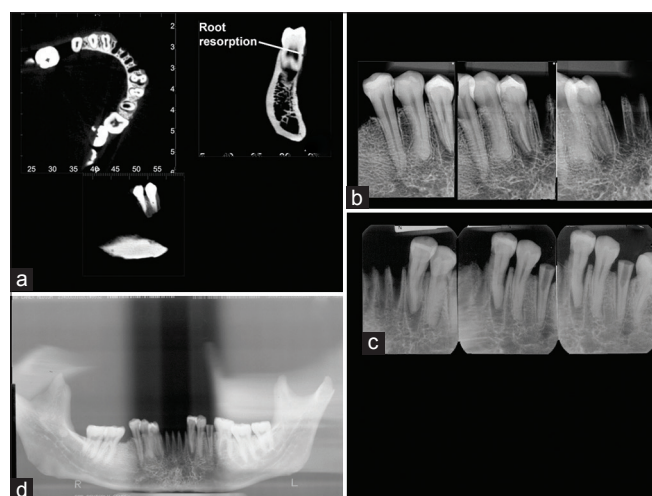


Figure 5: External root resorption images. (a) Cone-beam computed tomography. (b) Digital periapical radiography using parallax principle. (c) Conventional periapical radiograph using parallax principle. (d) Panoramic radiography

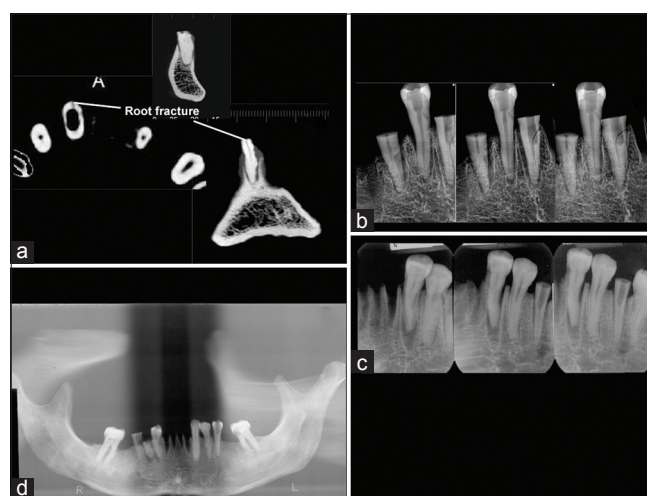


Figure 6: Vertical root fracture images. (a) Cone-beam computed tomography. (b) Digital periapical radiography using parallax principle. (c) Conventional periapical radiograph using parallax principle. (d) Panoramic radiography

Conflicts of interest

There are no conflicts of interest.

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