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RESEARCH ARTICLE

Accuracy of three cone-beam CT devices and two software systems in the detection of vertical root fractures

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Objectives : The aim of this study was to compare the accuracy of vertical root fracture (VRF) detection using three tomography devices and two software systems in teeth with different endodontic fillings.
Methods: The sample consisted of 45 premolars divided into 3 groups: No filling (NF, n=15); Gutta percha (GP, n=15) and Metallic Post (MP, n=15). Cone-beam computed tomography (CBCT) images were acquired in Kodak 9000 3D, Orthopantomography 300 (OP300) and PreXion 3D devices, before and after induced root fractures. Two oral radiologists analyzed all images using InVivoDental and e-Vol DX software systems. The analysis was repeated after 15 days in 30% of the sample. Data analysis compared receiver operating characteristic (ROC) curves, as well the areas under the ROC curves. Accuracy, sensitivity, specificity, positive and negative predictive value were calculated according to each tomographic device and software. Intra- and interexaminer reliability were tested using the Kappa coefficient.
Results: The highest accuracy was seen in the image set from the PreXion 3D, using InVivo (0.96) or e-Vol DX (0.92) in image analysis. The OP300 device presented a similar performance of the PreXion 3D in teeth with different endodontic fillings. When using e-Vol DX, the accuracy of Kodak 9000 3D improved from 0.62 to 0.74.
Conclusions: The PreXion 3D device is the most accurate when detecting VRF, with a performance similar to the OP300 in endodontic filled teeth. Kodak 9000 3D is indicated for teeth without fillings, with better accuracy using e-Vol DX software.
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Keywords: tooth fracture; cone-beam computed tomography; diagnostic imaging

Introduction

Detection of vertical root fractures (VRF) is a challenge in dentistry routine due to the absence of clinical signs in most cases and the use of two-dimensional (2D) radiographs for diagnostic investigation. Periapical radiographs are usually the first step in oral radiology for patients suspected of having VRF. However, this 2D exam only offers moderate accuracy in recognizing VRF because of the influence of X-ray beam angulation concerning fracture line, the overlapping of other anatomical structures and examiners' clinical experience in image interpretation.[1]

Cone-beam computed tomography (CBCT) is recommended to complement VRF diagnosis when 2D exams show uncertainty.[2–5] However, the detection of VRF using CBCT images is influenced by technical parameters, such as field of view (FOV), voxel size, milliamperage (mA) and kilovoltage (kV) involved in generating high-resolution images.[2,6] Besides, the production of artifacts on CBCT images when hyperdense dental materials are present can limit VRF diagnosis accuracy.[7] This limitation is mainly seen when the tooth with a

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suspicion of VRF has undergone endodontic treatment with intracanal materials.[8–14] For that reason, a false positive or false negative diagnosis can also occur and impact the clinical decision.[9,15]

Earlier studies have reported the use of image tools for CBCT exams to reduce artifact production, but without presenting evidence of accuracy in the diagnosis of VRF.[2,16–18] A new software, e-Vol DX (CDT Software, Bauru, SP, Brazil), has been used to improve image quality when artifacts are present, by applying specific filters for endodontic diagnostic purposes.[19–21] However, the accuracy of e-Vol DX software in different tomography devices for detecting VRF has not been tested. It must be considered that tomography devices can have different technical parameters for image acquisition, influencing image quality parameters.

We hypothesized that individual parameters related to the image quality of different tomographic devices could also influence image tools for artifact reduction in e-Vol software for VRF diagnosis. This study aimed to compare the accuracy of VRF detection using three tomography devices and two software systems, including the novel e-Vol DX, in teeth with different endodontic fillings.

Methods and materials

The Institutional Review Board previously approved this *ex vivo* study (number # 3.154.013).

Sample

This sample consisted of 45 teeth extracted for clinical purposes. The sample size was calculated based on the Hajian-Tilaki[22] report, considering a 0.83 accuracy, error limits of 0.1 and CI of 95%. These parameters resulted in a sample size of a minimum of 42 teeth.

The following inclusion criteria were: 1) first or second maxillary or mandibular premolars; 2) single root; 3) single root canal; and 4) complete root formation. The exclusion criteria were: 1) teeth with restoration or morphological anomalies; 2) visible root fractures; and 3) root canal calcifications or obliteration. The sample was divided into three groups of teeth according to the endodontic treatment: 1- No filling (NF) group: 15 teeth without root canal intervention; 2- Gutta-percha (GP) group: 15 teeth with root canal treatment and GP filling; and, 3- Metallic post (MP) group: 15 teeth with root canal treatment, filled with GP and an intracanal metallic post.

Sample preparation

30 teeth were chosen randomly and prepared by the same operator, using a Mtwo NiTi® rotary system (VDW, Munich, Germany) up to instrument 40. According to the manufacturer's instructions, teeth were then filled using a single-cone technique with Mtwo GP and AH 26 cement (Dentsply DeTrey GmbH, Konstanz, Germany).[9,23] The crowns of 15 teeth were removed using a diamond disc (Isomet 1000, Buehler Ltd, Bluff, IL), leaving a standard root size of 16 mm, measured with a digital caliper. Metallic posts were produced using a chrome-nickel alloy with the best fit possible inside the root canal walls.

Root fractures were randomly induced in 45 teeth. These specimens were placed in 25 mm high polystyrene resin blocks with a 10 mm hole. Periodontal ligament space was simulated with the addition of silicone fluid.[24] After the fractures had been completed, each root fragment was bonded using cyanoacrylate (Super Bonder, Loctite® Henkel, Itapevi, SP, Brazil). A set of five teeth randomly mixed from the three groups was placed at a time in a dry mandible to simulate real conditions in the mouth. The mandible was covered with a 3 mm wax (Epoxiglass, São Paulo, SP, Brazil) in order to simulate soft tissue attenuation, and was used as a phantom. For the best fit adjustment of the teeth in the alveolar bone, sockets were widened using a cylinder bur, when necessary.

Image acquisition and analysis

A CBCT acquisition was taken twice for all teeth, before and after root fracture. All samples were scanned in three tomography devices: Kodak 9000 3D (Eastman Kodak Company, Rochester, Nova Iorque, USA), Orthopantomography 300 (Instrumentarium Kavo Kerr, Tuusula, Finland) (OP300) and PreXion 3D (Teracom, San Mateo, CA) using the highest spatial resolution protocol for each device, as shown in Table 1. The mandible was placed with its inferior border parallel to the horizontal plane and the mid-sagittal plane was aligned perpendicularly to the horizontal plane. The region of interest was centrally positioned in the field of view (oriented by the laser lights and the scout image) to avoid distortion from the scanning position.[25] Each tomography device performed the image reconstruction, and then the DICOM files were exported for image analysis. Two oral radiologists with 5 years' experience were previously calibrated to perform the CBCT analyses, until intra- and interexaminer concordance indicated an intraclass correlation coefficient higher than 0.8.

The CBCT scans were randomly analyzed in two steps, in the same room, with appropriate lighting:

Table 1 Technical image parameters for each CBCT device

	Kodak 9000 3D	*OP300*	*PreXion 3D*
FOV (cm)	5 × 3.7	6 × 4	5.1 × 5.1
Voxel (mm)	0.076	0.085	0.1
kV	70	90	90
mA	10	10	4
Exposure type	Pulsed	Pulsed	Continuous
Acquisition time	10.8	6.1	37

CBCT, cone beam CT; FOV, field of view.

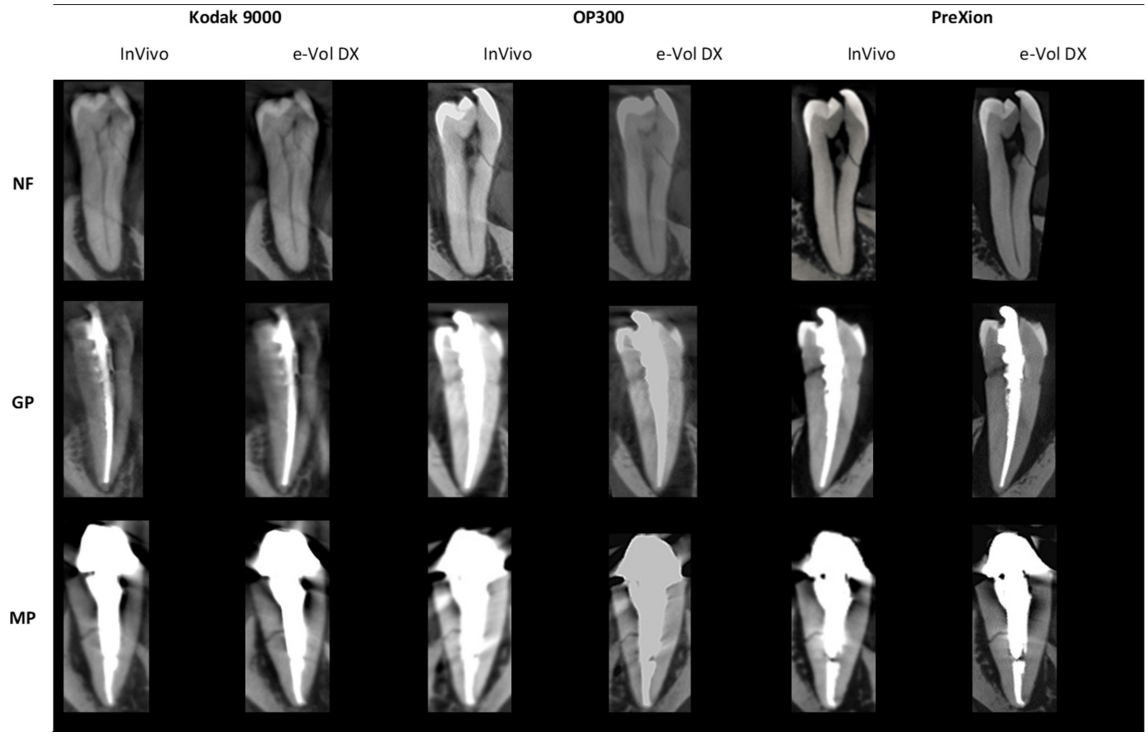

Figure 1 Sagittalviews of premolar teeth, scanned in different CBCT devices (Kodak 9000 3D, OP 300and PreXion 3D) in different image analysis software (InVivo and e-Vol DX) andendodontic filling groups (NF- no filling, GP- gutta-percha and MP- metallicpost).

1- using InVivo Dental Application (Anatomage, San Jose, CA), installed in a desktop computer, connected to a 24-inch and 1600 × 1200 pixel resolution monitor; and 2- using e-Vol DX software (CDT Software, Bauru, SP, Brazil) installed in a computer with a 23-inch and 1920 × 1080 pixel resolution monitor, after a 15 days interval from the first evaluation. The raw data were used for each software. For the second analysis, the examiners had the aid of a Blooming Artifact Reduction (BAR) filter, as one of the e-Vol DX software main tools. This feature allowed the examiners to switch between four BAR different levels, preset by the software, according to their visual acuity. During all evaluations, the analysis was performed in sagittal, coronal and axial views and the examiners were free to navigate dynamically throughout the CBCT volume.

The examiners classified the diagnosis of VRF with the following scores: 1- definitively absent; 2- probably absent; 3- unsure; 4- probably present; 5- definitively present. Figure 1 shows sagittal views of teeth with VRF in each group, obtained with the three CBCT devices. 15 days after the first evaluation, the examiners performed a second analysis of 30% of the sample to calculate inter- and intraexaminer agreement.

Statistical analysis

All data analysis was carried out using MedCalc software 19.0.3 (MedCalc Software, Mariakerke, Belgium). The reference standard for VRF was the direct visual inspection of each tooth root. The software created and compared receiver operating characteristic (ROC) curves, as well the area under the ROC curve (AUC) for each CBCT device,[26] with InVivo and e-Vol DX image sets according to groups.

The diagnostic tests of accuracy, sensitivity, specificity, positive predictive value and negative predictive value were calculated according to each CBCT device and software. Scores 1, 2 and 3 were considered VRF absence, while classifications 4 and 5 were considered VRF presence.

Intra- and interexaminer agreement were tested using κ coefficient,[27] considering: (1) poor: values ≤ 0; (2) slight: values > 0 and <0.2; (3) fair: values > 0.21 and <0.4; (4) moderate: values > 0.41 and <0.6; (5) substantial: values > 0.61 and <0.8 and (6) almost perfect: values > 0.81 and <1.

Results

Intra- (first examiner 0.71; second examiner 0.77) and interexaminer (0.79) reliability in this study was substantial.

Figure 2 shows the ROCs of three CBCT devices (Kodak 9000 3D, OP300 and PreXion 3D) and two image analysis software systems (InVivo and e-Vol DX) used in this study. The highest accuracy seen was the image set from PreXion 3D, using InVivo or e-Vol DX in image analysis. Table 2 shows the accuracy, sensitivity, specificity, positive predictive and negative predictive values

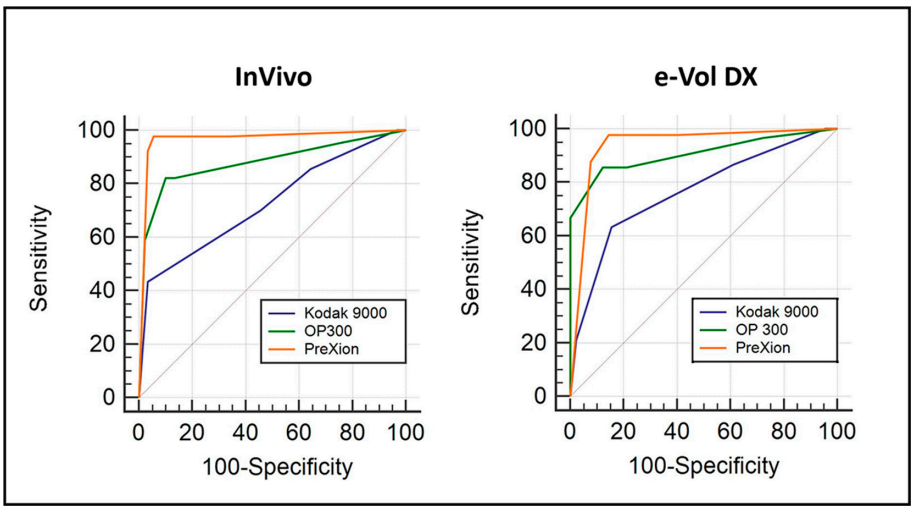

Figure 2 ROCof three CBCT devices (Kodak 9000 3D, OP 300 and PreXion 3D) and two imageanalysis software (InVivo e e-Vol DX).

of all CBCT devices and software systems. PreXion 3D presented the highest accuracy (0.96), shown by the results of sensitivity (0.94), specificity (0.98), positive predictive value (0.95) and negative predictive value (0.98), using InVivo software. Image analysis using e-Vol DX software for Kodak 9000 3D images showed higher accuracy (0.74) and almost all diagnostic tests values compared to the evaluation using InVivo. Sensitivity was the only exception, higher for InVivo (0.70), compared to e-Vol DX (0.63). OP300 showed better sensitivity (0.86) and negative predictive value (0.86) using e-Vol DX, while accuracy was slightly higher than InVivo.

ROC and AUC comparisons are shown in Figure 3 and Table 3, respectively. The worst overall ROC performance was obtained with Kodak 9000 3D, while the best was PreXion 3D. In terms of image analysis of different endodontic fillings, OP300 showed better ROC scores using e-Vol DX software when artifacts were present in the GP group. Each CBCT device's comparisons showed statistically significant differences between Kodak 9000 3D and OP300 and PreXion 3D devices using InVivo in the NF group, and a similar performance for the other two groups (GP and MP). The difference was also observed between OP300 and PreXion 3D for the GP group.

The OP300 and PreXion 3D presented similar performances, differing from Kodak 9000 3D in all groups. This result meant less accuracy for Kodak 9000 3D when compared to the other devices. For the GP group, all devices presented statistically significant differences using InVivo software (p =< 0.001), but the OP300 produced a better performance when using e-Vol DX (0.955; p = 0.05). The MP group showed the best performance in PreXion 3D, but with no statistical difference from the OP300 (p = 0.9307). The overall AUC comparison of the two software showed similar performances using the same CBCT device (Figure 4).

Discussion

The hypothesis of this study was confirmed. Therefore, the original imaging parameters of different CBCT devices influenced the accuracy in detecting VRF. The e-Vol DX software improved almost all diagnostic parameters when the images were acquired using Kodak 9000 3D. However, the potential of the BAR filter for removing artifacts and influencing VRF detection was not confirmed.

Our study showed that the PreXion 3D device had the best performance, irrespective of the image analysis software used. However, there was no statistically significant difference between the OP300 and the PreXion 3D in overall accuracy. Although Kodak 9000 3D showed the lowest diagnostic values compared to the other devices, its performance improved when image analysis was undertaken using e-Vol DX in NF teeth. However, this progress did not statistically impact accuracy when compared to the InVivo software, probably due to the balanced ratio of sensitivity and specificity changes, which occurred in both

Table 2 Accuracy, sensitivity, specificity, PPV e NPV for each CBCT device and software for VRF detection

	Accuracy		Sensitivity		Specificity		PPV		NPV	
CBCT device	InVivo	e-Vol DX	InVivo	e-Vol DX	InVivo	e-Vol DX	InVivo	e-Vol DX	InVivo	e-Vol DX
Kodak 9000 3D	0.62	0.74	0.70	0.63	0.54	0.84	0.60	0.80	0.64	0.70
OP300	0.86	0.87	0.82	0.86	0.90	0.88	0.89	0.87	0.83	0.86
PreXion 3D	0.96	0.92	0.98	0.98	0.94	0.86	0.95	0.87	0.98	0.97

CBCT, cone beam CT; NPV, negavtive predcitive value; PPV, positive predcitive value; VRF, vertical root fracture.

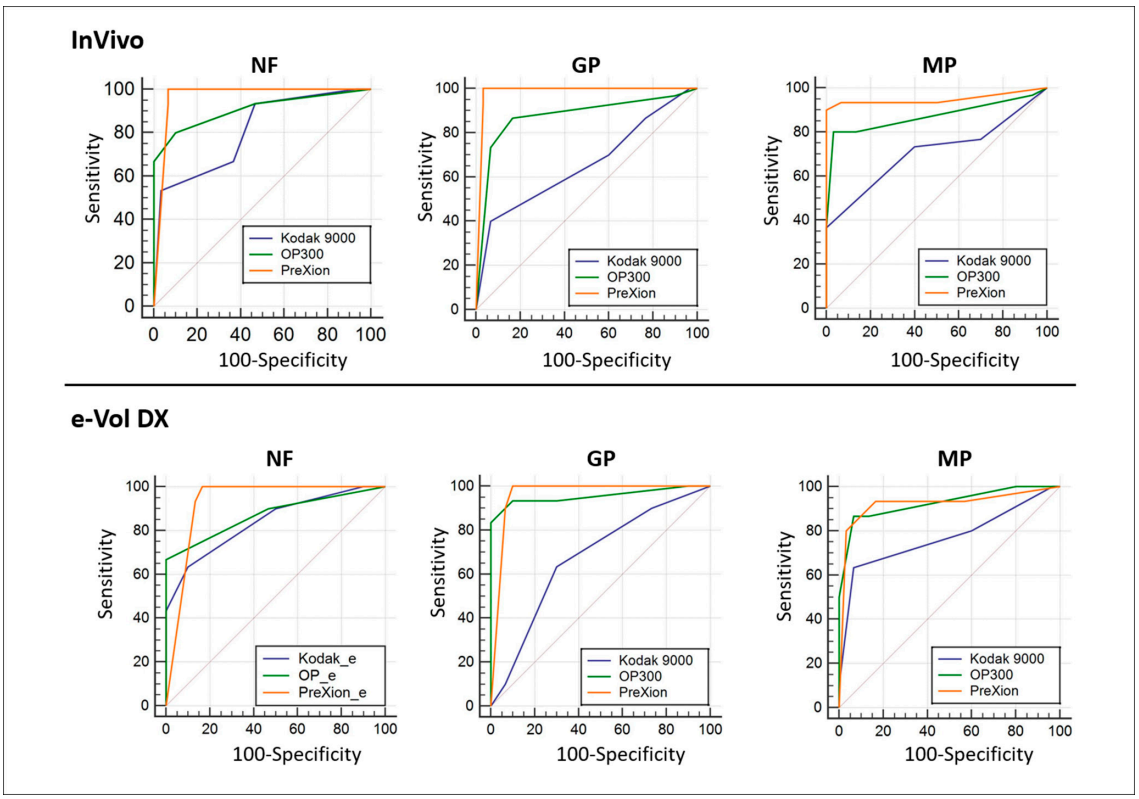

Figure 3 ROCof endodontic filling groups (NF, GP, MP) using InVivo and e-Vol DX softwaresystems.

software. When using InVivo, the Kodak 9000 3D device showed low specificity, explained by a high number of false positive diagnosis of VRF, which means an overdiagnosis of VRF when they were, in fact, not present.

Table 3 Area under the Receiver Operating Characteristic Curve (AUC) comparisons of each CBCT device and study groups in InVivo and e-Vol software systems

		CBCT DEVICES (AUC)			
GROUPS	*SOFTWARE*	*PreXion 3D*	*OP300*	*Kodak 9000 3D*	p-*value*
NF	InVivo	0.964[A]	0907[A]	0.807[B]	.0117
	e-Vol DX	0.928[A]	0.872[A]	0.840[A]	.1016
	p-value	0.14	0.34	0.51	
GP	InVivo	0.982[A]	0.875[B]	0.657[C]	<.0001
	e-Vol DX	0.962[A]	0.955[A]	0.674[B]	<.0001
	p-value	0.80	0.05	0.52	
MP	InVivo	0.949[A]	0.872[A]	0.710[B]	.0001
	e-Vol DX	0.921[A]	0.926[A]	0.770[B]	.0103
	p-value	0.15	0.26	0.44	

AUC, area under the receiver operating characteristic curve; GP, gutta-percha; MP, metallic post; NF, no filling.
Delong method comparison between tomography devices and software ($p < .05$). Different letters represent statistical significance between tomography devices and same letters no statistical significance.

False positive values have a direct influence on specificity results. The Kodak 9000 3D device resulted in a 40% false positive VRF and impacted its low specificity (0.54) when using InVivo software. In terms of clinical decisions, a false positive diagnosis could result in clinicians deciding on unnecessary tooth extractions. However, when Kodak 9000 3D was analyzed using e-Vol DX, false positive values were reduced to 20%.

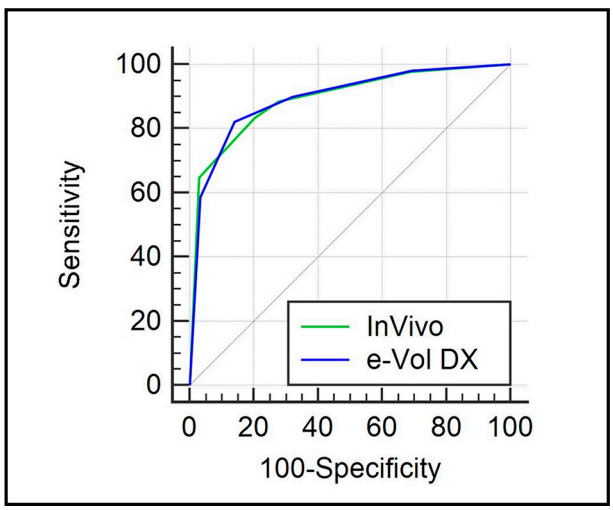

Figure 4 ROC comparison between InVivo and e-Vol DX software systems.

This notable improvement must be considered by oral radiologists when an image scan is performed with Kodak 9000 3D. Its association with image analysis software that enhances the diagnostic performance can result in better clinical decision-making.

Regarding endodontic filling impairing diagnosis, this study confirmed the result of other studies focusing on VRF detection.[10–12,14,28–32] High spatial resolution protocols are indicated when there is a suspicion of VRF in teeth with endodontic fillings. However, these high sensitivity values in the detection of VRF in teeth with root canal fillings must be considered with caution, since these results must suggest that streak artifacts could have induced examiners to misdiagnose fracture lines overly.[30,33]

Considering the three CBCT scanners in this study, Kodak 9000 3D had the highest voxel resolution protocol (0.076 mm) but showed the worst overall performance, reinforcing the other factors' importance that influence image quality. It is known that apart from spatial resolution, contrast-to-noise ratio also affects CBCT image quality.[34,35] Contrast-to-noise ratio can be enhanced by adjusting the parameters during acquisition, such as the field of view scanning size,[36] electric current (mAs),[33,37] tube voltage (kVp)[38,39] and number of basis images.[40] This can explain why Kodak 9000 3D differed from the other devices with higher kilovoltage. Likewise, lower kilovoltage implies increasing artifact formation,[33,38,41] which also leads to a poorer diagnosis. Although e-Vol DX appears to compensate image quality on images obtained with a low tube voltage device, further studies are necessary to confirm this hypothesis changing this variable independently in the same device.

Another essential information from our study is that images obtained with any of the three tomographs are sufficient to detect VRF in teeth with no endodontic filling when associated with the BAR tool. In this way, image quality can be balanced with a low radiation dose device, mainly because NF teeth are the least challenging scenario amidst the three investigated in this study.

PreXion 3D device's superior performance can be explained by its relatively high radiation dose, obtained by an increased exposure time and the emission of continuous radiation. The biologic risk of ionizing radiation is a factor that must be balanced when CBCT is prescribed..[42–44] Under the technical parameters of image acquisition and radiation dose studied by Mauro et al.,[42] OP300 represented 531.4 mGy.cm² of absorbed dose, compared to 2901.6 mGy.cm² for the PreXion 3D, with the same protocols used in the present study. There is a 5.46:1 ratio between the PreXion 3D and the OP300 in absorbed dose. Because the performance of the OP300 in VRF detection is similar, its use represents a favorable risk/benefit balance for the patient. On the other hand, adjustments in technical parameters of the PreXion 3D are also indicated, as the detection of VRF will not be affected by a low-resolution parameter for this device.[15] Further studies are still necessary to investigate the radiation dose of Kodak 9000 3D, compared to OP300 and PreXion 3D, taking into account the NF teeth cases.

It has been reported that the use of filters did not improve the diagnostic accuracy of images acquired with i-Cat tomograph.[45] Differently, the use of e-Vol DX in our study increased the accuracy for Kodak 9000 3D images, which had the worst accuracy using InVivo (with no filter). This finding suggests that depending on the device, enhancement tools are a viable alternative for CBCT devices. In this way, software companies should focus on developing these tools, aiming images acquired with different devices. Further studies should also be carried to demonstrate e-Vol DX's performance in different technical parameters from the same device. For now, it is not possible to assume if the Prexion 3D or OP 300 should be performed better with e-Vol DX by using different parameters.

The limitation of this study is related to its *ex vivo* study design, which may not represent a similar clinical condition. However, exposing patients to unnecessary ionizing radiation is unjustified for ethical reasons and *ex vivo* studies are an essential step in answering clinical questions. Another limitation is the sample size. For accuracy values under 0.83, a larger sample should be used to confirm the study's power.[22] Further studies using other technical parameters in association with e-Vol DX image analysis could contribute to new information.

Conclusion

We concluded that the PreXion 3D device is the most accurate and presented a similar performance of the OP300 for VRF detection in endodontic filled teeth. The Kodak 9000 3D is indicated for VRF detection in teeth with no filling and shows improved accuracy when using e-Vol DX software. The e-Vol DX software did not improve accuracy in images from either OP300 or PreXion 3D.

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Conflict of interest

The authors declare that there is no conflict of interest in regard to this work.

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