Original Research

Impact of Intracanal Post-Material on Vertical Root Fractures Diagnosis: A High-Resolution Cone-Beam Computed Tomography Study

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Abstract

Aim: Root fractures depict a challenge to dentists, especially when they are oriented vertically. They can be responsible for an important percentage of extractions of endodontically treated teeth. The objective of this research was to compare the accuracy of vertical root fractures (VRF) diagnosis in teeth treated endodontically and with posts in root canals, using images acquired by three different cone-beam computed tomography (CBCT) scanners and different acquisition protocols, a varying field of view (FOV), voxel size, kilovoltage (KVp), and milliamperes (mA). **Materials and Methods:** This study evaluated the diagnostic capacity of three different brands of CBCT devices. Overall, 240 images of single root teeth were included and they were divided into two groups: the test group in which teeth were artificially fractured, and the control group, without fractures. The CBCT images were assessed, reaching a consensus between three examiners. Descriptive statistics and a binary logistic regression test were performed. Sensibility, specificity, and accuracy values also were obtained. Statistical significance was set at $P < 0.05$. **Results:** Two studied scanners contributed 77.8% of diagnostic errors, and 61.1% of the errors were in the presence of metal in the root canal. There were no significant differences between the standard (STD) and high-definition (HD) protocols. **Conclusion:** The equipment brand and the condition of the tooth are important factors in the VRF assessment using CBCT.

Keywords: Cone-beam Computed Tomography, Diagnosis, Vertical Root Fracture

Received: 11-08-2021, **Revised:** 21-10-2021, **Accepted:** 24-11-2021, **Published:** 15-02-2022.

Introduction

Root fractures depict a challenge to dentists, especially when they are oriented vertically.[1,2] Vertical root fractures involve cement, dentine, and pulp. Besides, they have an incidence of approximately 1% in permanent dentition and frequently represent complication with a poor prognosis for the patient.[3,4] They are responsible for 10.9% of extractions of endodontically treated teeth.[5] Direct visualization of a radiolucent fracture line is fundamental for the detection of VRF, but this is not always easy to observe.[6] Often, signs and symptoms can simulate other dental conditions that require different treatment; thus, it is extremely important to reach an accurate diagnosis as early as possible.[7] When a VRF occurs, it extends to the periodontal ligament; so, detritus and bacteria can gain entrance to this area and induce an inflammatory process, resulting in a lesion of the periodontal ligament, loss of alveolar bone, and formation of granular tissue. Therefore, an early decision about treatment is necessary to minimize bone loss, in the interests of the patient's oral rehabilitation.[8]

Access this article online	
Quick Response Code:	**Website:** www.jioh.org
	DOI: 10.4103/jioh.jioh_209_21

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How to cite this article: de Lima Moreno JJ, Boessio Vizzotto M, da Silveira Tiecher PF, Assein Arús N, Arriola-Guillén LE, Dias da Silveira HL. Impact of intracanal post-material on vertical root fractures diagnosis: A high-resolution cone-beam computed tomography study. J Int Oral Health 2022;14:71-7.

Information supplied by the patient, together with clinical signs and symptoms and periapical X-rays, orients the diagnosis of VRF.[7] Studies have shown the low power of diagnosis by radiography, estimated as between 23% and 37.1%.[9,10] Mesiodistal fractures transversal to the incidence of the X-ray beam make the sensitivity of radiographic examination even lower, at 7.7%.[10] Digital radiography with intraoral receptors did not differ significantly regarding the diagnostic capacity for VRF compared with conventional radiography; both techniques produced the superposition of visibilized structures inherent to two-dimensional images.[11]

CBCT provides the possibility of obtaining images without overlapping with other structures, and therefore it is useful in the management of endodontic problems.[12,13] CBCT as used in dentistry has advantages over medical computed tomography (CT), such as lower radiation dose and fewer artefacts.[14-17] However, in the presence of HD materials such as metal post, the production of the artefacts in CBCT images still poses a big problem in clinical practice. CBCT allows the clinician to analyze the tooth in several planes, overcoming the limitations of two-dimensional images for the detection of VRF.[18,19] There are several CBCT scanners on the market nowadays. They vary in the rigor of their diagnoses, for example, for the detection of VRF.[20-22]

In this way, several studies have been carried out with the aim of assessing the diagnostic power of CBCT for VRF. They have demonstrated statistically significant differences in the detection of fractures when CBCT images were compared with X-ray images.[12,13,23] However, the CBCT scanner was more precise for the diagnosis of complete VRF, and the width of the fractures affected the diagnosis. Likewise, Jakobson *et al.*[24] reported that CBCT scanners had greater sensitivity than conventional and digital X-ray examination for the detection of VRF in teeth treated endodontically with and without posts; overall accuracy depended on the CBCT scanner used. Many studies carried out since the advent of CBCT have studied different protocols for the diagnosis of VRF, with different scanners, protocols, and root conditions.[18,23]

Considering all that has been just stated, and in view of the constant development of CBCT scanners, the aim of this study was to compare the accuracy of VRF diagnosis in teeth treated endodontically and with posts in root canals, using images acquired by three different CBCT scanners and with different acquisition protocols, varying FOV, voxel size, KVp., and mA. The null hypothesis to test was that there are no differences in the vertical root fractures diagnosis in teeth treated endodontically with posts in root canals, using images acquired by three different CBCT scanners and acquisition protocols.

Materials and Methods

Setting and design

An *in vitro* experimental study was carried out at the Rio Grande do Sul University, Porto Alegre, Rio Grande do Sul, Brazil, between 2017 and 2020.

Ethical approval

This study was carried out with the approval of the research committee and the ethics committee of the School of Dentistry; Federal University of Rio Grande do Sul (UFRGS) under the number: 17259.

Sampling criteria

The sample included 20 extracted single-rooted human teeth, which had been stored in a glass flask containing 5% buffered formaldehyde [Figure 1]. The type of sample selection method and selection criteria followed the methodology from a previous study.[25]

These single-rooted human teeth were inspected under magnification to confirm the absence of cracks and/or root fracture. After that, the teeth were sectioned at the cement–enamel junction level. Likewise, to prepare the specimens and simulate a clinical situation, each root was covered by a thin layer of wax (Cera Articulação, Epoxiglass, Brazil), simulating the periodontal ligament resiliency; for that the teeth were placed in 20 self-polymerizing acrylic cubes with a cylindrical empty space at the center, and surrounded by the plastified wax. This procedure ensured that the fractured teeth had no split nor were the fragments largely separated.

Also, the sample was randomly divided into two groups: experimental and control, with 10 samples in each group, with and without fractures, respectively. The groups were prepared for endodontic treatment and subsequently obturated with gutta-percha; the teeth were prepared with a number 2 width file (Maillefer/Caulk/Dentsply, Brazil) for inserting prefabricated metal posts (Angelus, Brazil) or

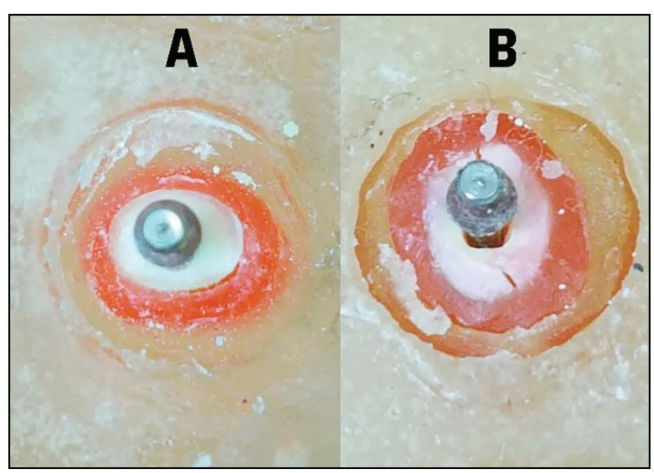

Figure 1: Teeth tested: (A) nonfracture tooth and (B) fracture tooth

Table 1: Image acquisition protocols adopted in each of the cone-beam computed tomography scanners used

Scanners protocols	Equipment 1 OP300 (Kavo. Dental)	Equipment 2 Ortophos SL3D (Sirona)	Equipment 3 PaX.i-3D (Vatech)
Protocol 1	FOV: 4.7 cm × 4.7 cm	FOV: 5 cm × 5.5 cm	FOV: 6.24 cm × 6.24 cm
STD	Voxel: 0.13	Voxel: 0.16 mm	Voxel: 0.13 mm
	kVp: 89	kVp: 85	kVp: 89
	mA: 8	mA: 10	mA: 5
	basis projections 452	basis projections 385	basis projections 450
Protocol 2	FOV: 4.7 cm × 4.7 cm	FOV: 5 cm × 5.5 cm	FOV: 6.24 cm × 6.24 cm
HD	Voxel: 0.08	Voxel: 0.08	Voxel: 0.08
	kVp:89	kVp:85	kVp:89
	mA: 10	mA: 6	mA: 5
	basis projections 706	basis projections 768	basis projections 624

fiberglass posts (Macro-Lock Post/X-RO/RTD, France), respectively, but previously the obturation material was removed from the coronal and middle thirds of the canals. Then, prefabricated metal posts were inserted in all teeth and the teeth were subjected to CBCT.

Afterward, the metal posts were withdrawn and replaced with fiberglass posts (Macro-Lock Post/X-RO/RTD, France), and CBCT was repeated on all teeth. The 10 teeth in the experimental / test group were immobilized and artificially fractured by means of a specially designed hammer and chisel. The control group was not subjected to fracturing. The same 20 teeth were subjected to tomography at two time points, once with metal posts inside them and the second time with fiberglass posts, making a total of 40 images. Thus, the sample was made up of the images acquired from the 40 teeth tested, which were placed in a container full of water; this aqueous environment was used to simulate the attenuation of the X-ray beam.

The samples were visually inspected under magnification to detect the absence or presence of VRF, representing the gold standard.

Methodology

For the acquisition of volumetric images, three CBCT devices, an Ortophos SL 3D (Dentsply Sirona International Headquarters, Salzburg, Austria), an Orthopantomograph OP300 Maxio (KaVo Dental GmbH Biberach, Riß, Germany), and a PaX.i-3D (VATECH CO, South Korea) were used. The images were acquired with the lowest available FOV for the scanner used, and in two different resolutions, namely STD and HD. These protocols are presented in Table 1. Therefore, 80 images were acquired for each one of the scanners, making a total of 240 images of single-root teeth with root canals sealed with gutta-percha and metal or fiberglass posts.

All the images were exported in Digital Imaging and Communications in Medicine (DICOM) and analyzed on the OnDemand software (KaVo Dental GmbH Biberach, Riß, Germany). These were displayed on a flat panel monitor (Dell 3008 WFP, Dell Inc.) at the highest resolution (2560 x 1600 pixels), at 32-bit color mode, and were seen in dimmed background lighting conditions [Figure 2].

Table 2: Percentage of errors in diagnosing vertical root fractures

		%
	PaX.i-3D (Vatech)	41.7
Scanners	Orthophos SL	36.1
	OP300	22.2
Protocols	Standard	52.8
	HD	47.2
Material in root canal	Fiberglass	38.9
	Metal	61.1

Observational parameters

Three blinded examiners who each had more than 7 years' experience in CBCT scans evaluated the CBCT images for the presence or absence of VRF individually. Each examiner carried out their evaluation by using a 5-point Likert scale to answer the following question: Is there a vertical root fracture? They answered (definitely yes, probably yes, uncertain, probably not, definitely not). Disagreements on the evaluation of the images were resolved by consensus, resulting in the dataset that was finally used for the statistical analysis. We used the kappa test for the interobserver and intraobserver calibration until a value higher than 0.8 was achieved for all comparisons.

Statistical analysis

Statistical analysis was performed using SPSS version 19.0 for Windows (IBM SPSS, Chicago, Illinois). Descriptive statistics to evaluate the percentages of errors in diagnosing vertical root fractures was conducted. Mann–Whitney U test and a binary logistic regression test were performed and sensibility, specificity, and accuracy values were obtained. Statistical significance was set at $P < 0.05$.

Results

First, the results were analyzed, looking for differences when the examiners were most mistaken in their diagnosis

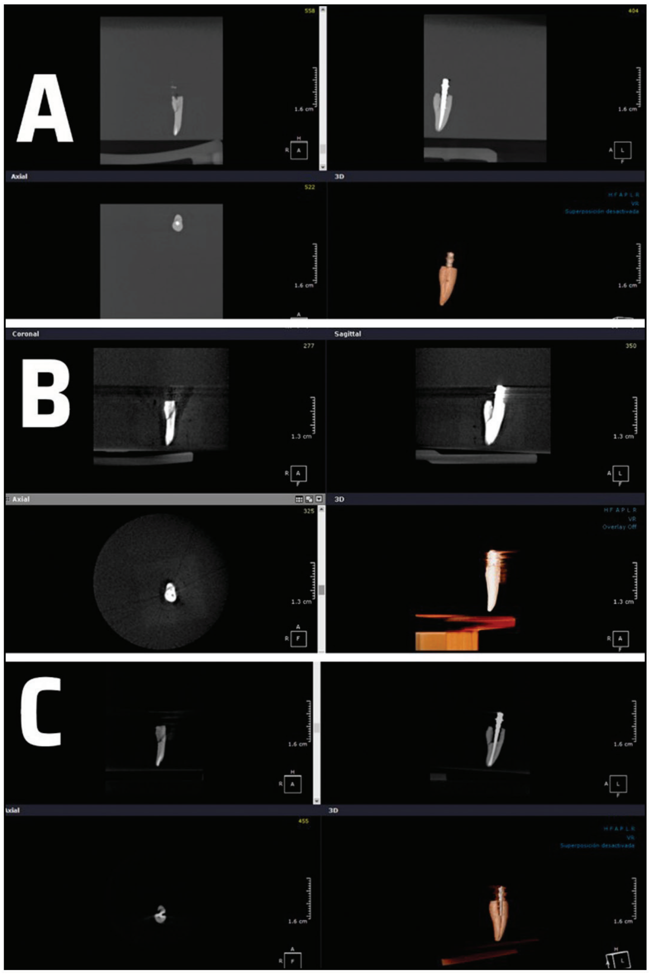

Figure 2: Image of (A) Ortophos SL3D, (B) PaX.i-3D, and (C) OP300

of VRF, and the conditions that were most often repeated when the examiners´ diagnoses were mistaken. The percentage of errors was calculated for the different conditions studied [Table 2].

The results show that the examiners made 41.7% of their errors using the PaX.i-3D (Vatech) scanner; 36.1% of their errors were made using the Ortophos SL 3D; and 22.2% of the examiners' errors were made using the OP300. This shows that out of the total of diagnostic errors, more than three-quarters arose from images taken by the PaX.i-3D (Vatech) and Ortophos SL 3D scanners; the images from both these scanners gave rise to 77.8% of the errors. In regard to the STD and HD protocols, there was no effect on diagnoses as the errors were distributed almost equally between them. When analyzed according to the material in the root canals, the results show that 61.1% of the errors arose when the teeth had metal posts, whereas when the root canals were filled with fiberglass the errors were 38.9%. In other words, for every two errors arising in teeth with fiberglass posts, there were three errors among the teeth with metal posts [Table 3].

Second, a technique was applied that allowed us to explain and predict the behavior of the gold standard of results. This was a binary or dichotomic technique examining limited dependent variables, in which the distribution was calculated for variables each having only two possible results. This Binary Logistic Regression technique, also known as the Binomial technique, permits prediction of the value of the variable considering the particular distribution of the results.

The closer the result is to 5.0, the greater the certainty of without fracture diagnosis. On the contrary, the closer the result is to 1.0, the greater the certainty of fracture diagnosis. The OP300 scanner was the one providing the greatest certainty to the examiners for correct diagnosis of the absence and presence of VRF, with the closest values to 5 and 1, respectively.

Using the OP300 scanner, comparison of both protocols yielded no numerical difference in Likert scores for the diagnosis of VRF. With the PaX.i-3D (Vatech) scanner, higher accuracy in VRF diagnosis was achieved by using the HD protocol ($P < 0.001$). Using the Ortophos SL 3D scanner, we found a greater influence on higher accuracy with VRF diagnosis when the HD protocol was employed [Table 4].

The results of sensitivity ranged between 88% and 92% and specificity ranged between 75% and 78% when the scanners were compared with each other. That evaluation according to the root filling material showed values of sensitivity of 92% and specificity of 85% when the root canals were filled with gutta percha or fiberglass post; however, when a metal post was present, sensitivity was 87% and specificity was 77%.

Discussion

Several studies have been carried out with the aim of evaluating the diagnostic power of CBCT scanners for VRF. The authors found statistically significant differences in fracture detection when CBCT images were compared with conventional radiography: Values for sensitivity and specificity were between 70% and 100%, respectively.[12,23] Further, tomography is superior to dental radiography in detecting VRF, although the root canals have metal inside the canal.[13] The present study found similar results: a sensitivity of 88% to 92% and a specificity of 75% to 78% when the scanners were compared with each other. However, evaluation according to the material filling the root canal yielded higher results, with a sensitivity of 92% and a specificity of 85% when the root canals were filled with gutta percha or fiberglass posts; however, when metal posts were present, sensitivity was 87% and specificity was 77%. In summary: If we ask, what were the best results? We must opt for the OP300 scanner with the HD protocol. The results show that in the presence of fiberglass or metal posts, diagnosis was more precise when posts were fiberglass rather than metal. This is in agreement with the 2013 study by Ferreira, who used two different CBCT scanners with restricted FOV to detect VRF in teeth with fiber resin posts and titanium posts. The scanners

Table 3: Mean and standard deviation (SD) of Likert scale results by scanner, protocol, and pin material

Scanners	Protocol	Pino	Cases without fracture		Cases with fracture	
			Mean	SD	Mean	SD
PaX.i-3D (Vatech)	STD	Fiberglass	4.20	1.317	1.40	1.265
		Metal	3.00	1.333	1.60	0.843
		Total	3.60	1.429	1.50	1.051
	HD	Fiberglass	3.60	1.506	1.30	0.949
		Metal	3.20	1.135	1.40	0.966
		Total	3.40	1.314	1.35	0.933*
	Total	Fiberglass	3.90	1.410	1.35	1.089
		Metal	3.10	1.210	1.50	0.889
		Total	3.50	1.359	1.43	0.984
Orthophos SL 3D	STD	Fiberglass	3.90	1.595	1.70	1.252
		Metal	3.30	0.949	1.80	1.229
		Total	3.60	1.314	1.75	1.209
	HD	Fiberglass	4.20	0.919	1.50	0.972
		Metal	3.50	0.972	1.70	0.949
		Total	3.85	0.988	1.60	0.940
	Total	Fiberglass	4.05	1.276	1.60	1.095
		Metal	3.40	0.940	1.75	1.070
		Total	3.73	1.154	1.68	1.071
OP300	STD	Fiberglass	4.10	1.197	1.10	0.316
		Metal	3.60	0.966	1.40	0.516
		Total	3.85	1.089	1.25	0.444
	HD	Fiberglass	4.30	1.252	1.40	1.265
		Metal	3.40	1.075	1.70	0.823
		Total	3.85	1.226	1.55	1.050
	Total	Fiberglass	4.20	1.196	1.25	0.910
		Metal	3.50	1.000	1.55	0.686
		Total	3.85	1.145	1.40	0.810
Total	STD	Fiberglass	4.07	1.337	1.40	1.037
		Metal	3.30	1.088	1.60	0.894
		Total	3.68	1.269	1.50	0.966
	HD	Fiberglass	4.03	1.245	1.40	1.037
		Metal	3.37	1.033	1.60	0.894
		Total	3.70	1.183	1.50	0.966
	Total	Fiberglass	4.05	1.281	1.40	1.028
		Metal	3.33	1.052	1.60	0.887
		Total	3.69	1.222	1.50	0.961

SD = standard deviation, STD = standard, HD = high definition

According to the Likert scale, 1 = definite vertical root fracture and 5 = definitely not a vertical root fracture

*$P < 0.05$ (Mann–Whitney *U* test)

were i-CAT (FOV 6 cm x 8 cm, 120 kVp, 36.12 mA, voxel 0.125 mm) and Scanora 3D (FOV 6 cm x 6 cm, 85 kVp, 8 mA, voxel 0.33 mm). A higher sensitivity of detection was obtained with the i-CAT images, and diagnostic accuracy was greater for root canals with fiber resin posts.

The condition of the root must, therefore, guide the choice of voxel resolution, with the 0.3-voxel being selected for teeth without endodontic fillings and the 0.2-voxel being selected for teeth with the root canals endodontically filled with metal posts. This shows that research investigations using a voxel of 0.2 and 0.3 are not so precise when diagnosing VRF. Recently, studies determined that there was no difference based on voxel size nor on the specific scanner used, but that there were significant differences depending on the width of the fracture.[21,22] These studies reported that all fractures over 200 microns wide may be seen under conventional X-ray techniques, and even by clinical examination; what is important, then, is the ability to diagnose fractures between 100- and 200-microns width, which were, indeed, the most difficult to diagnose and could only be visualized in images with a voxel lower than 80 microns. The present study compared different voxel sizes and three different scanners. Although there was no significant difference in VRF diagnosis with different voxels, the sensitivity was higher with smaller voxel size in all scanners. Likewise, the

Table 4: Sensitivity, specificity, and accuracy of vertical root fracture diagnosis by scanner type, protocol, and post-material

		Sensitivity	Specificity	Accuracy
CBCT device	Vatech	0.88	0.75	0.81
	Ortophos	0.88	0.80	0.84
	OP300	0.92	0.88	0.90
Protocols	STD	0.90	0.78	0.84
	HD	0.88	0.84	0.86
Posts	Fiberglass	0.92	0.85	0.88
	Metal	0.87	0.77	0.82
STD and posts	Fiberglass	0.93	0.83	0.88
	Metal	0.87	0.73	0.80
HD and posts	Fiberglass	0.90	0.87	0.88
	Metal	0.87	0.80	0.83
CBCT device x protocols	OP300 STD	1.00	0.90	0.95
	OP300 HD	1.00	0.90	0.95
	Vatech STD	0.85	0.75	0.80
	Vatech HD	0.90	0.75	0.83
	Ortophos STD	0.85	0.70	0.78
	Ortophos HD	0.90	0.90	0.90
OP300 and protocols and posts	STD and PF	1.00	0.90	0.95
	STD and PM	1.00	0.90	0.95
	HD and PF	0.89	0.91	0.90
	HD and PM	0.80	0.80	0.80

STD = standard, HD = high definition, FP = fiberglass post, MP = metal post

best results of specificity of 0.95% and accuracy of 0.86 were with smaller voxels. Furthermore, the scanner with the best results was the OP300, associating voxels sizes and metal and fiberglass posts achieving results of 100% for sensitivity, 90% for specificity, and 95% for accuracy.

A systematic review of the literature revealed that there are only a few studies that evaluate the impact of voxel size on diagnostic results of CBCT in the field of dentistry. Further high-quality studies are needed to determine concrete criteria to guide the use of CBCT for the diagnosis of VRF.[26] This study suggests that when a patient has a suspected root fracture and a metal post, it is better to use a STD protocol, since sensitivity is similar for STD and HD protocols. The specificity is greater with the HD protocols but the difference between STD and HD does not justify the greater radiation received. Where there is no fracture, an HD protocol identifies this more precisely; however, where there is a fracture, the diagnostic capability is similar with either protocol. Assessing those errors occurred more frequently when there was a fracture; however, in this case, it would not be. It is necessary to indicate an HD protocol, avoiding a higher radiation dose to the patient. Certainly, further high-quality studies are necessary to enable and support systematic reviews.

Jakobson *et al.*[24] reported that CBCT systems provided greater sensitivity than conventional X-ray and digital examinations for the diagnosis of VRF in endodontically treated teeth with or without posts; overall accuracy depended on the CBCT system used. In agreement with these results, there was a difference between the different scanners used, as in our study the scanners showed differences when compared. The percentage of errors was 41.7% with the PaX.i-3D scanner, 36.1% with the Ortophos SL 3D, and 22.1% with the OP300. Of the total diagnostic errors, more than three-quarters arose from images obtained from the Pax.i-3D and the Ortophos SL 3D, which, between them, gave rise to 78% of the mistaken results. It is important to clarify that of the total sample 15% were errors.

Several types of equipment and different protocols have been used in research studies to determine or compare their effectiveness for the early diagnosis of VRF, using different FOV, kVp., mA, and voxel size, but nowadays all CBCT systems have (the same or) similar protocols with respect to the variables used to obtain images. In this study, we reach the general conclusion that we agree with European guidelines that indicate the use of CBCT with restricted FOV and a high resolution to evaluate cases of suspected root fracture when conventional X-rays do not provide enough information on which to base a treatment plan.[10,18]

There were a number of limitations to this study. It was a laboratory study that excluded patient movements, metal crowns, implants, or radio-opaque materials in root canals of juxtaposed teeth, thus avoiding artifacts arising from real clinical situations. Three scanners were used in this study, but there are more CBCT scanners on the market to be studied. The experiment lacked clinical signs and symptoms that might have aided VRF diagnosis. Although the greatest of care was taken in the methodology used for creating root fractures, and we believe it was a simulation that was / very / close to reality, we cannot say that the resulting fractures were identical to real fractures arising in patients' mouths in clinical practice.

Conclusion

The study allows us to affirm that CBCT scanners have high diagnostic capabilities in cases of VRF. When making a diagnosis of VRF, it is important to know what type of equipment we are using, as there are differences in diagnostic capability between them. It is also very important to know the root endodontic condition because the diagnostic capability can vary.

Acknowledgement

Not applicable.

Financial support and sponsorship

This study was self-funded.

Conflicts of interest

There are no conflicts of interest.

Authors contributions

Study conception (JJLM, MBV, HLDS), data collection (JJLM), data collection and analysis, data interpretation (JJLM, PFDT, NAA, LEAG, HLDS), and manuscript writing (JJLM, MBV, PFDT, NAA, LEAG, HLDS).

Ethical policy and institutional review board statement

The study design was approved by the institutional review board (Federal University of Rio Grande do Sul (UFRGS) under the number: 17259). All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all patients for being included in the study.

Patient declaration of consent

Not applicable.

Data availability statement

All data that support the study results are available from the corresponding author (Dr. Luis Arriola-Guillén, email: luchoarriola@gmail.com).

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