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How protocol, posts, and experience affect fracture detection in multi-rooted teeth using cone-beam computed tomography: an *ex vivo* experimental study

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ABSTRACT

Objectives: This study aimed to evaluate the influence of cone-beam computed tomography (CBCT) acquisition protocol, the presence of intraradicular metal post, and examiner experience on the detection of complete root fractures in multi-rooted teeth.

Methods: Twenty human molar teeth filled with gutta-percha were placed into artificial alveoli created in bovine ribs. The sample was divided into two groups based on the presence or absence of intraradicular posts in the distal roots. CBCT scans were obtained using four acquisition protocols with varying voxel sizes (0.28, 0.2, 0.125, and 0.80 mm). Following the creation of controlled fractures using a chisel and hammer, CBCT imaging was repeated, resulting in 160 images. Five examiners assessed the images using OnDemand software (KaVo Dental GmbH). Sensitivity, specificity, and accuracy were calculated for each examiner, CBCT protocol, and post-condition. Statistical comparisons were performed using Cochran's Q test and McNemar test, and a significance level of 5%.

Results: In teeth without metallic posts, sensitivity, specificity, and accuracy values exceeded 0.70, 0.70, and 0.80, respectively. However, the presence of metallic posts significantly reduced diagnostic performance, particularly in low-resolution protocols evaluated by less-experienced examiners.

Conclusions: CBCT acquisition protocols should be selected based on the presence of metallic posts to optimize root fracture detection in multi-rooted teeth. Examiner experience also plays a critical role in diagnostic accuracy.

Keywords: Cone-beam computed tomography; Examiner experience; Root fracture

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INTRODUCTION

Root fractures have a poor prognosis and are responsible for 10.9% of extractions of endodontically treated teeth [1]. Unfortunately, the diagnosis of teeth with prior endodontic treatment is a significant challenge for clinical examination, because root fractures have signs and symptoms similar to those of failed endodontic treatment or periodontal disease [2,3], and for radiographic interpretation, because of structures superimposition [4]. To aid in diagnostic thinking and clinical decision-making, cone-beam computed tomography (CBCT) may be indicated for cases in which clinical findings are suggestive of root fracture but radiographs provide negative or ambiguous evidence, or when there is no strong clinical evidence but radiographs raise the possibility of fracture [5,6].

Several factors, such as acquisition parameters, root filling, tooth anatomy, and examiner experience, may affect CBCT accuracy. The voxel size is the most investigated acquisition parameter since it directly influences image resolution. Diverse authors claim that higher resolution images are better for increasing exam sensitivity [7–10], but studies also show that the benefit of using a smaller voxel depends on the root filling [9,11,12]. The accuracy of CBCT diagnosis for root fractures may be compromised when radiopaque materials like gutta-percha and metallic posts are present in the root canal due to the formation of artifacts [13–17].

Multi-rooted teeth are the most compromised by root fractures [18]. Nonetheless, few studies investigated multi-rooted teeth [14,16,19–21], and only two of them investigated different acquisition protocols varying the voxel size [16,20]. However, in these two studies, the authors compared protocols across different CBCT systems, potentially introducing bias to their evaluations. Moreover, examiner experience plays an important role, as experienced examiners perform better in the assessment of root fractures [22,23]. However, the performance of students, especially undergraduates, is still overlooked [24], which may impair their development in clinical practice and radiological training for root fracture diagnosis.

Given the clinical challenges and the potential impact of root fractures on treatment outcomes, understanding the interplay between CBCT acquisition parameters, intraradicular materials, and examiner expertise is crucial for improving diagnostic accuracy. While existing studies have explored various aspects of root fracture diagnosis [24–26], gaps remain regarding multi-rooted teeth, the influence of voxel size within the same CBCT system, and the diagnostic capabilities of less-experienced examiners, such as undergraduate students.

Therefore, the objective of this study was to evaluate the influence of CBCT acquisition protocol, the presence of intraradicular metallic posts, and the examiner experience in detecting complete root fractures in multi-rooted teeth.

METHODS

Study design

An *ex vivo* experimental study was performed with 20 multi-rooted human teeth. The teeth were provided by the Department of Morphology of Federal University of Santa Maria, and the Institution's Ethics Committee approved the study protocol (No. 39486614.2.0000.5346).

Sample preparation

Each tooth was inspected under a magnifying glass (×3; Jieda Tools Co., Ltd, Xinyu, China) to confirm the absence of cracks and/or fractures. Endodontic access was performed with a spherical drill No. 1014 (KG Sorensen, Barueri, Brazil) and a conical drill with inactive tip No. 3082 (KG Sorensen).

The root canals were instrumented using the quarter-turn pull technique with K-files (Dentsply-Maillefer, Ballaigues, Switzerland), which consists of manual instrumentation to shape and prepare the root canal. The K-file was inserted into the root canal until resistance was felt, followed by a 90° clockwise rotation (a quarter turn) to engage dentinal walls, and then the instrument was withdrawn along the same path. The mesial canals were instrumented with 30 size K-files, and the distal canals were instrumented until 40 size K-files up to the working length. Each canal was frequently irrigated with a 2.5% sodium hypochlorite solution. The root canals were filled with Endofill sealer (Dentsply-Maillefer) and gutta-percha cones (Dentsply-Maillefer) by cold lateral compaction.

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The sample was randomly divided into two groups, and a metallic intraradicular post was inserted in half of the sample. To place the metallic post, the gutta-percha was removed from the coronal and middle thirds of the distal root using a #4 Gates-Glidden drill (Dentsply-Maillefer) and a #4 Largo drill (Dentsply-Maillefer). Metallic posts (Angelus, Londrina, Brazil) were inserted in the prepared roots, leaving at least 4 mm of gutta-percha inside the root.

All teeth were inserted into artificial alveoli, created using spherical drills, in bovine ribs, to simulate the alveolar bone [27]. The teeth were fixed to the artificial alveoli with wax (Asfer, São Caetano do Sul, Brazil) and plaster (Asfer). Root fractures were performed using a tapered chisel inserted in the pulp chamber and gently tapped with a hammer.

Image acquisition

The tomographic images were acquired using an OP 3D tomographic device (KaVo, Joinville, Brazil). The rib-teeth set was adapted to a three-dimensional printed jaw, surrounded by a 15-mm layer of wax in order to simulate soft tissues [28]. The mandible was stabilized to the CBCT device, and the field of view (50 × 50 mm) was adjusted to the right lower molar region.

Four acquisition protocols were used: low resolution (voxel, 0.28 mm; exposure time, 1.2 seconds; 3.8 mAs; 90 kV), standard-resolution (voxel, 0.2 mm; exposure time, 2.3 seconds; 18.4 mAs; 90 kV), high resolution (voxel, 0.125 mm; exposure time, 6.1 seconds; 38.4 mAs; 90 kV), and endo resolution (voxel, 0.085 mm; exposure time, 8.7 seconds; 54.8 mAs; 90 kV).

CBCT scans were performed before and after the fracture of the specimens, meaning eight acquisitions for each tooth, 160 acquisitions in total.

Image evaluation

CBCT acquisitions were exported in DICOM files and evaluated using the OnDemand software (KaVo Dental GmbH, Biberach an der Riß, Germany). All images were evaluated on the same computer (Intel i5; Intel Core i5-3570 CPU @ 3.40 GHz) and LED screen monitor (1,920 × 1,080 resolution, 23-inch Dell U2312HMt; Dell Ltda, Eldorado do Sul, Brazil), in a windowless room with subdued artificial lighting. All examiners were instructed to use the '1.5×' sharpen filter to evaluate the images. The brightness, contrast, and zoom settings were adjusted according to each examiner's preference. CBCT acquisitions were randomized using the randomizer.org website.

Five trained examiners (three postgraduate students in the Division of Oral Radiology and two third-year undergraduate dental students) evaluated all 160 files each. Training consisted of a 1-hour meeting to discuss the condition evaluated in the study (root fracture) and software manipulation. After assessing each DICOM, the examiner answered the question "Is there a root fracture?" using a 5-point Likert scale: "definitely yes," "probably yes," "uncertain," "probably no," and "definitely no."

Statistical analysis

Sensitivity, specificity, and accuracy values were calculated for each examiner, CBCT acquisition protocol, and the presence of intraradicular posts. To calculate the diagnostic test values, the Likert scale was dichotomized: categories 'definitely yes' and "probably yes" were combined as 'presence of root fracture,' and "uncertain," "probably no," and "definitely no" were combined as 'absence of root fracture.' The true diagnosis was compared among the variables using the Cochran Q test. Statistical analysis was performed with the SPSS software ver. 13 (SPSS Inc., Chicago, IL, USA). A significance level of 5% was used.

RESULTS

The sensitivity, specificity, and accuracy values for each examiner, CBCT acquisition protocol, and the presence of intraradicular posts are presented in Table 1. Teeth with metallic posts consistently exhibited lower diagnostic performance, particularly in low-resolution acquisition protocols. This effect was more pronounced for less-experienced examiners, whose sensitivity dropped to 0.40, under these conditions.

Table 2 highlights the percentage of correct diagnoses (hits) for each examiner, stratified by CBCT acquisition protocol and the presence of metallic posts. A statistically significant difference was observed in examiner 1's evaluations. For teeth with metal posts, the low-resolu-

Table 1. Values of accuracy, sensitivity, and specificity for each examiner according to acquisition protocol and presence of metallic post

Variable	Acc (E1)	Sens (E1)	Spec (E1)	Acc (E2)	Sens (E2)	Spec (E2)	Acc (E3)	Sens (E3)	Spec (E3)	Acc (E4)	Sens (E4)	Spec (E4)	Acc (E5)	Sens (E5)	Spec (E5)
With post															
Low resolution	0.75	0.80	0.70	0.95	0.90	1.00	0.90	0.80	1.00	0.65	0.40	0.90	0.60	0.40	0.80
Standard resolution	0.95	1.00	0.90	0.90	0.90	0.90	0.90	0.80	1.00	0.80	0.80	0.80	0.85	0.80	0.90
High resolution	0.95	1.00	0.90	0.95	1.00	1.00	0.90	0.80	1.00	0.90	0.90	0.90	0.85	0.90	0.80
Endo resolution	0.95	1.00	0.90	0.95	1.00	0.90	0.95	0.90	1.00	0.80	0.70	0.90	0.85	0.80	1.00
Without post															
Low resolution	0.95	0.90	1.00	0.95	0.90	1.00	0.95	0.90	1.00	0.85	0.70	1.00	0.90	0.80	1.00
Standard resolution	0.95	0.90	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.80	1.00	0.95	0.90	1.00
High resolution	0.95	0.90	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.80	0.90	0.70	0.85	0.70	1.00
Endo resolution	1.00	1.00	1.00	1.00	1.00	0.90	0.95	0.90	1.00	0.90	0.80	1.00	0.95	0.90	1.00

Acc, accuracy; Sens, sensitivity; Spec, specificity; E1, examiner 1; E2, examiner 2; E3, examiner 3; E4, examiner 4; E5, examiner 5.

tion protocol resulted in significantly fewer correct diagnoses (75%) compared to the standard-resolution (95%), high-resolution (95%), and endo-resolution (95%) protocols (p = 0.028). For teeth without metallic posts, diagnostic performance remained consistently high across all acquisition protocols, with accuracy values generally above 0.85 for all examiners. Notably, the endo-resolution protocol achieved 95% or higher accuracy for most examiners, emphasizing its superior diagnostic potential in this scenario. Figures 1 and 2 show axial cone-beam computed tomography slices of the sample teeth without and with post, respectively, acquired on the four protocols.

DISCUSSION

The diagnosis of root fractures remains a challenging task due to their non-specific clinical signs and symptoms and often limited radiographic findings, particularly for beginners in dentistry [22,23,27–31]. Although CBCT is more effective than two-dimensional imaging for detecting root fractures, its diagnostic accuracy is influenced by various factors, such as fracture orientation and width [32], the presence of intraradicular materials [11,17], and image acquisition protocol [17,21,32]. This study evaluated the effects of CBCT acquisition protocol, the presence of intraradicular metallic posts, and examiner expertise in diagnosing complete root fractures in multi-rooted teeth. The findings revealed that the diagnosis is significantly impaired by the presence of metallic posts, especially when low-resolution acquisition protocols are interpreted by less-experienced examiners. By addressing these underexplored areas, this study not only clarified conflicting evidence but also aimed to provide actionable insights for optimizing CBCT protocols and enhancing training in dental radiology.

The negative impact of metal posts in the diagnosis of root fractures has been reported in previous studies [33,34]. High atomic number materials create beam-hardening artifacts, which can obscure fracture lines or even simulate false fractures [15], jeopardizing the diagnosis. To overcome this adversity, it is recommended to use high-resolution protocols when root fracture is suspected. However, the concept of having "as high as possible" spatial resolution (here referred to as "endo-resolution") invariably leads to an increase in radiation dose [35–37]. This reinforces the importance of tailoring the protocol to the specific diagnostic requirements, ensuring the lowest radiation dose that still provides sufficient image quality [5,38].

The influence of voxel size on root fracture diagnosis was the subject of study in several publications [24–26]. de Lima Moreno *et al.* [34] pointed out that the 0.3-mm voxel should be selected for teeth without root fillings, and the 0.2-mm voxel should be selected for teeth with the presence of metal posts. Likewise, Silveira *et al.* [9] demonstrated comparable diagnostic performance for 0.2- and 0.3-mm voxel resolutions in teeth without root fillings but superior performance with 0.2-mm voxel resolution for teeth with metallic posts. Thus, the selection of voxel resolution should be guided depending on

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Table 2. Percentage of hits for each examiner according to acquisition protocol and presence of metallic post

Presence of post	Acquisition protocol																			
	Low resolution					Standard resolution					High resolution					Endo resolution				
	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5
With post	75%^{Aa}	95%^{Aab}	90%^{Aab}	65%^{Aab}	60%^{Aab}	95%^{Ab}	90%^{Aab}	90%^{Aab}	80%^{Aab}	85%^{Aab}	95%^{Ab}	95%^{Aab}	90%^{Aab}	90%^{Aab}	85%^{Aab}	95%^{Ab}	95%^{Aab}	95%^{Aab}	80%^{Aab}	85%^{Aab}
Without post	95%^{Aa}	95%^{Aa}	95%^{Aa}	85%^{Aa}	90%^{Aa}	95%^{Aa}	100%^{Aa}	90%^{Aa}	90%^{Aa}	95%^{Aa}	95%^{Aa}	100%^{Aa}	90%^{Aa}	80%^{Aa}	85%^{Aa}	100%^{Aa}	100%^{Aa}	95%^{Aa}	90%^{Aa}	95%^{Aa}

E1, examiner 1; E2, examiner 2; E3, examiner 3; E4, examiner 4; E5, examiner 5.
Different lowercase letters in a row indicate significant differences regarding the acquisition protocol. Different capital letters in a column indicate significant differences regarding the presence of post.

the material present inside the root canals. The findings of this study align with these observations, suggesting that a low-resolution protocol (voxel, 0.28 mm) is suitable for teeth without endodontic fillings to minimize radiation exposure, whereas higher resolutions (voxel, ≤0.2 mm) are preferable for teeth with metallic posts or root canal fillings. These results underscore the need to implement the ALADAIP (as low as diagnostically acceptable, being indication-oriented and patient-specific) principle [39] in clinical practice.

While the fractures in this study involved complete displacement of fragments, which could simplify diagnosis, examiner expertise emerged as a significant factor. Less-experienced examiners achieved lower accuracy, particularly when interpreting low-resolution protocols for teeth with metallic posts. This finding aligns with Gao *et al.* [22], who reported that experienced radiologists demonstrate superior diagnostic accuracy compared to graduate students. The lower accuracy of less-experienced examiners is probably related to factors such as limited familiarity with CBCT software [40], difficulty in distinguishing artifacts from fractures, and lack of exposure to complex radiological cases. These results highlight the critical role of expertise in imaging interpretation and emphasize the necessity for advanced CBCT training in graduation, particularly for challenging cases [31].

This laboratory study was designed to narrow the presence of bias to the only assessed variables: CBCT resolution, presence of metal post, and examiner experience. However, as with any *ex vivo* research, certain limitations must be acknowledged. First, laboratory conditions do not fully replicate the complexity of real-world clinical scenarios. In clinical practice, CBCT scans are often affected by patient movement, restorations, and prosthetic structures that can introduce additional image distortions and beam-hardening artifacts, which may obscure or mimic root fracture lines. Moreover, X-ray beam attenuation differs significantly between *ex vivo* and *in vivo* settings due to the presence of adjacent soft and hard tissues in the latter. As a result, laboratory images generally exhibit superior quality, with reduced noise and enhanced contrast compared to clinical scans. To simulate soft tissue attenuation and mitigate this discrepancy, the entire mandible was cov-

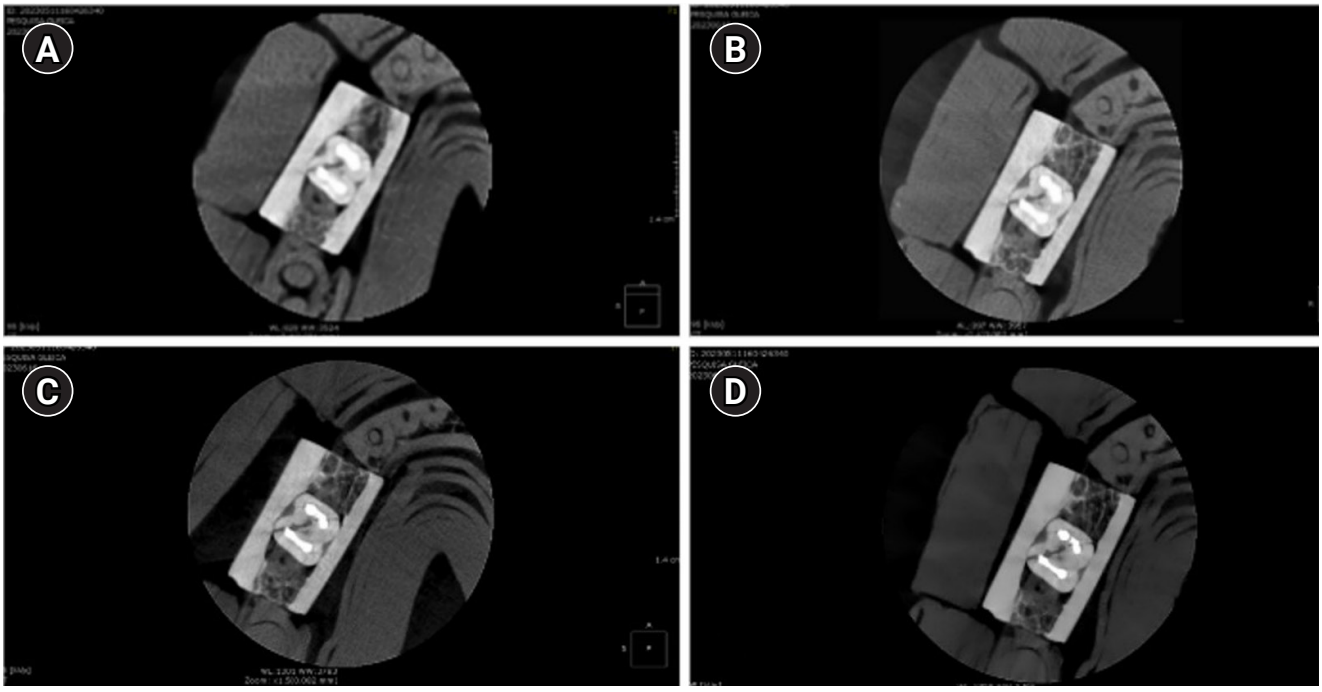


Figure 1. Axial cone-beam computed tomography slices of a sample tooth without post acquired on the four protocols. (A) Low dose resolution, (B) standard resolution, (C) high resolution, and (D) endo resolution.

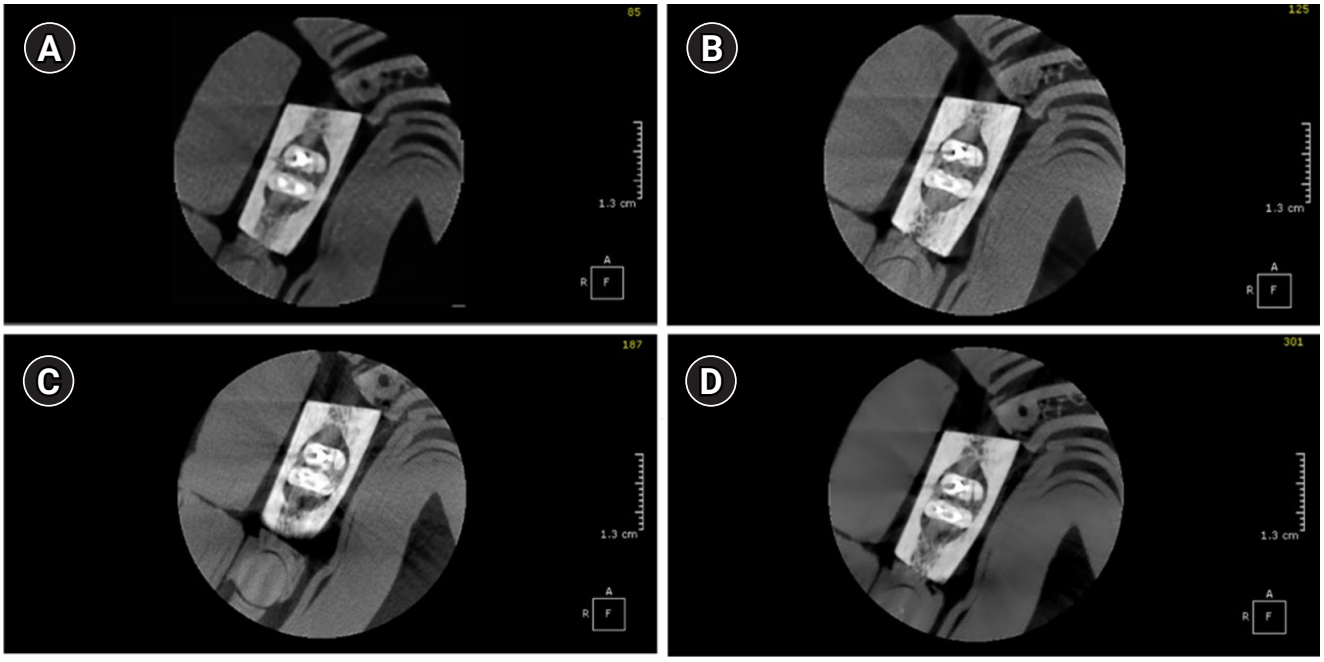


Figure 2. Axial cone-beam computed tomography slices of a sample tooth with post acquired on the four protocols. (A) Low dose resolution, (B) standard resolution, (C) high resolution, and (D) endo resolution.

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ered with wax, though this still represents a simplified approximation of actual clinical conditions.

CBCT image interpretation is inherently operator-dependent and labor-intensive. Thus, variability related to examiner fatigue and intra-observer consistency represents a potential source of error. These human factors, particularly fatigue in less-experienced examiners, remain underexplored in the context of CBCT interpretation and warrant further investigation under real clinical conditions. Additionally, the use of a single CBCT system limits the generalizability of the findings. While all available exposure parameters were tested, the results are specific to that scanner. Still, this choice was deliberate to avoid inter-scanner variability, which could introduce confounding variables.

Another limitation lies in the method used to induce fractures. Although controlled mechanical fractures were necessary to standardize comparisons, they may not fully represent the morphological diversity of naturally occurring root fractures. Clinically, root fractures may vary in location (coronal, middle, or apical third) and often present in early or incomplete stages, which are harder to detect. In contrast, the fractures in this study were complete and oriented in the coronal-apical direction. Additionally, larger and more obvious fracture lines are generally easier to detect [32,41], which may have influenced diagnostic performance. Nevertheless, all evaluations were conducted on the same fracture lines, ensuring internal consistency. Finally, this study did not incorporate clinical signs and symptoms, which are essential in real-life diagnosis and decision-making. This exclusion was intentional to isolate and evaluate the accuracy of CBCT imaging alone in detecting root fractures.

Despite the *ex vivo* design, the findings demonstrate that students can achieve accurate diagnoses, even for challenging cases like molar root fractures, when appropriate acquisition protocols are used. This reinforces the need to incorporate CBCT training early in dental education, covering topics such as digital imaging principles, exam justification, and software manipulation. Given the increasing reliance on CBCT in dental practice, equipping pre-doctoral students with these skills is essential.

CONCLUSIONS

In conclusion, root fracture diagnosis is highly dependent on the CBCT acquisition protocol, with high-resolution protocols recommended for cases involving metallic posts. Examiner expertise significantly affects diagnostic accuracy, particularly when low-resolution protocols are used. These findings highlight the importance of tailored CBCT protocols and early training in improving diagnostic outcomes.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

Conceptualization, Data curation, Formal analysis, Investigation: Savegnago GDO, Liedke GS. Funding acquisition, Project administration, Resources, Software, Supervision: Liedke GS. Methodology, Validation, Visualization: all authors. Writing - original draft: Savegnago GDO, Liedke GS. Writing - review & editing: all authors. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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