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Vertical root fracture diagnosis in teeth with metallic posts: Impact of metal artifact reduction and sharpening filters

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ABSTRACT

Purpose: This study examined the influence of a metal artifact reduction (MAR) tool, sharpening filters, and their combination on the diagnosis of vertical root fracture (VRF) in teeth with metallic posts using cone-beam computed tomography (CBCT).

Materials and Methods: Twenty single-rooted human premolars – 9 with VRF and 11 without – were individually placed in a human mandible. A metallic post composed of a cobalt-chromium alloy was inserted into the root canal of each tooth. CBCT scans were then acquired under the following parameters: 8 mA, a 5×5 cm field of view, a voxel size of 0.085 mm, 90 kVp, and with MAR either enabled or disabled. Five oral and maxillofacial radiologists independently evaluated the CBCT exams under each MAR mode and across 3 sharpening filter conditions: no filter, Sharpen 1×, and Sharpen 2×. The diagnostic performance was quantified by the area under the receiver operating characteristic curve (AUC), sensitivity, and specificity. These metrics were compared using 2-way analysis of variance with a significance level of $\alpha = 5\%$. Intra- and inter-examiner agreement were assessed using the weighted kappa test.

Results: Neither MAR nor the application of sharpening filters significantly impacted AUC or specificity ($P > 0.05$). However, sensitivity increased when MAR was combined with Sharpen 1× and Sharpen 2× ($P = 0.015$). The intra-examiner agreement ranged from fair to substantial (0.34-0.66), while the inter-examiner agreement ranged from fair to moderate (0.27-0.41).

Conclusion: MAR in conjunction with sharpening filters improved VRF detection; therefore, their combined use is recommended in cases of suspected VRF. ***(Imaging Sci Dent 2024; 54: 139-45)***

KEY WORDS: Tooth Fractures; Radiographic Image Enhancement; Cone-Beam Computed Tomography; Artifacts

Introduction

A vertical root fracture (VRF) is a dental fracture that extends longitudinally along the root. This condition predominantly affects teeth with canals that have been enlarged for root canal obturation, as this preparation reduces the tooth's resistance to fractures.[1-3] Accurately diagnosing VRF is challenging and requires a combination of clinical signs, symptoms, and imaging exams.[4,5] However, these clinical signs and symptoms may not always be present, making imaging exams an important tool for identifying VRFs.[4]

On periapical radiographs, a root fracture is visible if the central beam of the X-ray is parallel to the fracture line; however, this parallelism is not always achieved.[4,6] Additionally, the superimposition of anatomic structures complicates the diagnosis of VRF using 2-dimensional imaging.[7] Cone-beam computed tomography (CBCT) represents an alternative diagnostic tool. This 3-dimensional imaging technique has previously demonstrated comparatively high accuracy rates in the detection of VRF.[1,8,9]

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However, on CBCT exams, the presence of metallic posts can induce artifacts due to the hardening of the X-ray beam. These artifacts appear as hyperdense or hypodense streaks, which may either obscure an existing fracture line or falsely suggest the presence of a root fracture.[1,4,10] Adjusting the energetic parameters has been shown to mitigate these artifacts. Previous studies have found that higher milliampere (mA) values enhance image quality and diagnostic accuracy for VRF in teeth with metallic posts on CBCT exams.[11,12] However, increasing the mA also results in a higher radiation dose delivered to the patient.[13]

Metal artifact reduction (MAR) is a tool available with some CBCT devices that operates during image reconstruction, assigning a threshold to the image that corresponds to its normal gray values.[14] This process enhances the quality of the image. In addition, most CBCT software includes digital enhancement filters, such as sharpening filters, which modify the gray values of the image after reconstruction.[15] These enhancement filters have been found to be beneficial for diagnostic tasks, including the visualization of root resorptions.[16] While MAR and enhancement filters function differently, both tools can improve the visualization of CBCT images without the need to increase energy parameters, aligning with the principles of radioprotection.

Considering the challenges in diagnosing VRF when the suspected tooth contains a metallic post, along with the potential for improved diagnostic accuracy using a MAR tool, filter application, or a combination of both, the present study was conducted. This research aimed to investigate the impact of the MAR tool, sharpening filters, and their combined use on the detection of VRF in teeth with metallic posts.

Materials and Methods

The research was conducted with the approval of the local institutional review board (CAAE: 44164921.4.0000.5418), without any restrictions and in compliance with the Declaration of Helsinki.

Sample selection and preparation

Twenty single-rooted human premolars were selected. Based on the exclusion criteria, teeth with any previous root fractures or anomalies, internal/external root resorption, supernumerary canals, pulp calcification, or endodontic treatment were not included in the study. Following sample collection, the crowns of the teeth were removed to prevent bias related to memorizing the tooth's appearance or identifying a coronal fracture during image assessment.

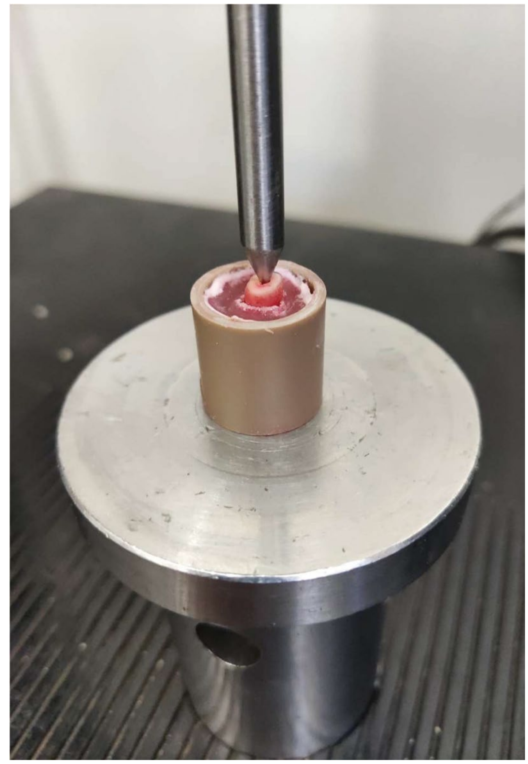

Fig. 1. A conical metal tip is positioned at the canal entrance to induce a root fracture.

The root canals were instrumented using an Mtwo NiTi rotary system (VDW GmbH, Munich, Germany) with distilled water serving as the irrigating solution. Nickel-titanium tips of 4 different diameters (25.07, 30.05, 35.04, and 40.04) were employed. Subsequently, a number 2 drill (Peeso Long Drill; Dentsply Sirona Endodontics, York, PA, USA) was used to prepare two-thirds of the root canal for the placement of the metallic post.

The sample was divided into a control group, consisting of 11 teeth, and an experimental group, comprising 9 teeth. To simulate VRF in the experimental group, each tooth was individually embedded in acrylic resin blocks (Fig. 1). Subsequently, an Instron testing machine (Instron Corporation, Canton, MA, USA) with a conical metal tip was utilized, following the methodology described previously.[4] Transillumination was employed to confirm the presence of VRF.

CBCT scan acquisition

First, a tooth with a metallic post composed of a cobalt-chromium alloy placed inside its root canal was inserted into the first premolar socket of a human mandible. Wax was positioned between the tooth and the dental socket to simulate the periodontal ligament space. Additionally, to mimic the attenuation and dispersion of X-rays caused by a patient's soft tissues, the mandible was placed inside a plastic canister filled with water.

All scans were obtained using an OP300 Maxio CBCT unit (Instrumentarium Dental, Tuusula, Finland), with settings of 8 mA, 90 kVp, a voxel size of 0.085 mm, a field of view of 5 × 5 cm, and 2 MAR modes (enabled and disabled). Consequently, a total of 40 CBCT scans were acquired (20 teeth × 2 MAR modes).

Image evaluation

For evaluation, all 40 scans were exported in the Digital Imaging and Communications in Medicine format and independently assessed by 5 oral and maxillofacial radiologists, each with over 5 years of experience in evaluating 3-dimensional images. The assessments took place in a quiet, low-light room using OnDemand 3D (Cybermed, Irvine, CA, USA) on a high-resolution monitor (MDRC-2124; Barco N.V., Courtray, Belgium). The examiners were blinded to the status of the MAR feature (disabled or enabled) for all examinations. For each evaluation, the examiners referred to a spreadsheet that indicated whether to apply Sharpen 1 × , Sharpen 2 × , or neither of the tested filters (Figs. 2 and 3). The sequence of scans with and without MAR, as well as the application of the filters, was randomized in the spread-

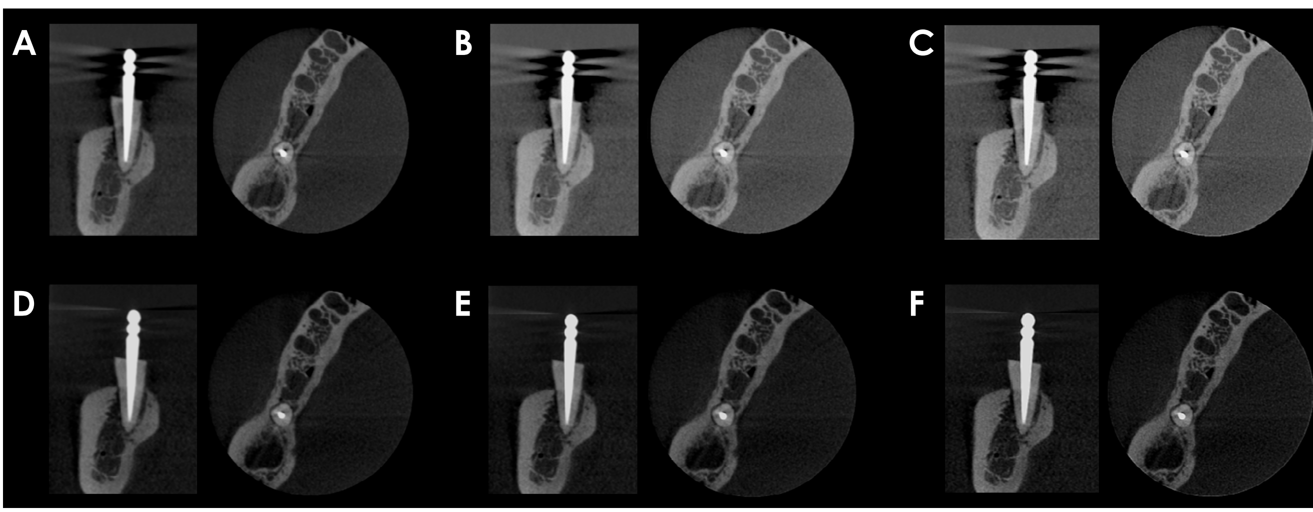

Fig. 2. Coronal and axial cone-beam computed tomography reconstructions of a tooth without vertical root fracture under various metal artifact reduction (MAR) tool settings and sharpening filter conditions. A. MAR disabled. B. MAR disabled + Sharpen 1 × . C. MAR disabled + Sharpen 2 × . D. MAR enabled. E. MAR enabled + Sharpen 1 × . F. MAR enabled + Sharpen 2 × .

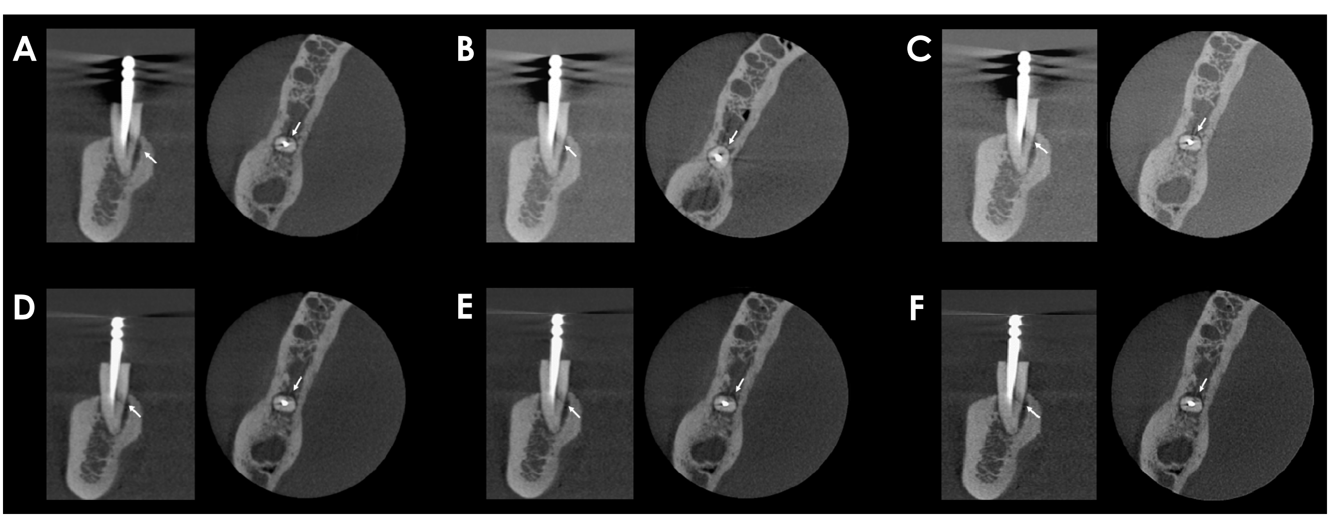

Fig. 3. Coronal and axial cone-beam computed tomography reconstructions of a tooth with vertical root fracture under various metal artifact reduction (MAR) tool settings and sharpening filter conditions. A. MAR disabled. B. MAR disabled + Sharpen 1 × . C. MAR disabled + Sharpen 2 × . D. MAR enabled. E. MAR enabled + Sharpen 1 × . F. MAR enabled + Sharpen 2 × . Arrows indicate vertical root fracture.

sheet to prevent potential bias from the examiners becoming over-familiar with the last conditions evaluated. Consequently, the conditions were assessed in a random order. In total, 120 CBCT scans were evaluated (20 teeth × 2 MAR modes × 3 sharpening filter conditions).

Before the CBCT analysis, scans not included in the final sample were utilized for examiner calibration. Each volume was rated on a 5-point scale as follows: 1) absence of VRF, 2) probable absence of VRF, 3) uncertainty, 4) probable presence of VRF, and 5) presence of VRF. The examiners were instructed to evaluate no more than 20 CBCT volumes per day to prevent fatigue. Adjustments to post-processing settings, such as brightness, contrast, and zoom, were permitted. One month after completing the assessments, 30% of the sample was randomly selected and re-evaluated to quantify intra-examiner reproducibility.

Statistical analysis

Power analysis was performed using Biostat version 5.3 (Instituto de Desenvolvimento Sustentável Mamirauá, Tefé, Brazil) to ensure the reliability of the results. This incorporated the minimum difference between the group means, the average standard deviation, and the number of repetitions per group, ultimately yielding a power of 75%. Statistical analyses were conducted with SPSS version 23.0 (IBM Corp., Armonk, NY, USA), with the significance level set at 5% ($P<0.05$).

The area under the receiver operating characteristic curve (AUC), along with sensitivity and specificity, was calculated by comparing the examiners' assessments to the actual condition of the root (that is, with or without VRF). These calculations were conducted for each examiner and for each tested condition. Subsequently, the results were compared using 2-way analysis of variance, incorporating the Tukey *post hoc* test to determine any potential effects and interactions of the variables on the diagnosis of VRF.

The agreement among examiners (both intra-examiner and inter-examiner) regarding the diagnosis of VRF was assessed using the weighted kappa test and interpreted according to the Landis and Koch scale.[17]

Results

Tables 1-3 present the metrics for AUC, sensitivity, and specificity. The values for AUC and specificity were not significantly influenced by the use of the MAR tool, the application of a sharpening filter, or the combination of these.

Under the various sharpening filter conditions, the AUC values ranged from 0.69 to 0.75 with MAR disabled and from 0.69 to 0.77 with MAR enabled. However, neither the application of the filter ($P=0.490$) nor the use of the MAR tool ($P=0.692$) was associated with a significant change in the AUC outcome, as shown in Table 1.

Table 2 demonstrates that sensitivity values increased with the use of MAR when the Sharpen 1× and Sharpen 2× filters were applied ($P=0.015$). Sensitivity values varied between 0.51 and 0.56 with MAR disabled and between 0.58 and 0.76 with MAR enabled, indicating a beneficial effect associated with the activation of this feature. Consequently, it appears that applying sharpening filters is advantageous in CBCT scans when MAR is enabled.

Under the sharpening filter conditions, the specificity values varied between 0.76 and 0.85 with the MAR tool

Table 1. Area under the receiver operating characteristic curve according to filter application and metal artifact reduction condition

Filter	Metal artifact reduction	
	Disabled	Enabled
Without	0.73 ± 0.14	0.69 ± 0.08
Sharpen 1×	0.75 ± 0.08	0.77 ± 0.11
Sharpen 2×	0.69 ± 0.03	0.75 ± 0.11
$P=0.490$	$P=0.692$	

Table 2. Sensitivity according to filter application and metal artifact reduction condition

Filter	Metal artifact reduction	
	Disabled	Enabled
Without	0.53 ± 0.12^{A}	0.58 ± 0.12^{A}
Sharpen 1×	0.56 ± 0.18^{B}	0.76 ± 0.14^{A}
Sharpen 2×	0.51 ± 0.06^{B}	0.69 ± 0.21^{A}
$P=0.33$	$P=0.015$	

Different uppercase letters indicate a significant difference between exams evaluated with metal artifact reduction disabled and enabled inside the same condition of filter application

Table 3. Specificity according to filter application and metal artifact reduction condition

Filter	Metal artifact reduction	
	Disabled	Enabled
Without	0.76 ± 0.22	0.75 ± 0.15
Sharpen 1×	0.80 ± 0.24	0.67 ± 0.17
Sharpen 2×	0.85 ± 0.17	0.71 ± 0.24
$P=0.880$	$P=0.201$	

deactivated and from 0.67 to 0.71 with MAR activated. The factors studied did not significantly influence these values (P filter = 0.880; P MAR = 0.201).

Considering that the sum of sensitivity and specificity for a diagnostic test should be at least 1.5 to adequately distinguish between abnormal and normal results, none of the combinations tested achieved adequate values for sensitivity and specificity.[18]

The intra-examiner agreement ranged from fair to substantial, with kappa values between 0.34 and 0.66. The inter-examiner agreement ranged from fair to moderate, as indicated by kappa values between 0.27 and 0.41.

Discussion

The study results demonstrated that when VRF is suspected in teeth with metallic posts, neither the use of a sharpening filter nor the activation of MAR alone significantly improved diagnostic accuracy. However, the combined application of these techniques did enhance fracture detection. Consequently, based on these findings, dentists should recognize that while employing these filters individually may be ineffective, their combined use with the MAR tool could improve the visualization of VRF.

According to the relevant literature, the application of enhancement filters on CBCT exams yields varying results.[15,16,19,20] Their use was shown not to enhance the visualization of endodontic complications, such as fractured files, perforations, or deviated posts, and only slightly improved the detection of external root resorption.[16,19] The present findings diverge from these outcomes, which may be attributed to differences in the diagnostic tasks assessed, the CBCT devices utilized, and the filters tested, as the above-mentioned studies used enhancement filters within XoranCat software (Xoran Technologies, Ann Arbor, MI, USA). Mouzinho-Machado et al.[20] investigated the effect of the same enhancement filters examined in this study on the detection of the second mesiobuccal canal in teeth filled with gutta-percha, finding that their use did not influence the performance of this diagnostic task. Furthermore, Gonzalez et al.[15] observed that applying a sharpening filter to CBCT exams conducted with low-dose protocols (e.g., low mA values) improved the diagnosis of root fractures in teeth filled with gutta-percha. Given that metallic posts and gutta-percha can create artifacts that compromise the quality of CBCT exams, the finding that sharpening filters can enhance the visualization of VRF is key.[21]

Previous objective analyses have concluded that hypodense and hyperdense streaks are smoothed when MAR is enabled.[22,23] However, this homogenization of gray values in areas affected by beam-hardening artifacts does not necessarily impact diagnostic tasks. Some studies have shown that activating MAR did not enhance the detection of dehiscence and fenestration defects, nor did it aid in identifying fractured endodontic instruments.[24,25] A systematic review reported that better VRF diagnostic values were achieved when MAR was disabled, and it was recently concluded that the visualization of horizontal root fractures was improved with the MAR tool deactivated.[2,26] The present results differ slightly from those of these previous studies. Specifically, while the MAR tool did not significantly improve diagnostic values without a filter, its activation resulted in increased sensitivity values when sharpening filters were applied.

The impact of applying an enhancement filter with a MAR tool warrants further investigation. A previous study assessed the effect of combining MAR with an enhancement filter on the detection of peri-implant fenestration defects located near zirconium implants.[27] The authors found that this combination improved the accuracy of detecting peri-implant fenestrations. Nonetheless, additional filters and diagnostic tasks should be examined to clarify the benefits of combining those tools.

In this study, no group without a metallic post was included, as previous research had already established the detrimental effect of metallic posts on the detection of VRF.[4,12,28] Consequently, the present investigation was focused on determining whether techniques such as MAR activation or the application of a sharpening filter could mitigate the negative impact of artifacts caused by the presence of metallic posts. Although numerous types of alloys are available, the metallic post used in this study was composed of a cobalt-chromium alloy. This selection was based on the superior biocompatibility of cobalt-chromium compared to other materials, such as nickel or palladium.[29] Additionally, the mA value was set at 8 for all CBCT acquisitions, as it has been shown that VRF visualization in teeth with metallic posts is enhanced when the mA level exceeds 4.[12]

The values obtained for intra-examiner and inter-examiner agreement ranged from fair to substantial, with a span of 0.27 to 0.66. To replicate a scenario frequently encountered in dental practice, the fractures created in this study were incomplete and lacked fragment displacement, which supports the observed agreement values. Moreover, prior research assessing the detection of VRF reported similar levels of intra- and inter-examiner agreement, highlighting the challenges associated with identifying VRF.[4,12,27]

In adherence to radioprotection principles, which aim to avoid repeated exposure of the same patient, the current study employed an *ex vivo* methodology. Consequently, it was not feasible to correlate clinical signs and symptoms with imaging results. Nevertheless, a human mandible with its dental sockets filled with wax was utilized to mimic the periodontal ligament space. Additionally, to simulate a clinical setting, the attenuation of X-rays by a patient's soft tissues was replicated by placing the mandible in a canister filled with water.

This research assessed the combination of a MAR tool and sharpening filters in the diagnosis of VRF. However, additional types of enhancement filters are available within various software programs, and other diagnostic conditions also require investigation, including horizontal root fractures and root resorptions. Consequently, future studies are encouraged.

The integration of a MAR tool with sharpening filters was found to improve the detection of VRF in teeth with metallic posts. Consequently, their use is recommended in cases of suspected VRF.

Conflicts of Interest: None

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