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Combination of metal artifact reduction and sharpening filter application for horizontal root fracture diagnosis in teeth adjacent to a zirconia implant

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ABSTRACT

Purpose: This study examined the influence of metal artifact reduction (MAR), the application of sharpening filters, and their combination on the diagnosis of horizontal root fracture (HRF) in teeth adjacent to a zirconia implant on cone-beam computed tomography (CBCT) examinations.
Materials and Methods: Nineteen single-rooted teeth (9 with HRF and 10 without) were individually positioned in the right central incisor socket of a dry human maxilla. A zirconia implant was placed adjacent to each tooth. Imaging was performed using an OP300 Maxio CBCT (Instrumentarium, Tuusula, Finland) unit with the following settings: a current of 8 mA, both MAR modes (enabled and disabled), a 5 × 5 cm field of view, a voxel size of 0.085 mm, and a peak kilovoltage of 90 kVp. Four oral and maxillofacial radiologists independently evaluated the CBCT scans under both MAR conditions and across 3 levels of sharpening filter application (none, Sharpen 1 ×, and Sharpen 2 ×). Diagnostic metrics were calculated and compared using 2-way analysis of variance ($\alpha = 5\%$). The weighted kappa test was used to assess intra- and inter-examiner reliability in the diagnosis of HRF.
Results: MAR tool activation, sharpening filter use, and their combination did not significantly impact the area under the receiver operating characteristic curve, sensitivity, or specificity of HRF diagnosis ($P > 0.05$). Intra- and inter-examiner agreement ranged from fair to substantial.
Conclusion: The diagnosis of HRF in a tooth adjacent to a zirconia implant is not affected by the activation of MAR, the application of a sharpening filter, or the combination of these tools. ***(Imaging Sci Dent 2024; 54: 289-95)***

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

Introduction

Horizontal root fracture (HRF) is a dental injury that typically results from traumatic incidents such as fights, sports injuries, and car accidents.[1,2] It commonly involves a horizontal division of the root structure of a tooth in the maxillary anterior region into 2 parts.[3] This type of injury tends to occur in fully erupted permanent teeth.[4]

Cone-beam computed tomography (CBCT) represents a valuable adjunctive tool in diagnosing HRF, as 2-dimensional images, even when captured from multiple perspectives, may not adequately visualize the condition.[5] However, CBCT has certain limitations. Previous research has indicated that the detection of HRF is compromised when an implant composed of high-density material is situated near the tooth under investigation.[6] This material introduces the beam hardening effect, which manifests as artifacts appearing as alternating hyperdense and hypodense streaks.[6] Such artifacts may interfere with the diagnosis of root resorptions, bone defects, and root fractures.[6-8]

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An alternative method to mitigate the effects of beam hardening is the activation of metal artifact reduction (MAR).[9] This tool operates during the reconstruction phase of the CBCT volume, assigning a threshold equivalent to normal gray values. This action reduces the extreme values caused by artifacts, resulting in more consistent gray values.[10] However, although objective analyses suggest that image quality improves with the use of MAR, its impact on diagnostic accuracy continues to be debated.[9,11]

Furthermore, some CBCT software offers digital enhancement filters.[12] These filters employ mathematical algorithms to adjust the gray values after the CBCT exam has been obtained, blurring the boundaries of anatomic structures (in the case of smoothing filters) or increasing their definition (as with sharpening filters).[12,13] Previous research has indicated that sharpening filters improve the visualization of fractured instruments and the measurement of apical bone loss.[14,15] However, studies assessing the impact of these enhancement filters on HRF diagnosis are currently lacking.

Recently, a study investigated the effect of combining MAR with an enhancement filter on the detection accuracy of fenestration defects near dental implants. The researchers concluded that the joint use of both tools can be recommended for this diagnostic task.[16] Given the difficulty in diagnosing HRF when the fracture is located near a high-density material, along with the potential for improved diagnostic accuracy using the MAR tool, a sharpening filter, or a combination of both, the present study aimed to assess the impact of MAR and sharpening filter application on the detection of HRF in a tooth adjacent to a zirconia implant.

Material and Methods

The current study was conducted with the approval of the local institutional review board, under protocol number CAAE: 39848520.0.0000.5418.

Preparation of the sample

For sample preparation, 19 anterior human teeth were selected according to specific inclusion criteria, which required the absence of caries lesions, restorations, root resorptions, gutta-percha, metallic posts, and other types of filling materials. Following selection, the samples were disinfected with 2% glutaraldehyde and stored in distilled water to prevent dehydration. Subsequently, the sample was divided into an experimental group, consisting of 9 teeth, and a control group, comprising 10 teeth. The sample size was determined based on previous studies.[17,18]

The experimental group underwent HRF induction through the application of mechanical force with a nail and hammer to the root of each tooth, which was positioned on a soft foundation to ensure stability. Following separation into 2 dental parts, cyanoacrylate was utilized to facilitate the reattachment of the fragments.[6] Teeth that exhibited root tissue loss as a result of HRF induction were excluded from the sample. Furthermore, the absence of root fractures in other orientations, such as longitudinal fractures, was verified using the transillumination method.

Image acquisition

Each tooth was individually placed in the dental socket of the right central incisor of a dry human maxilla, employing an *ex vivo* methodology. A zirconia implant measuring 4×11 mm (Z-Look 3; Z-Systems, Oensingen, Switzerland) was positioned adjacent to the tooth, in the socket of the right lateral incisor. For both the tooth and the implant, wax was used to fill the dental socket, simulating the periodontal ligament space in the resulting images. The dry human maxilla was then placed in a plastic box filled with water to emulate the attenuation and dispersion of X-rays by soft tissues. CBCT exams were performed using an OP300 Maxio CBCT device (Instrumentarium, Tuusula, Finland) under the following parameters: a voxel size of 0.085 mm, a field of view of 5×5 cm, a current of 8 mA, and a peak kilovoltage of 90 kVp. Both modes of MAR—enabled and disabled—were evaluated. Consequently, a total of 38 CBCT exams were acquired (19 teeth×2 MAR modes).

Image evaluation

For evaluation purposes, all 38 exams were exported in the Digital Imaging and Communications in Medicine format and independently assessed by 4 oral and maxillofacial radiologists, each with over 5 years of experience in evaluating 3-dimensional images. The evaluations were performed in a quiet, low-light environment using OnDemand 3D software (Cybermed, Seoul, Korea) and a high-resolution medical display (MDRC-2124, Barco N.V., Courtray, Belgium). The examiners were blinded to the status of the MAR tool (disabled or enabled) for each exam. For every exam evaluated, the radiologists referred to a spreadsheet that indicated whether to apply Sharpen 1×, Sharpen 2×, or neither filter. The sequence of scans conducted with and without MAR, as well as the application of the filters, was randomized in the spreadsheet. This was done to avoid potential bias from overtraining impacting the latter scans (Figs. 1 and 2). Consequently, the conditions were assessed in random order.

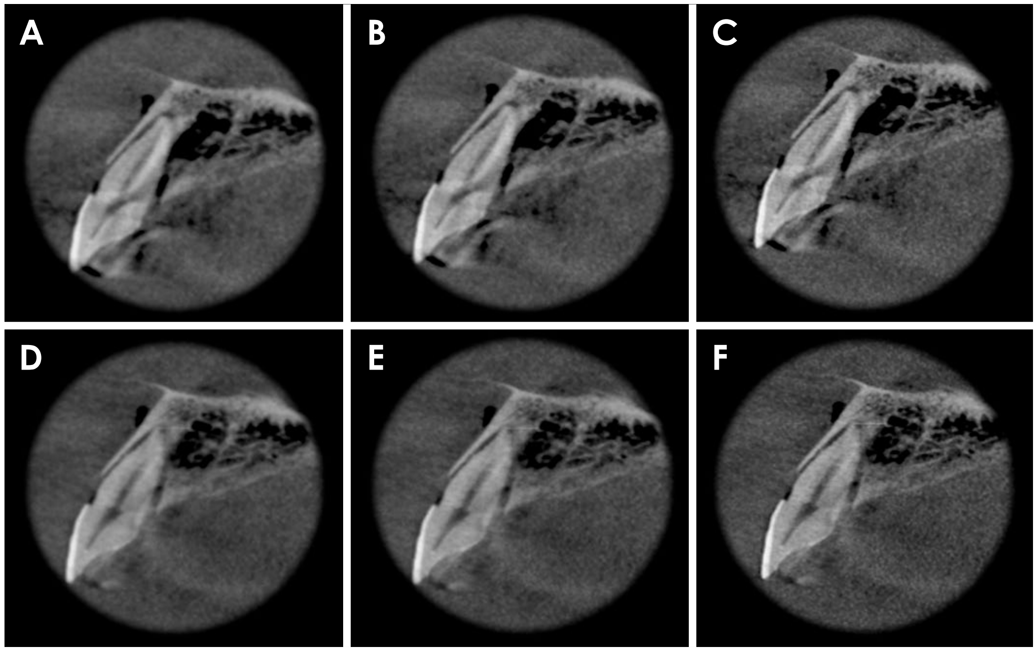

Fig. 1. Sagittal reconstructions of a cone-beam computed tomography volume of a tooth without a horizontal root fracture under various metal artifact reduction (MAR) tool and sharpening filter conditions. A. MAR disabled without filter. B. MAR disabled with Sharpen 1× applied. C. MAR disabled with Sharpen 2× applied. D. MAR enabled without filter. E. MAR enabled with Sharpen 1× applied. F. MAR enabled with Sharpen 2× applied.

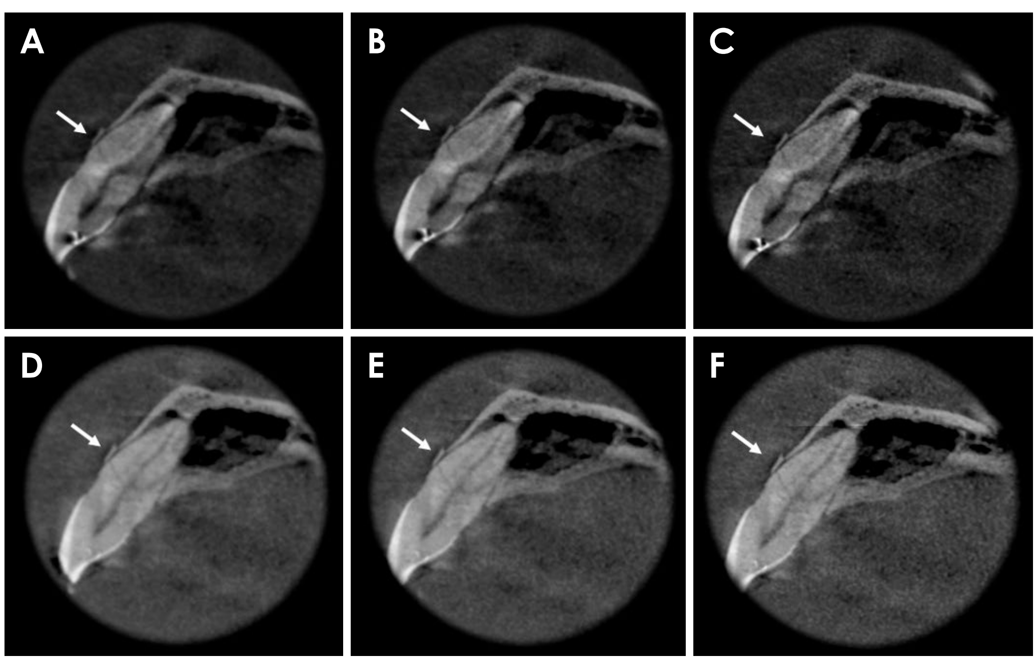

Fig. 2. Sagittal reconstructions of a cone-beam computed tomography volume of a tooth with a horizontal root fracture under various metal artifact reduction (MAR) tool and sharpening filter conditions. A. MAR disabled without filter. B. MAR disabled with Sharpen 1× applied. C. MAR disabled with Sharpen 2× applied. D. MAR enabled without filter. E. MAR enabled with Sharpen 1× applied. F. MAR enabled with Sharpen 2× applied. Arrows indicate the root fracture.

A total of 114 CBCT exams were evaluated, encompassing 19 teeth across 2 MAR modes and 3 sharpening filter conditions. The exams were rated using a 5-point scale: 1) absence of fracture, 2) probable absence of fracture, 3) uncertain status, 4) probable presence of fracture, and 5) presence of fracture. Prior to analyzing the CBCT images acquired for this study, the examiners were trained and calibrated for the assessment of HRF using CBCT images not included in the final sample. Examiners were instructed to evaluate no more than 15 CBCT exams per day and to take a 1-day break between sessions to avoid visual fatigue. They were permitted to make post-processing adjustments, such as zooming and modifying brightness and/or contrast. Inter-examiner agreement was determined based on these evaluations. Intra-examiner reproducibility was assessed by randomly re-evaluating 30% of the sample 1 month after the initial evaluations were completed.

Statistical analysis

SPSS version 23.0 (IBM Corp., Armonk, NY, USA) was used for all statistical analyses, with the significance level set at 5% ($P<0.05$). The area under the receiver operating characteristic curve (AUC), sensitivity, and specificity were calculated by comparing the examiners' responses to the gold standard, which was the known condition of the tooth with respect to HRF. This process was carried out for each examiner and condition tested, providing multiple parametric data points for each group. These were then compared using multi-way analysis of variance with the Tukey *post hoc* test to determine the potential effects and interactions of MAR and sharpening filters on the diagnosis of HRF. The power of the test was calculated based on the minimum difference between the means of the groups, the average standard deviation, and the number of repetitions for each group, yielding a power of 75%.

Intra- and inter-examiner agreement for the diagnosis of HRF was assessed using weighted kappa indices, which were then interpreted according to the Landis and Koch scale.[19] The null hypothesis posited that the studied factors had no influence on the diagnosis of HRF.

Results

Tables 1-3 present results regarding the diagnostic metrics (AUC, sensitivity, and specificity values, respectively), which were not significantly influenced by MAR tool use, sharpening filter application, or their combination ($P>0.05$). Given that the combined sensitivity and specificity of a diagnostic test should reach at least 1.5 to effectively differentiate between abnormal and normal findings, none of the tested combinations could be deemed a useful tool for diagnosing HRF.[20] These results underscore the detrimental impact of artifact-generating materials located

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

Filter	Metal artifact reduction	
	Disabled	Enabled
None	0.59±0.04	0.72±0.06
Sharpen 1×	0.74±0.06	0.74±0.15
Sharpen 2×	0.69±0.07	0.61±0.08
$P>0.05$	$P>0.05$	

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

Filter	Metal artifact reduction	
	Disabled	Enabled
None	0.44±0.16	0.50±0.14
Sharpen 1×	0.64±0.11	0.63±0.27
Sharpen 2×	0.50±0.14	0.47±0.11
$P>0.05$	$P>0.05$	

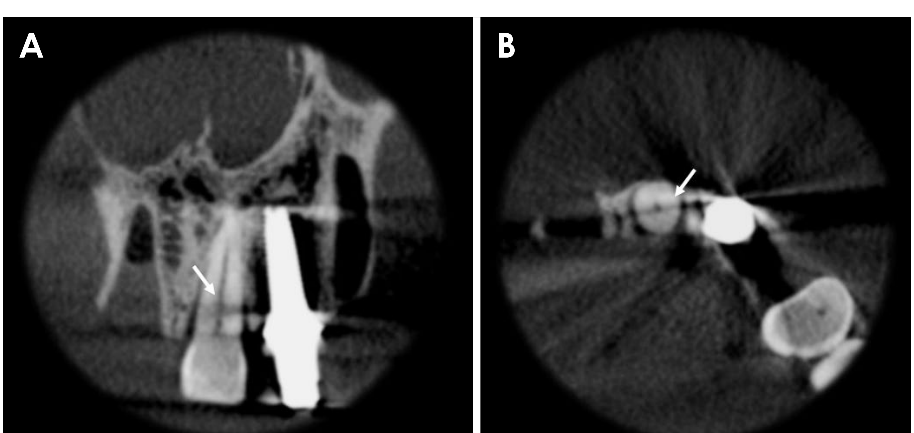

Fig. 3. Reconstructions of a cone-beam computed tomography examination show artifacts resulting from the presence of the implant. A. Coronal reconstruction image depicts a tooth without a horizontal root fracture. B. Axial reconstruction image of the same tooth. White arrows indicate hypodense streaks that could mimic a root fracture.

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

Filter	Metal artifact reduction	
	Disabled	Enabled
None	0.68±0.19	0.78±0.15
Sharpen 1×	0.58±0.10	0.77±0.05
Sharpen 2×	0.78±0.16	0.68±0.10
$P>0.05$	$P>0.05$	

Table 4. Intra- and inter-examiner agreement for the detection of horizontal root fractures

Examiner	1	2	3	4
1	0.601	0.313	0.314	0.330
2		0.723	0.336	0.393
3			0.633	0.379
4				0.717

near the region of interest. Specifically, hyperdense and hypodense streaks may obscure or mimic a root fracture, respectively; as such, they compromise the visualization of the CBCT results (Fig. 3).[6]

The intra-examiner agreement values were substantial (range: 0.601-0.723), while the inter-examiner agreement values were fair (range: 0.313-0.393), as shown in Table 4.

Discussion

The results indicated that when HRF is suspected adjacent to a zirconia implant, efforts to improve diagnostic accuracy with the MAR tool and/or sharpening filters were ineffective. As demonstrated in Tables 1-3, the AUC, sensitivity, and specificity were not significantly impacted by the application of MAR or sharpening filters. Given that the activation of MAR and the application of filters neither improved nor compromised the diagnosis of the assessed condition, clinicians may choose to use or forego these tools based on personal preference.

Artifacts generated by high-density materials can compromise the visualization of root fractures, making it crucial to explore strategies that can mitigate their impact.[6,21] One approach is to adjust the energetic parameters, such as increasing the milliamperage (mA) values. This adjustment has been previously demonstrated to improve diagnostic outcomes for fractured teeth that either contain metal posts or are located adjacent to dental implants.[6,8] In both cases, when levels above 4 mA were used during CBCT acquisition, the detection of fractures was improved.[6,8] However, an increase in mA levels also increases the radiation dose delivered to the patient.[22] Consequently, dentists must exercise caution when altering mA levels.

In comparison, strategies such as MAR tool activation and the application of sharpening filters may improve the quality of the CBCT examination without increasing the radiation dose. Since a previous study concluded that a level of 10 mA resulted in superior outcomes for HRF diagnosis, it is imperative to understand the influence of an intermediate mA level in combination with other tools (such as MAR and enhancement filters) on this diagnostic task, in an effort to reduce radiobiological risks to patients.[6] In previous analyses, enabling MAR resulted in the homogenization of hyperdense and hypodense streaks.[23,24] These analyses were performed objectively through the assessment of gray values; therefore, it is necessary to investigate whether changing the gray values also impacts diagnostic performance. Previously, a study concluded that MAR tool activation improved the visualization of proximal caries lesions on teeth located near restorative materials, while another investigation showed a decrease in the accuracy of vertical root fracture (VRF) detection on endodontically treated teeth when MAR was enabled.[25,26] However, additional research revealed that the detection of peri-implant and periodontal defects was not significantly affected by MAR, which is consistent with the findings presented in Tables 1, 2, and 3.[27] Variations among CBCT devices, interpolation algorithms, and technical parameters applied to MAR, along with differences in the diagnostic tasks investigated, may explain the divergent results.[25,28]

An enhancement filter is a post-processing tool that can influence the quality of a CBCT examination. Bastos et al. evaluated various filters available within XoranCat software (Xoran Technologies, Ann Arbor, MI, USA) and determined that the Sharpen Mild filter could be used to assess condyle defects.[29] Furthermore, de Azevedo Vaz et al. found that the Sharpen 3×3 filter marginally increased accuracy in diagnosing external root resorption.[30] In agreement with these findings, Gonzalez et al. observed that a sharpening filter improved the diagnosis of VRF in CBCT exams acquired with low-dose protocols.[12] Building on this evidence, the current study hypothesized that sharpening filters may facilitate the diagnosis of HRF in the presence of artifacts. However, the results showed that sharpening filter application did not alter the diagnostic outcome for HRF. While the prior studies focused solely on sharpening filters, they evaluated different diagnostic tasks using various CBCT software, which could account for the discrepancies in the results. Additionally, these studies involved either no artifacts or artifacts of a small magnitude (e.g., those produced by gutta-percha), which may also have contributed to the variation in findings.[12,29,30]

The use of sharpening filters appears to improve the definition of anatomical structures by making their boundaries more pronounced through increased contrast.[12,30] However, this subtle change in contrast can also introduce additional image noise, potentially compromising visualization on CBCT.[12] This phenomenon could explain why the diagnosis of HRF with these filters was not superior in the present study, as well as why the detection of the second mesiobuccal canal in teeth filled with gutta-percha was not improved in prior research.[13]

To avoid exposing patients to the X-rays from multiple examinations, this study adopted an *ex vivo* approach. Consequently, it was not possible to directly correlate clinical signs and symptoms with the imaging findings. However, a maxilla with dental sockets filled with wax, simulating the periodontal ligament space, was scanned. To simulate a clinical scenario, the X-ray attenuation caused by the patient's soft tissues was mimicked by immersing the dry human maxilla in a water-filled canister. Furthermore, Table 4 indicates that the intra- and inter-examiner agreement values ranged from fair to substantial. This finding aligns with previous studies that assessed the diagnosis of root fractures, demonstrating the reliability of the present results.[8,16] To improve intra- and inter-examiner agreement in future research, these values should be calculated during the calibration session. If deemed reliable, examiners can then proceed to evaluate the CBCT exams in the sample. Notably, however, diagnosing dental conditions in the presence of artifacts remains challenging, despite the benefits of CBCT.

The present research focused on the anterior region of the maxilla, due to its higher prevalence of HRF.[4] Given that zirconia implants offer superior aesthetic qualities compared to other materials, the authors opted for this type of implant to be placed in proximity to the region under examination.[31] Moreover, a zirconia implant was selected because it has a higher atomic number ($Z=40$) than metallic materials, such as titanium ($Z=22$), which produces more pronounced artifacts on CBCT scans.[32,33] Nevertheless, further research into the impact of other high-density alloys or implants on the diagnosis of HRF is recommended.

Further studies are also required to assess the impact of the MAR tool when used in conjunction with enhancement filters. Recently, researchers evaluated the effect of combined MAR and filters on the detection of peri-implant fenestrations, finding that diagnostic accuracy increased when both tools were utilized.[16] A similar result was observed in the diagnosis of VRF in teeth with metallic posts, as the combination of MAR and filters improved VRF detection.[34] Both the previous and present studies employed the same CBCT device, energetic parameters (mA and kVp), and sharpening filters.[34] However, the previous study focused on vertical fractures, characterized by a hypodense line extending longitudinally along the root, whereas the current study assessed HRF. Additionally, the present research employed a zirconia implant to generate artifacts, while beam hardening in the prior study was induced by a metallic post made of cobalt-chromium, metals with lower atomic numbers than zirconia ($Z_{Co}=27$ and $Z_{Cr}=24$). Another factor that could account for the differing results is the location of the artifact-generating object; it was placed inside the root in the previous study but adjacent to the root in the current investigation. As the combined use of MAR and enhancement filters may improve the visualization of CBCT images in certain cases, this approach should be investigated for other diagnostic tasks, such as root resorptions or caries lesions.

In this study, the diagnosis of HRF in a tooth adjacent to a zirconia implant was not significantly affected by the activation of MAR, the application of sharpening filters, or the combination of both. Clinicians therefore may opt to activate the MAR tool or apply sharpening filters based on personal preference.

Conflicts of Interest: None

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