ACCURACY OF METAL ARTIFACT REDUCTION ALGORITHM OF CONE BEAM COMPUTED TOMOGRAPHY IN IDENTIFICATION OF FRACTURED ENDODONTIC FILES (A DIAGNOSTIC ACCURACY STUDY)

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ABSTRACT

INTRODUCTION: A separated instrument in the root canal may compromise adequate treatment of the entire root canal system. Radiographic detection of retained instruments is a very important step for proper treatment planning. Cone Beam Computed Tomography (CBCT) scans provide three-dimensional (3D) imaging of maxillofacial anatomy. Yet, the presence of canal filling in close proximity to a fractured instrument may cause beam hardening artifacts in CBCT images that may reduce the diagnostic accuracy. So that, the need for Metal artifact reduction (MAR) tool is mandatory to improve image quality.
Objectives: The purpose of this study was to assess the accuracy of the MAR tool of CBCT in the detection of separated endodontic instruments in root canals.
METHODOLOGY: One hundred forty-four canals of mandibular molar teeth were divided into four groups: the control group having empty canals, the fracture group with a fractured file fragment, the fill group with gutta-percha points, and the fill/fracture group that was filled with presence of a fractured file fragment. The teeth were radiographed by CBCT with MAR tool application and periapical X-Ray using complementary metal oxide semiconductor (CMOS) sensor to evaluate the diagnostic accuracy of both techniques in the identification of the separated fragment.
RESULTS: In the presence of filling, periapical radiography showed greater diagnostic accuracy than CBCT with MAR tool activation. In the absence of filling, there was no statistically significant difference between the two radiographic techniques.
CONCLUSIONS: Periapical radiography is the best technique for detection of fractured instruments in filled and unfilled root canals.

KEYWORDS: Beam hardening artifact, Cone beam computed tomography, Metal artifact reduction tool, Separated instrument.

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INTRODUCTION

A fractured endodontic instrument in the apical part of the canal could prevent complete cleaning and shaping to the apex of the root which has a significant impact on treatment success (1-3).

Separation of instruments may occur during all stages of treatment. This happens as a result of multiple or inappropriate use of the instrument, existence of micro-cracks in new instruments, presence of calcification or curved geometry of the canal, or insufficient academic experience of the operator (4-6).

The dental operator is capable of choosing the proper treatment plan depending on various factors including the location of the separated instrument within the canal, the amount of remaining infected tissues, and the degree of tooth damage that may occur during instrument removal attempts (4, 7).

Moreover, in retreatment procedures, the operator has to identify the presence of any fractured instrument within the canals preoperatively to avoid any medico-legal problem (1).

Proper radiographic examination has a greater impact on treatment and retreatment procedures; It helps the clinician to achieve adequate diagnosis, preparation, and obturation of the canals till the insertion of the final restoration (8, 9).

Periapical radiography use in endodontics has been limited due to the conversion of three dimensional (3D) structures into a two-dimensional (2D) image (10). The introduction of cone beam computed tomography (CBCT) scans allowed visualization of the third dimension of teeth with the surrounding structures (11). Considering the high radiation dose, CBCT usage in endodontics should be confined to complex cases as cases with instruments fracture in the root canals (2, 12).

Despite the advantages of CBCT scans, the image quality is significantly affected when metallic elements such as endodontic files, amalgam restorations, implants or root canal filling are present in the field of view (4, 13, 14). Their existence creates artifacts named “beam hardening artifacts” that are formed due to the great density and the high atomic number of such materials. These artifacts appear as dark bands and white striae in the formed image affecting the ability to examine the areas adjacent to those materials (14). Therefore, the existence of a separated fragment generates beam hardening artifacts that when combined with artifacts generated by root canal filling material, will prevent proper detection of the fractured part (13).

Various CBCT companies have developed metal artifact reduction algorithm (MAR) to minimize the effect of beam hardening artifacts. This algorithm increases the contrast-to-noise ratio and reduces the variability of grey values in order to improve the image quality (13, 15).

The MAR algorithm acts by two techniques: the iterative approaches and projection completion methods. In iterative methods, image reconstruction is done using the non-corrupted images with ignoring other basis images that are affected by the beam hardening artifacts. In projection completion technique, the corrupted data are segmented and replaced by approximated values (14).

There was no enough clarification in literature about the diagnostic efficacy of using MAR tool in reducing beam hardening artifacts produced by separated endodontic instruments and gutta-percha points, and its comparability to periapical radiography in the detection of separated instruments in root canals.

Therefore, the aim of this study was to evaluate the accuracy of the MAR tool of CBCT images in the detection of separated endodontic instruments inside root canals with and without root canal filling materials.

The null hypothesis of this research was that there would be no statistically significant difference between digital periapical radiography and CBCT with MAR tool application in the detection of separated endodontic instruments.

MATERIALS AND METHODS

I. Sample size calculation

Sample size was estimated based on assuming alpha error= 5% and study power= 80%. According to Rosen et al, (2) sensitivity of periapical radiograph was 71.25%, while sensitivity of cone beam computed tomography (CBCT) was 41.25%. Kajan et al (16) reported that sensitivity= 76.67% when CBCT with metal artifact reduction tool (MAR) was used and 46.67% when MAR was not used. Based on comparison of proportions, sample size was calculated (17) to be 33 per group and this will be increased to 36 to make up for laboratory processing errors. The total sample size= number of groups × number per group= 4 X 36= 144 (18).

II. Sample selection

The study was approved by the research ethics committee of Alexandria faculty of dentistry (IRB NO: 00010556-IORG0008839), the sample consisted of 144 canals of mandibular first and second molar teeth extracted for periodontal reasons. The teeth were examined clinically and radiographically to confirm whether they match the inclusion criteria or not. The inclusion criteria were patent canals with closed apices, straight or moderately curved canals with 10-20 º of curvature measured by Schneider technique (19), while the exclusion criteria were teeth with previous endodontic treatment, root caries, cracks, perforation, and confluent canals.

The canals were divided randomly into four groups:

1. The control group with non-filled canals (n = 36).
2. The fracture group having non-filled canals with fractured files (n = 36).
3. The fill group with filled canals (n = 36).

4. The fill/fracture group having filled canals with fractured files (n = 36).

III. Teeth preparation

All steps of preparation were performed using the methodology proposed by Ramos Brito et al., (4) as follows:

For the fracture and fill/fracture groups, a diamond bur was used to form a fracture point in size #10 stainless steel K-files (MANI, Tochigi, japan) 2 mm from the file tip, then the file was placed inside the canal via the apical foramen and twisted to induce file fracture within the canals.

M-Pro #25 rotary instruments with a taper of .06 and a length of 25 mm (IMD, Shanghai, China) were used for instrumentation of root canals with profuse irrigation using 2.5% sodium hypochlorite solution.

For the fill and fill/fracture groups, a single gutta-percha cone (Dentplus, #25 cone, .06 taper; DIADENT, Republic of Korea) and Resin–based sealer (ADSEAL; META BIOMED, Republic of Korea) were used for obturation of the canals.

A 3 mm layer of utility wax was used to cover the roots in order to simulate the periodontal ligament space radiographically. Each tooth was placed individually in the alveolus of the lower right second molar of a dry human mandible for image acquisition. The mandible was placed into an acrylic box (3-mm thick) filled with water to simulate soft tissue attenuation of X-rays (4, 13).

IV. Image acquisition

The periapical radiographs were acquired with a direct system using complementary metal oxide semiconductor (CMOS) sensor (EzSensor HD, Vatech, Hwaseong, Republic of Korea). The exposure unit was Heliodent plus unit (Sirona Dental Systems GmbH, Bensheim, Germany) that was operated at 70 kVp and 7 mA. Paralleling technique was applied with a distal horizontal angulation at a 15º angle (1, 2, 4). A 2 mm acrylic block was used to simulate soft tissue attenuation (4).

Cone beam computed tomography images were taken with the activation of MAR algorithm using the same machine (Green Ct, Vatech, Hwaseong, Republic of Korea). The exposure parameters were 10 mA, 90 kVp, with a field of view of 50 x 50 mm and 0.08 mm voxel size. The images were exported in Digital Imaging and Communications in Medicine (DICOM) format to be examined by OnDemand3D™ version 1.0.10.4304 software (Cybermed international, Seoul, Republic of Korea).

V. Image evaluation

Three examiners (2 radiologists and 1 endodontist) calibrated on the method of evaluation examined the two techniques. They examined each canal for the presence or absence of fractured fragment according to a five-point rank scale proposed by Ramos Brito et al., (4) “1-definitely absent, 2-probably absent, 3-uncertain, 4-probably present, 5-definitely present”. Zoom, contrast, and brightness tools were available to be used during images examination. CBCT images were examined dynamically in the three orthogonal planes. All images were viewed on a 15.6-inch FHD LED monitor with a resolution of 1920 x 1080.

After 2 weeks, re-examination of 25% of the sample was done to test intra- and inter-examiner reliability (13). The evaluation results of periapical and CBCT images were recorded and submitted to statistical analysis.

VI. Statistical analysis

MedCalc Statistical Software version 19.0.5 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org; 2019) was used for Data analysis. Chi-square test was used for comparison of the accuracy of identification of fractured instruments using Ramos Brito (4) scale between the two radiographic techniques. Receiver operating curve (ROC) was used to determine the diagnostic accuracy of the two radiographic modalities, with multiple comparisons between the three independent ROC curves. Significance was inferred at p value < 0.05.

Reliability assessment

Calibration on the examination method was done for the three observers. Intra- and inter-examiner reliability were calculated and intraclass correlation coefficient ranged from 0.81 to 0.98 suggesting very good agreement between observers and across time.

RESULTS

Sensitivity and specificity values for the two radiographic techniques in the absence of filling were shown in table 1. There was no statistically significant difference between periapical radiography and CBCT with MAR tool in absence of root canal filling materials (Figure 1).

While in the presence of filling, periapical radiography showed greater sensitivity and specificity values than CBCT with MAR tool application as demonstrated in table 2 (Figure 2).

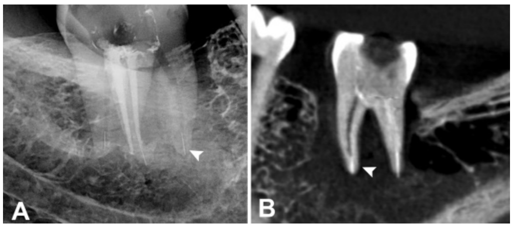

Figure 1: A fractured file located at the apical third of the mesio-buccal canal could be detected by the two techniques with no statistically significant difference between them; (A) digital periapical radiograph, (B) sagittal section of the canal by CBCT with application of MAR tool.

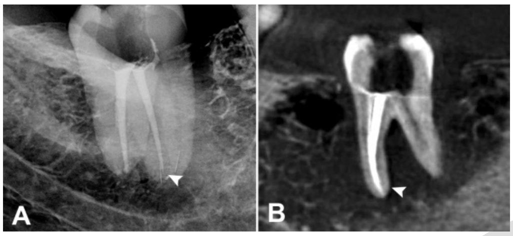

Figure 2: A fractured file located at the apical third of the mesio-lingual canal that was filled with gutta-percha points and resin-based sealer; (A) digital periapical radiograph showed better detection of the separated fragment, (B) sagittal section of the canal showed difficult detection of the separated file by CBCT with application of MAR tool

Table 1: Accuracy of detection of separated instruments by the two radiographic techniques in the absence of filling

	ensitivity	pecificity	rea under curve	tandard error	5% confidence interval	riterion value	value
eriapical	1.67	00	.96	.02	.88, 0.99	1	0.001*
BCT with MAR	8.89	7.22	.93	.03	.84, 0.98	4	0.001*
value	Periapical vs. CBCT with MAR: 0.45						

*Statistically significant at p value < 0.05

Table 2: Accuracy of identification of separated instruments by the two radiographic techniques in the presence of filling

	ensitivity	**pecificity**	**rea under curve**	**tandard error**	**5% confidence interval**	**riterion value**	**value**
eriapical	8.9	7.2	.93	.03	.84, 0.98	3	0.001*
BCT with MAR	5.0	7.8	.80	.05	.69, 0.89	3	0.001*
value	**Periapical vs. CBCT with MAR: 0.03***						

*Statistically significant at p value < 0.05

DISCUSSION

Instruments separation in root canals could prevent complete removal of infected pulp tissue in the apical part of the canal, that in turn will increase the risk of treatment failure (20).

Certain factors should be considered before determining the best treatment method. These factors include the type of the detached instrument, its precise position, the length of the fragment, and the canal shape. Therefore, radiographic examination is a necessary step in analyzing such aspects before deciding on the adequate treatment plan (21).

Periapical radiography is the gold-standard technique used before endodontic treatment to achieve appropriate diagnosis and treatment planning with minimal radiation dose, as concluded by Moiseiwitsch (22).

Cone beam computed tomography was introduced to the dental field to counteract the limitations of periapical radiography (23). It enables three-dimensional (3D) evaluation of teeth without superimposition of the anatomical structures (11). The production of metal artifacts by high-density materials in CBCT images could affect the image quality and the diagnostic ability (2). Hence, metal artifact reduction algorithm has been added to CBCT machines to correct beam hardening artifacts artifacts (24).

To the best of our knowledge, different studies concerned with comparing different techniques to identify the presence of separated fragments in root canals (1, 2, 4, 13, 24-29). However, our study was the first to compare periapical radiography to CBCT with application of MAR tool in the identification of the fractured instruments in filled and unfilled root canals.

In the current study, we tried to choose optimum image parameters as mentioned in the literature to achieve a precise diagnosis with minimal radiation exposure. For periapical radiography, we used a CMOS sensor, in reference to Ramos Brito et al. (4), as it showed greater spatial resolution in the identification of the separated fragments than PSP system especially in the presence of root canal filling. Periapical radiographs were captured with a distal horizontal angulation at a 15º angle to allow visualization of buccal and lingual canals without superimposition (1, 2, 4).

Cone Beam Computed Tomography scans were acquired with application of MAR tool at endo mode (5 x 5 cm FOV) to enhance image quality by decreasing scattered radiation (14). A voxel size of 0.085 was used to boost the spatial resolution (30).
Mandibular molar teeth were chosen as they have the highest incidence of files separation during treatment, ranging from 50% and 55% as concluded by Iqbal et al. (31).

Our results showed that there is no statistically significant difference between the two techniques in the absence of canal filling. However, in presence of filling, periapical radiography showed greater diagnostic accuracy than CBCT with MAR tool application.

Several studies have been conducted to identify whether the MAR algorithm could enhance the diagnostic accuracy of CBCT images in detecting separated instruments (13, 24). Costa et al., (13) compared the sensitivity and specificity values of various CBCT machines with and without MAR algorithm to detect separated instruments. They reported that the MAR tool application did not improve the ability to detect separated fragments in filled canals because the root canal filling material and the detached file had similar densities reducing the ability of differentiation between them. Nevertheless, in the current study, we could differentiate the fragment from the filling material in periapical radiographs suggesting that they have different densities. We assumed that the reduced effect of the MAR tool could be due to the algorithm acts by the projection completion approach; it segments the corrupted images and gives estimated values for them. Therefore, the separated fragment and the canal filling could be estimated by approximate values. Koç et al., (24) tested different CBCT machines with and without MAR tool application in detecting several endodontic complications such as instruments separation. They found that the machines act similarly with and without the MAR algorithm. In the current study, we also found that MAR algorithm application did not reduce the beam hardening artifacts sufficiently to improve the diagnostic accuracy.

It is worth noting that the sensitivity and specificity results of periapical radiographs were limited to the mandibular molar areas and could be affected if the study was made on the upper molar teeth due to the superimposition of palatal roots and zygomatic bone over the buccal roots (32, 33). Moreover, these results were limited to the current study as we used a specific CBCT machine and periapical sensor, thus the use of different machines, sensors, or acquisition parameters may alter the results. In addition, we used stainless steel hand files to be fractured in the canals, thus using NiTi files could change the results. Therefore, further studies on the accuracy of periapical radiographs and CBCT with MAR tool activation in identifying fractured instruments on upper premolar-molar areas and between straight and curved root canals are recommended. We also recommend using fractured NiTi files to compare the accuracy of the MAR tool on different materials with different radiodensities. Within limitations of the current study, the null hypothesis was rejected.

CONCLUSIONS

Periapical radiography is the imaging technique of choice to be used in identifying fractured endodontic instruments with a minimal radiation dose.

CONFLICT OF INTEREST
The authors declare that they have no conflicts of interest.
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