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INFLUENCE OF ARTIFACTS INDUCED BY DENTAL IMPLANTS ON THE DETECTION OF VERTICAL ROOT FRACTURES IN CONE BEAM COMPUTED TOMOGRAPHIC SCANS. AN IN-VITRO STUDY

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ABSTRACT

Aim: The aim of this study was to evaluate the influence of implant metal artifacts on the detection of vertical root fracture of teeth adjacent to dental implants.

Materials and Methods: Sixty extracted single-rooted teeth were randomly divided into vertical root fracture (VRF) and non-fractured groups (NVF) (n=30). Root fracture was induced in VFR, then teeth were positioned in the right and left posterior areas of epoxy- resin mandible model mesial and distal to two titanium implants. Three CBCT scan protocols were done: roots without implants, roots with implant without artifact reduction and roots with implant with artifact reduction. The images were evaluated by three observers. Area under the receiver-operating characteristic curve (ROC), diagnostic accuracy, sensitivity, and specificity were calculated.

Results: Statistically significant difference was found in diagnostic accuracy of CBCT of vertical root fracture for all test groups with highest accuracy in group without implant *(p* =0.022). Post hoc pairwise comparisons showed statistically significant difference between accuracy of group without implants and group with implants and without algorithm (p=0.019). Sensitivity, specificity, positive and negative predictive values were higher in group without implant but there was no statistically significant difference between the three groups.

Conclusions: Implant metal artifacts influenced the diagnostic accuracy, sensitivity and specificity for detection of vertical root fracture but still high levels were achieved and all image possessed high diagnostic quality. Artifact reduction tool improved the accuracy and specificity and can be recommended when the teeth involved are near dental implant.

KEYWORDS: Vertical root fracture, CBCT, titanium implants, metal artifacts, artifact reduction, diagnostic accuracy.

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INTRODUCTION

Intra-oral radiography has been the imaging method of choice for the diagnosis and treatment planning in many clinical cases in everyday dental practice. The advent of cone beam computed tomography (CBCT) has gained increasing popularity in the last decades and has proven significant reliability in diagnosing, treatment planning and final management of wide variety of challenging clinical situations in comparison to intra-oral radiography.(1) Among these challenging situations are root fractures which according to Elejalde *et al*(2), are considered the third most common cause of tooth loss.

According to the American Association of Endodontists; "true" vertical root fracture (VRF) can be defined as a complete or incomplete fracture initiated from the root at any level, usually directed bucco-lingually. VRFs are longitudinally oriented fractures of the root which extend from the root canal to the periodontium. (3) Chandhana *et al* (4) stated that the challenges encountered with detection of VRF are often more than those with coronal fractures, detection methods including bite tests, dyes and transillumination are not helpful enough and usually root exposure is required.

Usually diagnosis of VRF is based on clinical and radiographic presentation, the presence of signs and symptoms such as pain, sensitivity to palpation or percussion, sinus tract, gingival abscess, as well as radiographic findings of peraipical or lateral radiolucencies related to tooth root can suggest the presence of VRF. (5,6) Furthermore, it might be troublesome to radiographically detect VRF in non-endodontically treated teeth with 2D image acquisition using plain radiographs especially if fracture line and X-ray beam are not in the same direction resulting in superimposition of the fracture with surrounding bone and the remaining tooth structure. Gaêta-Arauj *et al* (7) highlighted that with the elimination of superimposition problem, CBCT images can be produced without overlapping of the adjacent structures, thereby VRF defect can be more accurately diagnosed and a tailored treatment planning can be implemented. (8)

Accuracy of CBCT in detection of VRF over plain periapical radiographs has been indicated by many clinical studies. Moreover, same findings were suggested by numerous in-vitro studies utilizing artificially induced VRF in extracted human teeth. (9-12)

Nevertheless, the diagnostic capability of CBCT images suffers from artifacts caused by beam hardening and scattered radiation produced from high-density objects such as different restorative materials, root canal filling materials and dental implants, etc. resulting in reduced overall diagnostic quality of the final produced images which was discussed in many studies as by Pauwels *et al* (14), Talwar *et al* (15) and Rueangweerayut *et al* (16). Moreover, metallic artifacts have the ability to lower contrast resolution, impair the detection of certain defects and obscure structures thus, compromising the interpretation and diagnosis. (17,18)

Limited studies are available regarding the effect of implant metal artifact on the identification and accurate diagnosis of VRF in teeth adjacent to dental implants. However, recent literature indicated that using artifact reduction algorithms may lead to improvement of the diagnostic capability of CBCT images. (14-19) Thus, this study was designed to evaluate the influence of implant metal artifact on the detection of vertical root fracture of teeth adjacent to dental implants.

The null hypothesis was that there would be no difference in vertical root fracture detection between the two imaging protocols with the presence or absence of dental implant.

MATERIALS AND METHODS

This study was approved by the research ethics committee of Faculty of Dentistry in 31 July 2019. Approval number 31719.

The PICO for this study was selected as follows:

Population: Single rooted human teeth

Interventions:

I1. CBCT imaging of teeth roots without vertical root fracture and without dental implant.

I2. CBCT imaging of teeth roots with vertical root fracture and without dental implant.

I3. CBCT imaging of teeth roots without vertical root fracture adjacent to dental implant.

I4. CBCT imaging of teeth roots with vertical root fracture adjacent to dental implant.

I5. CBCT imaging of teeth roots without vertical root fracture adjacent to dental implant with artifact reduction algorithm.

I6. CBCT imaging of teeth roots with vertical root fracture adjacent to dental implant with artifact reduction algorithm.

Control: Real condition of teeth in each group

Outcomes

Primary outcome: Detection of vertical root fracture on CBCT in the presence of implant metal artifact.

Secondary outcome: Detection of vertical root fracture on CBCT in the presence of implant metal artifact with or without artifact reduction algorithm.

Sample size for this study was calculated based on previous study by Freitas *et al* [20], where, total sample size of 10 (5 in each group) has 80% power to detect a difference between means of 0.049 with a significance level (alpha) of 0.05 (two-tailed) and 95% confidence intervals. In 80% (the power) of those experiments, the P value will be less than 0.05 (two-tailed) so the results will be deemed statistically significant. In the remaining 20% of the experiments, the difference between means will be deemed "not statistically significant". To ensure the reliability of qualitative data in this study due to the need to study six subgroups and to allow sufficient number of samples to be included in each subgroup; the total sample size was increased to 60 (30 in each group).

A total of sixty single rooted extracted human teeth were collected from the outpatient clinic of the department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Cairo university. Teeth were inspected visually using explorer (62012013, No. 54. Dentsply, USA) and transillumination as well as by periapical radiographs for eligibility criteria.

Inclusion criteria for this study were set to involve single rooted intact teeth with no to minimal curvature and average root length of 12-16 mm verified by digital caliper 952-140. ProDent- USA). Teeth with severe curvature were excluded to avoid assessment biases due to memorization of the root anatomical variations. Multirooted teeth and teeth with fractured roots were also excluded to eliminate bias by memorization of anatomic variation or fracture pattern.

Randomization in our study was carried out by a software (www.random.org) to ascertain that any risk of bias is eliminated. Randomization in this study was done in two stages; first stage randomization was performed in order to randomly divide the total number of samples (60 roots) into two equal groups (vertical root fracture and non-fractured group no=30). The second stage randomization was done after root fracture was induced in the roots assigned to the first group where software was used again to generate a new random sequence to assign all roots from both to 4 new groups (A-D) so they can be arranged in mandible model in relation to dental implants. This second randomization was also done to eliminate biases and to ensure random inclusion of all roots thereby a new set of 4 roots was included in each scanning. All procedural steps of sample selection, grouping and randomization, sample preparation, model preparation and dental implants insertion were performed by the same operator throughout the study. This study was double blinded where both outcome assessors and statistician were blinded to the assigned teeth (VRF or NVRF) in each CBCT scan. Moreover, assessors were also blinded to the scan protocol (with or without artifact reduction algorithm). This was also done to eliminate any risk of biases throughout the evaluation stage.

Sample preparation

All teeth were cleaned from calculus, soft tissue remnants and debris using ultrasonic scaler (Woodpecker UDS-K LED ultrasonic scaler, Guilin Woodpecker Medical Instrument, China), then disinfected and stored in distilled water. After cutting the teeth crowns at level 2mm above cemento-enamel junction, vertical root fracture was induced in half of the samples (n=30), where roots were inserted separately in acrylic resin blocks in an upright position and positioned in universal testing machine (INSTRON4411, Instron Corporation, Canton, MA, USA)

Dental implant insertion

Two titanium dental implants ISS-II bone-level implant (Neobiotech Co., Ltd, Seoul, South Korea) of 4mm diameter x 10mm length were inserted in the epoxy resin model made specifically for this study in right and left first molar positions. To resemble clinical situations, a root-implant distance of 1.5-2 mm on both mesial and distal sides of both implants was set. The distance was verified in vitro on model with periodontal probe.

A set of 4 roots were randomly selected from each randomized group (NVF and VF) ensuring there's no specific pattern that the assessors can detect during CBCT evaluation.

CBCT imaging

For simulation of x-ray beam attenuation and scattering by soft tissue, 12mm thick pink wax sheets were wrapped around the epoxy model. [21]

The model with 2 implants and a set of 4 roots was scanned using Planmeca ProMax 3D Mid CBCT machine and Planmeca Romexis 4.6.2.R software (Planmeca ProMax 3D Mid, Helsinki, Finland). CBCT machine parameters were adjusted to remain constant throughout the study at 90 kVp, 10 mA and 15.033 seconds exposure time with 0.15mm voxel size and field of view of size 8.0 x 5.0 cm.

After each scan, teeth set was changed with another one till all roots of both groups were scanned and a total of 45 CBCT scans (no=15 scan for each protocol) were obtained taking care that the same roots set is scanned in all three protocols in the same order. Three CBCT scanning protocols were used in this study: CBCT imaging with titanium implants without artifact reduction algorithm, CBCT imaging with titanium implants and with artifact reduction algorithm and CBCT imaging without titanium implants which served as control to evaluate the diagnostic accuracy of CBCT in vertical root fracture detection. **Figure (1)**

Image evaluation

Dicom data of each scan were imported on separate CDs then randomization was used again to generate a random sequence for all CBCT scans for the purpose of blinding the assessors in final evaluation. Three independent assessors (one radiologist, one prosthodontist and one endodontist) with at least 10 years' experience and trained on using and interpreting CBCT images, were given CDs with all CBCT scans after randomization with no indication of the scan group or the scanning protocols used and they were asked to evaluate the scans for the presence or absence of vertical root fracture.

Each data assessment was done independently through interactive image viewing in axial, coronal, sagittal, and 3D views to determine the presence or absence of vertical root fracture. **Figure (2)**

Assessors were asked to record their observations in three-point confidence scale as follows: (1)

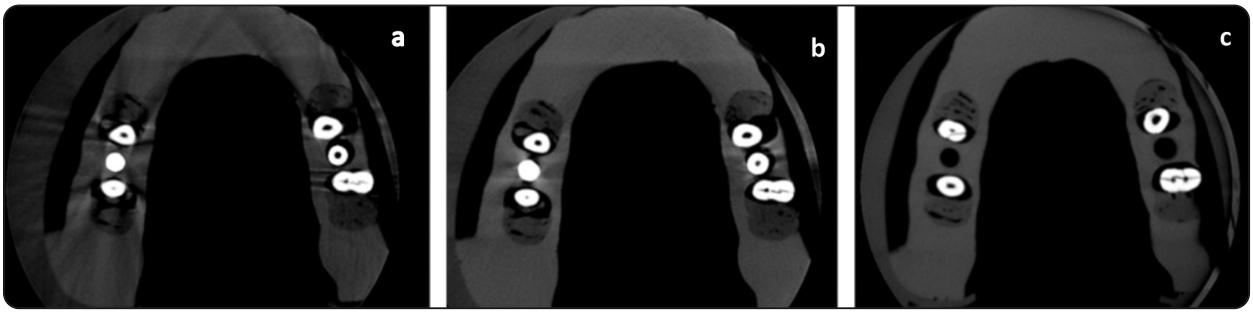

Fig. (1): CBCT image of VRF and NVF roots (axial view): (a) with implants without artifact reduction, (b) with implants with metal artifact reduction, and (c) without implants (Axial view)

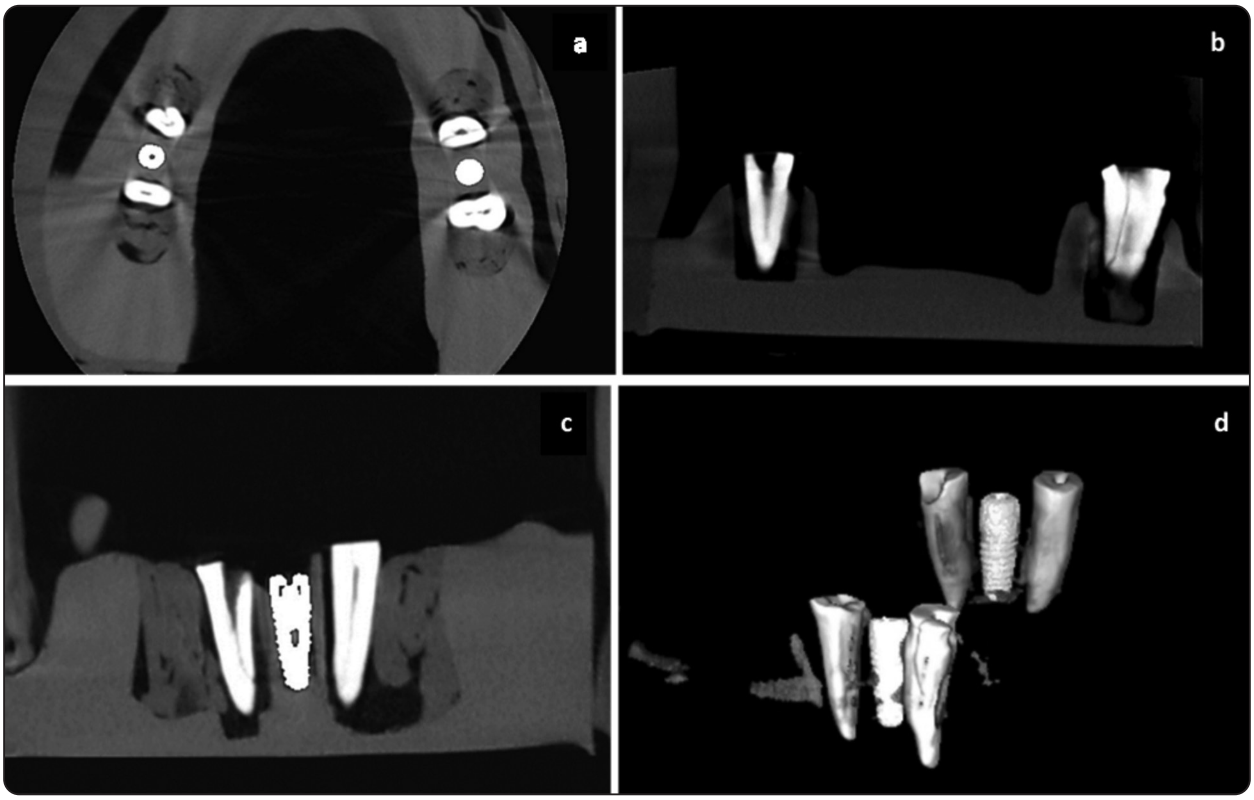

Fig. (2): CBCT image of model with implants: (a) Axial view, (b) Coronal view, (c) Sagittal view, and (d) 3D view

definitely present, (2) definitely absent, (3) unclear. Assessors were permitted to use zoom, brightness and contrast tools in viewing software for image manipulation and to click on any area of interest for better image visualization. Assessors were also instructed not to view more than five set of images per day (20 roots) to avoid eye fatigue. All images data set were viewed twice by each assessor with 15 days interval between assessment.

Statistical analysis

Categorical data were presented as frequencies and percentages and were compared using Cochran's Q test followed by pairwise comparisons utilizing McNemar's test with Bonferroni correction. ROC curve was constructed to determine the diagnostic accuracy of root fracture detection in different groups and was compared across groups using z-test. Inter and intra-observer reliability were analysed using

Fleiss's and Cohen's kappa coefficients respectively. Numerical data were presented as mean and standard deviation values and were compared using one-way ANOVA test. The significance level was set at $p \leq 0.05$ for all tests. Statistical analysis was performed with IBM® (IBM Corporation, NY, USA) SPSS® (SPSS, Inc., an IBM Company) Statistics Version 26 for Windows.

RESULTS

For inter-observer reliability, Fleiss Kappa analysis showed there was an excellent agreement between different observers in different groups. As for intra-observer reliability, Cohen Kappa analysis showed excellent agreement between different observations in different groups. Inter-observer and intra-observer reliability for different groups and observations are presented in **Table (1).**

TABLE (1): Inter-observer and intra-observer reliability for different groups

Group	Inter-observer reliability	Intra-observer reliability
Without implants	0.916[0.911-0.920]	0.953[0.868-1.000]
Implants without algorithm	0.912[0.909-0.916]	0.948[0.877-1.000]
Implants with algorithm	0.896[0.892-0.900]	0.921[0.835-1.000]

Diagnostic accuracy, sensitivity, specificity and predictive values in all samples within the three study groups are presented in **Table (2).** ROC curve analysis revealed that sensitivity of root fracture detection in samples without implants was (100.0%), specificity was (100.0%), positive predictive value was (100%), negative predictive value was (100%) and diagnostic accuracy was (100%). Area under the ROC curve (AUC) was 1 with 95% Confidence Interval (0.940– 1). For samples with implants without artifact reduction algorithm, sensitivity was (96.7%), specificity was (90.0%), positive predictive value was (90.6%), negative predictive value was (96.4%) and diagnostic accuracy was (91.7%). Area under the ROC curve (AUC) was 0.948 with 95% Confidence Interval (0.858– 0.989). while, for samples with implants and artifact reduction algorithm sensitivity of root fracture detection was (93.3%), specificity was (100%), positive predictive value was (96.6%), negative predictive value was (93.5%) and diagnostic accuracy was (95.0%). Area under the ROC curve (AUC) was 0.966 with 95% Confidence Interval (0.883– 0.996).

Intergroup comparisons for sensitivity, mean and standard deviation values for different groups showed no significant difference between values of different groups (p=0.380). The highest value was found in samples without implants (100.0±0.0) followed by samples with implants and without algorithm (96.7±3.4) while the lowest value was found in samples with implants and with algorithm (95.5±3.9). For specificity, intergroup comparison

TABLE (2) Diagnostic accuracy, sensitivity and specificity in groups; without implants, implants without algorithm and implants with algorithm

Group	Sensitivity %	Specificity %	Positive predictive value	Negative predictive value	Diagnostic accuracy	AUC	95% CI
Without implants	100%	100%	100%	100%	100%	1.000	0.940 - 1.000
Implants without algorithm	96.7%	90.0%	90.6%	96.4%	91.7%	0.948	0.858 - 0.989
Implants with algorithm	93.3%	100.0%	96.6%	93.5%	95.0%	0.966	0.883 - 0.996

of mean and standard deviation values also showed no significant difference between values of different groups (p=0.234). The highest value was found in samples without implants (100.0±0.0) followed by samples with implants and algorithm (98.9±1.9) while the lowest value was found in samples with implants and without algorithm (94.4±5.1). Area under the curve for different groups is presented in **Figure (3),** the difference between all study groups was not statistically significant.

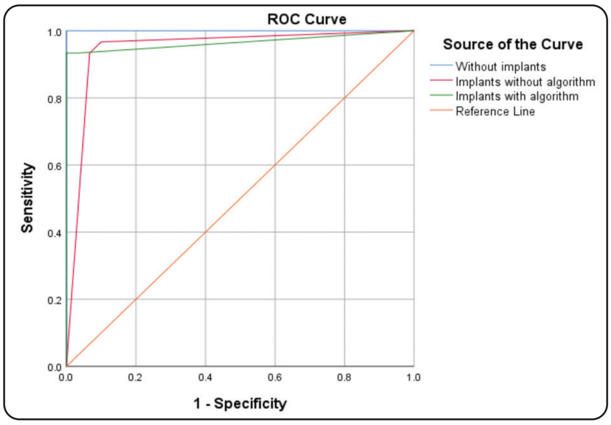

Fig. (3): ROC curve for root fracture detection in all groups

DISCUSSION

Vertical root fractures (VRF) are on the top of the most clinically challenging conditions, not only due to the difficulty in their diagnosis but also because the final prognosis is mostly catastrophic in the form of tooth extraction. (3) As vertical root fracture incidence is higher in endodontically treated teeth, most literatures were concerned with studying root canal filled teeth and the effect of different root canal filling materials on the artifact production in CBCT images that may hinder the detection of vertical root fracture. (21-29) To the best of our knowledge, there are very limited data in the literature targeting the effect of implant induced metal artifacts on the detection of vertical root fracture in CBCT images, (20,30,31) and even fewer literature that studied the effect of titanium implant artifacts on VRF detection despite its high clinical relevance due to the increase in number of patients with or requiring dental implant placement. This was the main motive behind conducting this study.

This study aimed to investigate the effect of implant induced metal artifacts on the detection of vertical root fracture in CBCT images with and without the use of artifact reduction algorithm (AR).

Our analysis showed an excellent interobserver agreement among all evaluators within different study groups with the highest score for study group without implant. These results were consistent with many studies that reported excellent agreement for the accuracy of detection of vertical root fracture on CBCT in the presence of metal artifact. (30, 32-34), However, our results disagree with Oliveira *et al* (35), who reported low levels of interobserver reproducibility which they attributed to the voxel size used in their study (0.085mm) where partial volume averaging might have limited the viewing of delicate vertical fracture lines.

The null hypothesis was rejected as high accuracy levels for detection of vertical root fracture represented by receiver-operator's curve (ROC) as well as high sensitivity and specificity were reported in all three study groups when compared to the real condition of the tooth (fractured and non-fractured). There was statistically significant difference in the diagnostic accuracy of CBCT of vertical root fracture between three study groups (*p-value* = 0.022). Scan group without implant recorded the highest accuracy (100%), while lower diagnostic accuracy was observed in group with implant and with AR (95.0%) and the lowest accuracy was recorded for scan group with implant without AR (91.7%). This indicates that the presence of metal artifacts in general has the ability to reduce the diagnostic ability of CBCT images Moreover, artifact reduction algorithm improved the diagnostic accuracy of CBCT in implant group than the implant group without AR algorithm (95.0% versus 91.7% respectively), which comes in agreement with Freitas *et* (20), Candemil *et al* [30], Al Hadi *et al*[32], Uysal *et al* [33], Abd-Elsattar *et al* [34] and Hekmatian et al[36].

These diagnostic accuracy results also disagree with Oliveira *et al* [35], who reported that the activation of MAR tool reduced the diagnostic accuracy of CBCT of vertical root fracture more than when MAR tool was deactivated. Their findings might be attributed to the use of small FOV (6x4 cm) and small voxel size (0.085 mm) which might result in higher signal-to-noise ratio and as MAR works by reducing the grey value of image, it was difficult under these circumstances to detect the hypodense fracture line against normal tooth structure.

The highest sensitivity (100%) were for scan group without implant with which denotes that CBCT images are highly accurate in vertical root fracture detection and diagnosis when metal artifacts are not present. [20,29,30,32-35,37,38]

The sensitivity level for scan group with implant without AR was 96.7%. The decrease in sensitivity means that metal artifact could obscure the fracture line in CBCT image giving false negative results. Observers reported false negative results of 3.3% in this group. The positive predictive value for this group was 90.6%. On the other hand, sensitivity of 93.3% was recorded in scan group with implant with AR. This decrease in sensitivity might be attributed to the reduction of gray value by AR tool as a result of the proximity of the tooth to implant, which lead to difficulty in identification of hypodense VRF in some samples. [35, 20]

Intergroup comparison for sensitivity showed statistically non-significant difference (*p-value*= 0.234) between all three study groups: without implant, with implant without AR and with implant with AR intergroup sensitivity were 100%, 96.7% and 95.5% respectively. These finding might be attributed to the standardization protocol followed in our study regarding the exposure parameters, small voxel size and FOV as was discussed in previous studies. [20, 30, 32-34]

While any decrease in sensitivity means that fracture lines could be overlooked in CBCT images, the decrease in specificity means that artifacts might imitate the fracture lines in non-fractured teeth resulting in false positive readings. Specificity was argued in many literatures to be more important than sensitivity as false positive readings can lead to unnecessary and unjustified extraction of teeth.

The highest specificity levels were reported for group without implant (100.0%) highlighting the high validity and diagnostic ability of CBCT in detection of vertical root fracture as reported in many studies to be attributed to the parameter's selection and the homogeneity of the study samples.[20,30,32,35,38] However, results by Dias *et al* [23] disagree as they reported poor specificity for CBCT in vertical root fracture with or without metal artifact presence.

Specificity for group with implant without AR was 90.0%. Evaluators reported false positive results of 1.7% and the negative predictive value for this group was 96.4%. the reduction in specificity in this group might also be attributed to the root-implant distance selected for our study [20]. On the other hand, 100% specificity was recorded for implant group with AR which suggests that artifact reduction algorithm can help improve the specificity and diagnostic quality of CBCT image as was reported in other studies. [20,26,27,36]

Intergroup comparison for specificity showed statistically non-significant difference (p-value= 0.234) between all three study groups: without implant, with implant without AR and with implant with AR intergroup specificity were 100%, 94.4% and 98.9% respectively.

One more factor that might have influenced the sensitivity and specificity levels in this study is the selected method for vertical root fracture induction. In our study universal testing machine was used to deliver load till fracture occurred without fragment displacement. While in other studies that reported lower levels of sensitivity and specificity, VRF induction was done manually which result-ed in variable degrees of fractures that were considered as confounding factors in root fracture assessment.[26,27,36] Moreover, no mechanical preparation or radicular instrumentation was performed in any of the roots included in this study to avoid removal of unnecessary amount of radicular dentine which can result in further weakening of the teeth which can be a confounding factor in VRF induction. [20, 30. 34]

Another influencing factor that might have contributed for high accuracy, sensitivity and specificity in this study is the distance between artifact inducing object and vertically fractured roots. While the distance between implants and root was adjusted and thoroughly checked to resemble clinical situations, the presence of implant at a distance not very close to vertical fracture line as it's the case with intra-radicular posts and filling material cause less pronounced artifacts in comparison to those caused by those materials and allows for better visibility and detection of fracture line on CBCT image. [20, 26, 27,30-32,34]

Regarding artifact reduction algorithm (AR) in this study, implant group with AR showed low sensitivity and higher specificity and accuracy than implant group without AR. These findings can be explained by the mode of action of metal artifact reduction algorithms which are mainly threshold based, meaning that all beam attenuation from hyperdense objects will be corrected which can reduce the ability to distinguish some true positive cases hence, reduce the ability to confirm fracture existence and false negative results might occur. [26,27]

Nevertheless, it should be noted that the clinical situations are more complex, and different clinical findings such as presence of bleeding, swelling, pain and localized periodontal lesions can all help to diagnose vertical root fracture along with the radiographic findings.

One of the limitations of this study is being an in vitro study, clinical situations can be different although we believe that this study would have been very difficult to carry out clinically with the same setting due to high risk of radiation exposure to the patients. Another limitation is this study investigated vertical root fracture only in single rooted teeth, multirooted teeth weren't included which might give different results. Moreover, the effect of different exposure parameters like current, voltage and voxel size weren't evaluated in this study as all exposure parameters were constant.

Conclusions

Within the limitations of this in vitro study, the following conclusions could be drawn as follows:

1. CBCT imaging showed high diagnostic accuracy in detection of vertical root fracture and can be considered a valuable diagnostic tool for this critical clinical situation.
2. Implant metal artifacts influenced the diagnostic accuracy, sensitivity and specificity for detection of vertical root fracture but still high levels were achieved and all image possessed high diagnostic quality.
3. Artifact reduction tool improved the accuracy and specificity and can be recommended when the teeth involved are near dental implant.

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