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ORIGINAL ARTICLE

The influence of voxel size and artifact reduction on the detection of vertical root fracture in endodontically treated teeth

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ABSTRACT

Objective: The aim of this study was to evaluate the effect of voxel size and artefact reduction (AR) on the identification of vertical root fractures (VRFs) in endodontically treated teeth.
Methods: A total of a hundred sound, extracted human mandibular single-rooted premolars were decoronated, after which root canal preparation was performed, canals were filled with gutta percha by single cone technique. Randomly selected fifty specimens were fractured, repositioned and glued together. The teeth were examined with cone beam computed tomography (CBCT) in five different voxel sizes (0.125, 0.200, 0.250, 0.300, and 0.400 voxels). Two scans were performed for each tooth, one with AR and one without AR. Two radiologists evaluated the CBCT scans.
Results: All voxel dimensions were successful in detecting VRFs in CBCT scans. But as the voxel size increased, the percentage of detecting VRFs decreased. High accuracy, sensitivity, specificity and predictive values were found for VRF detection on CBCT scans. Accuracy and sensitivity values decreased (from 100 to 82) while voxel dimensions increased (from 0.125 to 0.400). High-resolution images (0.125, 0.200, and 0.250 voxels) caused an increase in sensitivity for detection of VRFs. AR did not affect the accuracy, sensitivity, specificity and predictive values for VRF detection on CBCT scans.
Conclusions: High-resolution CBCT images resulted in an increase in sensitivity and specificity for detection of VRFs compared with lower-resolution CBCT images. The use of AR did not further improve its diagnostic potential.

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Introduction

Vertical root fracture (VRF) is defined as the fracture of the root extending from the root canal to the apical periodontium. It may contain the entire root or only a portion of the root. Root fractures are seen especially in endodontically treated teeth with an incidence of 2–5% [1]. Clinical and radiographic examination of VRF is extremely important for accurate diagnosis and treatment.

Periapical radiographs (PRs) are generally preferred considering their detail and high spatial resolution. However, detecting VRF may be quite difficult in PRs owing to their two-dimensional nature [2]. Tomographic screening, which has proved to be more effective than PRs, can be used in the diagnosis of VRFs [3]. Cone beam computed tomography (CBCT) has become more accessible to dentists and has replaced computerized tomography, particularly because of its low radiation dose and short screening times [4]. The advantage of CBCT over PR is that it shows fracture lines owing to its high contrast and 3D imaging capacity [5].

Various factors influencing image quality in the CBCT are scan area (FOV), voxel size, basic projection number and artefacts [6]. Different voxel dimensions may affect the quality of a CBCT scan and the radiation dose delivered to the patient [7]. The effect of root canal filling on VRF apparency may also vary between various CBCT scanners. CBCT images used for diagnosis may affect the diagnosis of VRF [2]. Materials that give hyperdense appearance, such as gutta-percha cones used in root canal filling can produce line artefacts that can mimic fracture lines [8]. High-density objects, such as intra-canal metallic posts, gutta-percha and metallic restorations can cause beam-hardening artefacts in the CBCT. These may, in some cases, affect the quality of the images and make endodontic diagnosis precarious [9].

Based on the variety of the factors with the potential to have an impact on identification of VRFs, this study aimed to evaluate the influence of voxel size and artefact reduction (AR) on the detection of simulated VRF in endodontically treated teeth.

Materials and methods

The Institutional Review Board was reviewed and approved the experimental protocol involving the use of extracted human teeth. One hundred intact human mandibular single-rooted premolar teeth without root fractures, which were extracted for orthodontic reasons included in the study.

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Table 1. Accuracy, sensitivity, specifity, positive and negative predictive values of observers with and without the use of AR.

Voxel size		Observer	Accuracy	Sensitivity	Specificity	PPV	NPV
0.125	With AR	1	100	100	100	100	100
		2	92	88.9	93.6	91.4	91.7
	Without AR	1	100	100	100	100	100
		2	92	88.9	93.6	91.4	91.7
0.200	With AR	1	94	91.7	95.7	94.3	93.8
		2	94	91.7	95.7	94.3	93.8
	Without AR	1	92	91.7	91.5	89.2	93.5
		2	92	91.7	91.5	89.2	93.5
0.250	With AR	1	94	91.7	95.7	94.3	93.8
		2	94	91.7	95.7	94.3	93.8
	Without AR	1	94	91.7	95.7	94.3	93.8
		2	94	91.7	95.7	94.3	93.8
0.300	With AR	1	86	69.4	97.9	96.2	80.7
		2	86	69.2	97.9	96.2	80.7
	Without AR	1	87	72.2	97.9	96.3	82.1
		2	87	72.2	97.9	96.3	82.1
0.400	With AR	1	82	58.3	100	100	75.8
		2	82	58.3	100	100	75.8
	Without AR	1	82	58.3	100	100	75.8
		2	82	58.3	100	100	75.8

Internal or external resorbed, fractured and curved roots were excluded. As the multirooted teeth may be different and may affect the results, multirooted teeth were not included in the study. The researchers were blinded to any data.

Until the CBCT scan, all the teeth were stored in distilled water. One hundred single-rooted extracted human teeth were inspected for the absence of root fracture with a 3.5X loupe. The crowns sectioned below the cement enamel junction so that the length of all roots was adjusted to approximately 16 mm. After a working length of 15 mm was calculated, the canals were prepared with Protaper (Dentsply Maillefer, Ballaigues, Switzerland) till F3 file size. Throughout the canal preparation using all the files, canal irrigation was done with 1 ml 2.5% Sodium Hypochlorite solution (NaOCl). After root canal preparation, the canals were dried with paper points (Dentplus, Almere, Netherlands) and filled with F3 Protaper (Dentsply, Maillefer, Ballaigues and Switzerland) and AH plus by single cone technique. After gutta-percha cones were cut, specimens were prepared for tests in autoclave at 37 °C.

All the root canals were prepared using the same technique. Fifty roots were randomly chosen and fractures were created by placing a nail in the root canal and tapping it with a hammer. The fragments were repositioned and adhered together with one layer of methyl methacrylate without any displacement (subjectively assessed with a magnifying glass). The other 50 roots were kept intact to serve as control. Fourteen teeth roots in the study group could not be repositioned and were excluded from the study. Three roots in the control group were excluded due to endodontic file separation during the root canal preparation.

The remaining teeth were divided into two groups as a control group of 47 teeth with no fractures and a study group of 36 teeth with fractures. Eight holes were drilled in a straight line in each bovine rib. Randomly distributed 83 roots were placed within the prepared holes to the 11 bovine ribs. To keep the teeth stable and to create the periodontal ligament space wax was added around the roots.

Table 2. Interobserver agreements of observers.

Voxel sizes		Observer 1–Observer 2 Kappa
0.125	With AR	82.8
	Without AR	82.8
0.200	With AR	100
	Without AR	100
0.250	With AR	100
	Without AR	100
0.300	With AR	100
	Without AR	100
0.400	With AR	100
	Without AR	100

In order to simulate soft tissues, the ribs were covered with three layers of wax.

The teeth were scanned with CBCT (I-Cat, Imaging Sciences Int., Hatfield, PA, USA) with 120 kVp, 5 mA and 26.1 s scan parameters in five different voxel sizes: 0.125, 0.200, 0.250, 0.300, 0.400 mm. 8×8 FOV was used for all the CBCT scans. During CBCT scans ribs positioned central in the FOV in order to avoid image quality differences. Two scans were performed for each tooth, one with AR and one without AR. Two previously trained independent dentomaxillofacial radiology specialists, who were particularly experienced in CBCT, evaluated the CBCT scans of 83 teeth for fracture. Data were recorded as fracture present or absent. CBCT images were evaluated in the three planes. ICAT Vision program was used for the evaluation of the CBCT scans. Under the same conditions 30 samples were re-evaluated by one of the observers after a 30-d interval to evaluate the reproducibility of the method.

The radiographic evaluations were compared with the gold standard (physical observations) using a two-sided chi-square test and kappa test to determine the accuracy, sensitivity and specificity, positive and negative predictive values of each system in detecting VRFs. The number of teeth was determined by calculation of power analysis with G* power, where 0.05 was the alpha (α) and 80% power value for 35 teeth. To assess the intraobserver and interobserver agreement, kappa was used. SPSS version 16.0 software was used to analyse the data (SPSS Inc., Chicago, IL, USA).

Results

Two-sided chi-square test showed that VRFs could be detected in CBCT scans in all voxel dimensions ($p<.05$). Although, CBCT scans could detect VRFs, as the voxel size increased from 0.125 to 0.400, the percentage of detecting VRFs decreased.

Kappa test showed high accuracy, sensitivity, specificity and predictive values for VRF detection on CBCT scans. Accuracy, sensitivity, specificity, positive and negative predictive values are shown in Table 1.

Observer 1 and 2 presented with high accuracy and sensitivity values according to Kappa Test. Accuracy and sensitivity values decreased while voxel dimensions increased. Observer 1 also showed high specificity, positive and negative predictive values. AR did not affect the accuracy, sensitivity, specificity and positive and negative predictive values for VRF detection on CBCT scans.

Table 3. Intraobserver agreement values of one of the observer.

Voxel sizes		1st.–2nd.
0.125	With AR	100
	Without AR	100
0.200	With AR	100
	Without AR	100
0.250	With AR	100
	Without AR	100
0.300	With AR	77.2
	Without AR	77.2
0.400	With AR	46.2
	Without AR	46.2

Interobserver agreements were perfect and the kappa values are presented in Table 2. Accordingly, Observer 2 re-evaluated the 30 specimens after 1 month from the first evaluation and intraobserver agreement values were found between 46.2 and 100 (Table 3).

Discussion

Tooth fractures are frequently encountered in dentistry. VRFs are relatively less frequent form of root fracture, but the prognosis may be poor if not treated appropriately. They are more common in endodontically treated teeth [10]. Chen et al. [11] monitored the teeth with root canal treatment for 5-year and stated that VRF was the main cause for extraction (32.1% of cases). It is also known that endodontic treatment and malocclusions play a role in the aetiology of VRFs [12].

The diagnosis of VRFs can sometimes be very difficult for dentists because of different clinical findings and the absence of any pathognomonic signs [13]. PR – a technique commonly used to detect tooth fractures – has low diagnostic accuracy, resulting in many undetected teeth fractures [14]. The introduction of CBCT into dentistry has enabled dentists to view three-dimensional radiographs of teeth and jaws with high spatial resolution and low radiation dose [15]. The diagnostic accuracy of CBCT in the diagnosis of tooth fractures has been shown [16], particularly in cases where PR failed [17]. CBCT examination may ensure more detailed information about tooth structure compared with PR, but at higher radiation dose [18]. As CBCT produces high-quality images and eliminates the superposition of structures due to its three-dimensional nature; it enables different aspects of teeth and jaws to be evaluated in thin sections and high contrast [8,19,20].

To detect VRF with CBCT in an *in vitro* study compared two different CBCT units using different resolutions of voxel dimensions and had better results in low voxel dimensions compared to high voxel dimensions [21]. However, the patients were exposed to greater amount of radiation and reconstruction times were prolonged. Likewise, this study showed that small voxel sizes achieved better results for the detection of simulated VRF. Since the image quality is proportional to the dose, the selection of the dose during shooting becomes a deciding factor affecting the image quality [22]. Small voxel size means increased spatial resolution [23].

Since VRF is considered one of the main causes of extraction of endodontically treated teeth, it is significant to evaluate the effect of gutta-percha root filling on the diagnosis of VRF [11]. The presence of root canal filling materials could lead to differential densities with a variety of artefacts produced [24]. Therefore in this study, VRF is investigated in endodontically treated teeth to evaluate the effect of gutta-percha root filling. Studies analysing the effect of root canal filling in detection of root fractures on CBCT images have indicated that the overall accuracy of CBCT scans did not reduce by the presence of root canal filling material, their specificity was significantly reduced. However, they were able to detect VRFs [8,25,26]. In this study, similarly to previous studies, results showed high accuracy but differently specificity and sensitivity were not influenced by the root canal filling. These different results could be caused by the variety of imaging protocols used in the studies.

Several AR algorithms have been used in recent years. However, those algorithms were performed subjectively in CBCT. Additionally, it was mentioned that, they have involved a single CBCT unit, leading to inconsistency and nonreproducibility of the results. Besides, AR corrections may not necessarily improve diagnostics [27]. In this study, not only the effect of gutta-percha root filling but also the effect of AR usage on the diagnosis of VRFs is investigated and two scans were performed for each tooth, one with AR and one without AR. Similar to Vasconcelos et al. [27] our results revealed that the AR did not improve the diagnosis. Studies also showed that AR algorithm did not improve the artefact appearance [28]. This study is consistent with these studies. Although an effective metal-artefact suppressing algorithm in the soft tissue region was reported [29], as VRFs are inside the hard tissues AR may not be effective adequately.

CBCT considered being the most reliable imaging method for VRFs diagnosis as it can prevent scanning of ROI-sensitive structures due to beam hardening. However, in a study conducted by Uzun et al. [29] no significant differences were found between observers or voxel sizes and pointed out that, especially in suspicious cases, high-resolution scanning is recommended in the diagnosis of VRFs, as it is difficult to visualize with PRs [29]. According to this study's results when VRFs are suspected small volume high-resolution CBCT scanning protocol could be used.

As for the relationship between voxel size and artefacts, Brito-Júnior et al. [30] utilized the artefacts of root canal fillings on CBCT images and indicated that more artefacts were seen in large voxel dimensions. In addition, clinical studies have indicated that the existence of gutta-percha does not significantly affect sensitivity, specificity or accuracy in the diagnosis of VRFs [14]. The results of this study are consistent with these previous findings and point that even in the presence of the root canal filling, the diagnosis of VRFs in the CBCT can be performed accurately.

The radiation dose should always be considered during CBCT screening. If the patient's clinical findings and conventional radiographic data are insufficient for the diagnosis of VRFs, CBCT imaging with small voxel size should be used. Image quality improves due to higher spatial resolution using smaller voxel sizes [31]. As the voxel size is related to the contrast and resolution of CBCT images, 0.125 mm voxel size produces images with the best resolution when

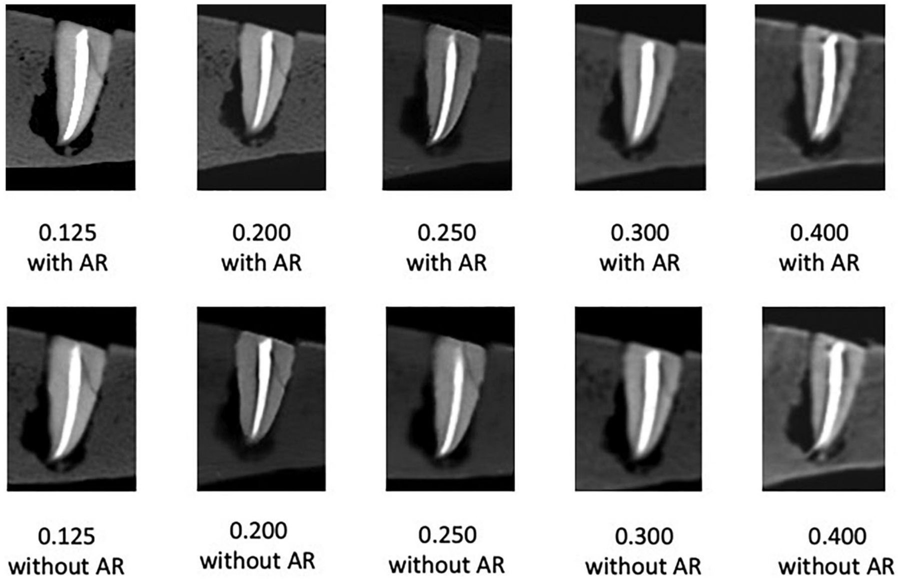

Figure 1. Different voxel images of the same VRF with and without AR demonstrate the 0.125 and 0.200 voxel images have better visualization.

compared to voxel size 0.200. Voxel sizes 0.300 and 0.400 mm should be avoided in the identification of VRFs.da Silveira et al. [32] investigated the appropriate voxel size for the detection of VRFs, which provides a low radiation dose and adequate diagnostic accuracy, and indicated the 0.2 mm voxel size as the most appropriate choice. Similarly, in this study, 0.125 and 0.200 mm voxels, because of their high image resolution, provided the best results as shown in Figure 1.

In the detection of VRFs, voxel sizes 0.125 and 0.200 mm were enough to produce high accuracy and voxel sizes 0.300 and 0.400 mm provided relatively poor accuracy. In this study, although the accuracy of the second observer for 0.125 voxel was normally high, it was found to be lower than the 1st observer. Observer 1 is more experienced in CBCT image interpretation and according to our opinion this experience affected the 0.125 resolution results. The AR algorithm used in this study was built into the machine and could not be modified by the user. It did not affect the diagnosis of VRFs.

The intraobserver agreement values gradually decreased after 0.250 voxels and reached its lowest value at 0.400 voxels. Although VRFs could be detected in 0.300 and 0.400 voxels, the percentage of detection decreased. Therefore, the intraobserver agreement value is very low only in these voxels.

Conclusions

Within the limitations of this study, it can be concluded that CBCT has a high diagnostic accuracy for root fractures for single-rooted teeth and can be used in clinical settings. High-resolution (0.125 and 0.200 mm voxel sizes) CBCT images caused an increase in sensitivity without affecting specificity for detection of VRFs compared with lower-resolution CBCT images and use of an AR in CBCT for VRF detection may not provide an additional benefit for an improved diagnosis. Radiation dose is important; however, if the problem could not solve with conventional radiography and lower resolution CBCT scan, the highest resolution can be preferred especially when the VRF is suspected.

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Disclosure statement

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