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Comparative evaluation of accuracy of cone beam computed tomography versus digital radiography in diagnosis of vertical root fractures in single rooted teeth, with different thickness parameters

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Abstract
Background: Vertical root fractures (VRFs) are longitudinal fractures originating from the apical end of the root and propagating coronally, posing diagnostic challenges in endodontic therapy using digital radiographs. This study aimed to carry out a comparison of the diagnostic accuracy of Cone Beam Computed Tomography (CBCT) and Radio Visio Graphy (RVG) in detecting simulated VRFs with varying thicknesses in extracted human single-rooted premolars

Materials and Methods: Sixty freshly extracted human single-rooted premolar teeth were collected and prepared. After decoronation, access was gained to the canal, and biomechanical preparation was performed. The teeth were categorized into three experimental groups and one control group. VRFs were then simulated in the three experimental groups by the mallet and chisel delivering force vertically from above, hence resulting in two vertical fragments of teeth which were re-attached at gaps of 0.4 mm (Group 1), 0.2 mm (Group 2), and less than 0.2 mm (Group 3). CBCT and RVG imaging were performed on all groups to detect VRFs. Descriptive statistics, chi-square tests, and Kappa coefficient tests were conducted using SPSS.

Results: CBCT scans demonstrated higher overall accuracy compared to RVG for detecting VRFs. The sensitivity of RVG compared to CBCT for 0.4 mm, 0.2 mm, and less than 0.2 mm fractures was 66.7%, 40%, and 25%, respectively. The Kappa coefficient test indicated non-significant agreement ($p>0.05$) between CBCT and RVG in diagnosing VRFs. CBCT was found to be significantly more accurate in detecting VRFs less than 0.2 mm thick ($p<0.05$) as compared to RVG.

Conclusion: Within the limitations of this in-vitro study, CBCT showed superior accuracy compared to RVG in detecting VRFs of different thicknesses, particularly for fractures less than 0.2 mm thick. CBCT exhibited higher sensitivity, making it a more reliable diagnostic tool for VRFs.

Keywords: Vertical Root Fractures (VRF), Cone Beam Computed Tomography (CBCT), Radiovisiography (RVG), Digital Radiography (DR), Diagnosis, Accuracy

1. Introduction

Vertical root fracture (VRF) refers to a fracture that runs longitudinally alongside the root, directed from the root canal to the surrounding periodontium [1]. It is characterized by the splitting of the tooth root structure along its vertical axis [2]. Retrospective studies indicate that the prevalence of VRF in permanent teeth ranges from 3 to 5%, with multiple contributing factors involved [3, 4]. The occurrence of VRF is notably higher in teeth that have undergone endodontic treatment (3.7-30.8%) compared to those that have not [5]. It has been documented that premolars and the mesial root of mandibular molars exhibit a higher prevalence of VRF [6, 7]. When a tooth has a vertical root fracture, it often presents with a variety of clinical signs and symptoms which include swelling or abscess formation around the affected area, the development of a sinus tract, increased mobility of the tooth, tenderness when the area is touched or tapped, and the appearance of deep, isolated periodontal pockets [8]. Radiographic findings typically associated with VRF include peri-radicular or laterally present radiolucency, a J-shaped radiolucency, furcation involvement and periapical pathology [8, 9].

Over time, the separation between fractured root fragments tends to increase, and resorption areas may become larger, negatively impacting the prognosis for further treatment [10]. Prompt intervention is crucial to prevent additional bone loss, which could complicate future reconstruction efforts.

Detecting VRF can be a meticulous task and usually needs a combined approach of clinical evaluation, radiographic assessment, and sometimes surgical exploration. Cone-beam computed tomography (CBCT) offers a much more reliable method for analyzing factors associated with fractures. CBCT imaging is a non-invasive technology that represents a significant advancement, offering detailed cross-sectional and three-dimensional views with minimal radiation exposure. Unlike medical CT scans, CBCT allows for the selection of a smaller field of view (FOV), which enhances image resolution and diagnostic accuracy. This approach uses a cone-shaped X-ray beam along with an area detector to gather a cylindrical volume of data at one time in a single scan.The benefits of CBCT include its ability to generate exceptionally precise, high-resolution cross-sectional and 3D images that are fully measurable and can be consistently reproduced [11].

Conventional two-dimensional radiographs may have limitations due to the overlap of adjacent structures, making fracture lines difficult to detect [5]. In Two-dimensional radiography, it is important to note that a root fracture might go unnoticed if the X-ray beam isn't properly aligned with the fracture line, so taking two or more radiographs at different angles (about 4 degrees) is recommended. Interpreting root fractures on radiographs can be particularly problematic if there is no evident displacement of the fragments due to granulation tissue and edema [12].

2. Materials and Methods

This study was performed to analyse the diagnostic accuracy of CBCT and Digital radiography (Radiovisiography) in diagnosing the presence of simulated VRFs in extracted human premolar teeth with different thicknesses of the gaps between fragments. 60 non-carious, single-rooted extracted premolars, with approximately similar buccolingual and mesiodistal dimensions, were selected for the study. After extraction, teeth were cleaned with water to remove blood and scaling was performed with scaler to remove any attached periodontal tissue, plaque and/or calculus.

They were immersed in 5% sodium hypochlorite (NaOCl) solution for 2 h to disinfect the surface and dissolve any superficial soft tissue. Preoperative X-rays were taken to confirm that the selected teeth were free from root caries, restorations, open apices, calcifications, fractures, or craze lines. To standardize the samples, each tooth was trimmed 1 mm above the cementoenamel junction (CEJ) using a flexible diamond disk with a slow-speed handpiece and ample water coolant (Figure 1). The roots were then standardized to a length of 14 mm, measured from the apex to the facial CEJ.

An access opening was made for each tooth, and the root canals were prepared with the ProTaper Universal Rotary NiTi Files (Dentsply Maillefer, Switzerland) upto F3 (#30/09) at a speed of 300 rpm using X Smart Endomotor (Dentsply Maillefer, Switzerland), beyond the apical foramen to weaken the roots. Teeth were then divided into 1 control and 3 experimental groups (0.2-mm VRF, 0.4-mm VRF, and crack). Each group consisted of 15 teeth. Grooves/ indentations were made coronally on root segments with diamond disc mounted in slow speed handpiece to aid in placement of mallet and chisel over it (Figure 2). Vertical root fractures were then created in 45 teeth, excluding the control group, by applying mechanical force using a mallet and chisel, following the method described by Wenzel *et al.* (Figure 3). The chisel was carefully positioned in the center of the root canals, and force was applied with a mallet, causing the root to split into two fragments, resulting in the formation of the following groups: Group 1: 0.4 mm VRF thickness; Group 2: 0.2 mm VRF thickness; Group 3: < 0.2 mm VRF thickness (crack); Group

3. Control Group

Modelling wax was placed between 2 fragments, and finger pressure was applied for integration. A digital vernier calliper was used to set the distance to 0.2 mm and 0.4mm (group 2 and group 1) between the 2 fragments. In the Crack Group, two separated fragments from 15 teeth were reattached using glue, with finger pressure applied until the glue set. The gap between the fragments was kept to less than 0.2 mm along the entire root (Figures 4-7). Sample Positioning was done on wax occlusal rims to simulate soft tissue surrounding the teeth.

Fig 1: 60 Human Single Rooted Decoronated Premolar teeth

Fig 2: Making groove over the tooth with diamond disc

Fig 3: Inducing VRF with chisel and mallet

Fig 4: 0.4mm VRF Sample

Fig 5: 0.2mm VRF Sample

Fig 6: <0.2mm / crack Sample

Fig 7: Control Group sample (No VRF)

Radiographic Scanning: Digital radiographs (RVG) using the Carestream 2100 were shot for all the groups, using a 7mA current, 60kV, and an exposure time of 0.16 seconds. Afterward, CBCT imaging was performed for all groups. (Figure 8-9). Three-dimensional, high resolution CBCT images were obtained from CBCT (CS 9300 Carestream) with a 6cm field of view (FOV) using 90kilovoltage, 4.0 mA and 20.0 s of exposure time. The images were transferred to CS 3D imaging software 3.8.7 (Carestream Health, Inc, USA) to be analysed later. CBCT images were evaluated in axial, sagittal, and coronal views, with a single reading taken for each tooth.

Evaluation of Experimental Groups: For both DR and CBCT readings, a single observer identified the cracked group by directly visualizing a radiolucent line on the root surface, without any separation of the fragments. For VRFs, thickness of 0.2 mm and 0.4 mm was decided visually, and the ‘‘distance measurement’’ feature of the software was not used. There was no time limit for making observations, and each observation was simply categorized as either "yes" or "no".

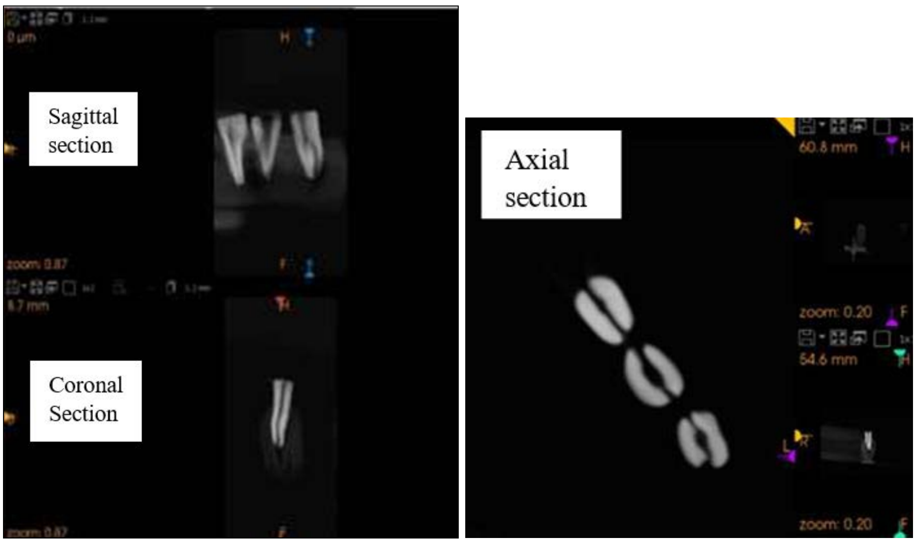

Fig 8: CBCT images of Samples

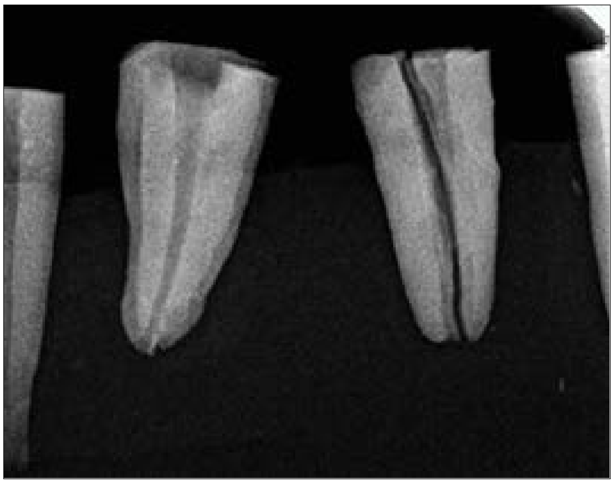

Fig 9: RVG Imaging of Samples

Data Analysis: Data was analyzed using SPSS v26.0 (IBM). The Chi-square test compared the frequencies of different categories. Degree of agreement between CBCT and RVG was estimated using Kappa coefficient. Statistics for diagnostic studies like sensitivity, specificity etc was done.

4. Results and Observations (Fig 11-14)

CBCT scans had a higher overall accuracy for detecting VRFs compared to RVG / Digital Radiography. Sensitivity of the RVG when compared with CBCT for different thickness 0.4mm, 0.2mm, <0.2 mm (crack) was 66.7%, 40%, 25% respectively.

A statistically significant difference was observed in the frequencies between CBCT and RVG for detection of VRF of thickness <0.2mm ($p<0.05$). This indicated that CBCT is notably more precise and dependable for detecting VRFs of <0.2mm thickness than RVG.

As found out by Kappa Coefficient test, there was a statistically non-significant agreement between the 2 modalities i.e. CBCT and RVG for detection of < 0.2mm thickness VRFs ($p>0.05$). This indicates that the two techniques have a poor level of agreement (RVG and CBCT) for detecting Vertical Root Fractures (VRFs) indicating that one technique (in this case CBCT) maybe better or more reliable than the other (in this case RVG) in accurately identifying VRFs.

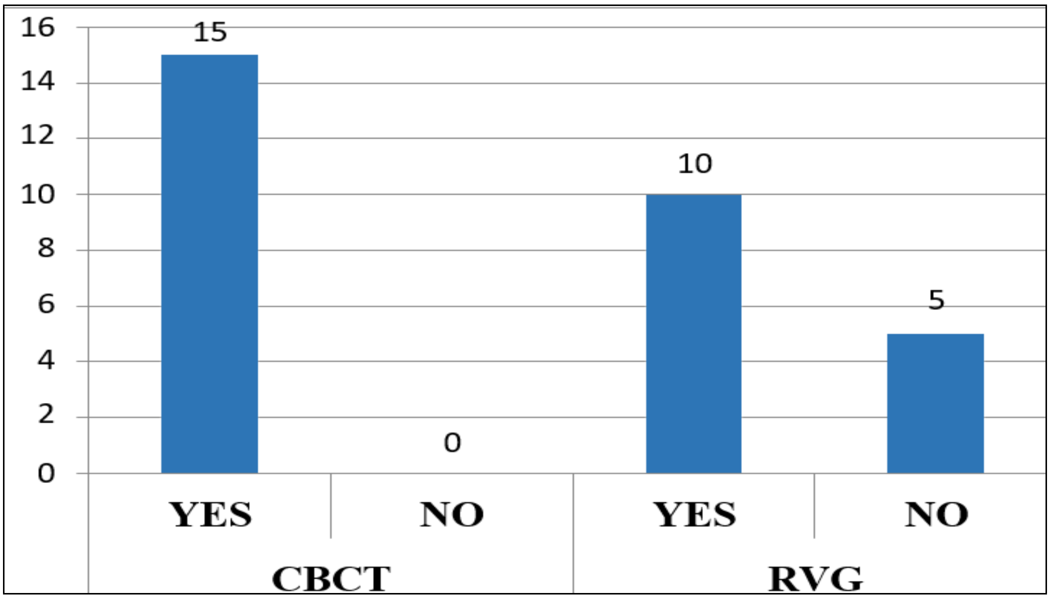

Fig 10: Intra group comparison of frequencies of RVG & Cbct for 0.4 Mm VRF Group

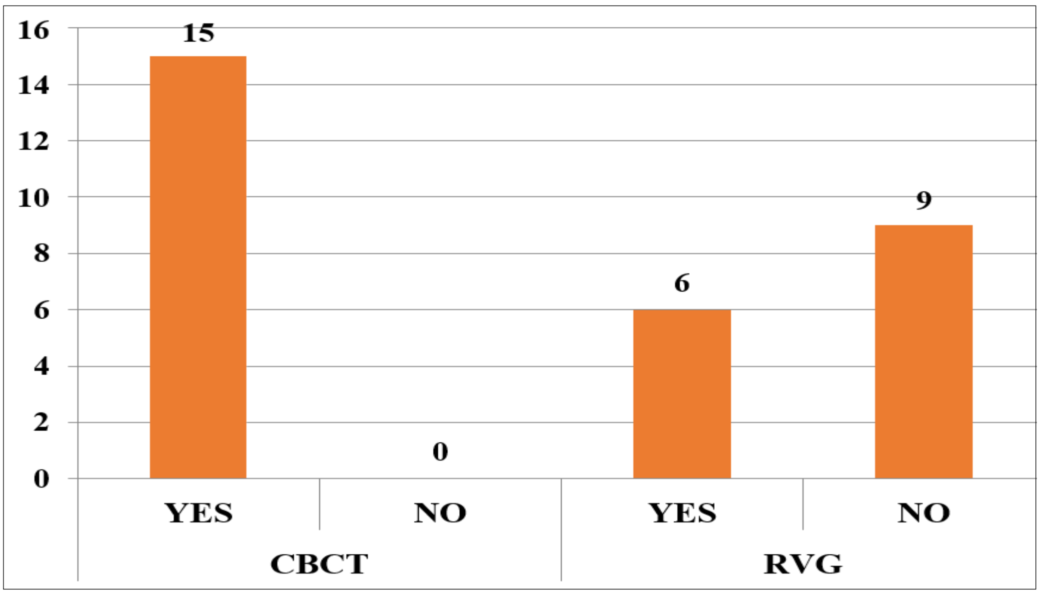

Fig 11: Intra group comparison of frequencies of RVG & Cbct for 0.2 Mm VRF Group

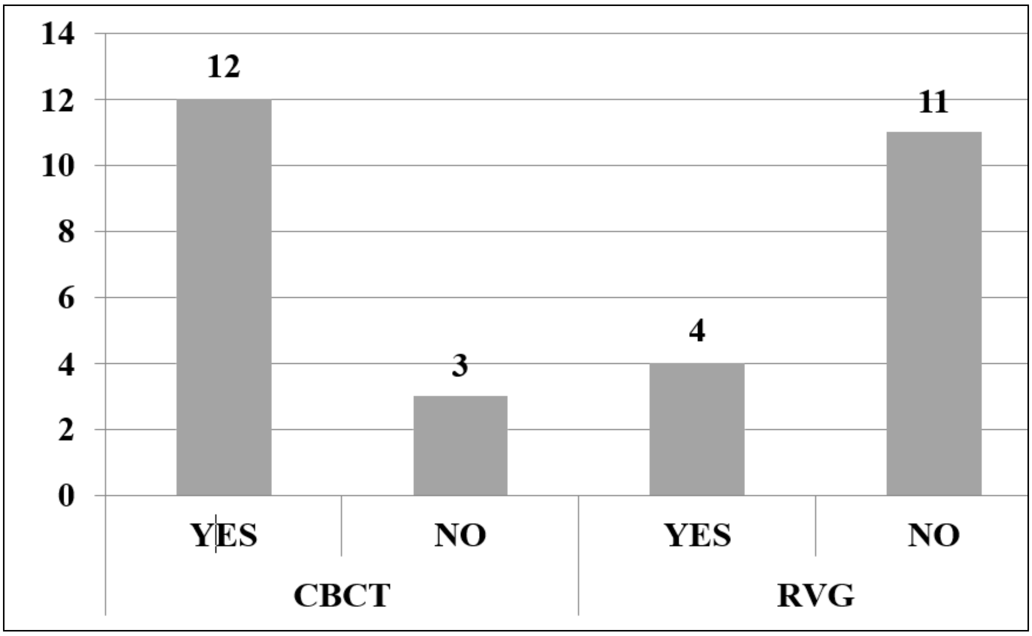

Fig 12: Intra group comparison of frequencies of RVG & Cbct for <0.2 Mm Vrf (Crack) Group

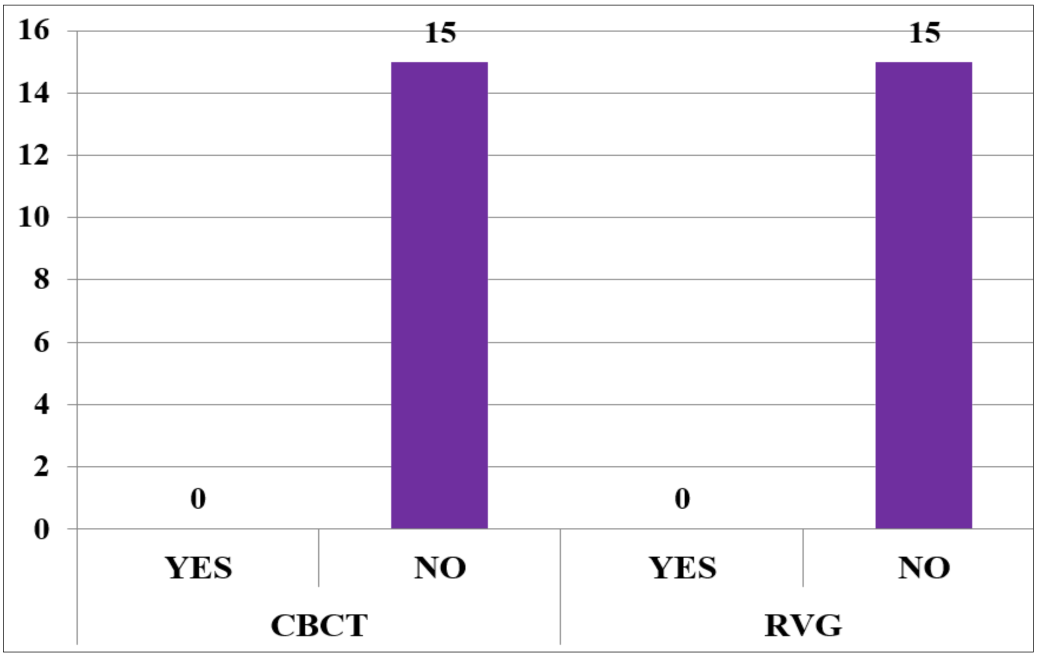

Fig 13: Intra group comparison of frequencies of RVG & Cbct for control group

5. Discussion

A vertical root fracture (VRF) is a type of fracture that runs lengthwise along the root of a tooth [13]. This condition is difficult to detect, posing challenges for both general practitioners and endodontic specialists. While VRFs commonly occur in endodontically treated teeth, they have also been occasionally reported in non-endodontically treated teeth. The symptoms and signs of VRFs can resemble those of endodontic or periodontal diseases, making diagnosis and management particularly challenging. Identifying and treating a VRF often requires thorough interpretation. There has been limited research comparing VRFs in teeth that have undergone endodontic treatment with those that have not [14].

The way a vertical root fracture shows up clinically can differ a lot from case to case. Severe pain is rarely associated with these fractures. However, teeth with such fractures may give history of pain during biting. If a tooth with an apparently well-performed root filling continues to cause discomfort after the procedure, a vertical root fracture should be considered. When a root-filled tooth exhibits 'pain on biting' along with a 'bad taste,' a vertical root fracture is highly likely. To replicate the patient's discomfort while chewing and confirm their primary complaint, a bite test is recommended. In contrast, for a cracked tooth, the patient is asked to bite down on cotton rolls and then quickly release the pressure. If pain occurs when the pressure is suddenly released, it helps confirm the diagnosis [15, 16]. A sinus tract found in a tooth with a vertical root fracture (VRF) is usually located more coronally rather than in the apical area, occurring in 35-42% of VRFs [1]. A deep periodontal pocket is a frequent sign one might see, observed in 64-93% of VRFs.

Roots with narrow mesiodistal widths, like those in maxillary premolars, are more likely to develop VRFs. [17, 18]. These fractures usually start in the part of the canal wall with the most curve because of uneven stress distribution [19]. Irregularities inside the canal can also increase localized stress. Research has looked into how canal shape, root shape, and dentin thickness influence stress distribution, finding that canal shape is the most important factor. An ovoid root and canal, especially with thinner dentin on the sides, raise the risk of vertical root fractures. Consequently, single-rooted premolars were chosen for our study to induce and evaluate VRFs.

Detecting a vertical fracture is clinically significant because infections can develop from the periodontium marginally, leading to the destruction of the adjacent bone. Therefore, vertical root fractures often leave the dentist with the option of tooth extraction. Preoperative detection of a fracture thus influences therapeutic strategies [20].

A characteristic "teardrop" radiolucency may appear on the radiograph. The widening of the periodontal ligament space and associated bone loss is often positioned more coronally towards the alveolar crest rather than centered at the apex. Visualizing a vertical root fracture line directly is challenging because the X-ray beam must pass almost directly down the fracture line for it to be visible. Small changes in horizontal angulation can make the fracture undetectable. Rud and Omnell *et al*. found that even a four-degree variation in horizontal angulation could prevent visualization of the fracture when examining an extracted fractured root with segments in apposition [21]. VRFs are longitudinally directed fracture therefore, a horizontal cross-section perpendicular to the VRF, with X-ray beams parallel to the fracture path, should provide the best detection [22].

Chen *et al*., in their 5-year follow-up study on extracted root canal-treated teeth found a 32.1% rate of tooth fractures. Given this high rate, early detection of a VRF is essential for improving the chances of successful future treatment, as it helps prevent additional bone loss and resorption of the surrounding tissues [23].

Two-dimensional intraoral X-ray systems can't show details about teeth and surrounding structures in three dimensions. The overlapping of other structures also makes it harder to detect longitudinal fractures accurately with these methods [24]. Because traditional imaging can't effectively capture VRFs, there's a need for advanced imaging systems like cone beam computed tomography (CBCT) or digital volume tomography [25, 26].

Vertical fractures were created using a chisel and mallet, applying mechanical forces as outlined by Wenzel *et al*. A tapered chisel was placed at the center of the root canals, and force was applied with a hammer to induce VRFs, resulting in the root splitting into two fragments. However, it's been suggested that this method of inducing fractures might not perfectly mimic real-life conditions, where VRFs in vivo could have gaps between the fractured pieces and might resemble other issues. To address the concerns raised by Hassan *et al*., we reconstructed and examined teeth with VRFs of 0.2 mm and 0.4 mm thickness in our current study. As suggested by Ann Wenzel *et al*, in the present study for the crack group (VRF <0.2mm), the root fragments were securely glued back in their original position, with care taken not to move them. This approach aims to replicate the immediate post-trauma condition, where the fragments haven't yet been displaced by swelling or granulation tissue [27].

According to Tamse *et al*. [28], a root fracture becomes visible on a radiographic image when the fragments are separated. The key sign of a root fracture is the movement of these fragments away from the original tooth structure, often caused by the buildup of granulation tissue. To replicate this separation in our study, various thickness parameters for the VRFs were considered. Yongbin Zhang *et al*. noted that radiopaque materials like gutta-percha cones and metal posts can create star-shaped streaks on tomographic slices, which might look like fracture lines on CBCT images and reduce observer confidence in diagnosing VRFs. Additionally, root canal fillings significantly reduced the overall accuracy and sensitivity of periapical radiographs (PRs), leading to more false-negative results [29]. Therefore, in this study, teeth were endodontically enlarged but left without any root filling materials in the canal to evaluate the diagnostic ability of CBCT and RVG in detecting VRFs.

According to a study by Jakobson SJ *et al*. [30], the favorable voxel size of CBCT ranges from 0.125 to 2 mm, and it can produce detailed images in multiple planes: Axial, sagittal, and coronal, along with minimal artifact interference, make it highly valuable for assessing maxillofacial structures. However, root-filling materials can cause artifacts, and beam hardening during CBCT may lead to erroneous VRF diagnoses.

Hassan *et al*. [26] compared the effectiveness of CBCT and Digital Radiography (DR) in detecting vertical root fractures in both root-filled and non-filled teeth, and found that CBCT scans were more effective than DR in identifying longitudinal root fractures. This aligns with our study, where CBCT scans demonstrated lower sensitivity compared to RVG scans across all experimental groups. This difference is likely due to better inherent contrast of CBCT compared to traditional 2D X-ray images. The three-dimensional view provided by CBCT scans lets one see fracture lines from various angles and very thin slices with high contrast. On the other hand, the flat, two-dimensional perspective of periapical radiographs (PRs) can make fractures harder to see clearly due to superimposition artifacts, explaining the low sensitivity of PRs in detecting VRFs. In our study, the overall specificity of PRs/RVG for detecting fractures was higher than their sensitivity. The high specificity of PRs can be attributed to the fact that most teeth were scored negatively for VRF in the 0.2 mm and <0.2 mm thickness groups because most fractures were not visible. Edlund *et al*. [31] evaluated how accurately CBCT detects suspected vertical root fractures in endodontically treated teeth by using exploratory surgery to verify whether a fracture was present. Their study found that CBCT was a superior diagnostic tool for detecting VRF.

Evidence indicates that the sensitivity and specificity of CBCT systems in detecting vertical root fractures are affected by the number of artifacts and vary based on voxel size, field of view (FOV) size, and the presence and type of intra-canal post, imaging system type, detectors, slice thickness, VRF dimension, and scanning parameters [32].

Changing the slice thickness does not significantly affect the number of artifacts [33] therefore, 1-mm thick slices were used in the current study. The Kappa Coefficient test for agreement between CBCT and RVG as VRF diagnostic modalities revealed a non-significant agreement between them ($p>0.05$), indicating that CBCT may be more reliable than RVG for VRF detection. Consequently, both modalities do not show agreement in diagnostic results, as one modality is superior to the other when correlated clinically.

6. Conclusion

Within the limitations of this present in-vitro study we can conclude that CBCT showed better results in detecting the vertical root fracture simulated in the natural human tooth as compared to RVG. These results may not fully represent real-life conditions since the samples were prepared *in vitro*. Nevertheless, CBCT proved more effective than RVG in accurately diagnosing cracked teeth, 0.4 mm and 0.2 mm thickness groups. The specificity of detecting the fracture of control group by RVG was 100% when compared with CBCT. The sensitivity of the RVG when compared with CBCT for different thickness 0.4mm, 0.2mm, 0.05) between CBCT and RVG in diagnosing Vertical Root Fractures (VRFs), suggesting CBCT's potential superiority over RVG for VRF detection. Further research comparing voxel sizes that balance high image quality with lower radiation doses would be beneficial for more accurate diagnosis and assessment of vertical root fractures.

Conflict of Interest
Not available

Financial Support
Not available

7. References

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