Medical Communication

Biosci. Biotech. Res. Comm. 11(1): 117-121 (2018)

BBRC
Bioscience Biotechnology Research Communications

# Effect of different exposure settings on the diagnosis of vertical root fractures on cone-beam computed tomography images

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## ABSTRACT

By considering the importance of vertical root fractures (VRF) and the known complications of incorrect diagnoses, the present study aimed to evaluate the effect of different kilovoltage peak (kVp) and milliampere (mA) settings in cone-beam computed tomography (CBCT) on the diagnosis of VRFs in endodontically treated single-canal premolars. Eighty intact human premolars were endodontically treated and coded. The roots of half of the samples were fractured, and CBCT images were taken by using four different combinations of maximum (max) and minimum (min) kVp (60-86) and mA (6-10) settings under the same conditions. The images were randomly observed twice by an experienced oral and maxillofacial radiologist over a two-week interval. The results were analyzed by Chi-square test. In the kVp max/mA max group, none of the images were diagnostic. In the kVp max/mA min group, 62 images (77.5%) were nondiagnostic. The results of these two groups showed significant statistical differences with the other two groups ($P<0.001$). Incorrect diagnoses were equal to 22.5% in the kVp min/mA min group, and 16.2% in the kVp min/mA max group with no significant statistical differences ($P<0.4$). It seems that the best view for identifying VRFs on CBCT images in axial sections can be obtained with kVp min/mA max setting. It can be concluded that kVp min/mA max and kVp min/mA min settings are suitable for the diagnosis of VRFs. Also, a lower kVp renders a lower patient radiation dose.

**KEY WORDS:** CONE-BEAM COMPUTED TOMOGRAPHY, TOOTH FRACTURES, DIAGNOSTIC IMAGING

**Article Information:***Corresponding Author: Sandramehr@yahoo.com
Received 27/02/2018 Accepted after revision 30/03/2018
Published: 30th March 2018 Pp- 117-121

Available at: https://bbrc.in/
Article DOI: http://dx.doi.org/10.21786/bbrc/11.1/16

## INTRODUCTION

Vertical and horizontal root fractures (VRF/HRF) have always been regarded as diagnostic predicaments since they are difficult to detect on intraoral radiographs. Conventional and digital intraoral radiographic techniques are the most common methods for detecting root fractures. These fractures can also be assessed by routine dental examinations (Özer, 2011; Edlund et al. 2011). Endodontic therapy is one of the major causes of root fractures (Taramsari et al. 2013; Uzun et al. 2015). VRFs are more prevalent in the patients over the age of 40 years and in maxillary and mandibular premolars and in the mesial roots of mandibular molars. In molars, VRFs usually occur in a buccolingual direction in separate roots, while mesiodistal fractures are less common. In anterior teeth, the fracture usually extends in a buccolingual direction (Li et al. 2002). The most common radiographic findings in root fractures include an increased thickness of the periodontal ligament (PDL), a deep local or vertical bone loss, and peri-radicular bone loss (Shi et al. 2009). Root fractures have become diagnosable since 1896 when two-dimensional (2D) radiography was introduced to dentistry (Li et al. 2002). However, if the angle of the projection is not perpendicular to the fracture line, these fractures may remain undiagnosed (Salineiro et al. 2015).

For a more accurate diagnosis, the conventional 2D radiography can be completed with a third dimension. Cone-beam computed tomography (CBCT) was introduced in 1998 for dento alveolar imaging (da Silveira et al. 2013). Many studies have proven the efficacy of this system in the detection and diagnosis of root fractures (Taramsari et al. 2013). The old techniques used for the diagnosis of VRFs are unreliable due to the presence of nonspecific signs and symptoms which lead to unnecessary tooth extractions. Moreover, VRFs may extend from the internal part of the root in buccal, lingual, apical, or cervical directions. In these cases, the induced inflammation will lead to bone loss and may create a radiographic view similar to that of periodontal diseases. Therefore, an accurate diagnosis of VRFs prevents the erroneous extraction of treatable teeth (Taramsari et al. 2013; Chang et al. 2016).

The X-rays projected from CBCT units are influenced by different factors such as the voxel size, field of view (FOV), degree of rotation, condition of the tube, and voltage, which can change the image quality, and therefore, should be selected carefully in different diagnostic cases (Jones et al. 2015; Neves et al. 2014; Kamburoğlu et al. 2013). In 2015, Jones et al assessed the range of eleven different CBCT parameters in the diagnosis of HRFs. The effect of these factors on the diagnosis of VRFs is still a matter of debate as the studies on the diagnosis of VRFs with the use of CBCT have focused on the effect of root filling materials (Taramsari et al. 2013; Neves et al. 2014), different image modes such as resolution, zoom, speed, or different voxel sizes (Taramsari et al. 2013; Neves et al. 2014, Uzun et al. 2015; Chang et al. 2016).

Therefore, an information gap is observed among these studies. The present study was performed to assess the effect of different kilovoltage peak (kVp) and milliampere (mA) settings of a CBCT unit on the detection of VRFs in endodontically treated single-canal premolars at the dental branch of Islamic Azad University, Tehran, Iran during 2015-16. The null hypothesis was that the changes in the kVp and mA of CBCT units have no effect on the detection of VRFs.

## MATERIAL AND METHODS

In this in-vitro diagnostic study, 80 extracted single-canal human premolars without any cracks or fractures were selected by using target-based sampling method. The surfaces of the teeth were cleaned of debris and tissue remnants.

*Root canal treatments:* Access cavities were prepared in all the teeth. A #20 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was selected as the initial file. A #35 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was selected as the master apical file (MAF). The root canals were widened to the #60 K-file (Dentsply Maillefer, Ballaigues, Switzerland) via step back technique. All the root canals were obturated by using #35 gutta-percha points (Dia-Dent, Burnaby, BC, Canada) and AH26 endodontic sealer (Dentsply DeTrey, Konstanz, Germany).

*Formation of VRFs in the dental roots:* In the roots of half of the teeth, a VRF was created by exerting a mechanical force by using a dental plugger, while the other half were left intact. For ensuring the presence of fractures, the teeth were stained with methylene blue dye, and then, they were coded. Also, the fracture site was covered with red wax. Afterwards, the teeth were kept in physiologic serum until the experiment.

*Placing the teeth in dental sockets:* The coded teeth were covered with a layer of red wax to compensate for the thickness of the PDL, and then, they were placed in the dental sockets of a dried human mandible. The longitudinal axes of the teeth were positioned perpendicular to the horizon.

*CBCT imaging:* CBCT images were taken of all the teeth by the use of the Rotograph Evo 3D Machine (Villa Sistemi Medicali, Milan, Italy) with four different combinations of maximum (max) and minimum (min) kVp (60-86) and mA (6-10) settings under similar conditions in terms of the distance, resolution, etc.

First group: kVp min(60)/mA min(6) Second group: kVp max(86)/mA min(6)
Third group: kVp min(60)/mA max(10) Fourth group: kVp max(86)/mA max(10)

*Image observation:* The CBCT images were saved and assessed by using the OnDemand3D software program (version 1.0, Cybermed Inc., Seoul, Korea). All the images (a total of 320 images in the four groups) were randomly put in the Viewer file such that the observer was unaware of the order and distribution of the images. The observer was an oral and maxillofacial radiologist experienced in interpreting CBCT images. A dental root was considered vertically fractured when a vertical radiolucent line was detected on both axial and coronal views. The results were entered in a data sheet. After two weeks, the observer reevaluated the images, and the results were registered in separate data sheets.

*Statistical analysis:* The cases of correct diagnoses (true positive (TP) + true negative (TN)), incorrect diagnoses (false positive (FP) + false negative (FN)), and nondiagnostic cases were determined. The data were entered into SPSS version 21 software program (IBM Co., Chicago, IL, USA) and were analyzed according to Chi-square test.

## RESULTS AND DISCUSSION

This study was performed on 80 endodontically treated, single-canal mandibular premolars divided into two groups (40 teeth with and 40 teeth without VRFs), and the images were obtained by using four different combinations of mA min, mA max, kVp min, and kVp max exposure settings.The distribution of the dental specimens according to mA=6 are presented in Table 1 categorized in two columns of the real fractures and the fractures observed on CBCT images. The images of 62 dental samples (38.7%) which had been exposed with mA=6 did not have the required quality for observation and detection of fractures and were excluded from the study. This table shows that the numbers of the correct diagnoses including the positive and negative cases were equal to 72 cases (73.4%), while the numbers of the incorrect diagnoses including the positive and negative cases were equal to 26 cases (26%).

Table 1. Distribution of the evaluated teeth according to the real fractures and the fractures observed on CBCT images (mA=6)

| Real vertical fracture<br>Detection of fracture on CBCT images | No | Yes | Total |
|---|---|---|---|
| No | 46 | 22 | 58 |
| Yes | 4 | 26 | 30 |
| Total | 50 | 48 | 98 |

Table 2. Distribution of the evaluated teeth according to the real fractures and the fractures observed on CBCT images (mA=10)

| Real vertical fracture<br>Detection of fracture on CBCT images | No | Yes | Total |
|---|---|---|---|
| No | 38 | 11 | 49 |
| Yes | 2 | 29 | 31 |
| Total | 40 | 40 | 80 |

The distribution of the dental specimens according to mA=10 are presented in Table 2 categorized in two columns of the real fractures and the fractures observed on CBCT images. Images of 80 dental specimens (50%) which had been exposed with mA=10 were nondiagnostic and were excluded. This table shows that the numbers of the correct diagnoses including the positive and negative cases were equal to 67 cases (83.5%), while the numbers of the incorrect diagnoses were equal to 13 cases (16%).

The distribution of the dental specimens according to kVp=86 are presented in Table 3 categorized in two columns of the real fractures and the fractures observed on CBCT images. Images of 142 dental samples (88.7%) which had been exposed with kVp=86 did not have a suitable quality for the detection of fractures and were excluded. This table shows that the numbers of the correct diagnoses including the positive and negative cases were equal to 18 cases (100%) with no incorrect diagnoses.

The distribution of the dental specimens according to kVp=60 are presented in Table 4 categorized in two columns of the real fractures and the fractures observed on CBCT images. Images of 160 dental specimens (100%) which had been exposed with kVp=60 were nondiagnostic and were excluded. This table shows that the numbers of the correct diagnoses including the positive and negative cases were equal to 129 cases (80.6%), while the numbers of the incorrect diagnoses were equal to 31 cases (19%).

Table 3. Distribution of the evaluated teeth according to the real fractures and the fractures observed on CBCT images (kVp=86)

| Real vertical fracture<br>Detection of fracture on CBCT images | No | Yes | Total |
|---|---|---|---|
| No | 10 | - | 10 |
| Yes | - | 8 | 8 |
| Total | 10 | 8 | 18 |

| Table 4. Distribution of the evaluated teeth according to the real fractures and the fractures observed on CBCT images (kVp=60) | | | |
|---|---|---|---|
| Real vertical fracture<br>Detection of fracture on CBCT images | No | Yes | Total |
| No | 74 | 25 | 99 |
| Yes | 6 | 55 | 61 |
| Total | 80 | 80 | 160 |

The distribution of the samples according to the correct and incorrect diagnoses categorized by the exposure settings is presented in Table 5 which shows that when the kVp max/mA max setting was used, none of the images were diagnostic, and when the kVp max/mA min setting was used, 62 images (77.5%) were nondiagnostic. In terms of the diagnostic ability, these two exposure settings showed significant statistical differences with the other two settings (P<0.001). When the kVp min/mA min setting was used, incorrect diagnoses (FP + FN) were made with regard to 18 images (22.5%), while when the kVp min/mA max setting was used, incorrect diagnoses (FP + FN) were made on 13 images (16.2%); Chi-square test showed no significant differences between these two exposure settings (P<0.4).

The present study showed that in the mA min(6)/kVp min(60) group, the observer was able to make correct diagnoses in 62 cases (77.5%), while in 18 cases (22.5%), the diagnoses were incorrect. In the mA min(6)/kVp max(86) group, the observer was able to make correct diagnoses in 18 cases (22.5%), while no incorrect diagnoses were made in this group, and also, 62 images (77.5%) were nondiagnostic. In the mA max(10)/kVp min(60) group, the observer made correct diagnoses in 67 cases (83.7%), while the diagnoses were incorrect in 13 cases (16.2%). In the mA max(10)/kVp max(86) group, the observer was unable to make a diagnosis with regard to any of the cases, and all the 80 images were nondiagnostic. Therefore, the kVp max/mA max and mA min/kVp max showed significant differences with the other two exposure settings (P<0.001), while the mA max/kVp min and mA min/kVp min exposure settings showed no significant statistical differences according to Chi-square test (P<0.4).

Therefore, it seems that in the diagnosis of VRFs in endodontically treated teeth on CBCT images, the changes in the kVp are more effective than the changes in the mA since the diagnoses have been more realistic with the kVp min/mA max exposure setting.

In 2015, Jones et al evaluated the effect of different exposure parameters of CBCT units on the detection of simulated HRFs. The kVp was set at 90 kV, while the size of the FOV and scan speed were constant, focusing only on the mA changes. Also, two different exposure times were used. The results showed that the highest levels of sensitivity and specificity were calculated when mA max was used. Also, the highest level of positive predictive value (PPV) and negative predictive value (NPV) was achieved in the cited study at mA max with an acceptable significance level. The results of the present study are similar to those of the cited study with regards to the effect of the mA and maintaining the mA max to achieve the best image quality, although, in the above-mentioned study (Jones et al. 2015), the kVp remained fixed. The present study showed that keeping the kVp at the minimum possible level with a fixed mA results in the best image quality.

Pauwels et al (2015) evaluated the improvement in the quality of CBCT images after reducing the mA. The results demonstrated that at low levels of mA and at mA min, the image quality degrades due to increased radiographic noise and the consequent increase in the contrast-to-noise ratio (CNR). Therefore, the cited study is in line with ours in terms of confirming a better image quality when using higher mA settings. In a study by Palomo et al, a reduced kVp and a fixed mA were used to decrease the patient dose. They demonstrated that by

| Table 5. Distribution of the evaluated samples according to the correct and incorrect diagnoses categorized by the studied groups | | | | |
|---|---|---|---|---|
| Definite diagnosis<br>Detection of fracture on CBCT images | TP+TN (%) | FP+FN (%) | Nondiagnostic (%) | Total (%) |
| | | | | |
| mA min/kVp min | 62(77.5) | 18 (22.5) | 0(0) | 80(100) |
| mA min/kVp max | 18(22.5) | 0 (0) | 62(77.5) | 80(100) |
| mA max/kVp min | 67(83.7) | 13(16.2) | 0(0) | 80(100) |
| mA max/kVp max | 0(0) | 0(0) | 80(100) | 80(100) |
| TP+TN=true positive + true negative, FP+FN=false positive + false negative | | | | |

a decrease in the kVp and changing the other exposure parameters, high-quality images can be obtained at a reduced patient dose. Therefore, the results of the mentioned study are in agreement with ours in terms of the use of kVp min settings to reduce the patient dose. Kim et al (2010) compared different exposure settings of different CBCT units and concluded that to achieve the best image quality, the mA can be increased up to 10 times with a constant kVp. It seems that the overall results of the cited study are in agreement with ours.

The results of the study by Neves et al in 2014 on the evaluation of the effect of different CBCT imaging parameters on the diagnosis of HRFs with different obturation materials showed that parameters such as the resolution and obturation materials in endodontic therapy are more important; however, they limitedly investigated the effect of the mA and kVp. Therefore, although their results are not directly comparable to ours, they are indicative of the importance of factors such as the resolution. In our study, the changes in the mA and kVp directly influenced the image resolution.

Although in the diagnosis of root fractures, which is among the most difficult diagnoses in dental imaging, CBCT can be used with the minimum patient radiation dose in comparison with other imaging modalities such as medical CT, by considering the "as low as reasonably achievable" (ALARA) principle, even in such cases, it is attempted to deliver a minimum radiation dose to the patient. In the present study, we adhered to the ALARA principle by minimizing the kVp and maximizing the mA to achieve high-quality images with the best resolution and the minimum patient radiation dose. The in-vitro design of the present study was a limitation since due to the presence of the PDL around natural teeth in vivo, they may show a different behavior than those under laboratory conditions. The positive points of the present study included its novelty, the simultaneous analysis of two exposure parameters, and a large sample size.

Since the X-rays projected from CBCT units are influenced by factors such as the voxel size, FOV, degree of rotation, and tube status, which can influence image quality, future studies to assess the effect of these parameters on the detection of VRFs are recommended for the accurate and definite diagnosis of this type of root fracture.

## CONCLUSION

The results of the present study showed that the best views for the detection of simulated VRFs on CBCT images in axial views are achieved with the mA max/kVp min exposure setting. Also, the patient radiation dose can be reduced by minimizing the kVp.

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