



# Influence of Tube Current Settings on Diagnostic Detection of Root Fractures Using Cone-beam Computed Tomography: An *In Vitro* Study

Ricardo Tangari-Meira, DDS, MSc,\* José Ricardo Vancetto, DDS, MSc,\*  
Livia Nordi Dovigo, DDS, MSc, PhD,<sup>†</sup> and Guilherme Monteiro Tosoni, DDS, MSc, PhD\*

## Abstract

**Introduction:** This study assessed the influence of tube current settings (milliamperes [mA]) on the diagnostic detection of root fractures (RFs) using cone-beam computed tomographic (CBCT) imaging. **Method:** Sixty-eight human anterior and posterior teeth were submitted to root canal preparation, and 34 root canals were filled. The teeth were divided into 2 groups: the control group and the fractured group. RFs were induced using a universal mechanical testing machine; afterward, the teeth were placed in a phantom. Images were acquired using a Scanora 3DX unit (Soredex, Tuusula, Finland) with 5 different mA settings: 4.0, 5.0, 6.3, 8.0, and 10.0. Two examiners (E1 and E2) classified the images according to a 5-point confidence scale. Intra- and interexaminer reproducibility was assessed using the kappa statistic; diagnostic performance was assessed using the area under the receiver operating characteristic curve (AUROC). **Results:** Intra- and interexaminer reproducibility showed substantial ( $\kappa_{E1} = 0.791$  and  $\kappa_{E2} = 0.695$ ) and moderate ( $\kappa_{E1} \times E2 = 0.545$ ) agreement, respectively. AUROC was significantly higher ( $P \leq .0389$ ) at 8.0 and 10.0 mA and showed no statistical difference between the 2 tube current settings. **Conclusions:** Tube current has a significant influence on the diagnostic detection of RFs in CBCT images. Despite the acceptable diagnosis of RFs using 4.0 and 5.0 mA, those settings had lower discrimination abilities when compared with settings of 8.0 and 10.0 mA. (*J Endod* 2017;43:1701–1705)

## Key Words

Cone-beam computed tomographic imaging, diagnostic imaging, root fractures, tube current

Cone-beam computed tomographic (CBCT) imaging shows promise for the diagnosis of root fractures (RFs) because it may allow complete visualization of the fracture lines as well as their location and direction (1–4). Currently, there is not enough evidence to suggest that it is a reliable method of RF detection in endodontically treated teeth (3, 5). CBCT imaging presents some limitations, such as a higher radiation dose than periapical imaging and the production of beam hardening artifacts. The quality of CBCT images and the radiation dose are related to several parameters, including the tube current setting (milliamperes [mA]). Many unit types have “standard” exposure setting parameters based on the patient’s physical size and/or different clinical applications. Proper selection of these parameters is crucial, and they should be individually selected to conduct image acquisition with a lower radiation dose (6–8).

The selection of mA must be made according to the “as low as reasonably achievable” principle (6, 8, 9). Justification, optimization, and dose limitation are 3 basic principles recommended for radiation protection care (10). Moreover, for RF evaluation, it is recommended that the field of view (FOV) size be limited to a single tooth and its adjacent area and that the spatial resolution be increased to a certain limit, which still provides a benefit to the patient (11). Lowering the mA might be a practical strategy for dose optimization; however, it reduces the signal-to-noise ratio and may cause image quality degradation (6).

Currently, the influence of mA on the diagnostic performance of RFs in teeth in all anatomic regions of the maxilla and mandible with the presence of gutta-percha within root canals is still unknown in laboratory studies of CBCT imaging. The bone thickness and presence of multirrooted teeth can significantly interfere with the selection of the appropriate mA. Therefore, the aim of this study was to assess the influence of mA on the diagnostic detection of RFs using CBCT imaging.

## Materials and Methods

### Teeth Preparation

The institutional research ethics committee approved this protocol (protocol #36452814.4.0000.5416). Sixty-eight extracted anterior and posterior human teeth were stored until use in thymol solution (0.1%, pH = 7.0) at 4°C. Teeth were analyzed with a stereoscopic magnifying glass (Carl Zeiss Microscopy GmbH, Göttingen,

### Significance

We show that in CBCT imaging, the mA setting influences the detection of root fractures. Given this influence, the mA should be selected with caution to prevent loss of diagnostic accuracy.

From the Departments of \*Oral Diagnosis and Surgery and <sup>†</sup>Social Dentistry, School of Dentistry, São Paulo State University (Unesp), Araraquara, São Paulo, Brazil. Address requests for reprints to Dr Ricardo Tangari-Meira, Department of Oral Diagnosis and Surgery, Araraquara Dental School, São Paulo State University, Humaitá Street 1680, Araraquara, SP 14801-903, Brazil. E-mail address: [tangarimeira@gmail.com](mailto:tangarimeira@gmail.com)  
0099-2399/\$ - see front matter

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Germany) at a magnification of  $10\times$  to ensure the absence of fractures and root resorption. The teeth used in this study were from both the maxilla and the mandible.

Coronal access was performed with 1014, 3080, and 3082 diamond burs (KG Sorensen, Cotia, SP, Brazil). Root canals were prepared using an Mtwo nickel-titanium rotary system (VDW, Munich, Germany) and irrigated with 1% sodium hypochlorite. The entire root canal length was instrumented with a basic sequence of files (10/.04, 15/.05, 20/.06, and 25/.06) and a sequence of wide canals (30/.05, 35/.04, 40/.04, and 25/.07). Then, 34 teeth were filled with Mtwo 25–40 (VDW) gutta-percha points and Endofill sealer (Dentsply Maillefer, Ballaigues, Switzerland).

### Fracture Induction

After simple randomization, RFs were induced in 34 teeth (17 anterior and 17 posterior) using an EMIC DL2000 universal electromechanical testing machine (EMIC, São José dos Pinhais, PR, Brazil). Anterior teeth were horizontally positioned on the device; a beveled metal tip was used on the tooth root with a continuous and controlled force of 500 N at a speed of 1 mm/min until RFs with or without displacement fragments were obtained (Fig. 1A). Posterior teeth were subjected to a similar protocol (Fig. 1B) but were vertically fixed on the device and a conical metal tip was placed within the root canal (12). The fragments were reattached using cyanoacrylate (Loctite Super Bonder; Henkel Ltda, São Paulo, Brazil). A stereoscopic magnifying glass at a magnification of  $10\times$  was used to confirm the cracks and RFs with nondisplacing fragments. Subsequently, the teeth were divided into 2 groups ( $n = 34$ ), a control group and a fractured group, as detailed in Table 1.

### Phantom Preparation

A dry skull from an adult human was used as a phantom. Two mandibles were alternately articulated to the skull to maximize alveolar processes from the superior and inferior arches. According to the anatomic region to be scanned, the tooth was removed from the arch and replaced by another tooth from the control or fractured group. To simulate X-ray beam attenuation through the soft tissues, the maxilla and mandible were coated with 2 layers of utility wax (Lysanda, São Paulo, Brazil), and the skull with the articulated mandible was placed into a plastic container (68.5 cm diameter  $\times$  16.0 cm high, 0.35-mm thick) filled with water (13) (Fig. 2A and B).

### CBCT Setting

The images were acquired using a Scanora 3DX CBCT unit (Soredex, Tuusula, Finland) according to the following exposure and

acquisition parameters: 90 kV, 6 seconds of exposure time, and FOV of  $50 \times 50$  mm in the high-resolution mode (0.1-mm voxel). Each tooth was maintained in the same position and was subjected to 5 different acquisitions using different mA (4.0, 5.0, 6.3, 8.0, and 10.0), resulting in a total of 340 imaging volumes (Fig. 3). These volumes were stored in a CBCT database and used in this study as needed.

The phantom was positioned with a support device, and the tooth was centered in the FOV according to the region that would be scanned. The values of dose area product were recorded for each acquisition. The CBCT unit gave the values of 195, 244, 307, 390, and  $488 \mu\text{Gy} \times \text{cm}^2$  for 4.0, 5.0, 6.3, 8.0, and 10.0 mA, respectively.

### Evaluation of Root Fracture

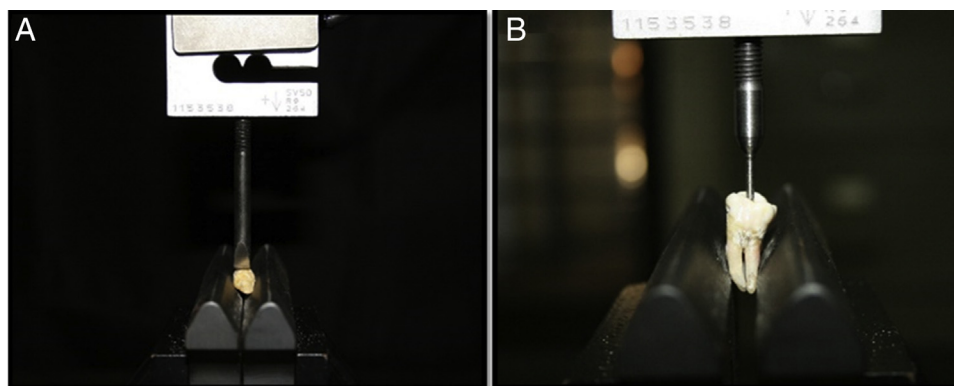
After a training period, statistical calibration was investigated among 3 oral and maxillofacial radiologists with at least 3 years of experience in CBCT scanning. The examiners (E1, E2, and E3) were blinded to specimen identification and independently performed the diagnoses.

The training was divided into 3 sessions. In each session, the principal investigator selected 8 volumes from the CBCT database. These images were randomized and distributed to each examiner, who evaluated the image for the presence or absence of RFs according to a 5-point confidence scale as follows: 0, definitely absent; 1, probably absent; 2, not sure; 3, probably present; and 4, definitely present. Between each session, doubts about image interpretation and software manipulation were discussed.

Subsequently, the calibration investigation used 20 imaging volumes that were randomly selected from the CBCT database and analyzed in duplicate by the 3 examiners, with a 15-day interval. Then, 270 additional imaging volumes were randomly selected from the CBCT database and distributed to 2 examiners. All images were interpreted in a quiet environment with dimmed light using OnDemand3D software (OnDemandDApp 1.0.9.2225; Cybermed, Inc, South Korea), a central processing unit (Dell Intel Xeon E52609, 2.40 GHz; Dell, Round Rock, TX), and a 24-inch LCD monitor (Dell U2410, 1920  $\times$  1200 resolution, 64 bits). The examiners evaluated all plans of multiplanar reconstructions corresponding to the tooth from the amelocemental junction in the coronal-apical, buccolingual (or palatal), and mesiodistal directions. Free use of “zoom,” “brightness,” and “contrast” tools was allowed.

### Statistical Analysis

Statistical calibration among examiners was evaluated with intra- and interexaminer reproducibility using kappa ( $\kappa$ ) statistics with linear weighting (14, 15). The degree of agreement was classified according to



**Figure 1.** Root fracture induction in (A) anterior and (B) posterior teeth.

**TABLE 1.** Teeth Distribution and Frequency according to Group

Teeth	Control group		Fractured group		Total
	Non–root filled	Root filled	Non–root filled	Root filled	
Central incisor	3	3	3	3	12
Lateral incisor	3	3	3	3	12
Canine	2	3	3	2	10
Premolar	5	4	4	5	18
Molar	4	4	4	4	16
Total	17	17	17	17	68

Landis and Koch (16). Comparison of the area under the receiver operating characteristic curves (AUROCs) was performed to evaluate the accuracy of each mA according to DeLong et al (17). A *P* value <.05 was considered significant.

### Results

Values for intraexaminer reproducibility were  $\kappa E1 = 0.791$ ,  $\kappa E2 = 0.695$ , and  $\kappa E3 = 0.437$  for E1, E2, and E3, respectively. Based on the low intraexaminer agreement, E3 was excluded from the study. Interexaminer reproducibility was  $\kappa E1 \times E2 = 0.545$ .

Table 2 shows the frequency of the correct and incorrect diagnoses of RFs according to mA. Correct diagnoses were more frequent than incorrect diagnoses regardless of the mA setting. Settings of 8.0 and 10.0 mA had lower frequencies of misdiagnosis.

AUROC classification (18) for 4.0, 5.0, and 6.3 mA showed excellent discrimination ability for the diagnosis of RFs, whereas 8.0 and 10.0 mA presented outstanding discrimination ability. A statistical comparison showed that 8.0 and 10.0 mA resulted in higher AUROCs ( $P \leq .0389$ ) compared with 4.0 and 5.0 mA (Table 3), suggesting better diagnostic ability.

### Discussion

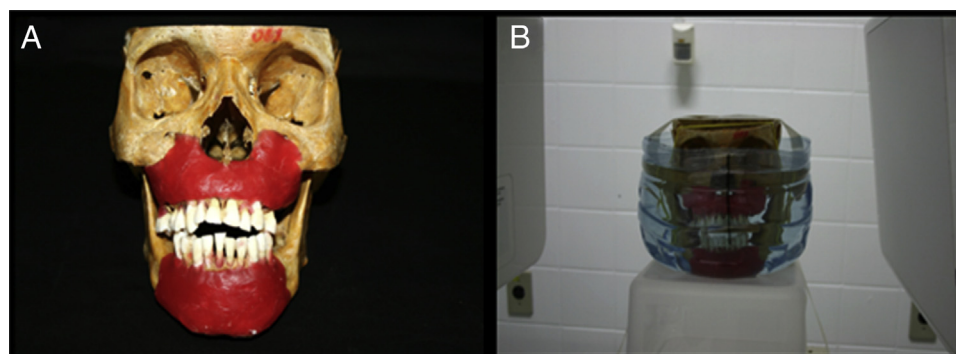
Our reproducibility data showed intraexaminer agreements classified as substantial for E1 and E2 and interexaminer agreement ( $E1 \times E2$ ) classified as moderate, which are considered suitable for RF studies (7, 13, 19). There is a gap in the literature regarding the ideal number of examiners for this type of investigation. RF studies have used 3, 5, or more examiners (7, 12, 19, 20). Higher numbers do not necessarily indicate increased data reliability because such studies have shown interexaminer agreement lower than or similar to this study. Other studies with 2 examiners have shown higher (21) and lower agreement (22). In fact, it is possible that increasing the number of observers in a study decreases the chance to obtain high reproducibility among them. As a result, errors are maximized, and

the data are less reliable, which can seriously affect the statistical analysis and interpretation of the results. Regarding the reproducibility of results, our images were acquired using fixed parameters of kV, sizes of FOV, and voxel; a heterogeneous sample of anterior and posterior teeth from both the maxilla and the mandible; and both horizontal and vertical types of fractures. It can be assumed that these findings had a minimum bias from the examiners and the parameters and that the differences were actually caused by mA variation.

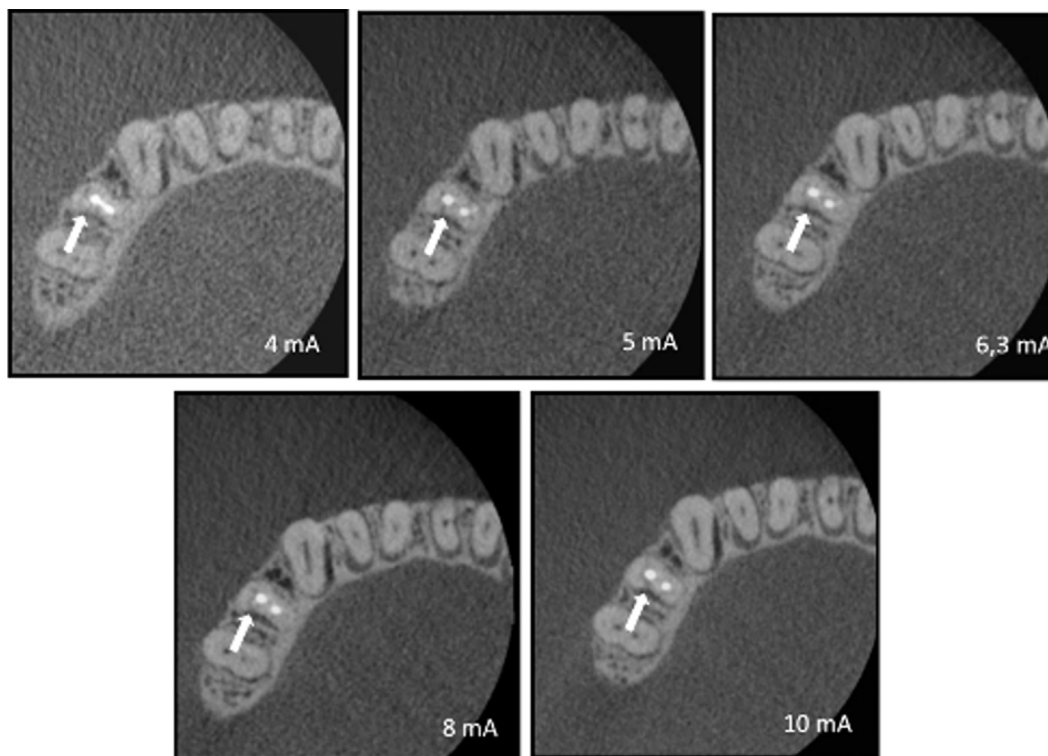
The best method to simulate the X-ray beam through the soft tissues using CBCT imaging has not been fully established. According to Pauwels et al (7), an inappropriate choice of a phantom inhibits image quality standardization. Some studies regarding RF diagnosis using CBCT imaging have only used a maxilla coated with wax (1, 23) or a mandible immersed in water inside a plastic container (22, 24). The patient biotype (physical constitution), the bone density of different anatomic structures, and an improper selection of mA can increase image noise and, eventually, hamper the diagnosis. After a pilot study, a dry adult human skull with large physical features was chosen. This skull was coated with 2 layers of wax and placed in a plastic container full of water; the conditions were considered similar to soft tissues in studies that used phantoms (25). Thus, the physical characteristics of the phantom permitted the reproduction of a more realistic clinical situation of X-ray beam attenuation in which different mA could interfere with image quality.

RFs were induced using an electromechanical testing machine that allowed a controlled force to be applied to the root. Thus, complex experimental specimens with cracks and RFs were obtained. Some *in vitro* studies have induced RFs by applying manual mechanical strength with a hammer, chisel, screwdriver, or circular blade (2, 21, 24, 26). However, Patel et al (12) reported that it was not possible to consistently induce incomplete fractures (<150  $\mu\text{m}$ ) using these techniques and that the fractures would be much larger (>200  $\mu\text{m}$ ) and easily detected.

Despite our specimens consisting of uni- and multiradicular root-filled and non–root-filled teeth showing different fracture patterns, the



**Figure 2.** Phantom preparation (A) coated with wax and then (B) immersed in a container of water.



**Figure 3.** CBCT axial reconstructions using different mA settings showing root fracture (arrows).

correct diagnosis was more frequently found than the incorrect one regardless of the mA used. In addition, it was observed that an increase in mA caused a decrease in error frequency. Thus, it can be inferred that mA influence the diagnostic performance of fractures because if mA increase, then the signal-to-noise ratio increases, producing low-noise images with higher diagnostic quality.

Previous studies reported good diagnostic quality with low mA, providing a significant reduction in radiation dose (8, 27, 28). According to Dawood et al (29), Vasconcelos et al (30), and Pauwels et al (7), mA can be significantly reduced and still be useful in some clinical conditions even if there is low image quality, such as dental implant planning. However, because of the degree of difficulty in RF diagnosis, fine-detail evaluation is necessary, and a low-noise image is recommended.

This study shows that it is possible to decrease the mA to a certain limit without a significant loss of diagnostic ability, even using a phantom with the features of a large adult. Thus, we must consider that physically smaller individuals, such as children (31), can benefit from the safer use of an even lower mA, which would allow the examination of this vulnerable group with less exposure to ionizing radiation.

**TABLE 2.** Frequencies of Correct and Incorrect Diagnoses of Root Fracture Using Cone-beam Computed Tomographic Imaging with Different Tube Current Settings (mA)

mA	Fracture diagnosis		Total
	Correct	Incorrect	
4.0	41	15	56
5.0	49	13	62
6.3	46	11	57
8.0	51	4	55
10.0	54	6	60
Total	241	49	290

AUROC analysis showed good diagnostic ability for all mA tested; however, the performance was higher with 8.0 and 10.0 mA because 6.3 mA was similar to 4.0 and 5.0 mA. Given that mA selection should be guided by the “as low as reasonably achievable” principle, 8.0 mA (Table 3) is the most recommended for RF diagnosis in adults, considering our experimental conditions. However, Jones et al (2) reported exceptional AUROC values for all mA tested. These results can be explained by the study methodology, such as the use of a homogeneous sample for X-ray beam attenuation, the use of only single-rooted teeth with or without horizontal fractures and without the presence of gutta-percha, and teeth being placed in a single anatomic region of a dry mandible.

Beam hardening artifacts caused by gutta-percha may influence the diagnostic ability. Patel et al (12) and Neves et al (13) evaluated RFs in teeth with gutta-percha and found relatively low AUROC values. However, similar to Edlund et al (32), our study also has shown higher diagnostic ability. This discrepancy among these results can be related to the lower mA used by Patel et al (12) and Neves et al (13) of 3.0 and 5.0 mA, respectively. However, Chang et al (3) reported that it is not possible to draw definitive conclusions about the diagnostic ability of

**TABLE 3.** Values Obtained for the Areas under the Receiver Operating Characteristic Curves (AUROCs) and the Respective Standard Error (SE) according to the Milliampere (mA) Setting Used

mA	AUROC <sub>s</sub>	SE
4.0	0.801 <sup>a</sup>	0.059
5.0	0.810 <sup>a</sup>	0.059
6.3	0.830 <sup>ab</sup>	0.054
8.0	0.934 <sup>b</sup>	0.034
10.0	0.914 <sup>b</sup>	0.038

Different letters indicate a significant difference ( $P \leq .0389$ ) according to DeLong et al (17) based on a comparison of the areas.



RFs in teeth with gutta-percha because those studies have shown a high risk of bias.

This *in vitro* study presents some limitations. Although careful criteria were used to reproduce a real clinical situation, the absence of clinical signs such as pain, edema, dental crown mobility associated with radiographic findings, widening of the periodontal ligament space, apical/lateral bone rarefaction to the root, and angular bone loss can significantly influence the diagnostic quality favoring the lower mA. Another limitation concerns the exposure parameters for each CBCT unit; the parameters used in this study are specific to the Scanora 3DX, and, therefore, the results cannot be extrapolated to other units. In conclusion, tube current has a significant influence on the diagnostic detection of RFs in CBCT images. Despite the acceptable diagnosis of RFs achieved with 4.0 and 5.0 mA, those settings had lower discrimination abilities compared with the settings of 8.0 and 10.0 mA.

## Acknowledgments

*The authors deny any conflicts of interest related to this study.*

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