Determination of Root Canal Length Up to Perforation Area Using Different Electronic Apex Locators and CBCT Images Obtained at Different Voxel Sizes: A Comparative Ex Vivo Study

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Objective: *To compare the accuracy of electronic apex locators in the presence of blood and CBCT images obtained with two different voxel sizes (0.125 mm and 0.25 mm) in determining root canal length up to the perforation area.*

Methods: *Forty extracted, single-rooted human teeth were selected and an artificial root perforation (0.4 ± 0.1 or 1.0 ± 0.2 mm diameter) was created in the middle third of the root. The actual root canal length up to the perforation area was determined under a stereomicroscope. CBCT images were obtained with a voxel size of 0.125 mm and 0.25 mm. The root canal length up to the perforation area was measured on CBCT images and recorded as the radiographic length. The teeth were embedded in alginate and root canal length up to the perforation area was measured using two different EALs (DentaPort ZX [Morita, Tokyo, Japan] and Gold Reciproc motor [VDW, Munich, Germany]) and recorded as the electronic length.*

Results: *In teeth with an artificial root perforation 0.4 mm in diameter, the measurements obtained with DentaPort ZX were more accurate than with the Gold Reciproc motor (P < 0.05), and on CBCT images, more accurate measurements were obtained with a voxel size of 0.125 mm compared to 0.25 mm (P < 0.05). In teeth with an artificial root perforation 1.0 mm in diameter, the radiographic length was closer to actual length than the electronic length (P < 0.05).*

Conclusion: *In artificial root perforations with a diameter of 0.4 mm, CBCT gives more reliable results than EALs. Both EAL and CBCT measurements were closer to actual length in artificial perforations that were 1.0 mm in diameter.*

Key words: *apex locator, CBCT, root perforation, voxel size*

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Root perforations are defined as a pathological pathway between the root canal and the periodontal tissues and may occur due to different aetiological factors including bacterial stimulation, trauma, caries and procedural errors (post-placement or removal, during endodontic preparation, etc.)[1-3]. During endodontic treatment, root perforation occurs in 2% to 12% of cases and teeth with root perforation have been reported to show slower healing than teeth without root perforation[3]. However, early detection of the location of the perforation and closure of the perforation area with a biocompatible material have been reported to increase the success rate of the treatment[4].

In endodontic treatment, radiographs are frequently used in the evaluation of teeth with root canal perforation[5-7]. Two-dimensional radiography has certain disadvantages, such as distortion, magnification and superimposition[7]. This causes limitations in determining the location of the perforations and makes their detection in the buccal and lingual areas difficult because the image of the perforation area is superposed over the root surface[7]. These limitations in two-dimensional radiography may make it difficult to choose the right procedures for the diagnosis and treatment of perforations. Recently, CBCT imaging has been used in diagnosis

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and treatment planning in endodontics in cases where two-dimensional radiography is insufficient[8]. The main advantage of CBCT is that it allows for 3D imaging and thus overcomes the limitations of two-dimensional radiography in detecting root perforations[9].

In CBCT, the voxel is defined as the smallest, distinctive box-shaped part of the 3D image. The voxel size affects the quality of the CBCT image, scanning and reconstruction time. In CBCT imaging, voxels are isotropic and images can be created in any plane with high accuracy[5]. Previous studies have evaluated the efficacy of CBCT in detecting root perforations and its ability to detect small perforation has been reported to be high[7,10,11]. However, no studies have evaluated the efficacy of CBCT images obtained with different voxel sizes in determining the length of the canal up to the root perforation.

Electronic apex locators (EALs) are effective because they offer advantages such as elimination of radiation exposure, ease of use and immediate results in the determination of root perforations in endodontic treatment[12]. DentaPort ZX (Morita, Tokyo, Japan) is an EAL that obtains data by measuring impedance at two frequencies, 0.4 and 8 kHz[13]. The Gold Reciproc motor (GRM) (VDW, Munich, Germany) is an endodontic engine with an integrated EAL. The latter can be used both during preparation and separately[14].

Both EALs and CBCT are used to determine the location of perforations by clinicians in endodontics. Many studies in the literature have compared the efficacy of different EALs and different CBCT parameters in determining the location of perforations[7,10,12,13]. In the present literature review, however, no study compared the effectiveness of CBCT and EALs in determining root canal length up to the root perforation.

The aim of this study was to compare the efficacy of CBCT images obtained with two different voxel sizes and two different EALs in determining the canal length up to the artificial root perforation (ARP). The null hypothesis was that there would be no difference between the EALs and CBCT measurements when determining the length of the canal up to the ARP.

Materials and methods

The study design was approved by a local ethics committee. Based on a previous study[4], a power calculation was performed using G*Power software (version 3.1, Heinrich Heine University, Dusseldorf, Germany).

Sample selection and preparation

Maxillary central teeth with 40 straight root canals were included in the study. For each tooth, periapical radiography was performed in buccolingual and mesiodistal directions and the root canal anatomy was evaluated. Teeth with incomplete root canal development, root canal calcification, root resorption and root fracture were excluded from the study. To obtain a stable and clear reference plane during the measurements, the crowns of the teeth were removed by using a diamond disc (Diatech, Charleston, SC, USA) under water cooling, and a flat reference plane was formed. Under a stereomicroscope at 20× magnification, the working length was determined to be 1 mm shorter than the apical foramen using a size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland). Canals were prepared using a size 15 K-file (Dentsply Maillefer). Following preparation, the canals were irrigated with 2 ml 5.25% NaOCl (CanalPro; Coltène-Whaledent, Allstätten, Switzerland) followed by 2 ml distilled water, and dried with paper points (Dia-Dent Group, Chongju, Korea). The teeth were randomly divided into two groups (N = 40) and ARPs of two different sizes, 0.4 mm diameter and 1.0 mm diameter, were created. For ARPs with a diameter of 0.4 mm (n = 20), the teeth were placed in a vice. ARPs with a diameter of 0.4 ± 0.1 mm were formed on the buccal surface of the roots at a distance of 5 mm from the apex using a drill (Magafor, Fontenay-sous-Bois, France) with a diameter of 0.4 mm at a 90-degree angle. For ARPs with a diameter of 1.0 mm (n = 20), the teeth were again placed in a vice and ARPs with a diameter of 1.0 ± 0.2 mm were formed on the buccal surface of the roots at a distance of 5 mm from the apex using size 010 round diamond burs (Komet, Lemgo, Germany) at a 90-degree angle. The diameter of the perforation areas was verified by measuring with an electronic caliper (Mitutoyo, Aurora, IL, USA).

Prior to the electronic and radiographic measurement, the root canal length up to the perforation area was determined using a size 20 K-file (Dentsply Maillefer) at 20× magnification under a stereomicroscope and recorded as actual length (AL).

Imaging

For the imaging procedures, each tooth was placed in the empty sockets of the right and left central incisors in a properly prepared dry maxilla. The dry maxilla was covered with a double layer of wax to simulate the soft tissue and was placed in a box filled with water[5]. CBCT images of the teeth were obtained using the i-CAT CBCT system

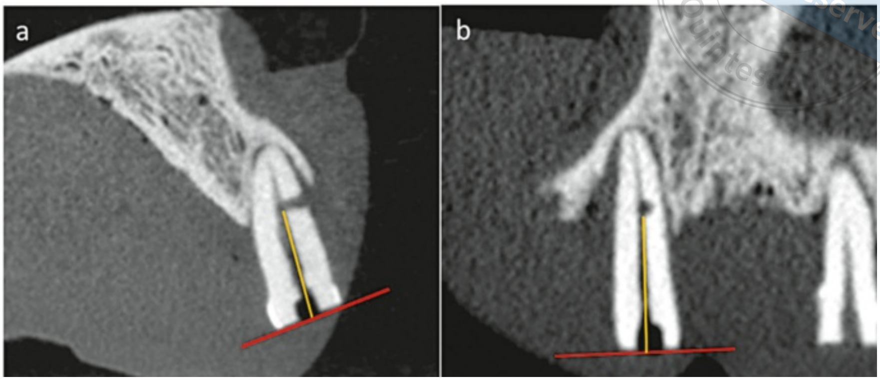

Fig 1 RL measurement of maxillary anterior teeth **(a)** on the vestibuloral section and **(b)** on the mesiodistal section. The red line shows the reference plane (passing through the most incisal edge of the teeth). The yellow lines show the measurements between the reference plane and the initial point of the ARP.

(Imaging Sciences International, Hatfield, PA, USA) with flat panel detector and by using the same field of view (FOV), 40 × 40 mm. Images were obtained at two different voxel sizes: 0.125 mm (120 kVp at 37.07 mAs with an exposure time of 26.9 seconds) and 0.25 mm (120 kVp at 37.07 mAs with an exposure time of 26.9 seconds).

Data collection

All CBCT measurements were performed independently by two observers. The images were evaluated at 2-day intervals and all images were re-evaluated after 1 month and intra-observer reliability showed a high correlation (correlation coefficient; 0.998 for observer 1 and 0.935 for observer 2). After the measurements were completed, inter-observer accuracy was calculated and a high correlation was found (correlation coefficient; 0.998) and the mean of the two observers' measurements were used for statistical evaluation.

i-CAT vision Q imaging software (Imaging Sciences International) was used for CBCT assessments. The CBCT sections were first reconstructed to be able to see the pulp chamber, reference plane, ARP and the entire length of the canal of the tooth analysed in a vertical position. This procedure was repeated for all teeth included to obtain the vestibuloral and mesiodistal section of the respective teeth[15]. On the vestibuloral and mesiodistal sections, the radiographic length (RL) was measured as the distance between the reference plane and the initial point of the ARP on the adjacent side of the pulp channel surface (Fig 1). The mean length measured in the vestibuloral and mesiodistal sections was obtained and recorded as RL[16]. No manipulation was performed on the image except for the image reconstruction procedure and saturation/contrast adjustments.

Electronic measurements

To mimic the resistance of the periodontal tissues, the teeth were embedded in alginate (Blueprint Xcreme, Dentsply Sirona, Charlotte, NC, USA) and the lip clip was contacted with the alginate[4].

The blood samples required for the study (20 ml) were provided by the authors and stored in ethylenediamine tetraacetic acid (EDTA) anticoagulant–containing tubes (K2EDTA blood tube, BD Vacutainer, Franklin Lakes, NJ, USA) to prevent coagulation before and during the procedure[17]. To mimic perforation-induced bleeding, the root canals were irrigated with 0.5 ml blood just before electronic measurements were taken. A size 20 K-file was used for the measurements, and when the EALs signalled an exit from the apex, the stopper of the file was fixed; this was recorded as electronic length (EL). The measurement was repeated three times for each tooth and the mean was taken. After the EAL measurements were completed, each sample was irrigated with 5 ml NaOCl, EDTA and distilled water to remove the remaining blood. All measurements were taken by the same operator experienced in the use of EALs. The difference was calculated by subtracting EL and RL from AL. The negative values were longer and the positive values were shorter than AL. The value of 0 indicates that EL and RL are equal to AL.

Statistical analysis

All statistical analyses were performed using SPSS for Windows (version 16.0, SPSS, Chicago, IL, USA). A Friedman and Wilcoxon signed-rank test were used to analyse the data. The level of significance was set at $P < 0.05$.

Table 1 Difference between EL/RL and AL (mean ± SD) for each EAL and each CBCT parameter (mm). Different superscript lowercase letters in the same row indicate a statistically significant difference (P < 0.05); different superscript uppercase letters in the same column indicate a statistically significant difference (P < 0.05).

	DentaPort ZX	GRM	0.125 mm	0.25 mm
ARP with 0.4 mm diameter	-0.54 ± 0.87^{Aacd}	-1.05 ± 1.01^{Ab}	0.19 ± 1.89^{Aac}	0.22 ± 1.89^{Aad}
ARP with 1.0 mm diameter	-0.28 ± 0.64^{Ba}	-0.49 ± 0.82^{Ba}	0.14 ± 0.41^{Ab}	0.21 ± 0.61^{Ab}

Results

In ARPs with a diameter of 0.4 mm, compared to the GRM, DentaPort ZX measurements were closer to the AL, and so too were the measurements obtained with a voxel size of 0.125 mm compared to 0.25 mm (P < 0.05). There was no significant difference between the measurements obtained with 0.125 mm and 0.25 mm voxel size and those obtained with DentaPort ZX (P > 0.05). Measurements obtained with the GRM compared to the other measurements were longer than AL (P < 0.05) (Table 1).

In ARPs with a diameter of 1.0 mm, there was no significant difference between GRM and DentaPort ZX measurements (P > 0.05). There was also no significant difference between 0.25 mm and 0.125 mm voxel size measurements (P > 0.05). The measurements obtained with both voxel sizes were more accurate compared to EAL measurements (P < 0.05).

Both EAL devices gave more accurate measurements for ARPs with a diameter of 0.4 mm than for those with a diameter of 1.0 mm (P < 0.05). There were no significant differences between the measurements obtained with the two voxel sizes for both diameters of ARP (P > 0.05). In addition, for both ARP diameters, the EAL measurements were longer than AL, whereas the CBCT measurements were shorter than AL.

Discussion

In endodontic treatment, knowledge of the position of the perforation is important to manage the treatment of the affected teeth. Debris formed during preparation in the teeth with root perforation and the solutions used during irrigation are likely to cause extrusion to and irritation of the surrounding tissues[16]. As such, determining the location of the perforation is important to reduce the risk of complications and improve the treatment prognosis. Periapical radiographs may be insufficient to determine the location and size of the perforation. For this reason, although the ionising radiation dose is higher, CBCT is frequently used as an additional imaging method[18].

In the literature, it has been reported that it is more difficult to detect root perforations in the middle third compared to the apical and cervical third, and in the buccal/lingual surface compared to the mesial and distal surface of the root[7]. In the light of this information, ARPs were formed in the present study in the middle third and buccal surface of the root, and to mimic the soft tissue in the CBCT measurements, the maxilla was covered with wax to eliminate errors that could be caused by the imaging procedure[5,19]. The maxilla was used instead of a full head, and artefacts caused by the contralateral structures were prevented. One limitation of CBCT is that the root canal and resorption zone cannot be observed on the same plane in teeth with a curved root canal. To eliminate this limitation, only maxillary anterior teeth with single and straight roots were included in the study. By performing these procedures, measurement errors that could be caused by the imaging method or observer were prevented.

The measurement mechanism of EAL devices depends on the different electrical resistance of the periodontal tissues and pulp[20]. EALs can thus detect the position of perforations when they reach the periodontal tissues. As in previous studies, the roots in the present study were embedded in alginate to simulate periodontal tissues. In this way, a blind experiment environment was created by preventing the practitioner from seeing the end of the file[4,21]. When the perforation reaches the periodontal tissues, there is a high probability that bleeding will occur during endodontic procedures. In addition, a study showed that the presence of blood may affect some variables in the measurement of electronic working length[20]. For this reason, measurements were performed in the presence of blood in the canal to mimic the clinical situation.

In the literature, there are several studies evaluating the effect of different voxel sizes in CBCT on the detection of ARPs. Liedke et al[22] reported that a voxel size of 0.20 mm and 0.30 mm is more reliable than 0.40 mm in the detection of different-sized ARPs (0.6, 1.2 or 1.8 mm in diameter and 0.3, 0.6 or 0.9 mm in depth). Venskutonis et al[23] stated that a voxel resolution of 0.20 mm was more reliable in detecting

ARPs (0.2, 0.3 and 0.4 mm in size) compared to voxel sizes of 0.25 mm, 0.30 mm and 0.40 mm. Dalili et al[24] reported that in the detection of external root resorption (0.25 mm depth and 0.5 mm diameter), the diagnostic value of the images obtained with small voxel sizes (0.125–0.150 mm) was higher than with larger sizes (0.200–0.240 mm). Consistent with these studies, the measurements obtained in the present study with 0.125 mm voxel size were closer to AL in ARPs with a diameter of 0.4 mm, but there was no difference between the two voxel measurements in ARPs with a diameter of 1.0 mm.

In the present study, no differences were found between the measurements obtained with the two voxel sizes in either ARP diameter. In contrast to this result, previous studies reported that it is easier to locate the perforation using CBCT when the perforation diameter is larger[25,26]. However, the discrepancy between these results may be due to differences in the diameter and location of the perforation, the CBCT device and operator experience.

When considering the studies comparing different EALs, Kaufman et al[27] reported no significant difference between EALs (Root ZX [Morita], Sono-Explorer Mark II Junior [Hayashi Dental Supply, Tokyo, Japan] and Apit III [Osada, Los Angeles, CA, USA) when detecting ARPs (0.25–0.60 mm). Likewise, D'Assunção et al[1] reported no significant difference between EALs (Root ZX II [Morita], Mini Apex Locator [SybronEndo, Anaheim, CA, USA] and Root SW [Dental Technology, Hunan, China]) when detecting ARPs with a 1-mm diameter. They also found no difference between the EALs in ARPs with a diameter of 1.0 mm in terms of determining canal length up to the ARP; however, DentaPort ZX was found to be a more successful device in teeth with an ARP 0.4 mm in diameter[1]. Similarly, Altunbaş et al[4] reported that DentaPort ZX (Morita, Kyoto, Japan) was more accurate than Rootor (Meta Biomed, Cheongwon-gun, South Korea) in detecting AL in ARPs. The contrasting results for the EALs in these studies may be due to working principles and technological differences.

In the literature, some studies compared the accuracy of EALs and CBCT in determining working length or root canal length, but no studies compare the two systems in determining canal length up to the root perforation. In detecting working length, Üstün et al[28] found no significant difference between the accuracy of two different EALs (Propex Pixi [Dentsply Sirona] and Raypex 6 [VDW]) and CBCT. Similarly, other studies reported no significant difference between the measurements obtained with Root ZX and CBCT when detecting working length[8,29,30]. In accordance with these studies, the present study found no difference between the measurements obtained with CBCT and DentaPort ZX in ARPs with a diameter of 0.4 mm. In contrast, Lucena et al[31] reported that the measurements taken using Raypex 6 were more reliable than CBCT measurements. Similarly, Yılmaz et al[5] stated that Root ZX is more reliable than CBCT. In contrast to these results, the present study found that CBCT was more successful than EALs in ARPs with a diameter of 1.0 mm. These different results may be due to factors such as tooth selection, perforation size, irrigant content, study design, CBCT parameters and EAL.

In previous studies, CBCT measurements were reported to be shorter in the range of 0.40–1.66 mm from the AL, and the digital caliper and EAL measurements were used as the gold standard[5,29-31]. Similarly, in the present study, the measurements obtained in a range of 0.14–0.22 mm were shorter with CBCT images compared to AL, and the gold standard was measurements on a stereo microscope. Numerical differences between studies can be attributed to observer performance, use of different CBCT systems, CBCT parameters and different gold standards.

The main limitation of this study is that it was performed using teeth with single and straight root canals. Although the radiation dose and cost of CBCT screening seem to be a disadvantage compared to EALs that are comfortable and fast to use, EALs do not provide information about the curvature and direction of the root canals. Different results could be obtained in studies carried out on a large sample with curved root canals and with a different perforation size[32].

Conclusion

The accuracy of both EALs was affected by the size of the perforation, but CBCT measurements were not. DentaPort ZX and CBCT were found to be more reliable in determining root canal length up to the perforation area in ARPs with a diameter of 0.4 mm. However, CBCT was found to be more reliable in determining root canal length up to the perforation area in ARP with a diameter of 1.0 mm. Considering the ionising radiation dose of CBCT, both CBCT and EAL can be used in clinical practice, taking into account the margin of error in teeth with root perforations.

Conflicts of interest

The authors declare no conflicts of interest related to this study.

Author contribution

Dr Zeliha UĞUR AYDIN designed the work, acquired and analysed the apec locator data and prepared the manuscript; Dr Duygu GÖLLER BULUT acquired and analysed the radiological data.

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