▶ ORIGINAL ARTICLE ◀

Sensitivity and specificity of cone-beam computed tomography and micro-computed tomography in the detection of calcified root canals

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Abstract

Objective: To evaluate the sensitivity and the specificity of cone-beam computed tomography (CBCT) and micro-computed tomography (micro-CT) in detection of calcified canals indiscernible in digital periapical radiographs (PA) compared to tooth-sectioning method, and to identify the sizes of calcified canals that could not be detected in CBCT and micro-CT.

Methods: Forty-eight roots with calcified canals indiscernible in PA were included. The roots were placed in a jaw model and scanned using a CBCT scanner (3D Accuitomo 170). The roots were removed from the model and re-scanned using a micro-CT scanner (SkyScan 1773). A presence of root canal along the root length was identified from either CBCT or micro-CT images in every 1-mm root slice. Each root was serially sectioned in 1 mm thick and examined under a stereomicroscope to confirm the presence of root canal at each level, which was compared to the results of CBCT and micro-CT. The sensitivity and the specificity of CBCT and micro-CT in detection of calcified canals were calculated (%). The sizes of root canals were measured and compared between micro-CT images and sectioned specimens. The average size of root canals only detected in the sectioned roots (but undetected in CBCT and/or micro-CT images) were reported.

Results: From 48 roots with 207 root slices, the sensitivity and the specificity in detection of calcified canals were 33.2% and 100% for CBCT, and 81.9% and 85.7% for micro-CT. The canal sizes in micro-CT images and the sectioned specimens were not significantly different ($p \geq .05$). The average sizes of canals undetected in the tomography were 0.071±0.041 mm for CBCT and 0.030±0.022 mm for micro-CT.

Conclusion: CBCT showed low sensitivity and high specificity to detect calcified canals, in which the canals larger than 0.07 mm could be identified. Micro-CT showed high sensitivity and high specificity to detect calcified canals that were larger than 0.03 mm. The canal sizes in micro-CT images and sectioned specimens were not different.

Keywords: calcified root canal, cone-beam computed tomography, micro-computed tomography, periapical radiograph, tooth sectioning

How to cite: Sirinimitpol C, Banomyong D, Yanpiset K. Sensitivity and specificity of cone-beam computed tomography and micro-computed tomography in the detection of calcified root canals. Thai Endod J 2022; 2: 94-102.

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Received: 7 September 2022 Revised: 25 November 2022 Accepted: 28 November 2022

Introduction

Success in endodontic treatment requires an understanding of root canal morphology, which is fundamental for the cleaning, shaping, and obturation of root canals. Periapical radiography (PA) is a two-dimensional radiographic method widely used for evaluating root canal morphology. However, the disadvantages of PA are the superimposition of anatomical structures and the image distortion (1). The root canals aligned in the buccolingual plane, complex root canal systems, or calcified root canals may not be identified in PA. Root canal calcification is a result of continuous apposition of secondary and tertiary dentin on root canal walls as well as diffuse mineralization in pulp tissues (2). The negotiation of calcified canals has a risk of complications by removing too much root dentin during locating the canals (2).

Cone-beam computed tomography (CBCT) is an advanced radiographic method to achieve a three-dimensional (3D) volume of a scanned object (3). The 3D volume is composed of multiple isotropic voxels that create 3D images into the axial, sagittal, and coronal planes (4). CBCT images are serially examined slice by slice depending on the set-up thickness (e.g. 1 mm interval). CBCT is superior to PA in the ability to eliminate the superimposition of anatomical structures. For instance, a calcified canal, which may be undetected in PA, is more likely to be revealed in CBCT (4, 5).

However, the resolution of CBCT is occasionally not high enough to reveal minute calcified canals even with the settings of the small voxel size (e.g. 0.125 mm) and the small field of view (FOV) (e.g. 4x4 or 6x6 cm) (6). When the canal radiolucency is not detected in PA and CBCT, a dental practitioner should try to locate the canal with an aid of a magnification such as using a dental operating microscope (DOM) in combination with the removal of calcified dentin around the canal orifice. In an *ex vivo* study, the ability of CBCT to detect second mesiobuccal canals (MB2) in maxillary molars was superior to DOM (7). Nevertheless, in that study, the calcified dentin around the orifice was not removed, the sizes of canals varied, and the observers were inexperienced undergraduates. Hence, the ability of CBCT to identify the minute calcified canals is a concern and still controversial. Theoretically, the canal is likely to be identified in CBCT if the size of the canal is not smaller than the voxel size (e.g. 0.125 mm). However, the actual size of the calcified canals possible to detect in CBCT has not been previously confirmed.

Recently, micro-computed tomography (micro-CT) becomes a fascinating tool in endodontic laboratory research (8). Micro-CT uses the principle of scanning objects similar to CBCT but provides a higher resolution (9). The 3D micro-CT images are created from the multiple voxels ranging from 8-50 µm, and the resolution depends on the scanning area or the size of the object (10). For instance, micro-CT scanning reconstructs high-resolution 3D images of root canal system morphology. Micro-CT is likely to be superior to CBCT in the detection of small calcified canals (11, 12). However, a limitation of micro-CT is the impossibility of use for *in vivo* or clinical studies. In addition, the canal size that could be detected in micro-CT has not been previously reported.

Other identification methods of calcified root canals are tooth-sectioning and tooth-clearing techniques. For example, in the tooth-sectioning method, the root is serially sectioned and examined under a high-magnification stereomicroscope to confirm the existence, size, and characteristic (partially or completely calcified) of the canals. This method has been formerly used in studying root canal morphology as a reference standard. Nevertheless, the sectioning technique has a limitation from sample destruction and two-dimensional evaluation (13, 14).

The purposes of this study were to evaluate the sensitivity and the specificity of CBCT (3D Accuitomo 170, J. Morita, Kyoto, Japan) and micro-CT (SkyScan 1173, SkyScan, Leuven, Belgium) in detection of calcified canals indiscernible in digital periapical radiographs (PA) compared to tooth-sectioning method, and to identify the sizes of calcified canals that could not be detected in CBCT and micro-CT.

Materials and methods

The study protocol was approved by the institutional ethic committee (MU-DT/PY-IRB 2016). A total of 300 extracted human anterior and posterior teeth were radiographed at 7 mA and 70 kV setting using a digital periapical radiography unit (Veraview iX, J.Morita, Osaka, Japan; and Digora™ Optime imaging plate scanner, Soredex, Finland) in the buccolingual and mesiodistal directions to find out any calcified canals that were indiscernible in the radiographs. A total of 33 teeth with the indiscernible 48 root canals were included and stored in 0.1% thymol solution at room temperature.

For CBCT scanning, each tooth was embedded into a segment of a pig maxilla to simulate a clinical situation, in which the six separated 'sockets' were created by drilling the jaw with a cylindrical carbide bur. The teeth were seated in the housing sockets and embedded in the alveolar bone up to the cementoenamel junction (CEJ) using dental pink wax. After the scanning, the teeth were removed, and a new set of teeth was replaced in the sockets.

The jaw model with the embedded teeth was placed on the platform for CBCT scanning. The 3D Accuitomo 170 CBCT scanner was operated by a radiologist. The parameters were set at 5 mA, 90 kV, exposure time 17.5 s, voxel size 0.125 mm, and FOV 60x60 mm. The CBCT images were analyzed using the i-Dixel One Volume Viewer 1.5.0 on a liquid crystal display (LCD) monitor with a resolution of 1920x1080 pixels (Sony® Bravia KDL- 40EX720, Sony Corp., Tokyo, Japan). The CBCT images were evaluated for detection of the calcified canal(s) from the axial (cross-sectional) images at every 1 mm interval; the presence or absence of root canals was recorded.

For micro-CT analysis, each tooth was removed from the housing socket after CBCT scanning and then re-scanned using a micro-CT scanner SkyScan 1173 at the highest resolution of 8 µm with the settings at 80 kV, 72 mA, and 1-mm aluminum filter. The 3D images of the roots were reconstructed using the NRecon software and examined on the monitor; the presence or absence of root canals was identified from the axial images at every 1 mm interval.

To confirm the existence of the calcified root canal, the tooth was serially sectioned, from the CEJ to the root apex with a 1 mm interval of sectioning distance, using a micro-blade (Accutom-50, Struers A/S, Ballerup, Denmark). The sectioned roots were examined under a stereomicroscope (Olympus, Tokyo, Japan) at 40x magnification and photographed using a digital camera (NIKON D60, Nikon, Tokyo, Japan).

The numbers of detected/undetected canals in CBCT, micro-CT, and the sectioning methods were recorded, which the existence of calcified canals indiscernible in PA was confirmed. In comparison to the calcified canals detected in the sectioned specimens (as a reference standard), the sensitivity and specificity of CBCT and micro-CT in the identification of calcified canals were calculated (%).

From all root slices, the sizes of root canals were measured (in mm) by NRecon software for micro-CT or Image J software for the sectioning method (**Fig.1**). The canal sizes were statistically compared between the two methods. Furthermore, the sizes of calcified canals undetected in CBCT or micro-CT, which were identified in the sectioning method, were calculated into the averages.

Statistical analysis

The sensitivity and the specificity of CBCT and micro-CT in the identification of the calcified canals compared to the sectioning method (as a reference standard) were calculated using the formula:

(1) Sensitivity of CBCT

$$\frac{\text{N canals detected in sectioning}}{\text{N canals detected in sectioning + N canals unidentified in CBCT}}$$

(2) Sensitivity of micro-CT

$$\frac{\text{N canals detected in sectioning}}{\text{N canals detected in sectioning + N canals unidentified micro-CT}}$$

(3) Specificity of CBCT

$$\frac{\text{N canals undetected in sectioning}}{\text{N canals undetected in sectioning + N canals identified in CBCT}}$$

(4) Specificity of micro-CT

$$\frac{\text{N canals undetected in sectioning}}{\text{N canals undetected in sectioning + N canals identified in micro-CT}}$$

The sizes of root canals in micro-CT images and sectioned specimens were plotted into a graph and compared using the paired T-test with a p-value <.05 as a significant level. In addition, the sizes of calcified canals undetected in CBCT or micro-CT were calculated into means and standard deviations.

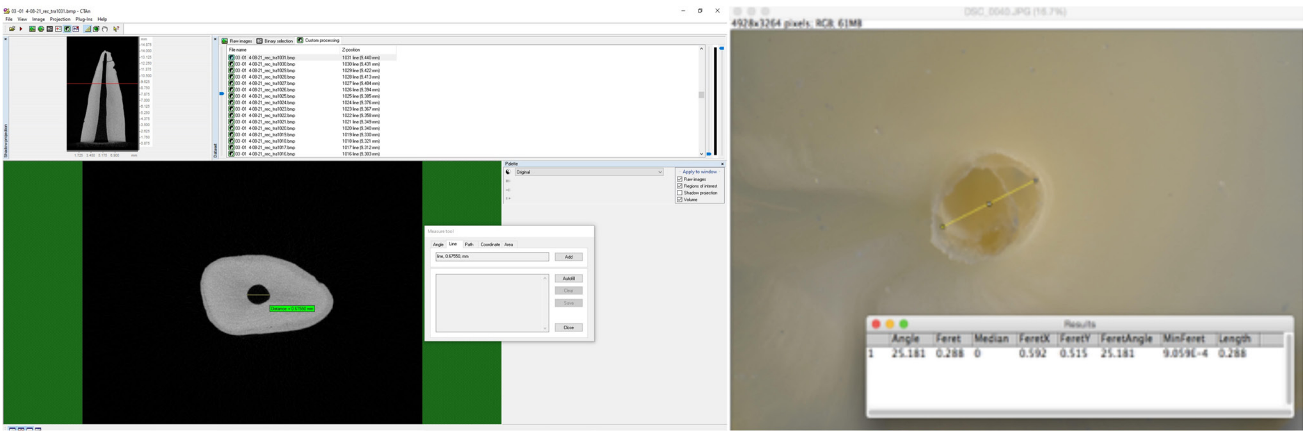

Figure 1 At 1-mm interval, the size of root canal was measured (in mm) from a micro-CT image using NRecon software (*left*) or from a sectioned specimen using Image J software (*right*).

Results

A total of 48 root canals in 33 teeth with 207 root slices were examined in this study. The number (%) of the calcified canals that were detected and undetected in CBCT and micro-CT in comparison to the sectioning method are presented in **Tables 1-2**. CBCT and micro-CT showed the sensitivity to detect the calcified canals at 33.2% and 81.9% and the specificity at 100% and 85.7% respectively.

The sizes of calcified root canals measured from micro-CT images and sectioned specimens ranged from 0 (completely calcified canal) to 0.45 mm; the majority of data was distributed between 0.05–0.2 mm (**Fig.2**). No significant difference in root canal sizes was observed between the micro-CT and the root sectioning method ($p \geq .05$).

Table 1 Number (%) of the calcified canals that were detected and undetected in CBCT in comparison to the sectioning method from 207 root slices.

Number of calcified canals in 207 root slices– N (%)		Sectioning method	
		Undetected	Detected
CBCT	Undetected	14 (100%)	129 (66.8%)
	Detected	0 (0%)	64 (33.2%)

Table 2 Number (%) of the calcified canals that were detected and undetected in micro-CT in comparison to the sectioning method from 207 root slices.

Number of calcified canals in 207 root slices– N (%)		Sectioning method	
		Undetected	*Detected*
Micro-CT	Undetected	12 (85.7%)	35 (18.1%)
	Detected	2 (14.3%)	158 (81.9%)

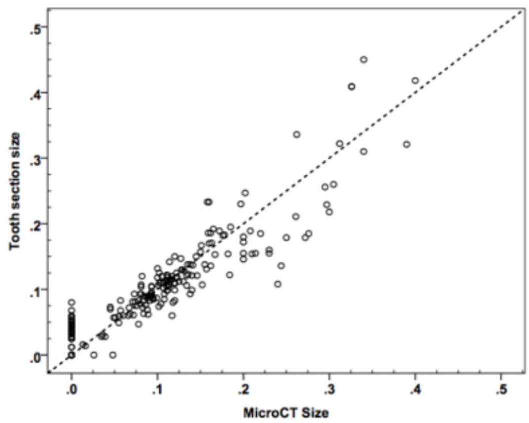

Figure 2 A plot graph presents the sizes of calcified canals (in mm) measured from the micro-CT images and the sectioned specimens (0 mm = a completely calcified canal). No significant difference in the canal sizes was observed between the two groups ($p \geq .05$).

Compared to the sectioned specimens, the calcified canals undetected in CBCT or micro-CT had average sizes of 0.071±0.041 mm for CBCT, and 0.030±0.022 mm for micro-CT. The representative images that show the superiority of micro-CT in the detection of the canals compared to CBCT are presented in **Figures 3-4**.

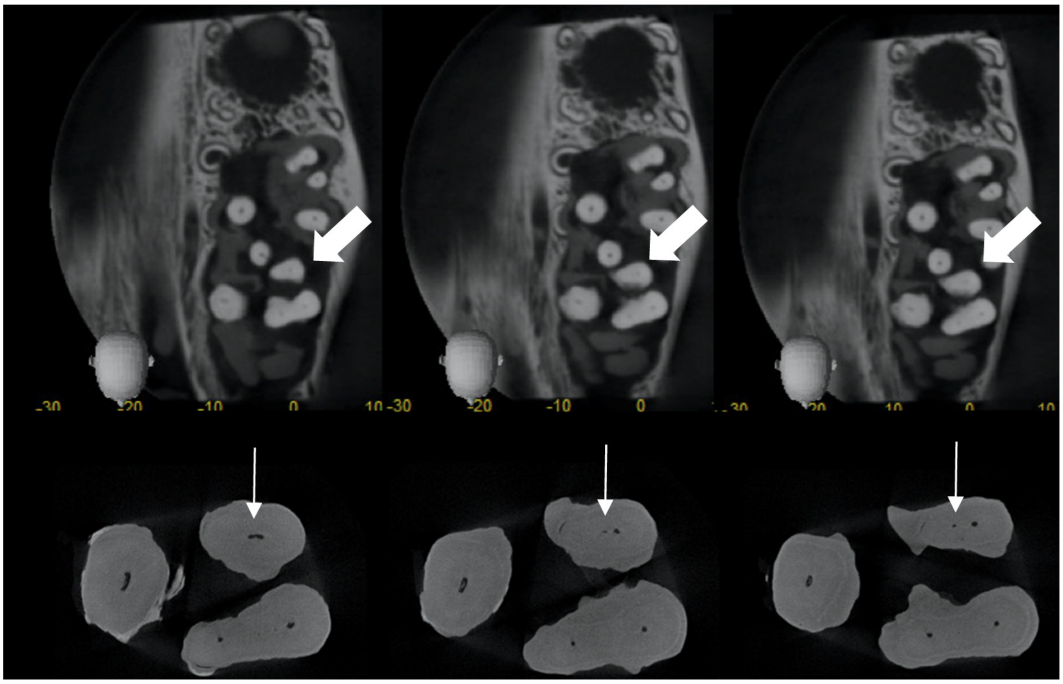

Figure 3 CBCT images show a single canal in the distobuccal root of maxillary molar (upper row) while two distobuccal canals was detected in in micro-CT images (lower row).

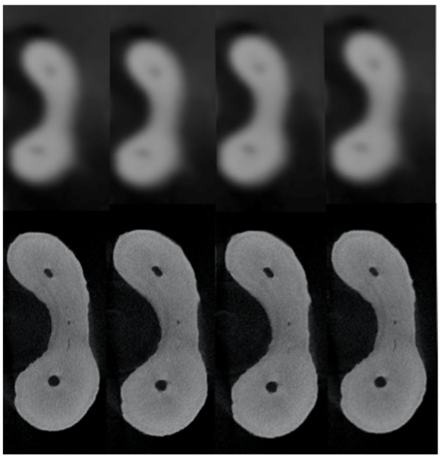

Figure 4 CBCT images at four cross-sectional levels show mesiobuccal and mesiolingual canals in the mesial root of mandibular molar (upper row) while a tiny middle mesial canal was additionally detected in micro-CT images (lower row).

Discussion

Detection a calcified root canal in a periapical radiograph is difficult by the superimposition from root dentin and bony structures. In this study, periapical radiographs were used for screening the calcified canals, which the root canals with radiopacity (absence of canal radiolucency) were included. CBCT is useful in the detection of small canals such as the second mesiobuccal (MB2) canals in maxillary molars with 96% sensitivity and 100% specificity as effective as a reference standard– the sectioning method (7, 13). However, the sensitivity of CBCT in detecting very small calcified canals markedly decreased to approximately 33% in our study although the specificity was perfect (100%). The lower sensitivity in detection the calcified canals in our study compared to the study in detection of the MB2 canals may be explained by the difference in canal sizes (calcified or not calcified). The MB2 canals were not calcified in those study and, therefore, mostly detected in CBCT. Hence, an endodontist should be aware and keep attention to locating and exploring the calcified canal even though it is not noticed in the CBCT. None of the canals detected in the CBCT image does not always mean that the canal is completely calcified.

The limitation of CBCT in the detection of very small canals can be simply explained by the voxel size of CBCT, which was already set as low as 0.125 mm (in a 6x6 mm small field of view) in this study. The root canals are likely to be indiscernible in the CBCT images if their sizes are smaller than the voxel size. Hence, the CBCT parameters must be selected to achieve a resolution as high as possible to identify very small or calcified canals (6, 15, 16). For example, the sensitivity of CBCT in detecting the mesiobuccal canals in maxillary molars has increased from 60.1% at 0.4 mm voxel size to 93.3% at 0.125 mm voxel size (6). In our study, the teeth were embedded in a jaw model before CBCT to simulate clinical situation, which the presence of surrounding bone may reduce the effectiveness in detection of calcified canals compared to the micro-CT method without the jaw model.

From our results, the size of root canals detected in CBCT should not be smaller than 0.07 (±0.04) mm in approximate, which was slightly smaller than the voxel size (0.125 mm). It can be assumed that the calcified canals were identified in the CBCT image even though the size of the canals was marginally smaller than the voxel size. However, we have noticed that the accuracy of canal identification was less than usual because of the blurred canal images, which the spatial resolution of CBCT has decreased when two objects with similar density (i.e. opposite root canal walls) are nearby (17, 18).

Micro-CT with a sensitivity of approximately 82% could detect the small calcified canals much better than CBCT. The canal sizes measured from micro-CT were accurately compared to the values directly measured from the sectioned specimens. Micro-CT scanning provides a better identification and detail of the calcified root canals because of using a higher exposure time (approximately 40 min) and lower voxel size (8 μm or 0.008 mm) compared to CBCT (exposure time 17.5 sec and voxel size 0.125 mm). Hence, micro-CT provides very high-resolution images with details of very small canals. However, micro-CT has limitations in detecting a calcified canal smaller than 0.03 (±0.02) mm.

Most importantly, this method cannot be used clinically. By the way, our results have confirmed that using micro-CT in studying root canal morphology *in vitro* is non-destructive and reliable method compared to the tooth sectioning.

Conclusion

Within the limitations of this study, CBCT showed low sensitivity but high specificity to detect calcified canals with an average size of approximately 0.07 mm or larger. Micro-CT showed high sensitivity and specificity to detect calcified canals with an average size of approximately 0.03 mm or larger. The canal sizes measured from micro-CT images were accurate as same as the sectioning method.

Acknowledgment

N/A

Funding

Residency Training Research Fund (Faculty of Dentistry, Mahidol University)

Conflict of interest

None

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