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Ex vivo detection of mesiobuccal canals in maxillary molars using CBCT at four different isotropic voxel dimensions

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Abstract

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Aim To study observers' ability to detect mesiobuccal (MB) canals in maxillary molars using iCAT cone-beam computed tomography (CBCT) at different voxel dimensions and to assess the impact of clinical experience on accuracy of detection.

Methodology Using 12 experimental models with two molars each, CBCT scans were acquired at four different voxel dimensions. From the cross-section view of these scans, 96 videos were generated. Five endodontic postgraduate students and two endodontic staff watched the videos and counted the MB canals in each root. Horizontal sections of the roots were evaluated under magnification to determine the true canal numbers. The detection of MB canals within the four resolutions was compared by odds ratio, and the weighted χ^2 test compared detection accuracy to raters' clinical experience. Rater agreement was measured by kappa statistics.

Results Overall, 92% of the maxillary molars had two MB canals upon analysis of horizontal cross-sections. The CBCT detection increased from 60.1% at 0.4 mm voxel size to 93.3% at 0.125 mm voxel size. Significant differences ($P < 0.01$) were observed between the different resolutions except for the 0.2 and the 0.125 voxel scans. Second-year trainees were significantly (CI = 0.2929–0.712) more accurate than first-year trainees and endodontic staff at MB canal detection (87.9% against 77.1% and 76.8%). Intra-rater reliability increased with higher-resolution scans (41.1% to 96.4%).

Conclusions The reliability of detection of maxillary molar MB2 canals in CBCT scans increased as the resolution improved. Accuracy of MB2 canal detection among observer groups could not be correlated with the observers' level of clinical experience.

Keywords: cone-beam computed tomography, mesiobuccal canal detection, resolution.

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Introduction

Many studies have reported the presence of two canals in the mesiobuccal (MB) root of the maxillary first and second molars. The occurrence of second MB canals (MB2) has been reported as high as 95%, depending on the method of detection (Weine *et al.* 1969, Seidberg *et al.* 1973, Gilles & Reader 1990). Kulild & Peters (1990) found the MB2 in the coronal half of 95.2% of the roots studied. Fogel *et al.* (1994) used surgical telescopes, headlamps and modified access preparations to clinically aid in the detection of MB2 and found that 71.2% of the roots had two treatable canals.

Several studies have addressed the importance of finding and treating the MB2 canal for the overall long-term success of root canal treatment (Wolcott *et al.* 2002, 2005, Cantatore *et al.* 2009). Wolcott *et al.* (2002) compared the incidence of MB2 canals in initial root canal treatment and retreatment cases. They found that the incidence of the MB2 canal in initial

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treatment was 59% whilst the retreatment incidence was 67%. Wolcott *et al.* (2002) indicated, 'the significant difference in the incidence of the MB2 canal between initial treatments and retreatments suggests that failure to find and treat existing MB2 canals will decrease the long-term prognosis'.

Even with improvements in film quality and the advent of digital receptors, the two-dimensional planar projection of intraoral receptors is most likely the limiting factor in detecting MB2 canals in maxillary first molars. Cone-beam computed tomography (CBCT) has been introduced to help clinicians to visualize images in the third dimension (Cotton *et al.* 2007) and has been used to assess root canal anatomy. Matherne *et al.* (2008) used evaluation of CBCT images by an oral radiologist as a 'gold standard' and compared the ability to detect root canal systems between a charged-couple device and photostimulable phosphor plates. Huumonen *et al.* (2006) evaluated 39 root filled maxillary molars with suspected apical periodontitis using two intraoral periapical radiographs with Kodak Insight (Eastman Kodak, Rochester, NY, USA) film and an axial CT. The MB root had two canals in 30 teeth of which 27 had an MB2 canal that was not filled. Additionally, the reliability of CBCT to detect the MB2 canal in maxillary molars has been further demonstrated when compared to the gold standard of visual inspection through physically sectioning the tooth (Blattner *et al.* 2010).

Despite the benefits and improvements in CBCT, which allow for decreased radiation with increased visualization, CBCT is still a source of ionizing radiation to the patient and therefore poses a risk as it is important to keep patient radiation to a minimum (Farman 2005). The benefit of the increased knowledge gained from a three-dimensional view must outweigh the potential risk to the patient. Patel (2009) indicated, 'CBCT should only be considered in situations where information from conventional imaging systems does not yield an adequate amount of information to allow appropriate management of the endodontic problem'. They also indicated that evidence-based selection criteria for the use of CBCT in dentistry and endodontics need to be established. Whilst Wolcott *et al.* (2002) indicated that CBCT may be used to evaluate root canal anatomy, there are no evidence-based criteria indicating scan parameters that are optimal for viewing small anatomical features, such as the MB2 canal. There are also no criteria for the use of CBCT as a laboratory standard. Matherne *et al.* (2008) used 0.4-mm voxel CBCT scans as their 'ground truth' to compare root canal systems detected by different 2D modalities. However, there is no evidence that the 0.4-mm voxel scan is as accurate as the traditional method of sectioning the roots.

The purpose of this study was to compare the detection of canals in the MB root of maxillary molar teeth using iCAT CBCT cross-sectional dynamic images (videos) at different acquisition parameters. The effect of clinical experience on detection of MB canals was also evaluated by comparing different groups of examiners: endodontic teaching staff, second-year endodontic specialty trainees and first-year endodontic trainees.

Material and methods

This observational cross-sectional *ex vivo* experiment was approved by an expedited review procedure through the Institutional Review Board (IRB) Human Studies Committee of the University of Louisville for a specimen study involving previously extracted human maxillary molars.

The test samples consisted of 24 extracted human maxillary molars with closed apices acquired from the University of Louisville Oral and Maxillo-facial Surgery department. The teeth were stored in 10% formalin for at least 7 days for disinfection (Dominici *et al.* 2001). Molars with carious lesions extending onto the root surfaces or with open apices were excluded. The teeth were removed from the storage medium and allowed to air dry for 24 h. A visual inspection for cracks was then made prior to any scans.

Twelve models were prepared with two teeth in each model embedded in modelling compound (Activ-Clay; Activa Products Inc., Marshall, TX, USA) for a support medium. The models and crowns were numbered with a black permanent marker for identification.

All CBCT scans were performed on an iCAT™ Classic (Imaging Sciences International, Hatfield, PA, USA). The device was operated at 3–8 mA (pulse mode) and 120 kV using a high-frequency generator with fixed anode and 0.5-mm nominal focal spot size. Because only the cross-sections of the roots were used, there was no concern with amalgam scatter in the crowns. This also allowed the imaging of 12 models to occur simultaneously reducing the total number of scans. The teeth were lined up on an iCAT platform that could attach in place of the chin mount. A small circular level was used to ensure that the platform was level at the time of image acquisition. The laser guide on the machine allowed the crowns of the extracted teeth to be placed just below the horizontal beam whilst the

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vertical beam was placed between the two rows of models. The scan used the mandibular mode on the CBCT instead of the maxillary mode because the maxillary teeth were placed upside down with the modelling clay/roots down.

An initial scout film was performed on each specimen to verify that the entire tooth was in the scan region. All specimens were then scanned at one of the following pre-set protocols incorporating various fields of view (FOV in centimetres), total number of basis images (time in s) and resolution (isotropic voxel dimensions in mm): (i) mandibular 6 cm (height) × 17.0 cm (diameter) FOV, 20 s (306 basis images), 0.4 mm voxel; (ii) mandibular 6 cm (height) × 17.0 cm (diameter) FOV, 20 s (306 basis images), 0.3 mm voxel; (iii) mandibular 6 cm (height) × 17.0 cm (diameter) FOV, 40 s (612 basis images), 0.20 mm voxel and (iv) mandibular 6 cm (height) × 8 cm (diameter) FOV, 40 s (612 basis images), 0.125 mm voxel.

Primary reconstruction of the data was performed automatically immediately after acquisition. Secondary reconstruction occurred in 'real time' and provided contiguous colour-correlated perpendicular axial, coronal and sagittal 2D multi-planar reformatted slices, with isotropic voxels in each orthogonal plane. The scans were reconstructed using an image acquisition software (XoranCat version 1.7.7; Xoran Technologies, Ann Arbor, MI, USA).

A preliminary set of scans was made using six different isotropic voxel dimensions. The scans were viewed with different filters and analysed by an oral radiologist to determine the best parameters to visualize the MB2. After evaluation, it was determined that four isotropic voxel dimension scans should be used with the super-sharpen-mild filter.

The cross-sections were presented to raters as a video rather than as a contiguous strip of static images. These videos were made using a screen capture video software (Snag-it; TechSmith Co., Okemos, MI, USA). The images were captured on the acquisition computer (Clientpro 585; MPC, Los Angeles, CA, USA) and monitor (EZIO flexscan L085; Hakusan, Ishikawa, Japan).

Each tooth at each resolution was placed with the cross-section in the cervical region of the tooth at the floor of the pulp chamber at 100% magnification. Using the Snag-it software and the mouse-driven cursor, a box was drawn around each tooth. Recording was initiated, and then, using the scroll wheel on the mouse, the cross-section was scanned to the apex of each tooth. The scans were standardized by timing the scans. Each scan took from 12 to 20 s depending on the length of the tooth roots. The resolution had to be adjusted on the Snag-it video software to allow the videos to have the same resolution as that viewed on the screen.

Twenty-four teeth were scanned at four different resolutions resulting in 96 video segments. Eight videos from each resolution were randomly repeated to determine intra-rater variability (24 teeth × 4 resolutions = 96 videos + 32 repeat videos = 128 videos). The digital videos were saved in the *.avi format to a portable hard drive (Western Digital, Lake Forest, CA, USA).

A random sequence of numbers was generated using the website http://www.random.org to determine the repeat videos from each set of models. A second random sequence was generated for 128 numbers (1–128) to determine the order of the video segments in the final video. The individual video files were combined into a single video file – avi format – using a movie software (Sony Vegas; Sony Creative Software, Madison, WI, USA). The final video displayed instructions to the viewers followed by the video segments with numbers displayed prior to each video.

Five endodontic postgraduate students (three first-year trainees and two second-year trainees) and two endodontic staff members were asked to view the video and independently assess the number of MB canals. The raters were given written instructions as well as verbal instructions at the beginning of the video. Observation conditions were standardized with each individual watching the video on the same computer terminal in a room with the lights dimmed (Dell Optiplex GX 745 with a Dell Plug and Play 19″ monitor; Dell Computers, Round Rock, TX, USA). Videos were played on a media player software (Windows Media Player; Microsoft, Redmond, WA, USA) set to full screen against a black background to better display the images. Raters were allowed to pause the video and repeat the previous segment, and no time constraints were placed on the raters' viewing session. Upon viewing, the raters were asked to rate the presence or absence of MB2 canals using a two-point confidence scale: (i) one canal detected and (ii) two or more canals detected. Each rater studied the 128 videos resulting in 128 ratings per observer. Thus, 896 ratings (128 ratings × 7 observers) were obtained.

After completion of the observations, each tooth was removed from the model and soaked in 5.25% sodium hypochlorite solution for a minimum of 24 h. The tooth roots were cleaned with a brush and scaling instrument. After 24-h dry time, the teeth were placed

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in labelled plastic cups filled with ortho-resin (Dentsply International, York, PA, USA). After 24 h, the excess resin was removed using a polishing lathe (Baldor Electric Co., St Louis, MO, USA) and a grinding disc. The molar crown was secured in the mounting apparatus of a low-speed diamond saw (Isomet; Buehler Ltd, Lake Buff, IL, USA), and the MB root was horizontally sectioned in 2-mm increments. Four to five sections were made depending on the root length. The resin sections were separated with a carborundum disc attached to the lathe. The sectioning of each tooth was initiated from the apex and proceeded coronally until the furcation was reached.

The resin wafers with the roots embedded were stained with methylene blue to highlight the canal space. Each root section was also viewed under a surgical operating microscope (Global Surgical Co., St Louis, MO, USA) to determine the presence of one or two canals. Photographs were taken through the microscope using a digital camera (Coolpix 950; Nikon, Tokyo, Japan). Two endodontic students blinded to tooth identity carefully examined the sections to determine the number of canals present. If two canals were detected at any root level, then the tooth was considered to have two or more canals.

Odds ratio with 95% CI limits was used to compare the accuracy of detection of MB2 canals within the four resolutions. Agreement between the raters' choice and the ground truth for the four resolutions was calculated with a kappa value. The three groups of raters were compared in rater accuracy with the weighted chi-square test. The *a priori* level of significance was set at $P \leq 0.05$. Odds ratio with 95% CI limits was also applied to compare the three groups of raters to each other. Inter-rater reliability was compared using kappa values.

Intra-rater reliability was calculated using the following definitions to help compare the difference in the ratings between the original and repeat images: (i) Consistent and Correct – observer rated correct MB2 numbers in the original and the repeat videos. (ii) Consistent and Incorrect – observer rated incorrect MB2 numbers in the original and the repeat videos. (iii) Inconsistent and Correct – observer rated incorrect MB2 numbers in the original video but correct numbers in the repeat video. (iv) Inconsistent and Incorrect – observer rated correct MB2 numbers in the original video but incorrect numbers in the repeat video. Intra-rater reliability was computed using the percentage of consistent and correct responses for each rater. The mean total per cent of disagreement for all raters was also calculated.

Results

Twenty-two of the 24 maxillary molars (92%) had two MB canals upon analysis of the 2-mm horizontal cross-sections of the MB root.

Correct identification of the number of MB canals on the videos of CBCT images was 60.3% at 0.4 mm voxel, 77.7% at 0.3 mm voxel, 88.8% at 0.2 mm voxel and 93.3% at 0.125 mm voxel (Table 1). The raters were able to correctly detect the number of MB canals with increasing percentage as the resolution increased. There was a significant difference ($P < 0.01$) for accuracy amongst the tested resolutions except the two highest ones (0.2 mm voxel and 0.125 mm voxel) (Table 1). The kappa values for agreement between the raters' choice and the true number of canals also increased correspondingly from 0.129 at 0.4 mm voxel to 0.657 at 0.125 mm voxel (Table 1).

The percentages of overall correct responses grouped by rater experience ranged from 68.8% to 88.3% (Table 2). Second-year students were significantly more accurate than the first-year students (CI = 0.2929–0.712) and endodontic staff (CI = 0.2861–0.7397) at MB canal detection in CBCT cross-sections, with detection rates at 87.9%, 77.1% and 76.8%, respectively (Fig. 1). There was no difference detected

Table 1 Mean percentage of raters' correct detection of mesiobuccal (MB) canals for each tested resolution and coefficient of agreement (kappa) between raters' choice and ground truth

Resolution (voxel size in mm)	Correct MB canals determination (%)	Kappa coefficient
0.4	60.3[a]	0.129
0.3	77.7[b]	0.351
0.2	88.8[c]	0.357
0.125	93.3[c]	0.657

Values followed by different superscript letters differ statistically by odds ratio with 95% CI limits

Table 2 Rater accuracy according to experience level

Rater	Experience	Correct responses (%)
1	2nd-year postgraduate student	88.3
2	2nd-year postgraduate student	87.5
3	1st-year postgraduate student	68.8
4	1st-year postgraduate student	73.4
5	1st-year postgraduate student	88.3
6	Teaching staff	76.6
7	Teaching staff	77.3

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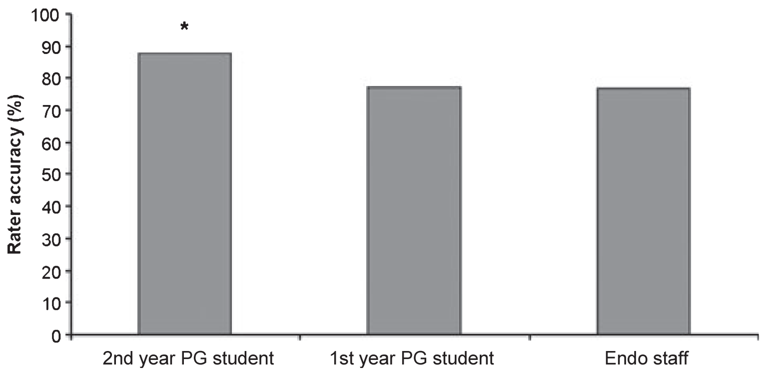

Figure 1 Rater accuracy according to clinical experience. The bar marked with (*) represent a statistically significant difference in accuracy when compared to other groups of raters (weighted χ^2 test = 13.882, odds ratio at 95% CI limits).

Table 3 Inter-rater agreement measured by percentage and kappa coefficient for each resolution tested

Resolution (voxel size in mm)	Inter-rater agreement (%)	Kappa coefficient
0.4	67.9	0.333
0.3	76.8	0.429
0.2	82.1	0.762
0.125	96.4	0.815

between first-year students and endodontic staff (CI = 0.6815–1.496) (Fig. 1).

The overall inter-rater agreement was 80.8%. Agreement measured by the kappa coefficient ranged from 0.333 to 0.815 (Table 3).

The percentages of consistently correct responses for each of the raters were 1 – 90.63%, 2 – 90.63%, 3 – 81.25%, 4 – 78.13%, 5 – 87.51%, 6 – 59.38% and 7 – 78.13%. Raters 1 and 2 were more consistent and correct as compared to the rest whilst rater 6 was considerably less consistent and correct than all other observers.

The influence of resolution on intra-rater reliability was also evaluated. Each rater had a general trend toward more correct and consistent reliability as the resolution improved from 0.4 mm voxel to 0.125 mm voxel. The overall average showed a steady increase in intra-rater reliability as the resolution improved (Table 4). Percentage intra-rater disagreement was then calculated. On the average, the raters disagreed with themselves 19.20% when looking at the same image at different points during the video. Intra-rater disagreement ranged from a low of 9.38% for raters 1 and 2 to a high of 40.63% for rater 6 (Table 5).

Discussion

In the present study, the roots were sectioned, and two MB canals were found at a rate of 91.7%. This is consistent with a previous study in which a second canal could be identified 90% of the time in maxillary first molars using a scanning electron microscope (Gilles & Reader 1990). Kulild & Peters (1990) concluded that the incidence of MB2 canals found clinically increased from 54.2% to 85.5% by carefully using a bur on the floor of the pulp chamber. Buhrley *et al.* (2002) reported a 93.0% incidence of MB2 canals using magnification in maxillary first molars, which is consistent with the rates determined in this study. It is more difficult in some teeth to determine the number of MB canals because there is an isthmus between the two canals. In this study, a tooth with an isthmus was determined to have two canals if the fin widened at the end or if it had a retentive area detected by an explorer tip. The reason for this definition is because when the raters were examining the cross-sections in the CT scan, it was most feasible to define two canals as any appearance of two canals at any place along the scan.

Table 4 Intra-rater reliability as measured by resolution

Resolution (voxel size in mm)	Consistent and Correct (%)	Consistent and Incorrect (%)	Inconsistent and Correct (%)	Inconsistent and Incorrect (%)
0.4	41.1	26.8	19.6	12.5
0.3	62.5	14.3	8.9	14.3
0.2	80.4	1.8	1.8	16.1
0.125	96.4	0	3.6	0

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Table 5 Individual and average intra-rater disagreement percentages

Rater	Experience	Disagreement (%)
1	2nd-year postgraduate student	9.38
2	2nd-year postgraduate student	9.38
3	1st-year postgraduate student	18.7
4	1st-year postgraduate student	21.8
5	1st-year postgraduate student	12.5
6	Teaching staff	40.63
7	Teaching staff	21.88
Total		19.2

The possibility exists that CBCT imaging may be more accurate than the previous standard used in multiple studies of visual inspection of 2-mm cross-sections of the tooth. Sequential axial images are obtained at lower resolution (0.4–0.125 mm) than anatomical sections. Therefore, CBCT imaging in the present study provides five cross-sections with the low resolution per 2-mm root slice and approximately 17 cross-sections per 2-mm section using the high-resolution protocol. It is possible that the CT scan has a higher detection rate by detecting small branches or widening of the canal fin in the 2-mm slice.

Even with these considerations, the rate of detection for this study was high compared to many radiographic studies using two-dimensional techniques (Vertucci 1984, Wolcott *et al.* 2002). CBCT is already being used as a standard for laboratory studies to replace the sectioning of the roots. Matherne *et al.* (2008) used CT as the standard to compare the detection of root canal systems with charged coupled devices and photostimulable phosphor plates. However, they used a low-resolution voxel size (0.4 mm) as their standard resolution instead of the highest 0.125 mm voxel size available. The present study clearly shows that increasing the acquisition resolutions of CBCT improves the detection of the MB canals in the MB root of maxillary molars. If CBCT is to be used as a standard to replace the sectioning of roots, the highest resolution available would produce a more accurate indication of the ground truth as determined by root sectioning.

This study has some limitations. One is the definition of multiple canals. The definition of multiple canals at any level does not necessarily translate into canals that are accessible clinically. Another limitation of this study is the use of extracted teeth. High-resolution scans depend upon the scanned object remaining still during the entire scan. Scans performed *in vivo* would likely be subject to less sharpness because of patient motion during a 20- or 40-s scan. It is possible that the advantages offered by the higher resolution would not be as pronounced if movement was greater in the 40- vs. the 20-s scan.

Another limitation is the use of clay as a holding medium for the extracted teeth. Bone has variable density, and scans of the head could be affected by the different density of bone around each tooth.

This study does not address complications of CBCT with root filling materials present in the canals as seen in retreatment cases. Visualization of root filled teeth could be complicated because of the effects of beam hardening from the root filling material. Silver points or metal carriers could cause scatter inhibiting the ability to identify the canal systems (Hartwell & Bellizzi 1982).

The ultimate limiting factor is the use of raters. Inter- and intra-rater agreement historically has been shown to be a difficult task. Goldman *et al.* (1972) reported that six radiographic examiners evaluating endodontic success were compatible only 47% of the time. In a 6- to 8-month follow-up study with three of the original examiners, they agreed with each other 55% of the time and agreed with themselves 75–88% of the time (Goldman *et al.* 1974). In the present study, there was no improvement on detection accuracy of MB canals with more elevated clinical experience (first-year specialty trainees versus endodontic staff). Therefore, experience did not seem to play a role in the ability to determine the correct number of canals in a cross-section view.

In this study, different isotropic voxel dimensions were compared. The radiation dose differs for the different scans. There is a direct correlation between the scan time and the radiation dose. The CBCT uses multiple short bursts of radiation exposure or basis images as the cone goes around the head. Twice as many exposures occur with the 40-s scan (612 basis images) as compared to the 20-s scan (306 basis images). Therefore, the higher-resolution scans at 40 s have double the exposure and double the radiation as the lower-duration scans of 20 s. The increase in resolution must be evaluated against this increase in radiation to the patient. One area where that is not a concern is the use of CBCT as a standard for laboratory studies instead of the traditional root sectioning. If CBCT is used for that task, the highest resolution possible should be used to provide the most accurate standard by which to compare the results. Matherne *et al.* (2008) used the 0.4-mm voxel scan as their gold standard to compare to charged-coupled device and photostimulable phosphor plate evaluation of root canal systems in multiple teeth. Their results showed

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a high success rate of detection by all three endodontist raters ranging from 76% to 84%, which is higher than a previous study (Ramamurthy *et al.* 2006). However, the CBCT at 0.4 mm voxel dimensions was used as the standard and may not have been able to accurately detect all canal systems present.

Conclusion

The iCAT CBCT scans were accurate in their ability to detect multiple canals in MB roots of maxillary molars when using the feature of three-dimensional cross-section, with increased accuracy as the isotropic voxel dimensions decreased. The correct identification of MB canal numbers using CBCT cross-sections was not improved by a higher level of clinician experience. CBCT at high resolution is accurate enough to be used in laboratory studies in place of the standard root sectioning.

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