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Comparison of micro-computerized tomography and cone-beam computerized tomography in the detection of accessory canals in primary molars

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ABSTRACT

Purpose: This study was performed to compare the accuracy of micro-computed tomography (CT) and cone-beam computed tomography (CBCT) in detecting accessory canals in primary molars.
Materials and Methods: Forty-one extracted human primary first and second molars were embedded in wax blocks and scanned using micro-CT and CBCT. After the images were taken, the samples were processed using a clearing technique and examined under a stereomicroscope in order to establish the gold standard for this study. The specimens were classified into three groups: maxillary molars, mandibular molars with three canals, and mandibular molars with four canals. Differences between the gold standard and the observations made using the imaging methods were calculated using Spearman's rho correlation coefficient test.
Results: The presence of accessory canals in micro-CT images of maxillary and mandibular root canals showed a statistically significant correlation with the stereomicroscopic images used as a gold standard. No statistically significant correlation was found between the CBCT findings and the stereomicroscopic images.
Conclusion: Although micro-CT is not suitable for clinical use, it provides more detailed information about minor anatomical structures. However, CBCT is convenient for clinical use but may not be capable of adequately analyzing the internal anatomy of primary teeth. (***Imaging Sci Dent 2015; 45: 205-11***)

KEY WORDS: X-Ray Microtomography; Cone-Beam Computed Tomography; Tooth, Deciduous; Decalcification Technique

Introduction

Endodontic treatment can prevent tooth extractions, making it possible to maintain the functionality and aesthetics of the affected tooth. The success of root canal treatment largely depends on the removal of pulp tissue and the complete filling of the root canals with an appropriate endodontic material.[1] Root canal morphology is often complex, and every detail of the root canal system should be taken into account in order to develop a proper plan for endodontic treatment.[2-5]

The ramifications extending in various directions from the main canal cause the root canal to have an intricate morphology, thereby complicating endodontic treatment. These ramifications are known as accessory canals. Some can reach the outer surface of the root, establishing a direct relationship between the dental pulp and the periodontal space.[1,6] Accessory canals originate from a localized failure in Hertwig's sheath during embryonic tooth formation and may be present in both primary and permanent teeth.[7] The presence of accessory canals, especially in primary

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teeth due to their irregular anatomy, inhibits the complete removal of the dental pulp, leading to the potential retention of residues of organic tissue, microorganisms, and their toxins in the root canal.[8] These infective irritants remaining in the root canal system can cause extraradicular lesions and reinfection if they reach the periodontal tissue.[9-12]

In previous studies that identified accessory canals in the primary and permanent teeth, various methods have been used, such as clearing techniques, histological sectioning, and radiological examination.[5,7,9] By using a scanning electron microscope, the dimensions of accessory canals in primary teeth were found to range between 10 μm and 180 μm.[13] These structures are so small that they can only be visualized by devices with high spatial resolution. Intraoral radiological techniques may be inadequate for imaging accessory canals due to the superimposition of anatomical structures on two-dimensional images. However, advanced imaging techniques, such as computerized tomography, generate three-dimensional images that reflect root canal morphology more accurately.[14,15] With the use of cone beam computerized tomography (CBCT) and micro-computerized tomography (micro-CT) it is possible to obtain sections from multiple planes, thereby creating three-dimensional images of teeth.[16,17]

CBCT has replaced medical CT for most dental diagnostic tasks and is now available for several clinical applications, especially for orthodontic purposes. CBCT can be used to assess the root canal morphology of teeth when used with an appropriately small field of view (FOV) and small voxel size.[16] Additionally, very thin sections can be obtained with micro-CT. This involves extremely high radiation doses that are not compatible with the human organism. Older models can only be used in *ex vivo* studies, but newer models are able to image small live animals.[18,19] Micro-CT has the capability of producing ultrahigh resolutions of 1 μm *ex vivo* using microfocal spot X-ray sources and high resolution detectors, and can be considered a radiological gold standard.[16,19] In contrast, sub-millimeter resolution in in vivo CBCT images ranges from 400 μm to as low as 76 μm, theoretically enabling the detailed examination of accessory canals.[18,20]

The aim of this study was to assess the ability of micro-CT and CBCT to detect accessory canals in primary molar teeth in comparison to direct observations made after the use of a clearing technique. The results of our study will be useful for future research on the internal anatomy of teeth.

Materials and Methods

Our sample consisted of 41 human primary first and second molars (20 maxillary and 21 mandibular) that were extracted due to extensive caries or periapical pathology. The extracted teeth were washed under running water and stored in separate ampoules containing distilled water.

For micro-CT analysis, each tooth was individually embedded in a wax block and scanned using a SkyScan 1174 compact micro-CT scanner (SkyScan, Kontich, Belgium) at 50 kVp and 800 μA with 2.0° rotation steps. A total of 1024 slices were acquired from each tooth and no filter was used. Each raw data set was reconstructed with Nrecon SkyScan software version 1.5.0 (SkyScan, Kontich, Belgium), providing axial cross sections with a pixel size of 18.0 μm × 18.0 μm.

For CBCT analysis, the samples were embedded in wax blocks in groups of four. All images were acquired using a 3D Accuitomo 170 CBCT device (Morita Manufacturing Corp., Kyoto, Japan) with image capture parameters set to 90 kV and 5.0 mA and an exposure time of 17.5 s. The FOV size was 40 × 40 mm and the voxel size was 0.08 mm.

After micro-CT and CBCT imaging, the teeth were prepared using a clearing procedure in order to obtain the gold standard for the present study. First, the coronal parts of the teeth were separated from the roots at the cemento-enamel junction using a diamond disk and a hand motor (EWL K11, KaVo, Osaka, Japan). Decalcification was carried out by separating each root from its crown and placing it in a burette containing 6% hydrochloric acid for 24 hours and then washing it with water for one hour. The roots were dehydrated using a series of ethyl alcohol rinses (70%, 80%, 90%, and pure solutions of ethanol), with the roots kept in each solution for five hours. The dehydrated roots were then placed in a mixed solution of methyl salicylate and absolute ethanol for five hours, followed by immersion in methyl salicylate until the roots became transparent. After the clearing process, drawing ink was injected into the coronal outlet of the root canal system, and care was taken to ensure that the ink did not overflow the canals. The roots that were injected with ink were then examined under a stereomicroscope (Leica Microsystems GmbH, Wetzlar, Germany) at 10× magnification.

Both the micro-CT and CBCT images were evaluated twice by a single observer using axial sections that were viewed on a 15.4 inch LCD monitor (TruBrite® WXGA, Toshiba Europe GmbH, Neuss, Germany) at 1280 × 800

Fig. 1. The accessory canals are seen on an axial cone-beam computed tomography image.

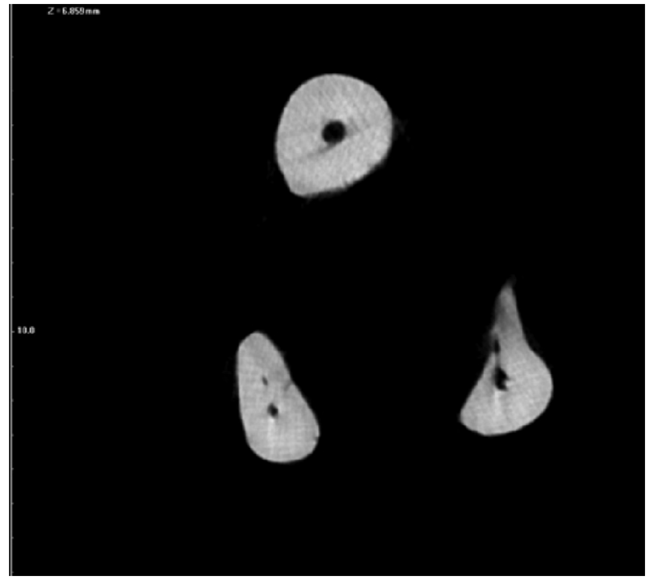

Fig. 2. The accessory canals are seen an axial micro-computed tomography image.

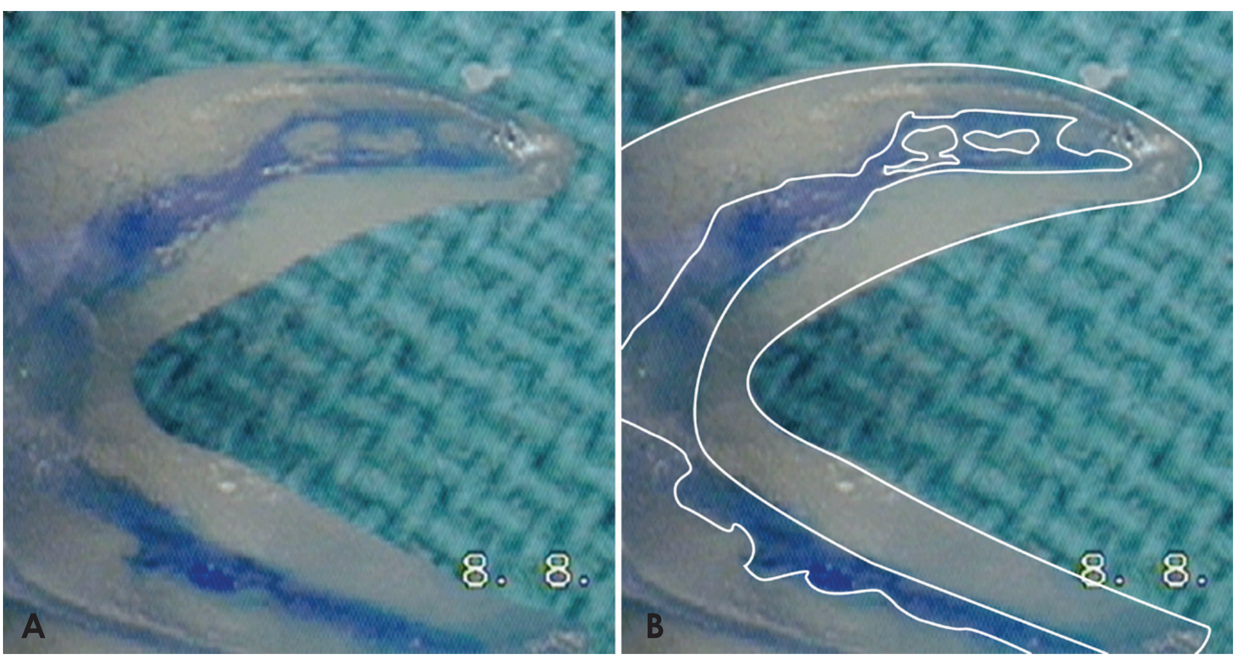

Fig. 3. A. The injected ink is visualized in the accessory canals under the stereomicroscope (10x). B. the main and accessory canals.

screen resolution, and the number of accessory canals was recorded. The second set of evaluations was performed by the same observer after a two-week interval. Accessory canals were defined as any branches of the main pulp, regardless of communication with the external surface of the root; loops that divide from and then rejoin the main canal; and isthmuses, which are ramifications that are surrounded by two different main canals. The data obtained from examination under the stereomicroscope was regarded as the gold standard. Figures 1 and 2 show the reconstructed three-dimensional images of the accessory canals obtained by micro-CT and CBCT, respectively. The appearance of the accessory canals under the stereomicroscope when ink was injected is shown in Figure 3A, and Figure 3B contains a schematic diagram of the main and accessory canals.

The specimens were classified into three groups: maxillary molars, mandibular molars with three canals, and mandibular molars with four canals. Statistical analysis was performed using SPSS version 15.0 for Windows (SPSS Inc., Chicago, IL, USA). Weighted kappa coefficients for each group were calculated to assess intraobserver reliability according to the following criteria: <0.10, no agreement; 0.10-0.40, poor agreement; 0.41-0.60, significant agreement; 0.61-0.80, strong agreement; 0.81-1.00, excellent agreement. Differences between the gold standard and the results obtained using micro-CT and CBCT images were evaluated using Spearman's rho correlation coefficient test. P-values <0.05 were considered to indicate significant agreement.

Results

Data were obtained from 20 maxillary and 21 mandibular primary molars. Table 1 shows the levels of intraobserver agreement calculated for each group of teeth according to the image type. For maxillary molars, kappa values were between 0.601 and 0.716 for the micro-CT group, indicating strong agreement, and between 0.355 and 0.574 for the CBCT group. In the micro-CT group, strong agreement was found for mandibular molars with three canals, for which the kappa values were between 0.605 and 0.797.

Table 1. Intraobserver agreement for each group of teeth by imaging type

	Maxillary teeth Weighted kappa (SE)	Mandibular teeth with three canals Weighted kappa (SE)	Mandibular teeth with four canals Weighted kappa (SE)
Micro-CT MB	0.601 (0.131)	0.643 (0.161)	0.750 (0.198)
Micro-CT ML	–	0.605 (0.160)	0.143 (0.112)
Micro-CT P	0.716 (0.117)	–	–
Micro-CT D	–	0.797 (0.131)	–
Micro-CT DB	0.621 (0.132)	–	0.750 (0.218)
Micro-CT DL	–	–	0.077 (0.242)
CBCT-MB	0.574 (0.160)	0.143 (0.107)	0.667 (0.219)
CBCT-ML	–	0.211 (0.210)	0.280 (0.212)
CBCT-P	0.355 (0.220)	–	–
CBCT-D	–	0.464 (0.229)	–
CBCT-DB	0.403 (0.170)	–	1.00 (0.00)
CBCT-DL	–	–	0.333 (0.385)

SE: standard error, CT: computed tomography, CBCT: cone-beam computed tomography, MB: mesiobuccal, ML: mesiolingual, P: palatal, D: distal, DB: distobuccal, DL: distolingual.

Table 2. Spearman's correlation coefficient showing agreement between observations made using each imaging method and the gold standard for each group of teeth

	Maxillary teeth				Mandibular teeth with three canals				Mandibular teeth with four canals			
	First observation		Second observation		First observation		Second observation		First observation		Second observation	
	SRCC	p	SRCC	p	SRCC	p	SRCC	p	SRCC	p	SRCC	p
GS-Micro-CT MB	−0.022	0.925	0.843	<0.001	0.736	0.002	0.452	0.091	0.904	0.013	0.889	0.018
GS-Micro-CT ML	–	–	–	–	0.911	<0.001	0.828	<0.001	0.775	0.070	0.730	0.099
GS-Micro-CT P	0.76	<0.001	0.819	<0.001	–	–	–	–	–	–	–	–
GS-Micro-CT D	–	–	–	–	0.915	<0.001	0.915	<0.001	–	–	–	–
GS-Micro-CT DB	0.972	<0.001	0.820	<0.001	–	–	–	–	0.890	0.018	0.985	<0.001
GS-Micro-CT DL	–	–	–	–	–	–	–	–	0.980	<0.001	–	–
GS-CBCT-MB	−0.024	0.925	0.317	0.174	0.559	0.030	0.600	0.018	0.495	0.318	0.433	0.391
GS-CBCT-ML	–	–	–	–	0.423	0.116	0.527	0.043	0.775	0.070	0.730	0.099
GS-CBCT P	0.598	0.005	0.353	0.127	–	–	–	–	–	–	–	–
GS-CBCT D	–	–	–	–	0.655	0.008	0.164	0.560	–	–	–	–
GS-CBCT DB	0.551	0.012	0.304	0.193	–	–	–	–	0.853	0.031	0.853	0.031
GS-CBCT DL	–	–	–	–	–	–	–	–	0.211	0.688	−0.211	0.688

SRCC: Spearman's rho correlation coefficient, GS: gold standard, CT: computed tomography, CBCT: cone-beam computed tomography, MB: mesiobuccal, ML: mesiolingual, P: palatal, D: distal, DB: distobuccal, DL: distolingual.

For mandibular molars with four canals, kappa values were between 0.077 and 0.750 in the micro-CT group and 0.280 to 1 in the CBCT group, showing poor to strong agreement.

Table 2 shows Spearman's correlation coefficient values that reflect the level of agreement between the gold standard and each imaging method for each group of molars. A statistically significant correlation was found between the evaluations made based on micro-CT images and the stereomicroscopic measurements of the maxillary molars, with correlation coefficients ranging from 0.760 ($p<0.001$) to 0.972 ($p<0.001$), whereas poor to strong agreement was found in the CBCT group, where the highest correlation coefficient value was 0.598. Similarly, in mandibular molars with three canals, the micro-CT images of accessory canals mostly displayed strong to excellent agreement, with correlation coefficient values ranging from 0.736 to 0.915, with the exception of the second reading in the mesiobuccal canals. In the CBCT group, the correlation coefficient values were between 0.164 and 0.655, indicating poor to strong agreement. In mandibular molars with four canals, the number of accessory canals detected in micro-CT images displayed strong to excellent agreement with the gold standard, with correlation coefficients ranging from 0.730 to 0.985 ($p<0.001$), whereas poor to strong agreement was observed in the CBCT group, where 0.853 was the highest correlation coefficient value.

Statistically significant correlations were observed between the presence of accessory canals in micro-CT images of maxillary root canals and the gold standard obtained by using the clearing technique and stereomicroscopic visualization. No statistically significant correlations were found between the CBCT images and the gold standard.

Discussion

The present study compared the ability of micro-CT and CBCT to detect accessory canals in deciduous molars. Several techniques have been previously used to examine root canal anatomy, such as the replication technique, the clearing technique, sectioning of teeth, and radiopaque dyes.[5,7,9,21-24] Among these techniques, the clearing technique is most commonly used because it is simple to perform and provides an accurate three-dimensional view of the root canal system. Moreover, the original morphology of the canals is preserved because the technique does not require instrumentation of the specimens.[25] Therefore, the clearing technique was used to obtain direct observations of the canals that served as the gold standard in this study.

Three-dimensional imaging techniques provide detailed information on the morphology of root canal systems with out the superposition of anatomical structures.[14,15] Accessory canals complicate the internal anatomy of root canals both in the permanent and primary teeth. Previous studies evaluating ramifications from the main canal have mostly concentrated on permanent teeh.[9,14,17,18,26] Few studies have assessed the detection of accessory canals in primary molars.[5,7,13] Kumar[13] reported that the diameter of the accessory canals of primary molars ranged from 10 μm to 180 μm, and that the most common diameter values were between 20 μm and 30 μm. These structures are so small that they can only be displayed radiologically using devices with high spatial resolution. Micro-CT provides images with a higher resolution than those obtained using CBCT, and it is therefore more appropriate for visualizing such small structures. Overall, the superior imaging features of micro-CT provide more detailed and accurate data regarding root canal systems than CBCT. The results of the present study confirm this assessment, as micro-CT was found to be more successful than CBCT in detecting the accessory canals of primary teeth. However, micro-CT has the major disadvantage of not being suitable for clinical use. It can only be used in laboratory-based studies, whereas CBCT is appropriate for patient care.[16] The smallest FOV option of CBCT should be used in endodontic examinations in order to obtain the most accurate information possible about the fine details of the root canal system with acceptable effective radiation doses. Although micro-CT is not feasible for clinical examinations of primary teeth, it can be used to arrive at a better understanding of the entire canal anatomy of primary molar teeth by detecting multiple accessory canals that can otherwise be impossible to be detect using other imaging techniques.

No studies have compared CBCT and micro-CT with regard to their accuracy in detecting accessory canals in primary teeth, making it impossible to directly contextualize the data obtained in the present study. However, several studies have used these techniques to investigate the anatomy of the permanent teeth, and some of those studies have compared the accuracy of CBCT and micro-CT, in addition to other techniques.[14,17,18,27-34]

Blattner et al.[28] compared CBCT with periapical radiography using clinical sectioning as the gold standard and found CBCT to be a reliable method of detecting second mesiobuccal canals in maxillary molars. Similarly, Baratto Filho et al.[33] reported that CBCT was successful in detecting second mesiobuccal canals in maxillary first molars and could be used for initial characterizations of the inter nal morphology of these teeth. Neelakantan et al.[29] compared the accuracy of several methods in identifying the root canal morphology of permanent teeth, finding CBCT to be as accurate as the clearing technique. The results of those studies conflict with the findings of the present study, in which no significant correlations were found between the CBCT findings and observations made using the clearing technique. A possible reason for this discrepancy is that we studied the accessory canals in primary teeth, which are much smaller than those in permanent teeth. Since micro-CT is more sensitive than CBCT, our results were not unexpected. Moreover, our findings are supported by many studies in which isthmuses in permanent teeth were successfully identified using micro-CT,[31,32,34] because these structures more closely resemble the accessory canals of primary teeth due to their narrow morphology and small dimensions.

In conclusion, CBCT is convenient for clinical use, but may be insufficient for analyzing the internal anatomy of primary teeth. Micro-CT seems to be a better alternative for studies investigating the root canal anatomy of primary teeth. Although it currently can only be used for research, future technological developments may allow micro-CT to become suitable for clinical use.

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