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ORIGINAL ARTICLE

Three-rooted premolar analyzed by high-resolution and cone beam CT

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Abstract
Objectives The aim of this study was to analyze the variations in canal and root cross-sectional area in three-rooted maxillary premolars between high-resolution computed tomography (μCT) and cone beam computed tomography (CBCT).
Materials and methods Sixteen extracted maxillary premolars with three distinct roots and fully formed apices were scanned using μCT and CBCT. Photoshop CS software was used to measure root and canal cross-sectional areas at the most cervical and the most apical points of each root third in images obtained using the two tomographic computed (CT) techniques, and at 30 root sections equidistant from both root ends using μCT images. Canal and root areas were compared between each method using the Student *t* test for paired samples and 95 % confidence intervals.
Results Images using μCT were sharper than those obtained using CBCT. There were statistically significant differences in mean area measurements of roots and canals between the μCT and CBCT techniques ($P<0.05$). Root and canal areas had similar variations in cross-sectional μCT images and became proportionally smaller in a cervical to apical direction as the cementodentinal junction was approached, from where the area then increased apically.
Conclusion Although variation was similar in the roots and canals under study, CBCT produced poorer image details than μCT.
Clinical relevance Although CBCT is a strong diagnosis tool, it still needs improvement to provide accuracy in details of the root canal system, especially in cases with anatomical variations, such as the three-rooted maxillary premolars.

Keywords Root canal anatomy · Maxillary premolar · High-resolution computed tomography · Cone beam computed tomography

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Introduction

High-resolution computed tomography (μCT) systems reproduce accurately the structures of small specimens in 3D images [1]. Although an advance over conventional CT because of its higher resolution, μCT emits high doses of radiation [2] and is not available for clinical use. The cone beam computed tomography (CBCT) can be used on patients as it exposes them to a lower radiation dose. Both techniques have advantages over those used previously to evaluate tooth morphology largely because they are not invasive [3].

Several studies have used μCT, such as three-dimensional evaluation of root canals [4], volume of the instrumented canal [1, 5], association between internal and external root macromorphology [6], root canal curvature [7], prevalence of isthmuses [8], as well as instrumentation techniques [4, 5, 9–11]. CBCT has been used in studies evaluating the effect of voxel size when assessing simulated external root resorption [12], identification of the root canal system [13], length and homogeneity of root fillings [14] and comparison of cervical canal preparation instruments [15]. A study comparing these techniques showed similar results when tooth germs were subjected to volume measurements [16].

The most currently used methodology for assessment of canal anatomy is clearing teeth. It consists of opening the canal, filling it with an ink and decalcifying, followed by the dehydration and immersion in methyl salicilate. This procedure jeopardizes tooth structure. Tomography and micro-CT have no effect on tooth structure.

A recent study described the anatomy of the root canal system in three-rooted maxillary premolars evaluated using μCT [17]. However, no studies have evaluated variation in root area within three-rooted maxillary premolars using such accurate assessment methods maintaining the integrity of tooth structure. Therefore, this study evaluated the applicability of μCT and CBCT as techniques to study the anatomy of three-rooted maxillary premolars.

Material and methods

The study was approved by the Ethics in Research Committee of Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS—protocol no. 10/05068).

Sample selection

The sample comprised 16 three-rooted human maxillary premolars with fully formed apices that had been extracted for therapeutic reasons. Teeth were excluded if they had restorations or caries that reached the pulp chamber or the root. Teeth were stored individually in 0.1 % thymol (Bellafarma, Caxias do Sul, Brazil).

High-resolution computed tomography

For the μCT analysis, the teeth were individually scanned cross-sectionally using a high-resolution desk-top μCT system at 50 kV (Skyscan 1072 Kontich, Belgium) in the School of Dentistry, Cardiff University (Cardiff, Wales, United Kingdom). For each tooth, 405 to 500 slices were obtained at a voxel size of $34 \times 34 \times 42$ μm.

Cone beam computed tomography

Teeth were aligned with their crown facing up and root apex fixed to a utility wax base (Wilson, Polidental, Cotia, Brazil). The specimens were then scanned using an i-CAT CBCT scanner at 120 KVp (Imaging Sciences International, Inc, Hatfield, PA) in a radiological clinic (Dental Imaging Diagnosis Centre, Porto Alegre, Brazil). In all, 90 to 118 sections per tooth were produced at a voxel size of $0.2 \times 0.2 \times 0.2$ mm.

Measurement of the root and canal area

The images captured using the Skyscan and i-CAT software were converted into a bpm format. They were evaluated by one pre-calibrated examiner who measured the cross-sectional areas corresponding to the roots and the canals in selected sections of the root thirds. When the root had more than one canal, both were measured and their areas were added. When the roots were fused, the areas were measured according to the projection of each root.

Comparison between CT techniques

To compare CT techniques, the roots corresponding to the mesiobuccal (MB), distobuccal (DB), and palatal (P) canals were divided into cervical, middle, and apical thirds (Fig. 1a). The reference points were the most cervical and most apical images of each root that had a canal lumen outlined by dentin. Two images of each third were selected for the measurement of each root and canal: the most apical and the most cervical.

Area variation

To study the variation in root and canal area in three-rooted maxillary premolars, only μCT images were used (Fig. 1b). In all, 30 sections (10 equidistant sections in each root third: cervical, middle, and apical) of each root (P, MB, and DB) were evaluated.

Root and canal areas were measured using the Adobe Photoshop CS software (Adobe Systems Inc., San Jose, CA) according to the number of pixels; values were recorded in a Microsoft Excel 2003 spreadsheet (Microsoft Corporation, Redmond, WA). One image from each technique was

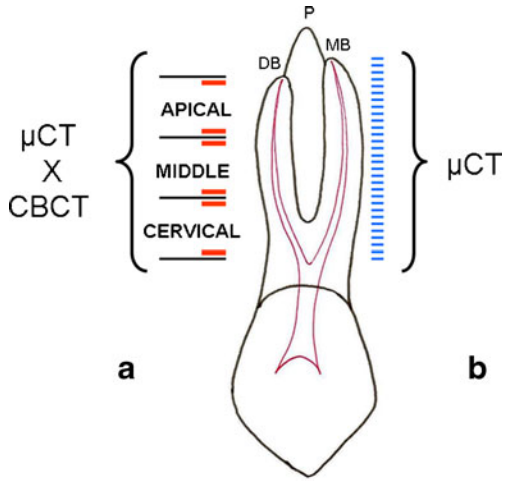

Fig. 1 **a** Sites measured to compare μCT×CBCT techniques; *red lines* represent the most cervical and most apical sections of each root third; **b** 30 equidistant points (*blue lines*) were analyzed using μCT to study area variation

transferred to the working area of AutoCAD software (Autodesk, San Rafael, CA). After the μCT and CBCT, image scales were made equivalent, the root and canal perimeters were outlined and the areas were measured in square millimeter. Calculations were made in triplicate, and the final area value was the mean of the three measurements. The values were then transformed from pixels to square millimeter.

Statistical analysis of results

Mean and standard deviations were calculated for each root and canal third. The canal and root areas were compared for each method using the Student *t* test for paired samples and 95 % confidence intervals. The level of significance was set at $\alpha=0.05$. To evaluate area variation, mean root and canal areas were plotted in relation to each cross-section of the specimen on the μCT images. Data were analyzed using SPSS 18.0 (IBM, Armonk, NY) and SigmaPlot Graphics 11 (Systat Software, San Jose, CA).

Results

The teeth were extracted for therapeutic reasons. Therefore there was no patient exposure to radiation. A total of 4,032 root and canal area measurements were made using 3,456 μCT and 576 CBCT images. The high number of μCT images is related to the ability of this equipment to do ultrathin slices, voxel size of 34×34×42 μm. Compared with CBCT, which were produced at a voxel size of 0.2×0.2×0.2 mm, this explains the possibility of acquiring greater number of μCT. The μCT images were sharper than the CBCT ones (Fig. 2a–d) and revealed a wealth of anatomic details, such as the presence of three and two canals in a MB and DB root in the middle third of one of the specimens (Fig. 2a), the presence of lateral canals (Fig. 2b), canal trifurcation in the apical third (Fig. 2c, d), as well as different shapes of root and canal sections. In contrast, the CBCT images were blurred (Fig. 2e–h).

Comparison between CT techniques

Table 1 shows that the root length measured using CBCT was shorter than when μCT was used.

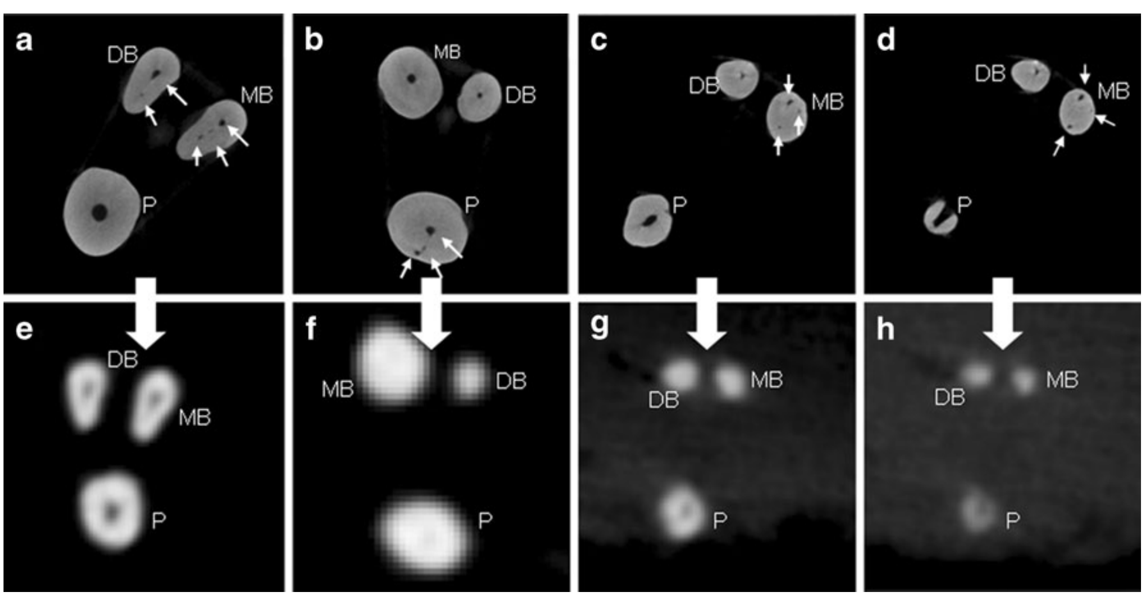

Fig. 2 Cross-section of maxillary premolar roots. Multiple canals (*small arrows*) in μCT images (**a**–**d**) and lack of details in CBCT images (**e**–**h**). Images in the same column correspond to neighboring sections of the same tooth

Table 1 Means and standard deviations of root lengths analyzed using µCT and CBCT

		CT technique	
Root	Third	µCT (mm)	CBCT (mm)
P	C	3.64±0.6	2.81±0.5
	M	3.60±0.6	2.69±0.4
	A	3.61±0.6	2.71±0.5
	C+M+A	10.84±1.8	8.21±1.4
MB	C	2.84±0.6	1.85±0.5
	M	2.81±0.6	1.73±0.5
	A	2.82±0.6	1.79±0.5
	C+M+A	8.46±1.8	5.36±1.6
DB	C	2.55±0.6	1.58±0.4
	M	2.53±0.6	1.44±0.4
	A	2.53±0.6	1.50±0.4
	C+M+A	7.61±1.8	4.51±1.2

P palatal, *MB* mesiobuccal, *DB* distobuccal, *C* cervical, *M* middle, *A* apical

Table 2 shows that there is a statistically significant difference ($P<0.05$) in most comparisons of root and canal area means between CT techniques in the different root thirds under study. When the root area was evaluated, areas measured using µCT tended to be greater than when CBCT was used to measure the cervical and middle thirds of all the roots. In the apical third, however, µCT measures were smaller.

When the canal area was evaluated, CBCT images had statistically greater areas than µCT in all the thirds of all the roots, except in the cervical thirds of the P and MB roots.

Area variation

Figure 3 describes absolute (root area+canal area) (Fig. 3a) and relative (canal area/root area+canal area) (Fig. 3c) variations. In general, variations were proportional in the different roots and thirds.

Absolute variation in MB and DB roots was similar, and the area decreased from cervical to apical. DB and P roots had the smallest and largest area values, respectively. In addition, P roots had a more marked variation than the other roots (Fig. 3a).

The analysis of canal area revealed that there was a decrease from cervical to apical up to a point close to the cementodentinal junction, where the area then increased apically, corresponding to the canal beyond the minor foramen (Fig. 3b, c).

Discussion

Maxillary premolars may have three roots [18]. When they are not detected clinically or using conventional radiographic techniques, CBCT may be an important complementary diagnostic resource [13]. Although it produces better image quality and detection of anatomic details, µCT is not used clinically because the scanner cannot be used for large samples and requires a long exposure time [2].

Results showed that the CT techniques were significantly different when used in the different root thirds (Table 2) and cannot, therefore, be compared. These differences may be explained by the lack of sharpness of the CBCT images (Fig. 2e–h) when compared with µCT images (Fig. 2a–d), which makes area measurements difficult, particularly for root canals, and also explaining the differences in the root

Table 2 Means and standard deviations of root and canal cross-sectional areas in the different thirds using both CT techniques

		Root area			Canal area		
		CT technique			CT technique		
Root	Third	µCT (mm^2)	CBCT (mm^2)	*P*	µCT (mm^2)	CBCT (mm^2)	*P*
P	C	13.34±2.8	11.26±2.4	<0.001	0.95±0.4	0.90±0.3	0.360
	M	9.42±2.2	8.25±1.8	<0.001	0.39±0.2	0.54±0.2	0.002
	A	4.68±1.2	5.29±1.3	0.004	0.17±0.7	0.30±0.1	<0.001
MB	C	7.54±1.8	6.15±1.3	<0.001	0.31±0.2	0.38±0.2	0.031
	M	5.22±1.2	4.82±1.0	0.006	0.14±0.07	0.27±0.1	<0.001
	A	2.61±0.8	3.56±0.9	<0.001	0.06±0.03	0.18±0.09	<0.001
DB	C	6.69±1.8	5.48±1.3	<0.001	0.22±0.1	0.32±0.2	<0.001
	M	4.71±1.4	4.38±1.0	0.163	0.13±0.07	0.24±0.1	<0.001
	A	2.43±1.0	3.27±0.8	0.003	0.06±0.03	0.17±0.1	<0.001

P palatal, *MB* mesiobuccal, *DB* distobuccal, *C* cervical, *M* middle, *A* apical

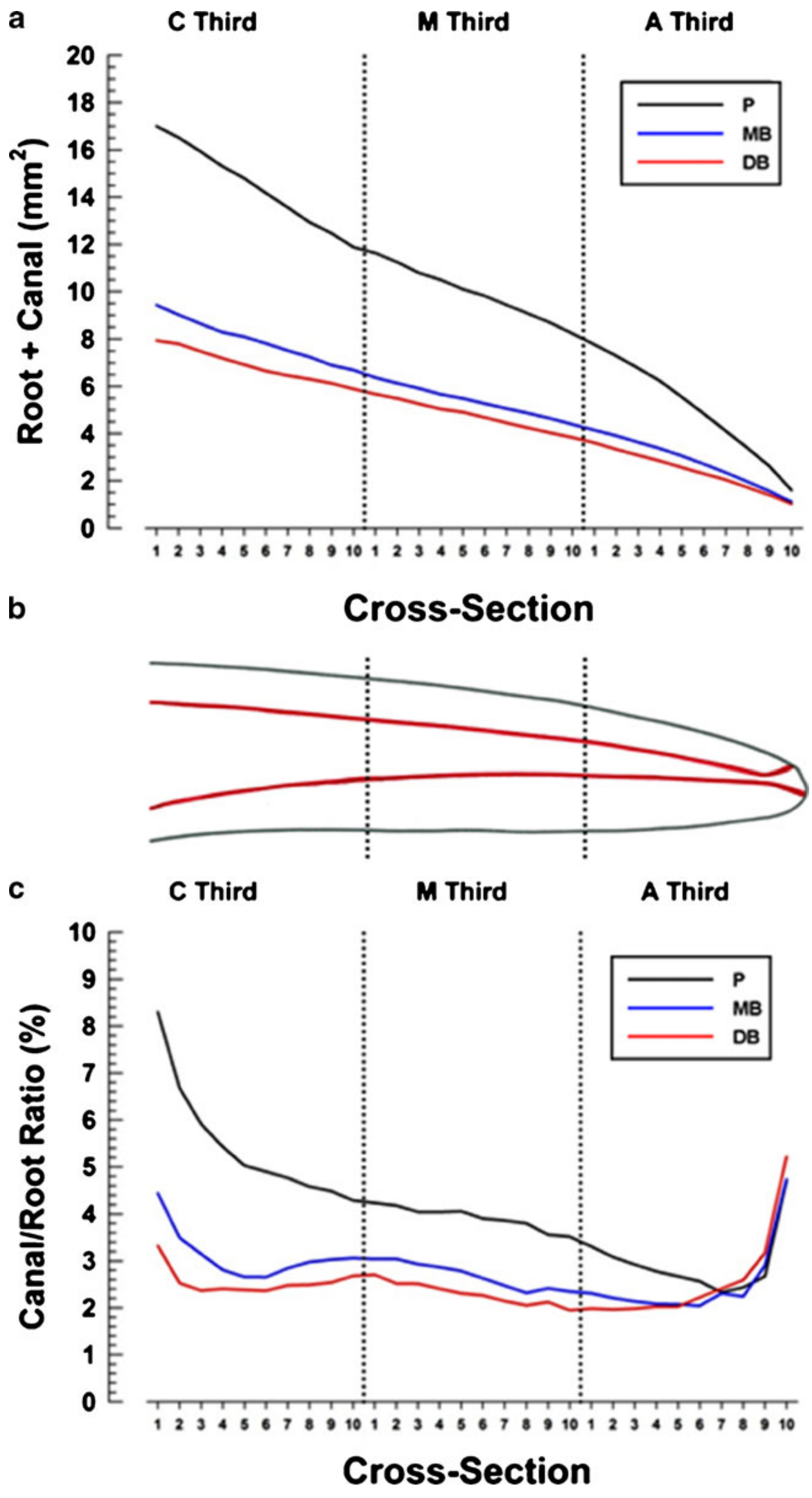

Fig. 3 Absolute (**a**) and relative (**c**) variations of the cross-sectional areas in the different thirds: cervical (*C*), middle (*M*), and apical (*A*) from the μCT images. The figure in (**b**) represents the study findings in a diagrammatic representation to allow visualization of what was viewed in each root

lengths between the techniques (Table 1). CBCT images are blurred in comparison with μCT images due to scattering, a physical process in which radiation deflects from its straight trajectory in the medium through which it travels and is dispersed. This effect is uncommon in μCT, and the fact that it accurately describes anatomic details, such as the presence of more than one canal in each root, of lateral canals, apical deltas, and variations of the cross-sectional area of the canal along its axis [17], makes it comparable to in vitro histology [19].

Human error when outlining the root and canal perimeters for area measurements might lead to incorrect measures.

To avoid such a problem in this study, the Adobe Photoshop CS software was used for outlining and for the measurement of the root areas. This has shown to be useful in previous studies [16, 20].

CBCT and μCT were similar statistically in a study on volume reconstruction in tooth germs using voxel sizes that were closer to each other, 41 μm for μCT and 76 μm for CBCT [16]. The present study followed parameters used in dental radiology, that is, 34 and 200 μm, and the ratio between methods was three times greater. Variations in voxel size may explain the differences in results from these studies, which may indicate that parameters currently used should be reconsidered.

MB root and canal had a greater area than DB root in all the root thirds (Fig. 3a), perhaps because the buccopalatal distance of the MB root was greater than that of the DB root, particularly in the cervical and middle thirds [17]. Maxillary first molars commonly contain two canals in the MB root [21]. A relevant anatomic finding was the presence of three and two canals in the MB and DB roots in one specimen, which was demonstrated using μCT (Fig. 2a). Another study using μCT did not find two canals in the MB root in any of the specimens, but especially in the cervical third, the MB canal had a “comma-like” cross-section, with the isthmus positioned palatally [17], which was also found in other specimens in this study.

The curve of relative area variation, in all canals, increased starting from the 28th section. The mean distance between this and the last section was 0.50 mm for all the canals of the three-rooted maxillary premolar, or 0.61, 0.47, and 0.43 mm for the P, MB, and DB canals. Other authors found a mean distance of 0.53 mm between the apical foramen and the constriction [22]. Therefore, the significant increase of the canal area apically (Fig. 3b, c) may be explained by the presence of the cemental canal between the minor and major foramina.

Conflict of interest The authors declare that they have no conflict of interest.

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