Canal transportation and centering ratio after preparation of curved canals: A comparative evaluation of cone-beam computed tomography and micro-computed tomography

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Abstract

Objectives: This study aimed to compare cone-beam computed tomography (CBCT) and micro-computed tomography (micro-CT) for evaluation of canal transportation and centering ratio after instrumentation of curved canals.

Materials and Methods: A total of 20 mesiobuccal canals of mandibular molars were prepared by sequential rotary system. All specimens underwent CBCT and micro-CT before and after instrumentation and the magnitude of transportation and centering ratio were measured. The accuracy and the agreement between the two modalities were calculated considering the acceptable transportation of $\leq$ 0.15 mm. The agreement between the modalities was also assessed by calculating the intraclass correlation coefficient (ICC).

Results: Transportation was detected by both modalities at all distances from the apex after instrumentation. Agreement between the two modalities in assessment of canal transportation was observed in 16 specimens at 1 mm, 17 specimens at 3 mm, and 15 specimens at 5 and 7 mm from the apex, out of 20 specimens, yielding 80%, 85%, 75% and 75% accuracy, respectively. ICC for transportation and centering ratio was much lower than 0.75 indicating poor agreement between the modalities.

Conclusions: CBCT and micro-CT do not have a good agreement in assessing transportation and centering ratio. Micro-CT is still recommended for evaluating transportation in vitro, due to higher resolution and better visualization of details.

Clinical relevance: CBCT is recommended for assessment of canal transportation in the clinical setting; however, it cannot replace micro-CT for in vitro studies, and micro-CT remains the modality of choice for in vitro assessments.

Introduction

A successful root canal treatment depends on efficient debridement and shaping of the root canal system. Mechanical preparation of the root canal system is performed aiming to eliminate the infected soft and hard tissues from the root canal system, providing a proper path for delivery of irrigating solutions and medicaments, and creating a uniform conical shape from the canal orifice to the apex to allow optimal obturation of the root canal with root filling materials [1].

The majority of root canal preparation methods cause canal transportation in curved canals due to the inherent tendency of the files to straighten up in curved canals [2]. Canal transportation provides a suitable space for accumulation of debris and microorganisms, and can result in insufficient cleaning of the root canal system and impaired root canal integrity, adversely affecting the treatment prognosis [3]. Canal transportation is acceptable by up to 0.15 mm [4]. However, canal transportation by 0.3 mm or higher negatively affects the long-term prognosis of endodontic treatment [5, 6].

The 2Shape rotary instruments (Micro-Mega, Besancon, France) are fabricated by the sequential rotational system and specific heat treatment (T-Wire), resulting in higher flexibility and cyclic fatigue resistance, while preserving the elasticity of NiTi alloy [7].

Several studies have assessed the quality of root canal instrumentation and transportation using different methods including radiography [8], tissue sectioning according to Bramante et al, [9] longitudinal tooth sectioning and measuring the canal curvature before and after preparation [10], resin models [11], root canal wall coloring and assessment under a microscope [12], making a silicone impression from the instrumented canal [13], computed tomography (CT) [14], cone-beam computed tomography (CBCT) [15], and micro-CT [16].

CBCT is a non-invasive clinical imaging modality that does not require destruction of specimens to assess the root canal anatomy before and after instrumentation [17]. Micro-CT has a higher resolution and better reveals the details than CBCT; however, it does not have clinical applications due to high radiation dose, long scanning time, and high cost [18]. To date, no study has compared the efficacy of CBCT and micro-CT for assessment of canal transportation and centering ratio. Thus, this study aimed to compare CBCT and micro-CT in assessment of canal transportation and centering ratio following root canal instrumentation with 2Shape rotary files to answer the question whether micro-CT has a significant difference with CBCT in assessment of canal transportation.

Materials And Methods

Sample size calculation:

The sample size was calculated to be 20 according to a previous study [19] assuming the effect size of 1.93, $\alpha = 0.05$, $\beta = 0.95$, and study power of 90% using PASS 15.

Sample selection:

The study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1399.036). A total of 150 mandibular first and second molars were evaluated. All roots were inspected under a stereomicroscope at x12 magnification, and the teeth with immature apex or external dentinal defects were excluded. Eligible teeth then underwent high-resolution CBCT in a NewTom VGI CBCT scanner (QR, SRL Co, Verona, Italy) with the exposure parameters of 110 kV, 9.5 mA, 0.1 mm voxel size, and 6 x 6 cm field of view. NNT Viewer version 8.0 (Quantitative Radiology, Verona, Italy) was used for assessment of different sections to determine the root canal classification and root curvature. The root curvature was measured by the Schneider’s method [20]. Molar teeth with Vertucci’s type IV mesial root, mesiobuccal root canal curvature of 20–40 degrees on the sagittal or coronal sections or both, no calcification, no internal and external root resorption, and no history of previous endodontic treatment were enrolled. All teeth were stored in 0.1% thymol solution during the experiment.

The crowns and distal root of the teeth were cut by a low-speed saw (Isomet 4000; Buehler Ltd, Lake Bluff, IL, USA) under water coolant, and the root length was standardized at 12 ± 1 mm from the apex.

To simulate the periodontal ligament, the root surface was wrapped with aluminum foil and mounted in a tube filled with acrylic resin (Kulzer GmbH, Leipziger, Hanau, Germany). After setting, the aluminum foil was removed and replaced with silicone impression material (GC Co, Tokyo, Japan). The specimens were immediately mounted back in the block [21].

All specimens were scanned twice before instrumentation, once with CBCT and once with micro-CT, as follows:

Micro-CT scanning was performed using a micro-CT scanner (LOTUS-inVivo, Behin Negareh Co., Tehran, Iran) with the exposure parameters of 31 μm isotropic resolution, 99 kV voltage, 88 μA amperage, 2-second exposure time frame with 0.5 mm thick aluminum filter, 360-degree resolution, and 0.3° rotation step.

CBCT scanning was performed using NewTom VGI CBCT scanner (QR SRL Co., Verona, Italy) with the exposure parameters of 110 kVp, 9.5 mA, 0.100 mm voxel size, 0.125 mm axial thickness, and 6 x 6 cm field of view.

Root canal preparation:

Working length was determined by introducing a #10 K-file (Mani Inc., Tochigi, Japan) into the canal until its tip was visible at the apex; 1 mm was subtracted from this length. Next, a glide path was created by a #15 K-file (Mani Inc., Tochigi, Japan).

Root canal instrumentation was performed by an experienced operator using an endo-motor (VDW Silver motor; VDW GmbH, Munich, Germany) according to the torque and speed recommended by the manufacturer. Each file was only used for two canals. The file sequence was as follows: TS1(25, 04) and TS2 (25, 06) with 1.5 N/cm torque and 300 rpm speed introduced into the canal with a progressive motion with pecking movement until the file reached the working length. After three pecking motions, the file was removed from the canal, its flutes were cleaned with a gauze, and the root canal was rinsed with 2 mL of 2.5% sodium hypochlorite [23]. After preparation of specimens, they underwent micro-CT and CBCT again with the same exposure parameters applied in the first scan.

Assessment of canal transportation and centering ratio:

Reconstructed micro-CT and CBCT images were transferred to a data viewer (RadiAnt DICOM Viewer 2020.2). Cross-sectional micro-CT and CBCT images before and after preparation of specimens were superimposed and the mesiodistal dimensions were measured at 1, 3, 5, and 7 mm from the apex (Fig. 1). Two trained and calibrated examiners evaluated all the sections and made the measurements twice with a 2-week interval. In case of disagreement between the observers, the images were re-assessed until a consensus was reached.

The Gambill's method was used to assess canal transportation and centering ratio [14]. Canal transportation was calculated using the formula (D2-D1)-(M2-M1) while centering ratio was calculated using the formula (D2-D1)/(M2-M1) and (M2-M1)/(D2-D1).

Canal transportation equal to 0 indicated no transportation. Positive values indicated the occurrence of canal transportation at the mesial while negative values indicated canal transportation at the distal root surface. For centering ratio, the numerator is always smaller or equal to the denominator; thus, the result always ranges from 0 and 1. The closer this value to 1, the higher the centering ratio would be.

Statistical analysis:

Data were analyzed by SPSS for Windows version 25.0 (IBM Co., Armonk, USA). The measures of central dispersion (mean and standard deviation) were reported for canal transportation and centering ratio. Repeated measures ANOVA was used to assess the change in root canal system after preparation compared with before at 1, 3, 4, and 7 mm from the apical foramen on axial sections. The Bonferroni test was applied for pairwise comparisons. The Shapiro-Wilk test confirmed the normality of data distribution. Level of significance was set at 0.05 ($\alpha = 0.05$).

The accuracy of CBCT and micro-CT and the agreement between the two modalities were calculated considering the acceptable transportation of ≤ 0.15 mm according to a study by Peters et al [4]. The intraclass correlation coefficient (ICC) was calculated for more precise comparison of values measured by the two modalities. ICC values ≤ 0.75 were considered unacceptable while ICC values > 0.75 were considered optimal and acceptable.

Since no clinically acceptable threshold has been mentioned in the literature regarding centering ratio, only the ICC value was calculated to assess the agreement of micro-CT and CBCT in measurement of centering ratio. Also, ICC values were calculated to measure the intraobserver (with a 2-week interval) and interobserver reliability.

Results

Transportation was detected by both modalities at all distances from the apex after instrumentation. The mean and standard deviation of transportation and centering ratio at 1, 3, 5 and 7 mm from the apex measured on micro-CT and CBCT are presented in Table 1.

Repeated measures ANOVA showed a significant difference in transportation value on axial images. Pairwise comparisons by the Bonferroni test revealed that the amount of transportation at 7 mm from the apex had a significant difference with the value at 1, 3 and 5 mm from the apex on CBCT scans ($P < 0.05$). Pairwise comparisons for micro-CT scans did not show significant differences in transportation values on axial sections($P > 0.05$).

Table 2 presents the agreement between micro-CT and CBCT in assessment of canal transportation. Agreement between the two modalities in assessment of canal transportation was observed in 16 specimens at 1 mm, 17 specimens at 3 mm, and 15 specimens at 5 and 7 mm from the apex, out of 20 specimens, yielding 80%, 85%, 75%, and 75% accuracy, respectively.

Table 3 presents the ICC values for the comparison of two methods regarding canal transportation and centering ratio. As shown, the ICC values were much lower than 0.75 regarding canal transportation and centering ratio, indicating no agreement between micro-CT and CBCT.

Table 4 presents the ICC values for the measurements made at different distances from the apex by the observers to assess the intraobserver and interobserver reliability. The ICC values for intraobserver reliability ranged from 0.98–0.99, and the ICC values for inter-observer reliability ranged from 0.97 to 0.99, indicating excellent intraobserver and interobserver reliability.

Table 1
Mean canal transportation (mm) and centering ratio at 1, 3, 5, and 7 mm from the apex

	Micro-CT				**CBCT**			
	Transportation		**Centering ratio**		**Transportation**		**Centering ratio**	
	Mean ± SD	***95% CI***	***Mean ± SD***	***95% CI***	***Mean ± SD***	***95% CI***	***Mean ± SD***	***95% CI***
1 mm	-0.015 ± 0.098	-0.061 to 0.031	0.372 ± 0.333	0.216–0.528	-0.004 ± 0.058	-0.036 to 0.028	0.648 ± 0.345	0.487–0.809
3 mm	0.004 ± 0.109	-0.048 to 0.055	0.415 ± 0.268	0.289–0.540	0.023 ± 0.067	-0.009 to 0.054	0.542 ± 0.384	0.362–0.722
5 mm	0.056 ± 0.119	-0.001 to 0.112	0.499 ± 0.300	0.358–0.640	0.007 ± 0.054	-0.019 to 0.033	0.653 ± 0.262	0.531–0.776
7 mm	-0.057 ± 0.146	-0.126 to 0.012	0.616 ± 0.241	0.503–0.729	-0.098 ± 0.111	-0.150 to -0.045	0.408 ± 0.282	0.276–0.540

Table 2
Agreement and accuracy for transportation measurement at different distances from the apex (considering acceptable transportation ≤ 0.15 mm)

Distance from apex	**Accuracy**	**Agreement**	**Disagreement**	**Total**
1 mm	80%	16	4	20
3 mm	85%	17	3	20
5 mm	75%	15	5	20
7 mm	75%	15	5	20

Table 3
Micro-CT and CBCT ICC values for transportation and centering ratio at different distances from the apex (considering acceptable ICC > 0.75)

Distance	Transportation	Centering ratio
1 mm	0.361	0.047
3 mm	0.093	-0.129
5 mm	0.115	0.152
7 mm	0.424	0.102

Table 4
ICC values for interobserver and intraobserver reliability at different distances from the apex

Distance	Interobserver	Intraobserver	
		Observer 1	Observer 2
1 mm	0.977	0.993	0.995
3 mm	0.977	0.987	0.991
5 mm	0.971	0.996	0.988
7 mm	0.990	0.999	0.998

Discussion

Resin blocks and natural teeth are commonly used for assessment of the quality of root canal preparation. Root canals simulated in resin blocks have advantages such as standardization of dimensions, length, and curvature of the root canal system; however, due to having mechanical properties different from those of dentin, such as microhardness and particle size, they may not be able to optimally simulate the oral environment. Standardization of extracted natural teeth is more difficult due to anatomical variations; however, they can better simulate the clinical setting.

Many studies assessing the outcome of treatment have reported that mandibular molars have the lowest success rate in endodontic treatment [24, 25]. One important reason for this finding is the apical curvature of mesial roots that makes them susceptible to procedural errors [24]. According to morphological studies, the mean curvature of the mesial root of mandibular molars is > 20 degrees [26–28]. Thus, mandibular molars with a mesiobuccal canal curvature of 20–40 degrees were used in the present study. A systematic review showed that in case of using similar systems, no significant difference would be found in canal transportation and centering ratio between rotary and reciprocal systems [29]. Thus, a rotary system (2Shape) was used for root canal preparation in the present study.

In the current study, the magnitude of canal transportation following root canal instrumentation with 2Shape rotary system was lower than that reported in previous studies [30, 31]. The centering ratio calculated in this study after root canal preparation was similar to that in a study by Nehme et al [31]. Maximum transportation was noted in the coronal third. Canal transportation in the coronal third of the root is important since it results in excessive removal of dentin, weakening of the root, and increased risk of strip perforation [6]. However, the magnitude of transportation in this region in the present study was < 0.15 mm, and was therefore clinically acceptable [4].

High number of articles on canal transportation following different instrumentation techniques on different in vitro models such as simulated root canals or extracted teeth highlights the significance of this topic [32]. Of different techniques proposed for assessment of canal transportation, 3D imaging has recently gained increasing popularity since it enables comprehensive assessment of the root canal system without its destruction [19, 29, 33–36]. The accuracy of 3D imaging is determined by the voxel size [32]. The voxel size of CBCT ranges from 76 to 400 μm, which can be larger than the size of transportation; thus, it may not be able to precisely reveal the transportation [32, 37]. Larger voxel sizes of CBCT result in partial volume effect, and complicate precise measurement [34]. Nonetheless, CBCT is still used for assessment of root canal changes following instrumentation [19, 38].

Micro-CT has a smaller voxel size and optimal resolution. It reveals greater details, and enables precise 3D quantitative analysis of the root. Thus, it is extensively used for assessment of the effect of instrumentation on root canal anatomy; however, its application is limited to in vitro setting due to high radiation dose, limitation in size of specimens, long scanning time, and high cost [18].

Micro-CT has been compared with some common methods for assessment of canal transportation and centering ratio in the literature. Zanesco et al. [39] showed no significant difference between digital subtraction radiography and micro-CT for assessment of apical transportation, and suggested digital subtraction radiography as an alternative to micro-CT for assessment of canal transportation. However, Poly et al. [40] found a significant different between double digital radiography and micro-CT, and reported that double digital radiography could not detect significant differences in canal transportation and centering ratio between different groups. Freire et al. [41] compared cross-sections and micro-CT methods for assessment of apical transportation in curved canals after root canal instrumentation, and found a significant difference between them, such that the results of micro-CT were more accurate and closer to the clinical settings. They suggested micro-CT as the preferred method for assessment of apical transportation.

To the best of the authors’ knowledge, no previous study has compared micro-CT and CBCT for assessment of canal transportation and centering ratio. Thus, this study was conducted to compare micro-CT and CBCT for assessment of canal changes after instrumentation. Root canal anatomy gradually changes along the Z axis, and it has been demonstrated that 34 μm isotropic resolution provides an acceptable quality for assessment of the root canal anatomy [42]. Thus, micro-CT with 31 μm isotropic resolution was used in the present study.

In the current study, clinically acceptable transportation was considered to be 0.15 mm according to the study by Peters et al [4]. To compare CBCT and micro-CT for evaluation of canal transportation considering the acceptable transportation of ≤ 15 mm, the agreement between the two modalities was calculated. ICC values were also calculated for more precise assessment of the level of agreement. ICC values ≤ 0.75 were considered unacceptable. Since no clinically acceptable threshold has been mentioned in the literature regarding centering ratio, only the ICC value was calculated to assess the agreement of micro-CT and CBCT in measurement of centering ratio.

Although a good agreement has been reported between CBCT and micro-CT in assessment of root canal morphology [43], the present study showed unacceptable agreement between them in assessment of changes in root canal morphology after instrumentation. The obtained ICC values in comparison of CBCT and micro-CT for assessment of canal transportation and centering ratio in the present study were much lower than the acceptable threshold of 0.75, and were even negative in some cases (Table 4), which points to the significant difference between the two modalities in this respect. Thus, CBCT cannot serve as an alternative to micro-CT, and micro-CT remains the preferred modality for in vitro investigations.

Conclusion

CBCT and micro-CT do not have a good agreement in assessment of canal transportation and centering ratio. Micro-CT is still recommended for assessment of canal transportation in vitro, due to higher resolution and better visualization of details. CBCT cannot replace micro-CT, and its application should be limited to the clinical setting.

Declarations

Author Contribution

A,B,D,E,F– research concept and design.

A,C,G – collection and/or assembly of data.

A,G– data analysis and interpretation.

A – writing the article.

B – critical revision of the article.

B – final approval of the article

Ethics Approval

The study was approved by the ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.DRC.REC.1399.036).

Consent to Participate – Humans

Not Applicable.

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Conflict of Interests

The authors deny any conflict of interest related to this study.

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Figures

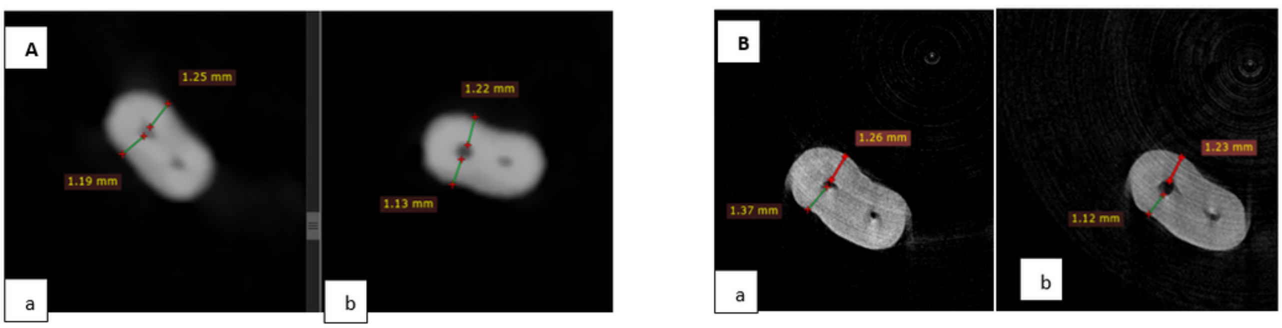

Figure 1

Measuring the mesiodistal dimension of root before (a) and after (b) root canal instrumentation on CBCT (A) and micro-CT (B) images showing the same cross-sections of the same root in the same row.