



## Comparative Evaluation of Canal Transportation and Centering Ratio in Curved Canals: A Study of Cone-beam Computed Tomography and Micro-computed Tomography

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**Introduction:** This study aimed to compare the accuracy and agreement between cone-beam computed tomography (CBCT) and micro-computed tomography (micro-CT) in the assessment of canal transportation and centering ratio following root canal instrumentation with rotary files. **Material and Methods:** Twenty mesiobuccal canals of mandibular molars were prepared using the 2Shape sequential rotary system. CBCT and micro-CT scans were performed before and after instrumentation, and the magnitude of transportation and centering ratio were measured. The acceptable transportation was set at  $\leq 0.15$  mm. The accuracy and agreement between CBCT and micro-CT were calculated, and the intra-class correlation coefficient (ICC) and kappa coefficient were determined to assess the agreement between the two modalities. Statistical analyses were performed using repeated measures ANOVA. **Results:** Transportation was detected by both modalities at all distances from the apex after instrumentation. The agreement between CBCT and micro-CT in assessing canal transportation was observed in 80%, 85%, 75%, and 75% of specimens at 1-, 3-, 5-, and 7-mm from the apex, respectively. The ICC for transportation and centering ratio was much lower than 0.75, indicating poor agreement between the modalities. The kappa coefficient did not show acceptable agreement between the methods. **Conclusions:** CBCT and micro-CT demonstrated poor agreement in assessing canal transportation and centering ratio. Micro-CT remains the preferred modality for in vitro investigations, while CBCT should be limited to clinical settings.

**Keywords:** Canal Transportation; Cone-beam Computed Tomography; Micro-computed Tomography; Shaping Ability

### 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]. Particularly rigid, austenitic instruments certainly represent more complex situations, considering the tendency to straighten the curvature compared to martensitic NiTi rotary instruments [3]. Precisely in this regard, controlling the torques developed by rotary instruments as "operative torque" is essential to avoid excessive instrumentation [4].

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 [5]. Canal transportation is acceptable by up to 0.15 mm [6]. However,



canal transportation by 0.3 mm or higher negatively affects the long-term prognosis of endodontic treatment [7, 8].

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 [9].

Several studies have assessed the quality of root canal instrumentation and transportation using different methods including radiography [10], tissue sectioning according to Bramante *et al.* [11] longitudinal tooth sectioning and measuring the canal curvature before and after preparation [12], resin models [13], root canal wall coloring and assessment under a microscope [14], making a silicone impression from the instrumented canal [15], computed tomography (CT) [16], cone-beam computed tomography (CBCT) [17], and micro-CT [18].

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 [19]. 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 [20]. 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 [21] assuming the effect size of 1.93,  $\alpha=0.05$ ,  $\beta=0.1$ , and study power of 90% using PASS software version 15 (NCSS, Utah, USA).

### Sample selection

A total of 150 mandibular first and second molars were evaluated. All roots were inspected under a stereomicroscope at 12 $\times$  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 $\times$ 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 $\pm$ 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.

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

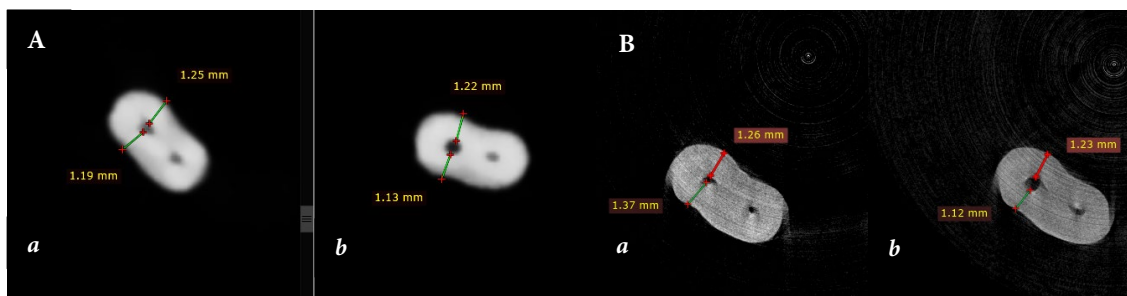
Micro-CT scanning was performed using a micro-CT scanner with the exposure parameters of 31  $\mu$ m isotropic resolution, 99 kV voltage, 88  $\mu$ A amperage, 2-sec exposure time frame with 0.5 mm thick aluminum filter, 360-degree resolution, and 0.3 $^\circ$  rotation step.

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  $\times$  6 cm field of view.

### Root canal preparation:

The 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 were 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. After preparation of specimens, they underwent micro-CT and CBCT again with the same exposure parameters applied in the first scan.



**Figure 1.** A) Measuring the mesiodistal dimension of the root (a) before and (b) after root canal instrumentation on CBCT; B) Micro-CT images showing the same cross-sections of the same root in the same row

### Assessment of canal transportation and centering ratio

The reconstructed micro-CT and CBCT images were transferred to a data viewer (RadiAnt DICOM Viewer 2020.2; Medixant, Poznan, Poland). 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 (Figure 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 [16]. 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). Intra-class correlation coefficient (ICC) values were calculated to measure the intra-observer (with a 2-week interval) and interobserver reliability. The measures of central dispersion (mean and standard deviation) were reported for

**Table 1.** ICC values for interobserver and intra-observer reliability at different distances from the apex

Distance	Interobserver	Intra-observer	
		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

canal transportation and centering ratio. The Shapiro-Wilk test confirmed the normality of data distribution. 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. 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  $\leq 0.15$  mm according to a study by Peters *et al.* [6]. The ICC was calculated for more precise comparison of values measured by the two modalities. ICC values  $\leq 0.75$  were considered unacceptable while ICC values  $> 0.75$  were considered optimal and acceptable. Also, the kappa coefficient was used for assessing the agreement between the two methods.

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.

### Results

The ICC values for intra-observer reliability ranged from 0.98 to 0.99, and the ICC values for inter-observer reliability ranged from 0.97 to 0.99, indicating excellent intra-observer and interobserver reliability. Table 1 presents the ICC values for the measurements made at different distances from the apex by the observers.

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 2.

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 3 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. No acceptable kappa coefficient was observed between the methods (Table 3).

Table 4 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.

## 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 [22, 23]. One important reason for this finding is the apical curvature of mesial roots that makes them susceptible to procedural errors [22]. According to morphological studies, the mean curvature of the mesial root of mandibular molars is  $>20$  degrees [24-26]. 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 [27]. Thus, a rotary system (2Shape; MicroMega, Besancon, France) 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 [28, 29]. The centering ratio calculated in this study after root canal preparation was similar to that in a study by Nehme *et al.* [29].

Table 2. 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 (0.068)	-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 3. Agreement and accuracy for transportation measurement at different distances from the apex (considering acceptable transportation  $\leq 0.15$  mm)

Distance from apex	Accuracy	Agreement	Disagreement	Kappa coefficient (Standard Error)	Total
1 mm	80%	16	4	-0.081 (0.064)	20
3 mm	85%	17	3	-0.071 (0.051)	20
5 mm	75%	15	5	0 (0)	20
7 mm	75%	15	5	0.286 (0.245)	20

Table 4. 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



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 [7]. However, the magnitude of transportation in this region in the present study was  $<0.15$  mm, and was therefore clinically acceptable [6].

High number of studies 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 [30]. 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 [17, 21, 31-38]. The accuracy of 3D imaging is determined by the voxel size [30]. The voxel size of CBCT ranges from 76 to 400  $\mu\text{m}$ , which can be larger than the size of transportation; thus, it may not be able to precisely reveal the transportation [30, 39]. Larger voxel sizes of CBCT result in partial volume effect, and complicate precise measurement [17]. Nonetheless, CBCT is still used for assessment of root canal changes following instrumentation [21, 40].

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 [20].

Micro-CT has been compared with some common methods for assessment of canal transportation and centering ratio in the literature. Zanesco *et al.* [41] 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.* [42] found a significant difference 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.* [43] 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  $\mu\text{m}$  isotropic resolution provides an acceptable quality for assessment of the root canal anatomy [44]. Thus, micro-CT with 31  $\mu\text{m}$  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.* [6]. To compare CBCT and micro-CT for evaluation of canal transportation considering the acceptable transportation of  $\leq 15$  mm, the agreement between the two modalities was calculated. The ICC and kappa values were also calculated for more precise assessment of the level of agreement. ICC values  $\leq 0.75$  were considered unacceptable. Kappa values  $< 0.4$  are considered poor (a Kappa value of 0 indicates that there is no difference between the observers and chance alone). 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 [45], the present study showed unacceptable agreement between them in assessment of changes in root canal morphology after instrumentation. The kappa values in comparison of CBCT and micro-CT for assessment of canal transportation were much lower than the acceptable threshold of 0.4, and were even zero in one case (Table 3), which shows no acceptable agreement between the methods. 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.

## Conclusions

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.

Conflict of Interest: 'None declared'.

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