ORIGINAL ARTICLE

Effect of continuous irrigation on apical transportation, centering ability and volume of removed dentin in curved root canals: a micro computed tomography study

ABSTRACT

Aim: *To assess the effect of continuous irrigation (CI) on apical transportation, centering ability and volume of removed dentin during root canal shaping with different file systems using micro-computed tomography (micro-CT).*
Methodology: *Twenty mandibular molars with a curvature of 25-35° were included. The teeth were scanned with micro-CT before shaping procedures and randomly divided into 4 groups (5 teeth, 10 canals) as follows: CI and WaveOne Gold (CI-WOG), CI and Hyflex EDM (CI-HEDM), Traditional irrigation and WaveOne Gold (T-WOG) and Traditional irrigation and Hyflex EDM (T-HEDM). Following root canal shaping procedures, all the teeth were re-scanned with micro-CT. Apical transportation and centering ability were evaluated through axial sections at the level of 1, 2, 3, 5 and 7 mm from the apical foramen. The amount of dentin removed was also analyzed by using micro-CT.*
Results: *The CI-WOG and CI-HEDM groups resulted in significantly less apical transportation at 7 mm bucco-lingually compared to the T-WOG group. The CI-HEDM group was able to stay bucco-lingually centered at 7 mm significantly more than the T-WOG group. No statistically significant difference was observed among the groups in terms of the volume of removed dentin.*
Conclusion: *It can be concluded that CI caused less apical transportation and better centering ability at 7 mm level in bucco-lingual direction.*

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Introduction

Cleaning of pulp and necrotic tissue residues, intracanal disinfection, biomechanical shaping, and hermetic root canal filling are important for the success of endodontic treatment (1). The morphology of the root canal is also critical to the success of root canal treatment as canal curvature is a factor that complicates treatment (2, 3). During the shaping of the curved root canal, iatrogenic problems such as apical transportation, ledge formation, perforation and failure in canal centering can be observed (4). In order to prevent such procedural errors, many different endodontic files with high flexibility and high cyclic fatigue resistance operating with rotation or reciprocating motion have been developed (5). There are many studies examining the ability of rotational or reciprocating files to induce apical transportation and centering ability, all of which report conflicting results (6-8). The shaping ability of the root canal file indicates that it can expand in taper, starting from the coronal part of the canal and narrowing towards the apex. The centering ability describes the ability of the root canal file to stay aligned with the canal axis during shaping (9). Endodontic files should show these features without producing errors such as ledges or perforations.

Root canal disinfection is important for eliminating of bacteria from the root canal system. It has been demonstrated that root canal is harbored with detectable amounts of bacteria after shaping procedures (10). Irrigation procedures such as irrigation agitation techniques and the CI method have been proposed to increase the effectiveness of irrigation solutions in the root canal (11). The application of the CI method during root canal shaping can aid in avoiding inadequate irrigation. However, there is no study in the literature examining the effect of CI on root canal shaping. Therefore, the aim of this study is to compare CI and traditional irrigation methods in terms of apical transportation and centering ability during root canal shaping with various endodontic files that working different movement principle. The null hypothesis was that there would not be a significant difference between the CI and traditional syringe irrigation groups.

Material and Methods

Selection of the samples

Ethical approval was obtained from the Ethical committee of University of A. The study was funded by the University of Atatürk with a grant number of TDH-2020-8678. The power analysis was performed based on the data of a previous study to obtain sample size (12). The sample size was determined using GPower 3.1.9.2 software and was estimated at n = 9 samples in each group by considering a=0.05, a study power of 80%.

In this study, 20 mandibular first molar teeth, which were extracted for periodontal reasons, were used and the mesio-buccal and mesio-lingual canals were examined.

The teeth to be included in the study were examined by cone-beam computed tomography. Teeth in the curvature class of mesio-buccal and mesio-lingual canal were selected according to the Schneider (13) method.

Inclusion Criteria:

1. no calcification of the root canal,
2. wide restoration or absence of caries in the tooth,
3. curvature of root canals between 25-35°,
4. not having had root canal treatment before,
5. no root resorption,
6. no root fracture or crack,
7. no pulp stones,
8. mature root,
9. adequate root length.

Exclusion Criteria:

1. calcification of root canal,
2. having had prosthetic treatment,
3. having straight roots,
4. having large root canal morphology,
5. root resorption,
6. vertical root fracture,
7. presence of pulp stone,
8. immature root,
9. inadequate root length.

Preparation of samples
The selected specimens were mechanically and ultrasonically cleaned of debris and soft tissue residues. Then, the teeth were disinfected in a solution containing 0.1% thymol and subsequently stored in saline. In order to distinguish the buccolingual aspect of the teeth, the buccal parts were marked with diamond burs.
The teeth were numbered and 20 were randomly divided into 4 groups (n=5) before starting the procedure using a website (www.randomizer.org). The 4 groups with these 5 teeth (10 canals for each group) are as follow.

1. CI and WaveOne Gold (CI-WOG)
2. CI and Hyflex EDM (CI-HEDM)
3. Traditional irrigation and WaveOne Gold (T-WOG)
4. Traditional irrigation and Hyflex EDM (T-HEDM)

Imaging with Micro-CT before Shaping
The teeth were scanned with a micro-CT device (Bruker Skyscan 1272, Billerica, Massachusetts, ABD) to obtain images before shaping (Figure 1). Scanning was done using 92 kV and 108µA settings and with 180° rotation around the vertical axis and a rotation step of 0.3°. The pixel size of the images is 16 µm. Scanning time for each sample took approximately 1 hour and 20 minutes.

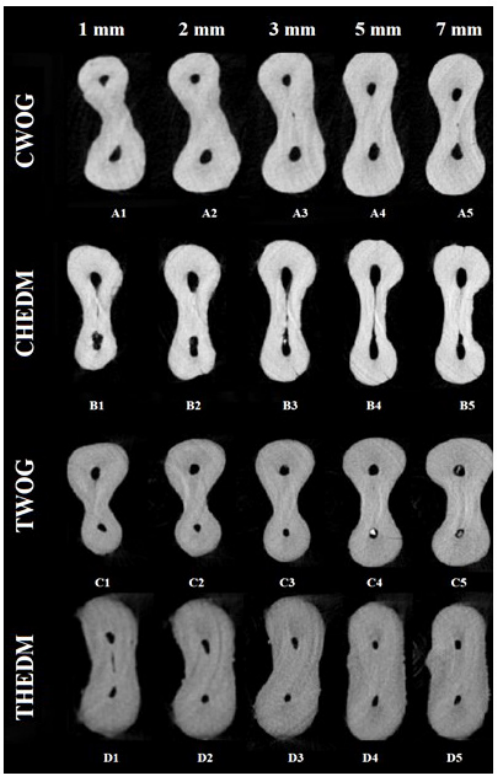

Figure 1
Sample Micro-CT Images of Pre-Shaping.

Access cavity preparation and root canal shaping
All procedures were performed by a single operator. A traditional cavity was opened using a diamond round bur. A #10 K-file was inserted into the root canal until its tip was visible at the major apical foramen, and the working length was determined by subtracting 1 mm from this length. In this study, 2 canals were excluded because one #10 K-type hand file (Mani Inc., Tochigi-Ken, Japan) was broken in each of the CI-HEDM and T-WOG file groups during canal length determination.

Canal shaping with continuous irrigation
In the CI group, a glide path was established using #10 and #15 K-files, respectively. The pump of the Self-Adjusting File (SAF; Re-Dent-Nova, Ra'anana, Israel) device was fixed to the endo-motor for canal shaping in the CI group. The flow rate of the SAF device was set to 10 ml/min. The WOG Primary file was used in "WaveOne ALL" mode with the VDW Silver Reciproc Endo-Motor (VDW GmbH, Munich, Germany). The HyFlex EDM OneFile file was used with the VDW Silver Reciproc Endo-Motor to perform a full rotation with 500 rpm and 2.5 Ncm torque. Shaping was performed with sodium hypochlorite (NaOCl) (Clinix, Dental Sky, UK) at room temperature for 30 seconds at each canal. Final irrigation was performed with 5 ml NaOCl at room temperature with a 31G disposable side-ventedneedle (Ultradent, South Jordan, UT) tip. A total of 10 ml of NaOCl was used for irrigation. The file was cleaned after every 3 pecking motions. These processes were continued until the working length was reached. Each file was used only once.

Canal shaping with traditional irrigation
In the traditional irrigation group, a glide path was established using #10 and #15 K-files, respectively. The WOG Primary file

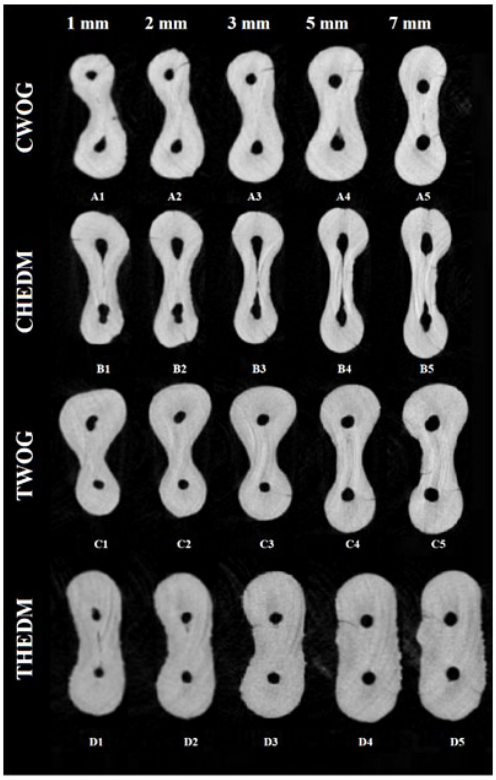

Figure 2
Sample Micro-CT Images after Shaping.

was used in "WaveOne ALL" mode with the VDW Silver Reciproc Endo-Motor. The HyFlex EDM OneFile file was used with the VDW Silver Reciproc Endo-Motor to perform a full rotation with 500 rpm and 2.5 Ncm torque.
After every 3 pecking movements, 2 ml of 2.5% NaOCl was irrigated into the canal using a 31G disposable side-vented needle. Irrigation was completed with a total of 10 ml of NaOCl. The file was cleaned after each use. The canal was prepared with an apico-coronal motion until the working length was reached. Each file was used only once.
After the canals were shaped, a second set of images were obtained by scanning using the same parameters as the first scans (Figure 2).

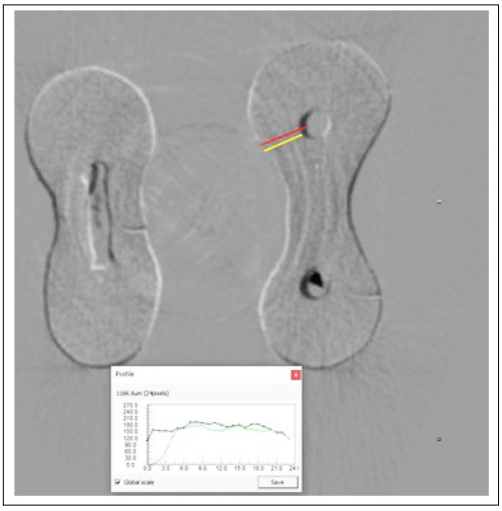

Figure 3
Sample Measurements before and after Shaping.

Evaluation of apical transport and canal centering ability
The 3D registration function of the Data-Viewer v.1.5.4.0 program was used to superimpose the pre- and post-instrumentation images (Figure 3).
Apical transportation was assessed using axial sections at 1, 2, 3, 5, and 7 mm distance from the apex of the tooth. The amount of transportation due to shaping in the apical region of the canal was calculated by subtracting the distance between the canal and the outer wall after shaping from the distance between the canal and the outer wall before shaping.
Centering ability was also evaluated using axial slices at 1, 2, 3, 5, and 7 mm from the apex of the tooth. The canal centering abilities were evaluated by rationing the distance between the canal and the outer wall before shaping and the distance between the canal and the outer wall after shaping.
The following formulas were used for apical transportation (AT) and centering abilities (CA):

$$AT=(B1–B2)–(L1–L2) \text{ and } (M1–M2)–(D1–D2)$$

$$CA=(B1–B2)/(L1–L2) \text{ and } (M1–M2)/(D1–D2)$$

A positive AT value indicates that the canal is carried in the buccal or mesial direction, while a negative value indicates that the canal is carried in the lingual or distal direction. An AT value of zero means that the canal expands equally in all directions.
The CA value represents a ratio. When calculating the CA value, the smaller number is written in the numerator. This value ranges from 0 to 1. If this value is close to 0, it deviates from the center, if it is close to 1, it remains in the center.

Statistical analysis
The SPSS 18.0 (SPPS Inc, Chicago, IL, USA) statistical package program was used for the evaluation of the study data. The Shapiro-Wilk test was used to determine whether the data showed normal distribution or not. The groups showing homogeneous distribution according to the result of the Levene test were evaluated using a one-way Anova test, which is a parametric test, to determine whether there was a statistically significant difference. Groups that did not show homogeneous distribution according to the results of Levene's test were evaluated with the Kruskal-Wallis test, which is a non-parametric test, to determine statistical significance. A % 95 confidence interval (P=0.05) was used in the evaluation of all data.

Results

Apical transportation
According to the results of the statistical analyses, no significant differences were observed between the groups in the mesio-distal direction in terms of apical transport values (Table 1).
While there was no significant difference in terms of apical transportation at 1, 2, 3, and 5 mm bucco-lingually a significant difference was observed between the CI-WOG and T-WOG groups at 7 mm bucco-lingually (Table 2).
The CI-WOG group caused significantly less apical transport at 7 mm bucco-lingually compared to the T-WOG group. At the same time, a significant difference was observed between the CI-HEDM and TWOG at 7 mm bucco-lingually. The CI-HEDM group caused significantly less apical transport at 7 mm compared to the T-WOG group.

Centering ability
No significant differences were observed between the groups in terms of centering abilities mesio-distally (Table 3). While no significant difference was observed in bucco-lingually centering abilities at 1, 2, 3, and 5 mm, a statistically significant difference was observed between the CI-HEDM and T-WOG in terms of bucco-lingually centering abilities at 7 mm (Table 4). The CI-HEDM group was able to stay bucco-lingually centered at 7 mm significantly more than the T-WOG group.

Volume of dentin
The volumes of dentin removed were also evaluated and it was observed that the volumes of dentin removed was similar between the groups, no statistically significant difference was observed (Table 5).

Discussion

In this study, the root canal shaping ability of Ni-Ti rotary file systems, which work with two different movement principles, with traditional syringe and CI methods, were evaluated using micro-CT. The null hypothesis was rejected as the CI technique showed less apical transportation and better centering ability compared to the traditional syringe irrigation technique.
It is known that root canal irrigation has

Table 1
Mean ± standard deviation values of apical transportation in the mesio-distal direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.06 ± 0.04	0.04 ± 0.03	0.06 ± 0.05	0.11 ±0.05	0.13 ± 0.11
CHEDM	0.04 ± 0.04	0.06 ± 0.05	0.06 ± 0.05	0.12 ± 0.14	0.15 ± 0.2
TWOG	0.09 ± 0.07	0.07 ± 0.05	0.09 ± 0.11	0.1 ± 0.12	0.24 ± 0.24
THEDM	0.11 ± 0.15	0.1 ± 0.15	0.04 ± 0.03	0.1 ± 0.08	0.14 ± 0.11
P Value	*0.582*	*0.548*	*0.121*	*0.771*	***0.121***

Table 2

Mean ± standard deviation values of apical transportation in the bucco-lingual direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.07 ± 0.05	0.09 ± 0.08	0.11 ± 0.09	0.13 ±0.12	0.05^{a} ± 0.02
CHEDM	0.08 ± 0.06	0.07 ± 0.06	0.1 ± 0.05	0.09 ± 0.06	0.07^{a} ± 0.5
TWOG	0.1 ± 0.09	0.12 ± 0.04	0.06 ± 0.03	0.12 ± 0.15	0.21^{b} ± 0.1
THEDM	0.04 ± 0.05	0.09 ± 0.09	0.09 ± 0.08	0.14 ± 0.13	0.15^{ab} ± 0.15
P Value	*0.347*	*0.319*	*0.576*	*0.771*	***0.005***

Different superscript letters indicate statistically significant differences between groups.

Table 3

Mean ± standard deviation values of centering ability in the mesio-distal direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.4 ± 0.3	0.57 ± 0.29	0.49 ± 0.22	0.45 ±0.24	0.43 ± 0.24
CHEDM	0.42 ± 0.21	0.48 ± 0.27	0.48 ± 0.36	0.4 ± 0.29	0.5 ± 0.33
TWOG	0.32 ± 0.19	0.37 ± 0.21	0.41 ± 0.31	0.46 ± 0.32	0.32 ± 0.21
THEDM	0.51 ± 0.39	0.53 ± 0.28	0.73 ± 0.22	0.19 ± 0.52	0.57 ± 0.23
P Value	*0.548*	*0.431*	*0.097*	*0.902*	***0.263***

an effect on apical transportation during root canal shaping (14). However, there is no study examining the effect of CI on root canal shaping. According to the results of this study, significantly less apical transportation was observed in the 7 mm bucco-lingually CI-WOG group compared to the T-WOG group. This result shows that, despite using the same file, preparation with CI offers a better shaping ability. It is known that the removal of debris during root canal shaping reduces the risk of apical transportation due to debris accumulation (15). Less apical transportation in the CI group may be explained by the removal of debris by Ci solution replacement depending on the technique (16). Previous research has shown that delivering CI solution into the canal with the SAF system, which is similar to the CI technique, is effective in removing the debris residues (17). It is believed that the CI

Table 4

Mean ± standard deviation values of centering ability in the bucco-lingual direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.34 ± 0.28	0.32 ± 0.27	0.32 ± 0.25	0.35 ±0.26	0.33ab ± 0.25
CHEDM	0.27 ± 0.16	0.52 ± 0.31	0.25 ± 0.17	0.42 ± 0.22	0.59a ± 0.24
TWOG	0.46 ± 0.29	0.28 ± 0.19	0.48 ± 0.26	0.51 ± 0.28	0.24b ± 0.18
THEDM	0.46 ± 0.29	0.44 ± 0.25	0.17 ± 0.47	0.36 ± 0.24	0.38ab ± 0.18
P Value	*0.336*	*0.314*	*0.056*	*0.509*	***0.025***

Different superscript letters indicate statistically significant differences between groups.

Table 5
Mean ± standard deviation values of the amount of dentin removed.

Groups	N	Mean	Std. Deviation
CWOG	10	0.852	0.456
CHEDM	9	1.297	0.410
TWOG	9	1.252	0.378
THEDM	10	1.163	0.511

system used in this study provides CI solution into the canal, facilitating the extrusion of debris coronally, and thus creating a lubricating effect. This could be the reason for less apical transportation.
It has been reported that the SAF system, which has a working principle similar to the CI system, may cause inadequate irrigation in the apical area (18). In one study examining the effectiveness of the Quantec-E CI system for smear layer removal and canal cleaning, significant results were obtained only in the coronal region (19). Based on these findings, the fact that this study produced a significant result at 7 mm can be attributed to the facts that the flow of the solution is greater in the coronal region and that root canal curvature begins in the coronal region.
In addition, significantly less apical transportation and better centering ability were observed in the 7 mm buccolingual CI-HEDM group compared to the T-WOG group based on the results of the current study. Single file systems working with-continuous rotation and reciprocating motion were used to evaluate the effect of CI technique on canal shaping ability in this study. No significant differences were observed between the traditional syringe irrigation groups with HEDM and WOG files in apical transportation and canal centering ability. One study in the literature used simulated S-shaped resin block canals to compare the shaping ability of WaveOne Gold Primary, Hyflex EDM OneFile, and Reciproc R25 files. No statistically significant difference was observed between the WaveOne Gold Primary and Hyflex EDM OneFile files (20). Another study on simulated L-shaped resin block canals compared Protaper Universal, Protaper Next, Hyflex CM, Hyflex EDM, and WaveOne Gold files for apical transportation and observed no difference in apical transportation between the WaveOne Gold and Hyflex EDM file groups (21). Similar to the results of these studies, in the present study, no difference was observed between the WOG and HEDM files in traditional syringe irrigation groups in terms of shaping abilities. However, when the HEDM file was used with the CI technique, it has exhibited less apical transportation and better centering ability than the WOG file used with traditional syringe irrigation. These findings show that the CI technique has a positive effect on the root canal shaping ability by providing fewer procedural mistakes.
Centering ability is affected by root canal anatomy, the design and alloy of the root canal file, and the shaping technique with the canal file (22). In the literature, there are studies showing that continuous rotation movement in root canal shaping creates less apical transportation compared to files working with reciprocating movement (23). There are also studies showing that the reciprocating motion preserves the root canal anatomy better than the continuous rotation motion (24).
Several studies have evaluated the effects of file kinematics, taper, and design features on canal shaping ability (9, 26). In the present study, the Hyflex EDM working with continuous rotation motion and the WaveOne Gold Primary file working with reciprocating motion were used with both traditional syringe irrigation and CI tech-

niques. While no significant difference was observed between the HEDM and WOG files used with the traditional syringe irrigation method, the HEDM file used with the CI technique showed significantly less apical transportation and better centering ability compared to the WOG file used with the traditional syringe irrigation technique. The CI technique and the design differences of the files could be factors in this result. While there was no significant difference between the T-HEDM and T-WOG groups when the centering ability was evaluated, the CI-HEDM group showed better centering ability compared to the T-WOG group, showing that the CI technique had a positive effect on the centering ability.

The biggest issue in the use of extracted human teeth is their anatomically variability. In order to minimize these variables, the mesial canals of mandibular first molars, which have similar anatomical features as much as possible, were used. Apical patency control was provided with a #15 K-file to closely select the apical foramen width of each canal. Teeth in which the #15 K-file could reach the apex were selected. Although an attempt was made to minimize variables in this way, it is not possible to standardize them completely. Failure to achieve this standardization is the main limitation of the study.

Finally, the results of this study showed that dentin volumes removed in the CI and traditional syringe irrigation groups were similar. There is no a previous study comparing the amount of dentin removed using WOG and HEDM files. Therefore, there is no other study to which the dentin removal rates of WOG and HEDM files can be compared. However, according to a study, there was no statistically significant difference between rotary and reciprocating files in terms of the canal volume changes. This finding is in consistent with the results of the present study (27). In addition, in another study in which the ProTaper file was used with full rotation and reciprocal motion and canal volume change was compared, no significant difference was observed between the two groups (28). At the same time, a further study evaluating the canal volume change of full rotational motion and reciprocal motion observed no statistically significant difference between the 2 groups (29). The finding of the amount of dentin removed in this present study supports this information in the literature. In addition, this finding can be evaluated as a first since there is no study in the literature comparing the amount of dentin removed using WOG and HEDM files. Further studies examining the effect of the CI technique taking into account different variables are needed.

Conclusion

Within the limitations of the study, it can be concluded that CI technique caused less apical transportation and better centering ability at 7 mm level in bucco-lingual direction.

Clinical Relevance

This is the first study revealed that root canal shaping under continuous irrigation results in less canal transportation and improves the centering ability of the file.

Conflict of Interest

The authors declare that there is no any conflict of interest.

Acknowledgements

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