Comparison of the Effects of WaveOne Gold, TruNatomy, and Conventional Hand Files on Remaining Dentin Volume in the Coronal Part of the Root and Preparation Efficiency in Mandibular Molars

İrem Eren, DDS, PhD,* and Berkant Sezer, DDS, MSc†

ABSTRACT

Introduction: The use of file systems that work with different principles in root canal treatment is becoming widespread. The aim of this study was to evaluate the remaining dentine volume in the coronal region of the root and preparation efficiency after the use of conventional hand files, WaveOne Gold; which works with reciprocating motion, and TruNatomy; which works with rotational motion in the root canal treatment of mandibular molar teeth. **Methods:** All canals of permanent mandibular molars ($n = 36$) were used. Root canals in each group ($n = 12$) were prepared with conventional hand files, WaveOne Gold, and TruNatomy. The three-dimensional images were evaluated for remaining dentine volume in the coronal two-millimeter region of the root and change in volume of the entire root canal space. **Results:** There was no statistically significant difference between the groups in terms of mean differences pre and postpreparation ($P > .05$). The mean differences after preparation were observed the most in the WaveOne Gold group and the least in the TruNatomy group in the coronal two-millimeter region of the root and entire canal volume, but the differences were not significant ($P > .05$, $P > .05$, respectively).
Conclusions: Conventional hand files, WaveOne Gold working with reciprocating motion, and TruNatomy working with rotational motion, which are the file systems used in the study, are not superior to each other in terms of remaining dentin volume in the coronal two-millimeter region of the root and preparation efficiency in the entire root canal space in mandibular molars. *(J Endod 2023;49:1027–1034.)*

KEY WORDS

Endodontic treatment; reciprocating files; remaining dentin volume; root canal treatment; rotary files

SIGNIFICANCE

Conventional hand files, WaveOne Gold, and TruNatomy file systems are not superior to each other in terms of remaining dentin volume in the coronal part of the root and preparation efficiency in the root canal space.

The main goal in root canal preparation is to remove bacteria, necrotic tissues, and infected dentin that may cause infection in the pulp and periapical tissues of the root canal system[1-3]. Nickel-titanium (Ni-Ti) instruments are systems developed for the preparation of the root canals more effectively than traditional hand files[4,5]. Besides, another aim of development of the Ni-Ti instrument systems is to reduce the risks of anatomical deformities and instrument accidents through the effective preparation of curved canals because of their flexibility. Excessive dentin removal during preparation makes the root of the tooth more susceptible to fractures. Some studies have reported that excessive dentin removal is directly associated with an increased incidence of root fractures[6-8]. For this reason, in order to prevent weakening of the root, the preparation of the coronal region of the root should be performed carefully[9]. In addition, it is known that the coronal region of the root is the most sensitive part of the tooth structure to fracture caused by functional and nonfunctional occlusal forces, and this region is affected by root canal preparation[10,11].

From the *Department of Endodontics, †Department of Pediatric Dentistry, School of Dentistry, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye

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

İ.E. and B.S. designed the study; İ.E. collected the data; B.S. analyzed the data; B.S. wrote the manuscript, and all authors read and approved the final manuscript.

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Address requests for reprints to Dr Berkant Sezer, Department of Pediatric Dentistry, School of Dentistry, Çanakkale Onsekiz Mart University, Çanakkale, 17100, Türkiye.
E-mail address: berkant.sezer@comu.edu.tr or dt.berkantsezer@gmail.com
0099-2399/$ - see front matter

Copyright © 2023 American Association of Endodontists.
https://doi.org/10.1016/j.joen.2023.05.020

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.

While intracanal restorations such as fiber posts are applied to teeth with different amounts of residual tooth structure, the intracanal space in the coronal part of the root is used as a basis for the strength of the restoration[12,13].

Traditionally used endodontic hand files are stainless steel instruments and are still an option for root canal treatment. However, these manually used instruments are time consuming and can lead to various iatrogenic errors[14]. Ni-Ti instruments have been developed to eliminate the difficulties in the use of stainless-steel instruments[15].

The recent development of tools and alloys has led to the improvement of more up-to-date file systems, such as WaveOne Gold (WOG) (Dentsply Maillefer, Ballaigues, Switzerland), the reciprocating single file system that changes movement of 170° counterclockwise and 50° clockwise with a reverse helix and a semiactive guiding tip[16,17]. This is a single-file system that applies a special heat treatment to instruments to achieve improved physical properties (gold alloy technology). According to the manufacturer, the tip diameters, tapers, and cross-section of the instrument have been modified to increase file flexibility compared to previous WaveOne system (Dentsply, Tulsa Dental)[18].

The TruNatomy (TRN) File System (Dentsply Maillefer, Ballaigues, Switzerland) are instruments with a special design, heat-treated with an off-center parallelogram square section, produced to increase resistance to fatigue and increase elasticity[19,20]. TRN shaping instruments are given in three distinct sizes: small (20/0.04 taper), prime (26/0.04 taper), and medium (36/0.03 taper). The system has a regressive taper and a smaller initial wire blank of 0.8 millimeters (mm) diameter in the shaping files[19].

Numerous methods have been used to assess canal shape before and after preparation to investigate the effectiveness of instruments and techniques developed for root canal preparation. During the decision-making process on the choice of reciprocal or rotary instruments, the effectiveness they exhibit during the cleaning and shaping processes and the changes in the anatomy and structure of the root canals should be evaluated. For this purpose, the best way to perform a more accurate evaluation is through the use of micro-computed tomographicimaging[21,22]. However, micro-computed tomographic imaging has some disadvantages, such as its high-cost and time-consuming nature[23,24]. As an alternative, cone-beam computed tomography (CBCT) imaging stands out as a noninvasive technique for analyzing the canal geometry and evaluating the effectiveness of shaping techniques in three-dimensions (3D). It is possible to make an accurate analysis by comparing the 3D anatomical structure of the root canals before and after preparation with CBCT[24-27].

The aim of this *in vitro* study was to evaluate and compare the effectiveness of stainless-steel conventional hand files, reciprocal Ni-Ti files (WOG), and rotary Ni-Ti files (TRN) in root canal preparation, as well as the percentage reduction of dentin volume with preparation in the coronal 2-mm region of the root canals. The null hypothesis of the study is that there was no difference in remaining dentin volume in the coronal 2-mm region of the root and in the entire root canal space after root canal preparation with three different file systems.

MATERIALS AND METHODS

This *in vitro* study was approved by the Çanakkale Onsekiz Mart University Clinical Research Ethics Committee (with application number of 2022-92). This study followed the Checklist for Reporting *in-vitro* Studies guidelines. Patients who applied to the Oral Diagnosis Clinics of School of Dentistry, Çanakkale Onsekiz Mart University between June and November 2022 were examined by a dentist who was blinded about the study, and a treatment plan was created. Detailed information about the study was given to the patients who had teeth that were indicated for extraction and met the inclusion criteria. After obtaining verbal consent, a detailed informed consent form was signed. The study was carried out in accordance with all the ethical principles of the Helsinki Declaration. The inclusion criteria for the teeth were as follows: mandibular permanent first and second molars, teeth without root fracture and external or internal root resorption symptoms, teeth without prosthetic crown restoration, teeth without radicular caries, teeth without partial or complete obliteration of root canals, teeth that have not undergone root canal treatment before, and teeth with a root angle of less than 20°. Tooth extraction was performed by a maxillofacial surgeon who was blinded to the study. After extraction, the residuary tissues on the root surface of the extracted teeth were eliminated with a brush under irrigation with sterile saline, and the teeth were examined with a headlamp and loupe for potential perforations, fractures, developmental root anomalies, and/or root caries. Teeth were then stored in a 0.1% thymol solution until used for study within 1 month.

Sample Size Calculation

G*Power statistical software (v. 3.1.9.6, Universitat Kiel, Kiel, Germany) was used to calculate the sample size. Based on the data from Reddy et al[28], which showed that the statistically significant differences between the ProTaper (Dentsply Maillefer) (0.32 ± 0.04 mm) and Reciproc Blue (FKG Swiss Endo) (0.25 ± 0.07 mm) study groups in the thickness of root canal dentin removed at the apical root canal at a seven-mm section, a total sample size of 32 was calculated to be enough to achieve power of 95% at 1.228 effect size with a significance level (α) set at 0.05. Considering the 10% dropout risk, the minimum sample size of the study was determined as 12 for each group and a total of 36. Thus, the study was carried out on 36 mandibular permanent molars, whose extraction is indicated for various reasons.

Randomization, Access Cavity Preparation, and Initial Imaging

Periapical radiographs were first taken from the extracted teeth, and they were checked again for root angles or inclusion criteria. Thirty-six permanent mandibular molar teeth that met the inclusion criteria were grouped with 12 teeth in each group using the random integer generator tool of the random.org website. Teeth were numbered from 1 to 12 in each group. If any, coronal caries, or fillings, were cleaned from all teeth with the help of an aerator (NSK, Japan), and a suitable access cavity was prepared. The teeth were lined up in order of numbers, and the surrounding area was covered with wax in groups of six. The long axis of the teeth was placed in the tomography device to be compatible with the cross-sections in the image to be obtained. 3D images of all teeth were obtained with CBCT in 3D high-resolution (Hi-Res) denture scan mode with 100 micron voxel size and 8*5 field of view (FOV) area (NewTom 5G XL CBCT device, Tokyo, Japan) at 110 peak kilovoltage, 12 mA, and 9 seconds exposure time right after the access cavities were prepared, so teeth have become ready for the root canal preparation phase. Thus, images of six teeth were obtained together in each exposure.

Preparation of Root Canals

All procedures related to root canal preparation were performed by an experienced single endodontist (İ.E.) in line with the manufacturer's recommendations.

Conventional Hand Files

The root canals were prepared with conventional hand instrumentation using stainless steel hand files (DiaDent, K files, Burnaby, Canada) sizes 10–40 to working length with a filing motion using an Ethylenediaminetetraacetic Acid (EDTA)-containing gel (Cerkamed, Stalowa Wola,

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.

TABLE 1 - The Mean, Standard Deviation, Minimum and Maximum Values of the Pre and Postpreparation Dentine Volumes, and Mean Difference for Each Group

	Mean	SD	Min.	Max.	*P* value*
Preprep. dentine volume (mm^3)					
Hand files	113.44	18.21	91.48	146.68	>.05
WaveOne Gold	124.29	21.82	89.83	159.33	
TruNatomy	129.35	17.16	106.60	164.66	
Postprep. dentine volume (mm^3)					
Hand files	103.85	18.93	77.40	133.03	>.05
WaveOne Gold	114.39	21.39	80.65	154.00	
TruNatomy	122.61	18.42	101.30	159.12	
Mean difference					
Hand files	9.58	7.39	2.36	29.10	>.05
WaveOne Gold	9.89	3.86	5.33	17.66	
TruNatomy	6.73	4.76	2.90	19.77	

Max., maximum; Min., minimum; mm^3, millimeter cube; Postprep., postpreparation; Preprep., prepreparation; SD, standard deviation.
*One-way ANOVA.

Poland) as a lubricant. Canals were irrigated with 1.5 ml of 5.25% sodium hypochloride (NaOCl) after each file with a 27-gauge needle (Ayset Medical Products) placed three-mm short of their working length and a final 1.5 ml rinse to complete a total of 9 ml of NaOCl. The effective preparation time of the canal did not exceed five minutes[29].

WaveOne GoldFiles

The root canal was prepared using one new WOG (Dentsply Maillefer, Ballaigues, Switzerland) primary file (size 25, .07 taper) activated in a VDW Gold Reciproc motor (VDW, Munich, Germany), at the RESIPROC ALL setting, adjusted for reciprocating motion at 350 rpm speed. The file was used with a short up-and-down motion with minor apical pressure in three cycles, 1 to prepare each third of the canal (coronal, middle, and apical) using an EDTA-containing gel as a lubricant. After each cycle, the file was cleaned with wet gauze to remove dentine debris and the EDTA-containing gel, and the canal was irrigated with 3 ml of 5.25% NaOCl using a 27-gauge needle placed three mm short of its working length to complete a total of 9 ml of NaOCl for each canal. The effective working time of the file inside the canal did not exceed 1 minute[29].

TruNatomyFiles

The root canal was prepared using TRN instruments (Dentsply Maillefer, Ballaigues, Switzerland) operated with the X-Smart Plus endodontic motor (Dentsply Sirona, Tulsa, OK), adjusted at 500 rpm and 1.5 Ncm torque following the manufacturer's instructions. A TRN orifice modifier was used in the coronal 1/3 of the root, followed by a TRN glider and the primary instrument. All the files were used with two to three gentle 2–5 mm movements into the root canal; the file was then withdrawn, its grooves were cleaned, and the canal was irrigated with 3 ml of 5.25% NaOCl using a 27-gauge needle placed 3 mm short of its working length to complete a total of 9 ml of NaOCl for each canal[30].

After the preparation processes were finished for all three groups, 3D images of the teeth were obtained again with the same parameters and in the same order on the same CBCT device to be able to compare the obtained data before and after preparation.

TABLE 2 - The Percentage (%) Difference of Dentine Volume Removed in the Coronal Two-mm Region of the Root

	% Difference		
Files type	**Hand files**	**WaveOne Gold**	**TruNatomy**
Sample number			
1	1.86	5.19	8.53
2	4.85	13.08	7.17
3	8.71	7.87	2.69
4	2.20	6.78	3.31
5	9.31	7.58	2.38
6	5.41	10.23	4.75
7	7.84	7.34	1.92
8	8.10	3.35	4.98
9	16.70	12.96	2.85
10	6.20	7.45	3.37
11	6.32	6.76	6.33
12	24.88	8.15	15.60
Mean % difference	8.53	8.06	5.32
P value*	>.05		

*One-way ANOVA with Tukey's post hoc test. The mean difference is significant at the .016 level.

Evaluation of Three-Dimensional Images

The pre and postpreparation tomographic images of each tooth were transferred one by one to the image processing software (3D-Doctor Modeling Software, Able Software Corporation, Lexington, KY) in Digital Imaging and Communications in Medicine format. After the transfer of the images, the base of the pulp chamber was detected in the axial images. Then, two-mm more apically were descended from this section[31]. The segmentation process was performed semiautomatically by choosing a range of gray tones that encompasses the density of the dentin, and each section was examined individually, so the selection status of the region to be segmented was adjusted. Subsequently, related fields were modeled in 3D in "Stereolithography" (.stl) format, and volumetric data were recorded. The same procedure was repeated for the before and after images for the entire canal cavity, from the canal entrance to the radiological apex. Thus, volume changes due to preparation in the entire root canal and coronal two-mm region of the root were recorded. In addition, the amount of dentin reduction in the coronal two-mm region of the root by dentin volume before preparation was also calculated as a percentage. Thus, the amount of volume change of the dentin in the coronal two-mm region of the root was determined.

Statistical Analysis

Variables were expressed as the mean, standard deviation, minimum, and maximum values. All statistical analyses were performed using the SPSS software version 26.0 (SPSS Version 26.0, International Business Machines Corporation, Chicago, IL). The normality of the data distribution was examined using the Kolmogorov-Smirnov test, whereas

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.

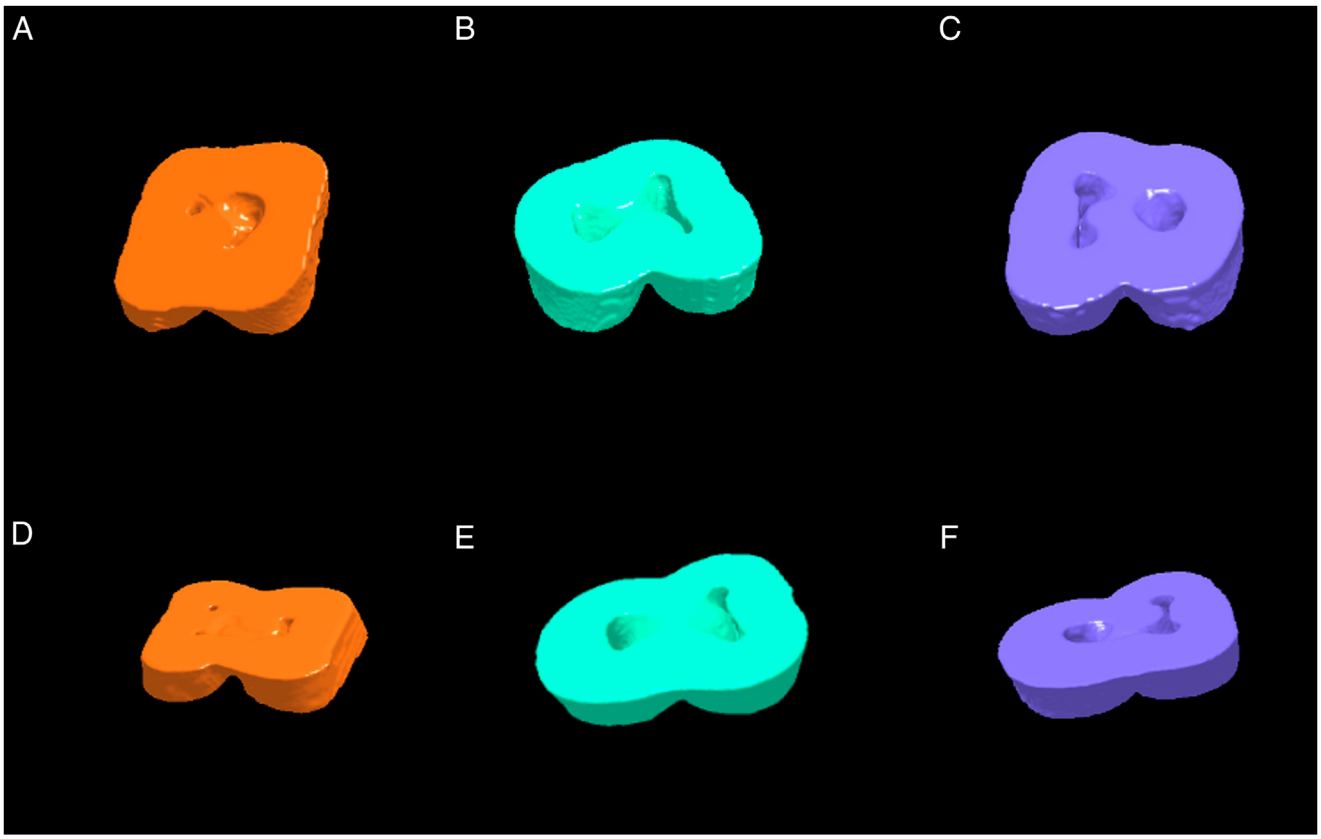


FIGURE 1 – Three-dimensional modeling of the coronal two-mm region of the root before and after preparation with different file systems. The top line shows the prepreparation models, the bottom line shows the postpreparation models. From left to right, preparations were made with hand files (*A*, *D*), and WaveOne Gold (*B*, *E*), and TruNatomy (*C*, *F*) file systems, respectively.

homogeneity was tested using Levene's test. The comparison of group means was made using a one-way ANOVA, and post hoc analyses were performed with Tukey's test. The statistical significance level was determined to be 0.05 in all analyses.

RESULTS

There was no statistical difference between the groups in terms of pre and postpreparation dentin amounts in the coronal two-mm region of the root (Table 1) ($P > .05$). That is, there was volumetric compatibility in the coronal two-mm region of the root included in the groups. The volumetric difference in the coronal two-mm region of the root after preparation was 9.58 mm^3, 9.89 mm^3, and 6.73 mm^3 for hand files, WOG, and TRN, respectively. There was not a statistically significant difference between groups in terms of volumetric decrease in the coronal two-mm region of the root ($P > .05$).

Considering the percentage change in the amount of dentin reduction in the coronal two-mm region of the root, it was found to be 8.53%, 8.06%, and 5.32% for hand files, WOG, and TRN, respectively (Table 2). Similarly, no statistically significant difference was found between the percentage changes ($P > .05$), which is consistent with the volumetric change results. Although it was not statistically significant, the least change in the amount of dentin in the coronal two-mm region of the root, both in percentage and volume, was measured in the TRN group. The dentin volume reduction in the coronal two-mm region of the root before preparation and the remaining dentin volume in this region after the preparation with different file systems are shown in Figure 1. While Figure 1*A–C* are the

TABLE 3 - The Mean, Standard Deviation, Minimum and Maximum Values of the Pre and Postpreparation Entire Root Canal Cavity Volume and the Mean Difference for Each Group

	Mean	SD	Min.	Max.	*P* value*
Preprep. root canal space (mm^3)					
Hand files	10.58	6.77	4.68	26.75	>.05
WaveOne Gold	12.27	4.86	3.79	22.57	
TruNatomy	11.59	4.57	3.28	20.72	
Postprep. root canal space (mm^3)					
Hand files	13.59	7.42	5.03	29.35	>.05
WaveOne Gold	15.51	5.46	4.56	23.37	
TruNatomy	14.03	4.92	5.66	23.37	
Mean difference					
Hand files	3.00	2.11	0.35	7.64	>.05
WaveOne Gold	3.25	2.02	0.77	8.01	
TruNatomy	2.44	1.22	0.02	4.31	

Max., maximum; Min., minimum; mm3, millimeter cube; Postprep., postpreparation; Preprep., prepreparation; SD, standard deviation.
*One-way ANOVA.

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.

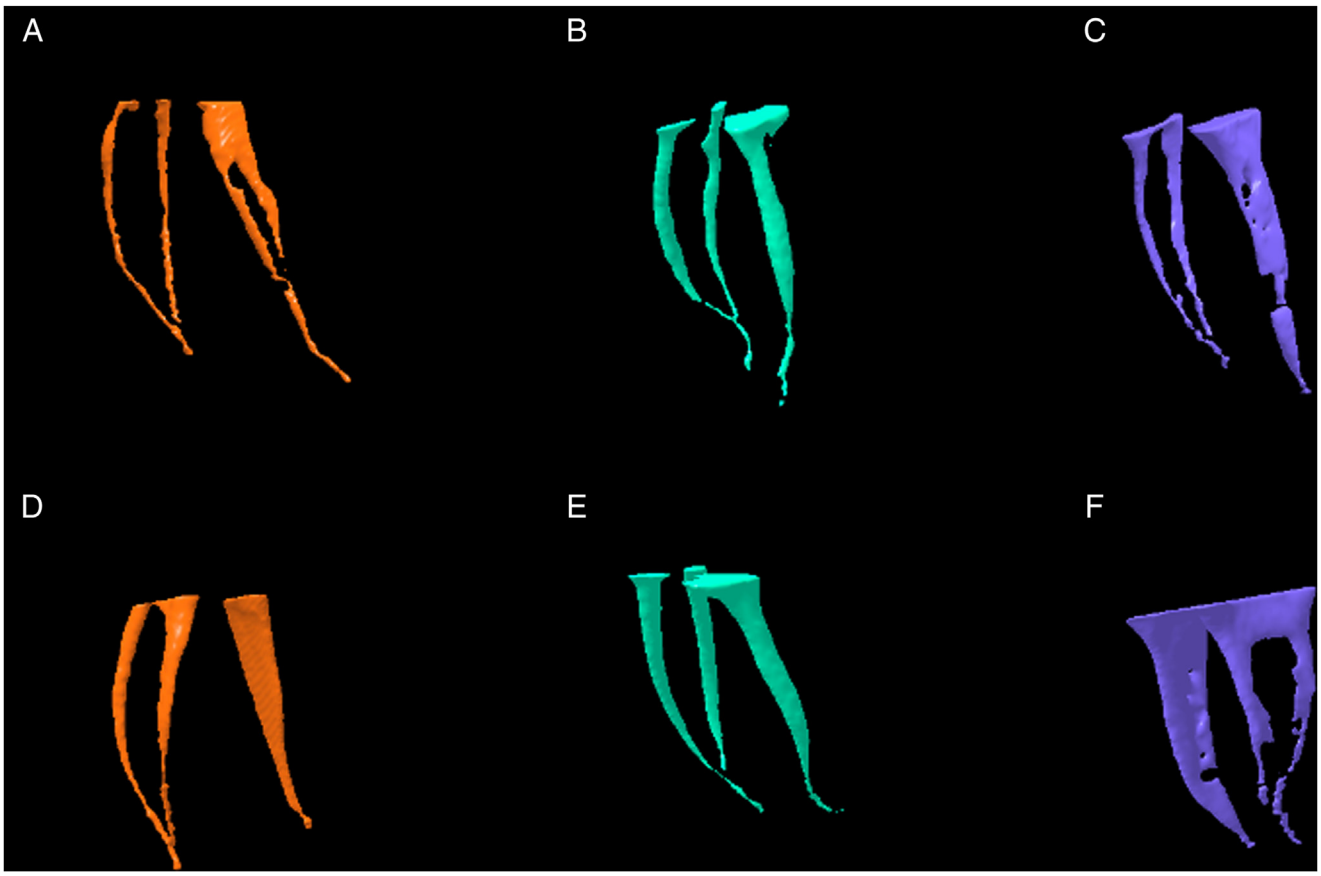


FIGURE 2 – Three-dimensional modeling of the entire root canal volume before and after preparation with different file systems. The top line shows the prepreparation models, the bottom line shows the postpreparation models. From left to right, preparations were made with hand files (*A*, *D*), and WaveOne Gold (*B*, *E*), and TruNatomy (*C*, *F*) file systems, respectively.

prepreparation images taken with hand files, WOG, and TRN, respectively, Figure 1*D–F* are the postpreparation 3D images in the same order.

Table 3 shows the volume of the entire root canal cavity from the canal entrance to the radiological apex pre and postpreparation with three different instrumentation files. There were no statistically significant results in terms of mean volumes of before and after preparation between the three groups ($P > .05$). It was observed that there was no statistically significant difference when the volumetric expansion amounts of each instrumentation system in the entire root canal cavity were compared ($P > .05$). The mean volumetric differences were found to be 3.00 mm^3, 3.25 mm^3, and 2.44 mm^3 for hand files, WOG, and TRN, respectively. This result showed statistically that all three systems were similarly effective in terms of the prepared dentin volume in the entire root canal cavity. The change in the volume of the entire root canal space pre and postpreparation with different file systems is shown in Figure 2. While Figure 2*A–C* are the prepreparation images taken with hand files, WOG, and TRN, respectively, Figure 2*D–F* are the postpreparation 3D images in the same order.

DISCUSSION

Developments in modern endodontic preparation protocols and instrumentation systems have focused on the concept of minimally invasive endodontics and, accordingly, the preservation of root and pericervical dentin. This study compared conventional hand files, WOG, which works with reciprocating motion, and TRN, which works with rotational motion, for their effects in the coronal two-mm region of the root and preparation efficiency of permanent mandibular molars.

Restoration of a root canal-treated tooth is highly complex due to dental caries, an existing restoration, trauma, and endodontic access cavity preparation of most or all of the coronal tooth structure that would normally be used in the retention of a restoration. Insufficient dentin volume and thickness may require the use of a post and core or coronal-radicular core to sustain restoration[32]. The amount and volume of dentin removed from the root and remaining in the root have been the subject of some studies in terms of restoration of the remaining tooth structure in nonvital teeth. It is generally accepted that the ferrule design, which provides coronal dentin above the finish line, increases the fracture resistance of root canal-treated teeth[33]. In addition, preservation of pericervical dentin is essential to maintain the biomechanical response of radicular dentin[34]. In this study, the remaining dentin volume in the coronal two-mm region of the root was evaluated after root canal preparation using three different file systems, and no significant difference was observed in prepreparation and postpreparation measurements in all three groups. In the study of Tomer et al[35], in which they evaluated the impact of three different and current rotary files on the dentin thickness of permanent teeth after root canal treatment using CBCT, it was concluded that the ProTaper Gold system removed more dentin from the root than Revo-S and NeoEndo[35]. Kumar et al[36] evaluated the amount of

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.

remaining dentin after biomechanical root-canal preparation with five different rotary Ni-Ti file systems, and it was reported that there was no statistically significant difference between the groups at three-, five-, and seven-mm distances in the buccolingual direction[36]. Chaudary et al[37] evaluated the effects of manual Protaper, rotary Mtwo, and reciprocal WaveOne systems on cleaning efficiency and remaining dentin thickness. In conclusion, the authors stated: WaveOne is a highly recommended rotary endodontic instrument that does not cause a significant lowering in remaining dentin thickness after biomechanical preparation[37]. Recent studies indicate that the root width and thickness of the remaining dentin do not significantly affect the treatment success, but the nonhealed roots show lower remaining dentin thickness values than the properly healed roots[38]. Therefore, as mentioned, although different findings have been obtained in many studies evaluating the effects of different file systems on the amount and volume of remaining dentin, the amount of remaining dentin is important for both root healing and the restoration of the remaining tooth structure.

In line with the development of minimally invasive endodontics in recent years, many rotary file systems have been introduced by different companies. These have been the subject of various studies with the claim that they are superior to each other in different subjects. In this regard, the WOG and TRN file systems have been playing with various advantages in recent years. When the articles that include both file systems in their studies are examined, TRN has been reported to preserve the original apical canal curvature better than WOG in S-shaped curved canals[39]. Roshdy and Hassan[30] reported that WOG produced less extruded debris than TRN in curved canals. On the other hand, in a study evaluating the effects of TRN, WOG, 2Shape, ProTaper Next, and Reciproc Blue file systems on the amount of apically extruded debris, it was reported that TRN produced statistically significantly less debris than all other systems[40]. Bhojwani et al[41] evaluated postoperative pain at different times after root canal treatments with WOG and TRN file systems in teeth with irreversible pulpitis and stated that the probability of pain after preparation with TRN was higher than that after preparation with WOG, and they attributed this result to more apical extrusion of debris in preparation with TRN. However, the preparation efficiencies of both systems are also important at this point[41]. It has also been reported that TRN preserves the original curvature better than WOG after root canal preparation[42]. Besides all these, no statistically significant difference was observed in terms of dentin removal performance between conventional hand files, WOG, and TRN throughout the entire root canal during preparation. This study focuses on the volume of dentin prepared, unlike the study by Shaheen et al[42], that dealt with the original curvature changes. When the results of both studies are evaluated together, it can be concluded that TRN shows the same preparation efficiency as WOG without causing any anatomical changes in the root canals.

The results of the aforementioned studies show that these file systems may have advantages over each other in various subjects. There seems to be no study evaluating the remaining dentin volume or thicknesses in the coronal two-mm region of the root of these file systems in mandibular permanent molars. In the current study, no statistical significance was observed between the conventional hand files, WOG, and TRN in terms of the remaining dentin volume after preparation. In addition, after the preparation with all three file types, there was no statistically significant difference between the groups in the volume of the entire root canal space. Therefore, the null hypothesis of the current study was accepted. As a result, this situation will guide clinicians in the use of these current file systems, especially considering that they have been evaluated for the first time in the scientific literature.

This study has some strengths and limitations. The selection of all teeth included in the study by following the inclusion criteria and grouping them by randomization method can be qualified as strengths. It is also important that all preparations are made by a single, trained endodontist to avoid bias. Although this study used *in vitro* methodology, its results point to an important issue; the choice made by considering the anatomical and morphological structure of the roots of the files used in the root canal treatment of permanent mandibular molar teeth. Therefore, in future studies, new instrumentation protocols should be tried with files developed in line with different physical and mechanical properties. In addition, clinical studies should be conducted to compare these files to determine the effect of the mechanical preparation technique on the success of endodontic treatment and to determine the amount of dentin remaining in the root in order to achieve ideal treatment results.

ACKNOWLEDGMENTS

The authors thank Prof. Hakan Eren for his support and assistance in the imaging and image evaluation process.

REFERENCES

1. de Pablo OV, Estevez R, Péix Sánchez M, et al. Root anatomy and canal configuration of the permanent mandibular first molar: a systematic review. J Endod 2010;36:1919–31.
2. Amato M, Pantaleo G, Abtellatif D, et al. An *in vitro* evaluation of the degree of pulp tissue dissolution through different root canal irrigation protocols. J Conserv Dent 2018;21:175–9.
3. Manchanda S, Sardana D, Yiu CKY. A systematic review and meta-analysis of randomized clinical trials comparing rotary canal instrumentation techniques with manual instrumentation techniques in primary teeth. Int Endod J 2020;53:333–53.
4. Pedullà E, Kharouf N, Caruso S, et al. Torsional, static, and dynamic cyclic fatigue resistance of reciprocating and continuous rotating nickel-titanium instruments. J Endod 2022;48:1421–7.
5. El Abed R, Alshehhi A, Kang YJ, et al. Fracture resistance of heat-treated nickel-titanium rotary files after usage and autoclave sterilization: an *in vitro* study. J Endod 2022;48:1428–33.

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.

6. Brasil SC, Marceliano-Alves MF, Marques ML, et al. Canal transportation, unprepared areas, and dentin removal after preparation with BT-RaCe and ProTaper next systems. J Endod 2017;43:1683–7.

7. Shemesh H, Roeleveld AC, Wesselink PR, et al. Damage to root dentin during retreatment procedures. J Endod 2011;37:63–6.

8. Adorno CG, Yoshioka T, Jindan P, et al. The effect of endodontic procedures on apical crack initiation and propagation *ex vivo*. Int Endod J 2013;46:763–8.

9. Rodrigues RCV, Zandi H, Kristoffersen AK, et al. Influence of the apical preparation size and the irrigant type on bacterial reduction in root canal-treated teeth with apical periodontitis. J Endod 2017;43:1058–63.

10. Nawar NN, Kataia M, Omar N, et al. Biomechanical behavior and life span of maxillary molar according to the access preparation and pericervical dentin preservation: finite element analysis. J Endod 2022;48:902–8.

11. Lin CY, Lin D, He WH. Impacts of 3 different endodontic access cavity designs on dentin removal and point of entry in 3-dimensional digital models. J Endod 2020;46:524–30.

12. Hou QQ, Gao YM, Sun L. Influence of fiber posts on the fracture resistance of endodontically treated premolars with different dental defects. Int J Oral Sci 2013;5:167–71.

13. Arunpraditkul S, Saengsanon S, Pakviwat W. Fracture resistance of endodontically treated teeth: three walls versus four walls of remaining coronal tooth structure. J Prosthodont 2009;18:49–53.

14. Hariprasad R, Anoop VN, Raj PR, et al. Evaluation of crack propagation after root canal preparation with continuous and reciprocating files and final finishing with XP endo finisher - an *in vitro* study. J Pharm BioAllied Sci 2021;13:S1700–4.

15. Shaik RT, Uppalapati SVV, Uppu LN, et al. Cone-beam computed tomography assessment of canal-centering ability for traditionally used nickel titanium and nickel titanium files with reciprocating hand piece and wave-one files. J Pharm BioAllied Sci 2021;13:S88–91.

16. Özyürek T. Cyclic fatigue resistance of reciproc, WaveOne, and WaveOne gold nickel-titanium instruments. J Endod 2016;42:1536–9.

17. Thomas J, Lynch M, Paurazas S, et al. Micro-computed tomographic evaluation of the shaping ability of wave one gold, TRUShape, EdgeCoil and XP-3D shaper endodontic files in single, oval-shaped canals: an *in vitro* study. J Endod 2020;46:244–51.

18. Ruddle CJ. Single-file shaping technique. Available at: https://www.dentsplysirona.com/content/dam/dentsply/pim/manufacturer/Endodontics/Glide_Path__Shaping/Rotary__Reciprocating_Files/Shaping/WaveOne_Gold_Reciprocating_Files/WaveOneGold_Jan2016%20Ruddle_WPaper.pdf. Accessed May 15, 2023.

19. Peters OA, Arias A, Choi A. Mechanical properties of a novel nickel-titanium root canal instrument: stationary and dynamic tests. J Endod 2020;46:994–1001.

20. Kabil E, Katić M, Anić I, et al. Micro-computed evaluation of canal transportation and centering ability of 5 rotary and reciprocating systems with different metallurgical properties and surface treatments in curved root canals. J Endod 2021;47:477–84.

21. de Siqueira Zuolo A, Zuolo ML, da Silveira Bueno CE, et al. Evaluation of the efficacy of TRUShape and reciproc file systems in the removal of root filling material: An *ex vivo* micro-computed tomographic study. J Endod 2016;42:315–9.

22. Da Silva AG, Braitt A, De Martin A, et al. Micro-computed tomographic evaluation of 2 nickel titanium instrument systems in shaping root canals. J Endod 2016;42:496–9.

23. Nair MK, Nair UP. Digital and advanced imaging in endodontics: a review. J Endod 2007;33:1–6.

24. Zhang D, Chen J, Lan G, et al. The root canal morphology in mandibular first premolars: a comparative evaluation of cone-beam computed tomography and micro-computed tomography. Clin Oral Investig 2017;21:1007–12.

25. Gergi R, Rjeily JA, Sader J, et al. Comparison of canal transportation and centering ability of twisted files, path file-protaper system, and stainless steel hand K-files by using computed tomography. J Endod 2010;36:904–7.

26. Bernardes RA, Rocha EA, Duarte MA, et al. Root canal area increase promoted by the endo sequence and pro taper systems: comparison by computed tomography. J Endod 2010;36:1179–82.

27. Venskutonis T, Plotino G, Juodzbalys G, et al. The importance of cone-beam computed tomography in the management of endodontic problems: a review of the literature. J Endod 2014;40:1895–901.

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.

28. Reddy KS, Prasad SD, Kumar CS, et al. Comparison of remaining root dentine thickness after three rotary instrumentation techniques by cone beam computerised tomography-an *in vitro* study. J Res Adv Dent 2014;3:32–9.

29. Caviedes-Bucheli J, Rios-Osorio N, Rey-Rojas M, et al. Substance P and calcitonin gene-related peptide expression in human periodontal ligament after root canal preparation with reciproc blue, WaveOne gold, XP EndoShaper and hand files. Int Endod J 2018;51:1358–66.

30. Roshdy NN, Hassan R. Quantitative evaluation of apically extruded debris using TRUShape, TruNatomy, and WaveOne gold in curved canals. BDJ Open 2022;8:13.

31. Yılmaz F, Eren İ, Eren H, et al. Evaluation of the amount of root canal dentin removed and apical transportation occurrence after instrumentation with protaper next, oneshape, and edgefile rotary systems. J Endod 2020;46:662–7.

32. Bandlish RB, McDonald AV, Setchell DJ. Assessment of the amount of remaining coronal dentine in root-treated teeth. J Dent 2006;34:699–708.

33. Al-Wahadni A, Gutteridge DL. An *in vitro* investigation into the effects of retained coronal dentine on the strength of a tooth restored with a cemented post and partial core restoration. Int Endod J 2002;35:913–8.

34. Clark D, Khademi J. Modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010;54:249–73.

35. Tomer AK, Miglani A, Chauhan P, et al. An *in-vitro* evaluation of remaining dentine thickness through CBCT using different files. IOSR J Dent Med Sci 2017;16:121–4.

36. Kumar T, Mittal S, Keshav V, et al. A comparative evaluation of remaining dentin thickness following biomechanical preparation of teeth using different rotary file systems: an *in vitro* study. J Conserv Dent 2022;25:32–6.

37. Chaudhary NR, Singh DJ, Somani R, et al. Comparative evaluation of efficiency of different file systems in terms of remaining dentin thickness using cone-beam computed tomography: an *in vitro* study. Contemp Clin Dent 2018;9:367–71.

38. Glera-Suárez P, Pallarés-Serrano A, Soto-Peñaloza D, et al. Influence of root width and dentin wall thickness evaluated by endoscopy upon the outcome of periapical surgery. A cohort study. Med Oral Patol Oral Cir Bucal 2022;27:e383–91.

39. Kim H, Jeon SJ, Seo MS. Comparison of the canal transportation of ProTaper GOLD, WaveOne GOLD, and TruNatomy in simulated double-curved canals. BMC Oral Health 2021;21:533.

40. Abduljalil M, Andac G, Basmaci F. Impacts of different nickel-titanium rotary and reciprocating root canal preparation systems on the amount of apically extruded debris. Aust Endod J 2022 [Epub ahead of print].

41. Bhojwani PR, Paryani MJ, Mankar N, et al. The comparative evaluation of postoperative pain after the use of WaveOne Gold and TruNatomy filing systems in a tooth with irreversible pulpitis: an observational study. Cureus 2022;14(10):e30707.

42. Shaheen NA, Elhelbawy NGE. Shaping ability and buckling resistance of TruNatomy, WaveOne Gold, and XP-endo shaper single-file systems. Contemp Clin Dent 2022;13:261–6.

Downloaded for Anonymous User (n/a) at Çanakkale Onsekiz Mart University from ClinicalKey.com by Elsevier on October 24, 2023. For personal use only. No other uses without permission. Copyright ©2023. Elsevier Inc. All rights reserved.