https://doi.org/10.48047/AFJBS.6.15.2024.8903-8933

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Apical Transportation Induced by Reciprocating Files in Removal of Guttacore and Single-Cone from Curved Root Canals: A Micro-CT Analysis

Abdulkareem Ramadhan Ibrahim[1], Regir Ramadhan Hassan[2*]

[1] Department of Conservative Dentistry, College of Dentistry, University of Duhok, Kurdistan Region-Iraq.

[2] Department of Conservative Dentistry, College of Dentistry, University of Duhok, Kurdistan Region-Iraq.

***Corresponding author: Regir Ramadhan Hassan[*]**

Regir.mezori@gmail.com

Volume 6, Issue 15, Sep 2024

Received: 15 July 2024

Accepted: 25 Aug 2024

Published: 05 Sep 2024

doi: 10.48047/AFJBS.6.15.2024.8903-8933

ABSTRACT

Background: During the preparation process of root canals, endodontic instruments deviate from the long axis of the canal. This study aimed to assess and compare the apical transportation induced by different reciprocating single-file systems in curved canals. These canals were obturated with GuttaCore and single-cone obturation techniques using microcomputed tomography (m-CT).

Mehtods: A total of sixty-four mandibular molar teeth were selected, which have root canal systems with two independent severely curved canals in the mesial root. The root canals were first instrumented using the WaveOne Gold primary file and subsequently obturated using either the Single-cone or GuttaCore obturation techniques. Following the first m-CT scan, the samples were divided into four classes for each obturation technique (sixteen canals for every group). Next, these groups were categorized based on the retreatment system, as follows: group R) the Reciproc R25 file, group RB) the Reciproc Blue R25 file, group WO) the WaveOne primary file 25, and group WOG) the WaveOne Gold primary file 25. After the retreatment procedures, a second m-CT scan was conducted, and the apical transportation was calculated for analysis at 2, 3, and 4 mm from the apex. *Results:* In the Reciproc and WaveOne groups, apical transportation was significantly higher than in the Reciproc Blue and WaveOne Gold groups. *Conclusion:* Reciproc and WaveOne files have higher apical transportation than the Reciporc Blue and WaveOne Gold files. The lowest apical transportation occurred at 2 mm from the apex.

Keywords: Reciproc, Reciproc Blue, WaveOne, WaveOne Gold, GuttaCore, Single-cone, Severely Curved Root Canal, Micro-CT

1. Introduction

Root canal retreatment, a common procedure to treat teeth with failed previous root canal treatment aimed to remove the old filling material, disinfect the root canals, and then fill them with a new material [1]. In curved canals, the potential of apical transportation during filling removal is a challenge of root canal retreatment, resulting in the difficult achievement of adequate cleaning, disinfection, and refilling. In addition, apical transportation during root canal retreatment can increase the probability of apical extrusion, leading to the potential extrusion of irrigation solution, debris, and/or filling materials towards the apical area [2,3]. Single file systems have emerged as a significant advancement in endodontic instrument science, characterized by their cross-sectional design and alloy treatment. These files have demonstrated superior efficacy in root canal preparation than conventional multifile systems, particularly in addressing additional walls of the root canal system. Also, their enhanced mechanical properties are well-suited for the efficient removal of gutta-percha [4,5].

The Reciproc (VDW) and WaveOne (Dentsply Sirona) file systems, as single file systems with different cross-sectional designs, are used in reciprocation mode and developed utilizing M-Wire technology. Also, M-Wire files provide a safer option for use in curved canals due to their superior resistance to fatigue compared to traditional nickel-titanium (NiTi) alloy files [6,7]. The upgrade of Reciproc and waveOne single-file systems resulted in the development of the Reciproc Blue (VDW) and waveOne gold (Dentsply Sirona) file systems. These new systems are manufactured using an innovative heat treatment technique, which has significantly improved their strength and flexibility compared to the earlier versions [8-10].

The development of carrier-based obturation systems simplifies root-filling procedures. However, the removal of carrier-based systems can be more time-consuming and challenging in cases

requiring retreatment [11,12]. Dentsply Sirona, the manufacturer of Thermafil, has introduced a novel core-carrier system called GuttaCore, which replaces the traditional plastic carrier with a cross-linked gutta-percha core [13].

In endodontics, a tooth with straight root canals is uncommonly encountered since most teeth have some degree of curvature [14], leading to extreme difficulty in completely disinfecting the canals and removing the obturation material [15].

Micro-computed tomographic (m-CT) imaging reliably and non-invasively evaluates root canals in three dimensions (3D). A few studies compare the effects of different file systems on the removal of various obturation materials in severely curved canals during non-surgical retreatment procedures, specifically using m-CT imaging [16].

Therefore, the present study aimed to measure and compare the apical transportation induced in the removal of different obturation materials (single-cone and GuttaCore) for the curved root canal systems retreated with Reciproc, Reciproc Blue, WaveOne, and WaveOne Gold files using m-CT.

2. Material and methods

2.1.Sample selection

In the present study, a total of sixty-four extracted human lower (mandibular) molar teeth were included after meeting specific criteria. These teeth were soaked in a 0.1% thymol solution until they were ready for use. Prior to the experiment, Cone-Beam Computed Tomography (CBCT) was performed to ensure the inclusion criteria: mesial roots classified as type IV according to Vertucci's classification [17], complete formation of the apex, absence of canal calcification, no previous root canal treatments, and no external or internal resorption. Following access cavity preparation, standardized periapical radiographs measure the radius and angle of curvature of the teeth.

The root apex of each tooth was embedded in wax and mounted for radiography to ensure a consistent and stable position. A paralleling device was utilized, with the dental sensor positioned in a manner, in which the center of the X-ray beam was perpendicularly aligned to the root canal. The long axis of the root canal was kept parallel to the surface of the sensor.

For consistency, all radiographs were captured using the same source-to-sensor distance and object-to-sensor distance, along with identical exposure times. A computerized program, specifically designed for processing digital images (AutoCAD 2021 v.24.1 program), was utilized to calculate the degree of canal curvature and radius [18].

The angle and radius of the root canal curvatures were measured using Schneider's and Schafer's methods [19,20], respectively. Teeth with root canal curvatures were specifically selected, ranging from 25 to 40 degrees, and radius curvatures between 1.23 and 2.57 mm.

2.2.Preparation and instrumentation of the samples

The flattened teeth crowns with a diamond disc obtained an 18-mm tooth length, initially established with a digital caliper. A K-file no.10 was carefully inserted into the canal until it was visible at the apical foramen to determine the working length. Then, 0.5 mm was subtracted, and the remaining length was established as the working length. Furthermore, a no. 15 K-file was used to create a glide path in the canal prior to these measurements. Each tooth was placed in polyvinylsiloxane impression material and stabilized on a vise to clinically simulate the alveolar position. All endodontic procedures were performed with the roots in the aforementioned stabilized position [21].

The WaveOne Gold (Dentsply Sirona) primary file, along with the VDW Silver endomotor device, was used to instrument all of the canals; the endomotor device was set to the WaveOne all mode. The file was removed and cleaned, after each of the three pecking movements to instrument the canal. The canals were irrigated with 2 ml of 5.25% sodium hypochlorite (NaOCl). For the final irrigation, 1 ml of 17% EDTA was applied for 1 minute, followed by 1 ml of 5.25% NaOCl (for 30 seconds) and finally 1 ml of normal saline. Paper points were used to dry the root canals. The instrumented teeth were divided into two obturation techniques (32 teeth: 64 canals each), as follows: group SC: single-cone technique: using single point gutta-percha and AH Plus (Dentsply Sirona) canal paste and group GC: GuttaCore technique: using AH Plus (Dentsply Sirona) canal paste and a warmed gutta-percha carrier-based system (Dentsply Sirona) by heating a size 25 GuttaCore obturator in the ThermaPrep heater obturator oven (Dentsply Sirona). and subsequently introducing it into the root canal system at the working length. Following the manufacturer's instructions, the GuttaCore obturator was cut at the cement-enamel junction and compacted.

After the root canal obturation, the access cavities were sealed with temporary filling material (Cavit; 3 M ESPE, St Paul, MN), and teeth were stored for a week to allow the sealers to set in an incubator with 37°C temperature and humidity of 100%.

The m-CT device (Skyscan 1275 (Bruker microCT, Kontich, Belgium) was separately used for each sample scan, based on the following parameters: 18-µm isotropic voxel size with a copper-aluminum filter, x-ray voltage of 80 kV, 125 mA, 360 rotations, and a 0.3-rotation step. All the samples were then stored in an incubator at 37°C temperature and humidity of 100% for 1 month.

2.3.Removal of obturation material

The samples were randomly subdivided into 4 groups per each obturation technique, according to the used retreatment system. Each instrument was used in the removal of obturation materials from three canals in each group, as follows:

Group R: Reciproc system

The VDW endomotor was utilized with the Reciproc R25 file (tip size 25; variable taper 0.08) in reciprocation Reciproc All mode. According to the manufacturer's instructions, the file was apically advanced using an in-and-out pecking motion with an extent of 3-millimeter around; light apical pressure was also applied with a brushing motion on the lateral walls. After three pecking movements, the file was taken out of the canal, cleaned using sterile gauze, and irrigated with 5.25% sodium hypochlorite (NaOCl). This technique was repeated until the instrument reached the Working Length (WL).

Group RB: Reciproc Blue system

The obturation material was removed with the Reciproc Blue (RB) R25 file (tip size 25; variable taper 0.08) using the same retreatment technique described for Group R.

Group WO: Wave One system

The WaveOne (WO) 25.08 Primary file was utilized with the VDW motor set to reciprocation in WaveOne All mode. The retreatment technique was the same as that used in the previous groups.

Group WOG: Wave One Gold system

The WaveOne Gold (WOG) primary file (tip size 25; variable taper 0.07; Dentsply Sirona Endodontics) was implemented with the VDW motor set at reciprocation WaveOne all mode. Additionally, the retreatment technique was the same as that used in the previous groups.

Prior to each file reinsertion, around 2 mL of 5.25% NaOCl was used to irrigate the canal, and an overall of 20 ml was used for each canal. Following the retreatment procedures. A total of 3 ml of 17% EDTA was employed to effectively remove the smear layer, which was followed by the final rinsing protocol, including rinsing the canal with 3 ml of 5.25% sodium hypochlorite (NaOCl) for 30 seconds and a rinse with 1 ml of saline solution for an additional 30 seconds.

Retreatment finished when each instrument reached the WL five consecutive times with no remaining filling material visible on the file. The canals were dried with paper points. After the removal of obturation materials, the samples were individually scanned using the same m-CT device and the same parameters for the first scan.

2.4.Apical transportation evaluation

The horizontal cross-sectional m-CT images at 2-, 3-, and 4-mm levels from the apex were selected for the apical transportation evaluation. The apical transportation was measured during the pre-and post-retreatment periods using the method described by Prati et al, 1996 [as ,[21follows:

$$(X1 – X2) - (Y1 - Y2). \qquad \text{Eq (1)}$$

where X1 is the shortest distance from the mesial end of the canal to the mesial end of the root, and Y1 is the shortest distance from the distal end of the canal to the distal end of the root; X2 and Y2 are the shortest distances between the mesial and distal corners after the retreatment (Fig.**Figure 1**); the result 0 shows no apical transportation. Negative and positive results show that the transportation is toward the furcation (distal side), and transportation is backward (mesial side), respectively.

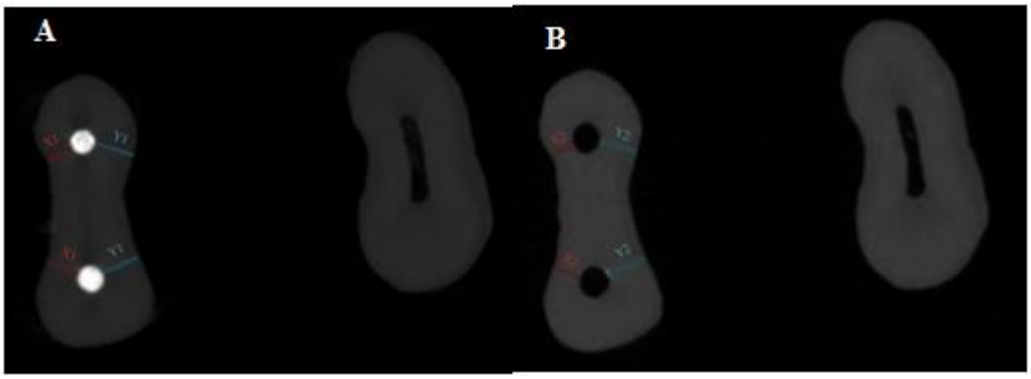

Fig.1. Illustration of the used method for measurement of dentin walls from mesial to distal for apical transportation (A) Post obturation (B) Post retreatment

2.5.Statistical analysis

The normality of the data was assessed using the Kolmogorov-Smirnov test, and statistical tests, such as Kruskal-Wallis, Mann-Whitney U, and Dunn tests were applied to compare the apical transportation between the experimental groups using IBM SPSS Statistics software (version 25.0; IBM Corp).

3. Results

All four files induced transportation to some extent (Fig.**2**)

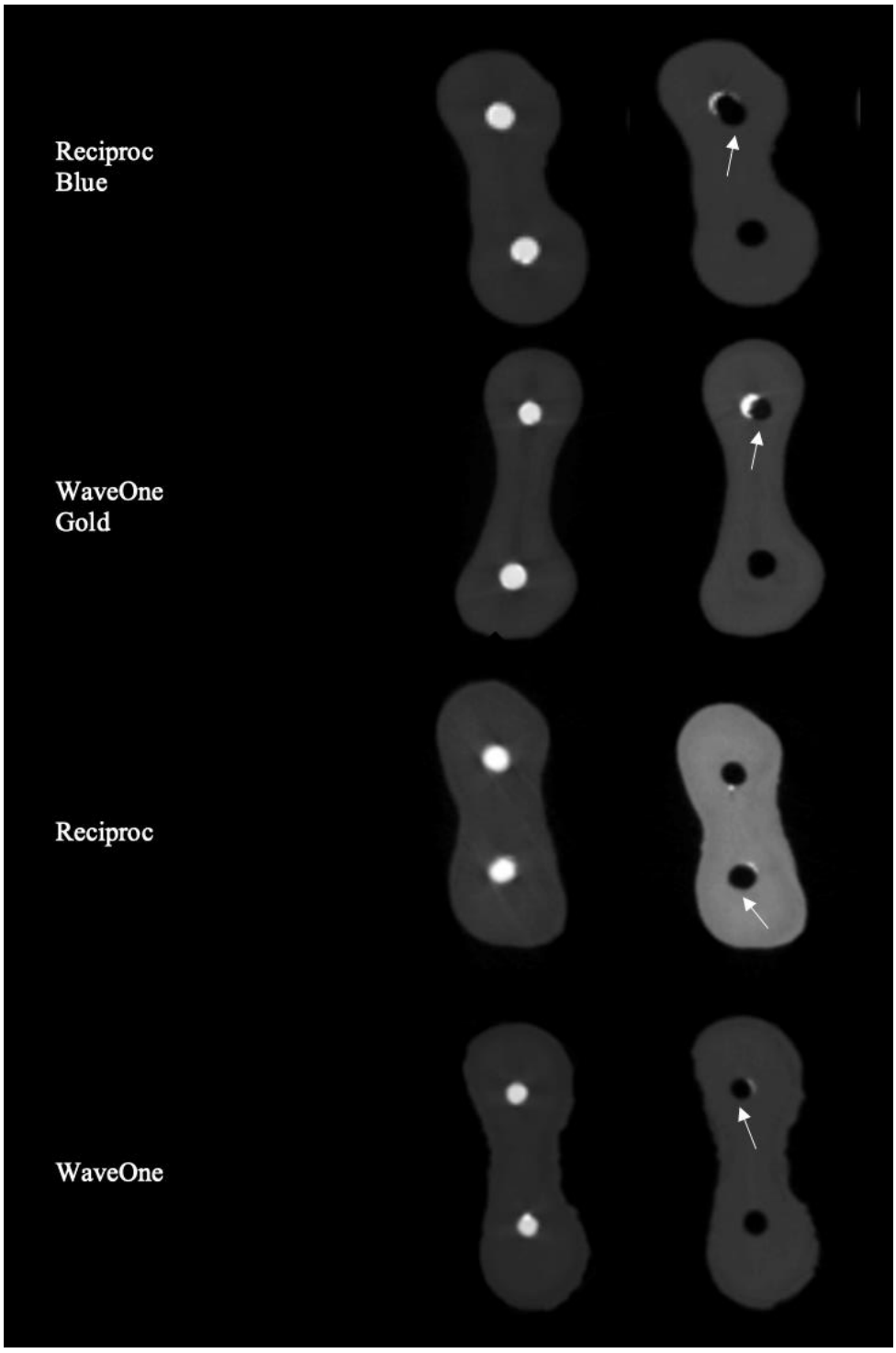

Fig.2. Apical transportation induced by the different reciprocating files

3.1.Apical transportation induced by different file systems used in the removal of single-cone obturation materials.

Table 1 and Figure 3 comprehensively summarize the descriptive and statistical analysis of both intergroup and intragroup results of apical transportation. The RBSC group exhibited the lowest mean value of apical transportation at the 4-millimeter level (-0.02 mm), while the RSC group demonstrated the highest value of apical transportation at the 4-millimeter level (0.127 mm). These findings highlight the variations in apical transportation among different groups and levels. The intergroup comparison revealed a statistically significant difference (*P-value* < .05) between all four groups at all measured levels. Specifically, the RSC and WOSC groups displayed significant differences compared to the RBSC and WOGSC groups. The RSC, WOSC, and WOGSC groups exhibited higher AT of the 4mm level (0.127 ± 0.074), (0.084 ± 0.12), and (0.032 ± 0.029), respectively when comparing the Apical Transportation (AT) at the three levels within each group after removal of obturation materials. In contrast, the RBSC group showed a higher AT of the 3-millimeter level (0.026 ± 0.037).

Regarding intragroup comparisons, no significant difference was observed between the 2-, 3-, and 4-millimeter levels in the WOSC group. However, the three levels were significantly different in the other groups. Specifically, in the RBSC group, the 2-millimeter level significantly differed from the 3- and 4- millimeter levels. In the RSC and WOGSC groups, the 2- millimeter level significantly differed from the 4-millimeter level.

Table 1. Mean and standard deviation (± SD) of apical transportation (mm) of each group after removal of single-cone obturation materials, considering root canal levels.

Levels	**N**	**RSC**	**RBSC**	**WOSC**	**WOGSC**	P-value
2mm	16	0.044 ± 0.046 A^{a}	-0.02 ± 0.03 B^{a}	0.041 ± 0.045 A	0.009 ± 0.026 B^{a}	0.000**
3mm	16	0.067 ± 0.038 A^{ab}	0.026 ± 0.037 B^{b}	0.046 ± 0.041 A	0.021 ± 0.022 B^{ab}	0.003**
4mm	16	0.127 ± 0.074 A^{b}	0.023 ± 0.09 B^{b}	0.084 ± 0.12 A	0.032 ± 0.029 B^{b}	0.000**
P-values		0.000 **	*0.*006**	*0.*46	0.04*	
	Different uppercase letters in rows represent statistical differences between evaluated groups. Different lowercase letters in the column represent statistical differences between the evaluated millimeters in each group. (P <0.05) Kruskal Wallis test was performed for statistical analyses.					

	The pairwise comparisons were examined in nonparametric comparisons for all pairs using Dunn method for joint ranking. * Significant difference at the 5.0% level ** highly Significant difference at the 5.0% level

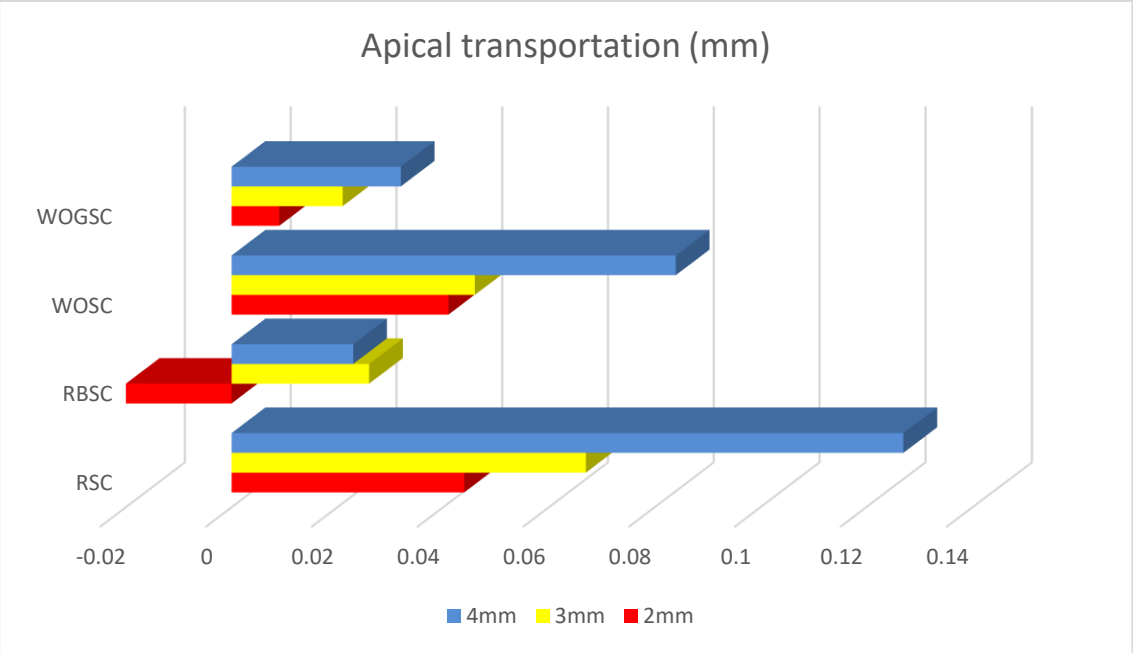

Fig. 3. Apical transportation induced by different file systems used in the removal of single-cone obturation materials.

3.2.Apical transportation induced by different file systems used in the removal of GuttaCore obturation materials.

Table 2 and Figure 4 comprehensively summarize the descriptive and statistical analysis of both intergroup and intragroup results of apical transportation. The WOGGC group at the 2-millimeter level showed the lowest transportation, as indicated by the lowest mean values (0.004 ± 0.02). Conversely, the WOGC group at the 2-millimeter level displayed the highest values (0.104 ± 0.041)

of apical transportation. These findings emphasize the differences in transportation observed among the various groups and levels.

When comparing the Apical Transportation (AT) at the three levels within each group after the removal of obturation materials, the WOGC and RBGC groups exhibited higher AT for the 2-millimiter level, with mean values of 0.104 ± 0.041 and 0.073 ± 0.062, respectively. On the other hand, the RBGC and WOGGC groups displayed higher AT for the 4-milimiter level, with mean values of 0.045 ± 0.034 and 0.04 ± 0.093, respectively.

In the RGC group, intragroup comparison revealed no significant difference between the 2-, 3-, and 4-millimeter levels. However, the three levels were significantly different in the RBGC and WOGC groups. Specifically, the 4-millimeter level significantly differed from both the 2-, 3-, and 4-millimeter levels. In the WOGGC group, the 2-4-millimeter level showed a significant difference compared to both the 3- and 4-millimeter levels.

Table 2. Mean and standard deviation (±SD) of apical transportation (mm) of each group after removal of Guttacore obturation materials, considering root canal levels

Levels	N	RGC	RBGC	WOGC	WOGGC	P-values
2mm	16	0.073 ± 0.062 A	0.026 ± 0.082 B^{a}	0.104 ± 0.041 A^{a}	0.004 ± 0.021 B^{a}	0.000**
3mm	16	0.057 ± 0.05 AB	0.029 ± 0.052 B^{a}	0.08 ± 0.052 A^{a}	0.038 ± 0.061 AB^{b}	0.044*
4mm	16	0.066 ± 0.075	0.045 ± 0.034 ^{b}	0.023 ± 0.049	0.04 ± 0.093	0.657

				b	b	
P-values		0.64	0.033*	0.000**	0.043*	

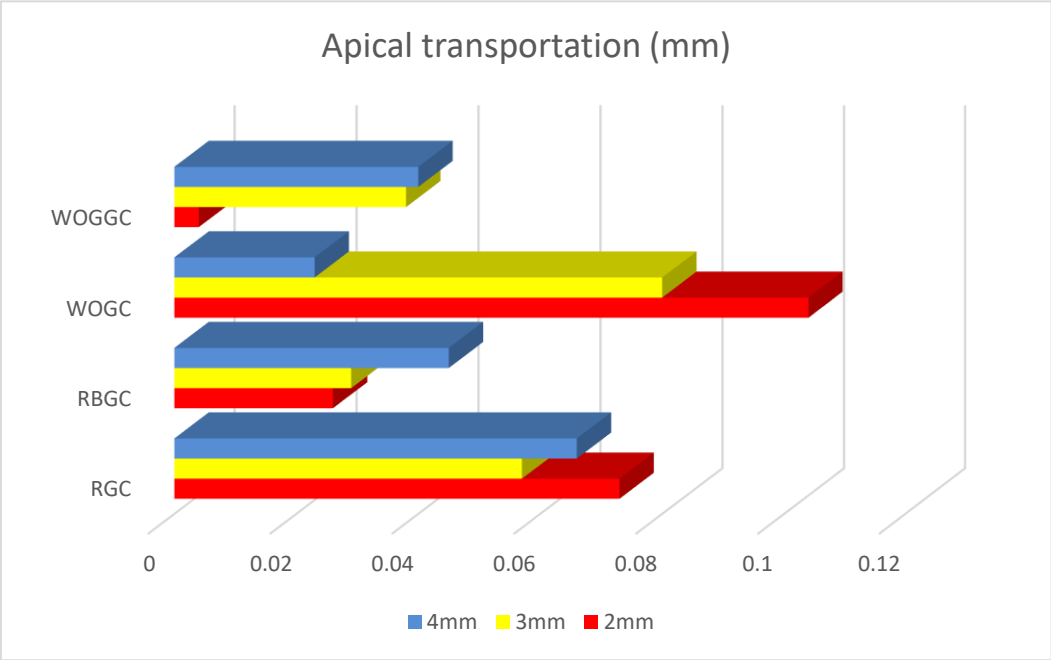

Fig.4. Apical transportation induced by different file systems used in the removal of GuttaCore obturation materials

3.3.Apical transportation induced by different file systems used regardless of the obturation materials removed

Table 3 and Figure Figure **5** illustrate the descriptive and statistical analysis of intergroup and intragroup results of apical at the 2-millimeter level, the RB group exhibited the lowest apical transportation (the lowest mean values of 0.004 ± 0.065). At the 4- millimeter level, the R group had the highest values of apical transportation (mean values of 0.096 ± 0.08).

The intergroup comparison revealed significant differences (*P-value* > .05) between the groups at the 2-, 3-, and 4- millimeter levels. Further, the R and WO groups were significantly different from the RB and WOG groups, highlighting the variations in apical transportation among the different groups and levels in the study.

When comparing the Apical Transportation (AT) at the three levels within each group after removal of obturation materials, the R, WOG, and RB groups exhibited higher AT at the 4-millimeter level, with mean values of 0.096 ± 0.08, 0.036 ± 0.068, and 0.034 ± 0.068, respectively. Conversely, the WO group demonstrated higher AT at the 2-millimeter level, with a mean value of 0.073 ± 0.053. However, the intragroup comparison shows no significant difference between the 2-, 3-, and 4-millimeter levels in the R and WO groups, the three levels are significantly different in RB and WOG groups, and 2mm were significantly different from 3mm and 4mm in the RB and WOG groups.

Table 3. Mean and standard deviation (±SD) of apical transportation (mm) induced by the reciprocating single-file systems regardless of the obturation material removed, considering root

Levels	**N**	**R**	**RB**	**WO**	**WOG**	**P-values**
2mm	32	0.058 ± 0.056 A	0.004 ± 0.065 B^a	0.073 ± 0.053 A	0.007 ± 0.023 B^a	0.000**
3mm	32	0.062 ± 0.044 A	0.028 ± 0.044 B^b	0.063 ± 0.049 A	0.03 ± 0.046 B^b	0.000**
4mm	32	0.096 ± 0.08 A	0.034 ± 0.068 B^b	0.053 ± 0.095 A	0.036 ± 0.068 B^b	.002**
P-values		0.089	0.001**	0.146	0.002**	

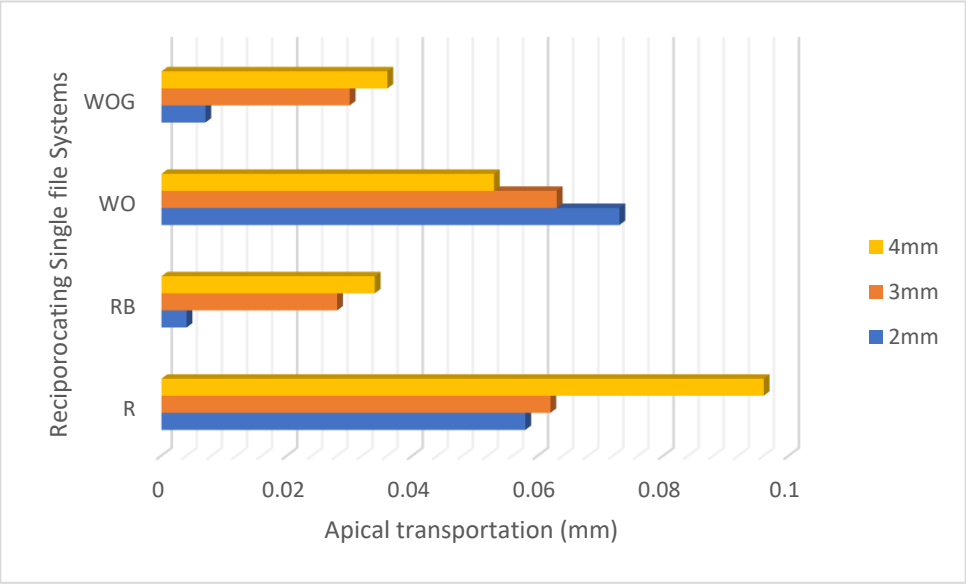

Fig. 5. Apical transportation induced by different file systems used regardless of the obturation materials removed.

3.4.Apical transportation induced by removal of obturation materials regardless of the file systems used

Table 4 and Figure 6 present the descriptive and statistical analysis of both intergroup and intragroup results of apical transportation. The SC group at the 2-millimeter level demonstrated the lowest apical transportation, as indicated by the lowest mean values of 0.019 ± 0.045. Conversely, the SC group at the 4-millimeter level exhibited the highest values of apical transportation, with mean values of 0.066 ± 0.093. The intergroup comparison revealed significant differences (*P-value* > .05) between the two groups at the 2-millimeter level, leading to notable variations in apical transportation between the SC and GC groups at that specific level.

When comparing the apical transportation at the three levels within each group after the removal of obturation materials, the SC group displayed higher AT for the 4-millimeter level, with a mean value of 0.066 ± 0.093. On the other hand, the GC group showed higher AT for the 2- millimeter

level, with a mean value of 0.052 ± 0.068, resulting in underscoring the differences in apical transportation across different levels within the SC and GC groups.

In the GC group, intragroup comparison revealed no significant difference between the 2-, 3-, and 4-millimeter levels in the induced apical transportation. However, the apical transportation induced by the removal of a single cone at the 2-millimeter level was significantly different from the levels at 3- and 4-millimeter. Accordingly, there were no significant variations in apical transportation among the different levels within the GC group. However, comparing the 2-millimeter level to the 3- and 4-millimeter levels are significantly different after the removal of a single cone.

Table 4. Mean and standard deviation (±SD) of apical transportation (mm) induced by removal of obturation materials regardless of the file systems used, considering root canal levels

	N	**SC**	**GC**	**P-values**
2mm	64	0.019 ± 0.045 A[a]	0.052 ± 0.068 B	**0.016***
3mm	64	0.040 ± 0.039 [b]	0.051 ± 0.056	**0.401**
4mm	64	0.066 ± 0.093 [b]	0.043 ± 0.067	**0.262**
P-values		0.000**	0.815	

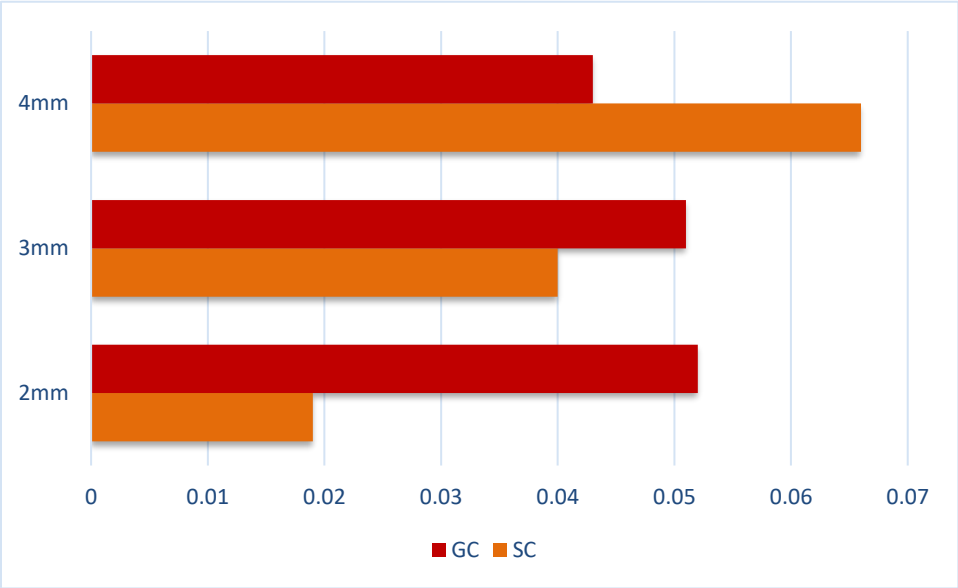

Fig.6. Apical transportation induced by different file systems used regardless of the obturation materials removed.

3.5.Apical transportation induced at the different level of apical third

Table 5 shows that the highest and lowest apical transportation was at the 4mm (0.055 ± 0.082) and the 2mm (0.036 ± 0.059), respectively. The three levels are significantly different, and 2-millimeter level was significantly different from 3- and 4-millimeter levels.

Table 5. Mean and standard deviation (±SD) of apical transportation (mm) induced in the apical third at different root canal levels

Levels	**N**	**Mean ± SD**	**P-value**	**Dunn**
2mm	128	0.036 ± 0.059	**0.006****	**A**
3mm	128	0.046 ± 0.049		**B**
4mm	128	0.055 ± 0.082		**B**
Kruskal Wallis test was performed for statistical analyses. The pairwise comparisons were examined in nonparametric comparisons for all pairs using Dunn method for joint ranking. ** highly Significant difference at the 5.0% level Different uppercase letters in column represent statistical difference between the evaluated millimeters in all group. (P < .05)				

4. Discussion

During the preparation process of root canals, endodontic instruments deviate from the long axis of the canal, especially, in which the canal with a higher degree of curvature and in retreatment situations [Root canal transportation increases the ris .[22k of ledging, zipping, and perforation, particularly in the apical third, and also weakens the tooth structure [22].

Comprehensive removal of the bulk of obturation material is mandatory to ensure the creation of enough space for irrigation solutions and instruments. Regardless of the morphology of the root canal systems, the reciprocating files are just as effective in retreatment as the rotary ones [23].

In the present study, the reciprocating instruments R, RB, WO, and WOG were not specifically developed for retreatment; however, they were already tested [3,24-27] with controversial results.

In the current study, GuttaCore was investigated, consisting of cross-linked gutta-percha carriers, removed during retreatment by simply trephining through the core [28]. The brittleness of GuttaCore's carrier, insolubility in solvents, heat resistance, and inability to remove the core in one piece are all potential drawbacks to its retrieval [29]. Moreover, the same tip size (0.25 of the four file systems) was used since the larger file of the four systems had different tip sizes; the removal of dentine could induce dentinal defects, leading to vertical root fracture [30]. Nevertheless, the use of the same file tip size or larger than that used for the initial canal instrumentation is needed for the retreatment procedures [25,31].

In the present study, mesial roots of Vertucci's class IV mandibular molars with two separated mesial canals were analyzed, which are particularly interesting due to not only the anatomical difficulty of the usually curved and narrow canals but also the possibility to test both systems in the same root. This strategy reduces the bias related to canal selection [32].

The crowns were maintained and used as a reference for working length to precisely mimic and simulate the clinical practice, and the dentine could create tensions on the files while negotiating the curved part of the canal [33]. The samples were mounted in silicone impression material to simulate periodontal ligaments. The Silicon layer causes limited freedom of movement while avoiding external reinforcement [34].

The m-CT, as a non-destructive technology to accurately reproduce the tooth in three dimensions without destroying the specimens or losing root material during sectioning [16], was utilized for assessing the residual filling material.

In the present study, the apical preparation was limited to size 25 since exceeding the apical preparation size to 25 leads to increasing the measurement of apical transportation. This limitation avoided potential biases in the research, as larger apical preparation sizes could lead to higher values of apical transportation. As a result, this study aimed to minimize this potential bias and ensure consistent measurement of apical transportation across the samples using a standardized size 25 apical preparation. The size 25 as the maximum apical preparation size was selected to maintain uniformity and reduce the influence of variables in the results [35].

The file systems in reciprocating movement were implemented to increase the centralization of the preparation and reduce the risk of deformation of the canals. These points are all related to the relief of the torsional and flexural tensions during reciprocating motion [36]. Instruments with this movement exhibited the ability to maintain the original axis of curved canals [37]. Some studies compared the apical transportation, caused by different instruments during the preparation of root canals for initial treatment, but only a few were evaluated for retreatment [3,28,38].

This study aimed to evaluate the morphological alterations of severely curved root canals represented in apical transportation, resulting from the removal of single cone and GuttaCore obturation materials with four reciprocating single-file systems with different designs and metallurgical properties. Here, all the files induced apical transportation to some extent, which is in line with previous studies [2,3,26,39]. Additionally, the mean apical transport, ranged from -0.02 to 0.127 mm, which is within the limit considered acceptable of 0.15 mm as exposed by Pinto *et al*., [40], who evaluated lower molar mesial canals through m-CT. The prognosis of the canal treatment was not negatively affected when the apical transportation was less than 0.3 mm [41].

The maximum transportation value, in the present study, was 0.127 mm, showing that the four reciprocating single files did not pose risks in terms of complications, such as perforations, stepping, and zipping, in the curved root teeth during the retreatment.

In the current study, three different levels in the apical third of the canals were evaluated to review the apical transportation, analyzed in levels 2, 3, and 4 mm from the apical foramen.

Based on our findings, both the general comparison of all four file systems (Table 3) and the comparison within the single-cone obturation group (Table 1) revealed that the M-wire Reciproc and WaveOne files significantly caused greater apical transportation compared to the heat-treated Reciproc Blue and WaveOne Gold files at the 2, 3, and 4-millimeter sections. As a result, files with a more flexible structure are less likely to induce apical transportation (It is worth noting that .(46 the current study's results contradict those of Romeiro et al.[39], and Kırıcı et al. [26] in which no significant difference in apical transportation was found between Reciproc and Reciproc Blue files after removing single cone obturation materials.

Accordingly, there were no significant differences between the groups at the 4-millimeter level during the removal of GuttaCore obturation materials. However, at the 3-millimeter level, only the WaveOne file group showed a significant difference compared to the Reciproc Blue group. At the 3-millimeter level, both the Reciproc and WaveOne files significantly induced more apical transportation compared to the Reciproc Blue and WaveOne Gold files. To the best of our knowledge, no study has specifically examined the effect of these files on inducing apical transportation during the removal of GuttaCore obturation materials.

When comparing the levels of apical transportation in the apical third of the teeth (Table 5), the lowest apical transportation was at the 2-millimeter level from the apex, which is significantly different from the apical transportation values at both the 3- and 4-millimeter levels [2,3]; it is

probably due to the action of the instruments in the cervical third, resulting in more direct access to the apical portion of the canal and a decrease in transport in this level.

However, the removal of two obturation materials is not significantly different at the 3- and 4-millimeter levels, the groups filled with GuttaCore (as shown in Table 2) exhibited higher apical transportation at the region of 2mm. This can be attributed to the higher rigidity of GuttaCore, as described by Patel and Owen [42]. The increased rigidity of GuttaCore can cause the file to deviate from the obturation material from its original path within the canal, particularly in the more apical location. This deviation could have contributed to the higher apical transportation at the 2-millimeter level in the GuttaCore-filled groups.

5. Conclusion

The Reciproc and WaveOne files induced higher levels of apical transportation compared to the Reciproc Blue and WaveOne Gold files. Additionally, the removal of GuttaCore obturation materials can result in higher apical transportation at the 2-millimeter region compared to the removal of single-cone obturation materials. Therefore, the selection of the file system and the type of obturation material can influence the extent of apical transportation during endodontic procedures.

Declaration Section

Author contributions

Regir Ramadhan Hassan and Abdulkareem Ramadhan Ibrahim contributed to the design and implementation of the research, the analysis of the results, and the writing of the manuscript.

Ethics Approval and Consent to Participate

Not applicable

Funding

No funding was obtained for this study.

Conflict of interest

All the Authors have no conflict of interest.

References

[1] Y.L. Ng, V. Mann, K. Gulabivala, A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health, International endodontic journal 44 (2011) 583-609. https://doi.org/10.1111/j.1365-2591.2011.01872.x.

[2] D. Delai, A.P. Jardine, L.B. Mestieri, D. Boijink, V.R.C. Fontanella, F.S. Grecca, P.M.P. Kopper, Efficacy of a thermally treated single file compared with rotary systems in endodontic retreatment of curved canals: a micro-CT study, Clinical oral investigations 23 (2019) 1837-1844. https://doi.org/10.1007/s00784-018-2624-6.

[3] G. Nevares, D.S. de Albuquerque, L.G. Freire, K. Romeiro, H.M. Fogel, M. Dos Santos, R.S. Cunha, Efficacy of ProTaper NEXT compared with Reciproc in removing obturation material from severely curved root canals: a micro–computed tomography study, Journal of endodontics 42 (2016) 803-808. https://doi.org/10.1016/j.joen.2016.02.010.

[4] D. Altunbas, B. Kutuk, A. Kustarci, Shaping ability of reciprocating single-file and full-sequence rotary instrumentation systems in simulated curved canals, European Journal of Dentistry 9 (2015) 346-351. https://doi.org/10.4103/1305-7456.163221.

[5] A.A. Azim, L. Piasecki, U.X. da Silva Neto, A.T.G. Cruz, K.A. Azim, XP shaper, a novel adaptive core rotary instrument: Micro–computed tomographic analysis of its shaping abilities, Journal of endodontics 43 (2017) 1532-1538. https://doi.org/10.1016/j.joen.2017.04.022

[6] A.M.K. AlRahabi, R.M. Atta, Surface nanoscale profile of WaveOne, WaveOne Gold, Reciproc, and Reciproc blue, before and after root canal preparation, Odontology 107 (2019) 500-506. https://doi.org/10.1007/s10266-019-00424-8.

[7] P. Van der Vyver, C. Jonker, Reciprocating instruments in Endodontics: a review of the literature: clinical review, South African Dental Journal 69 (2014) 404-409.

[8] L.C.F. Canali, J.A. Duque, R.R. Vivan, C.M. Bramante, M.V.R. Só, M.A.H. Duarte, Comparison of efficiency of the retreatment procedure between Wave One Gold and Wave One systems by Micro-CT and confocal microscopy: an in vitro study, Clinical oral investigations 23 (2019) 337-343. https://doi.org/10.1007/s00784-018-2441-y.

[9] G. De-Deus, E.J.N.L. Silva, V.T.L. Vieira, F.G. Belladonna, C.N. Elias, G. Plotino, N.M. Grande, Blue thermomechanical treatment optimizes fatigue resistance and flexibility of the Reciproc files, Journal of endodontics 43 (2017) 462-466. https://doi.org/10.1016/j.joen.2016.10.039.

[10] H.S. Topçuoğlu, S. Demirbuga, S. Düzgün, G. Topçuoğlu, Cyclic fatigue resistance of new reciprocating files (Reciproc Blue, WaveOne Gold, and SmartTrack) in two different curved canals, Journal of investigative and clinical dentistry 9 (2018) e12344. https://doi.org/10.1111/jicd.12344.

[11] F. Baratto Filho, E. Ferreira, L. Fariniuk, Efficiency of the 0.04 taper ProFile during the re-treatment of gutta-percha-filled root canals, International Endodontic Journal 35 (2002). https://doi.org/10.1046/j.1365-2591.2002.00514.x

[12] Frajlich, Massone, Cantarini, Artaza, Comparative study of retreatment of Thermafil and lateral condensation endodontic fillings, International endodontic journal 31 (1998) 354-357. https://doi.org/10.1046/j.1365-2591.1998.00168.x.

[13] B. Jorgensen, A. Williamson, R. Chu, F. Qian, The efficacy of the WaveOne reciprocating file system versus the ProTaper retreatment system in endodontic retreatment of two different obturating techniques, Journal of endodontics 43 (2017) 1011-1013. https://doi.org/10.1016/j.joen.2017.01.018.

[14] K.M. Hargreaves, S. Cohen, Cohen's pathways of the pulp, Elsevier2010.

[15] F.R. Alves, M.F. Marceliano-Alves, J.C.N. Sousa, S.B. Silveira, J.C. Provenzano, J.F. Siqueira Jr, Removal of root canal fillings in curved canals using either reciprocating single-or rotary multi-instrument systems and a supplementary step with the XP-Endo Finisher, Journal of endodontics 42 (2016) 1114-1119. https://doi.org/10.1016/j.joen.2016.04.007.

[16] U. Aksoy, M. Küçük, M. Versiani, K. Orhan, Publication trends in micro-CT endodontic research: a bibliometric analysis over a 25-year period, International Endodontic Journal 54 (2021) 343-353. https://doi.org/10.1111/iej.13433.

[17] F.J. Vertucci, Root canal anatomy of the human permanent teeth, Oral surgery, oral medicine, oral pathology 58 (1984) 589-599. https://doi.org/10.1016/0030-4220(84)90085-9.

[18] S. Bürklein, S. Flüch, E. Schäfer, Shaping ability of reciprocating single-file systems in severely curved canals: WaveOne and Reciproc versus WaveOne Gold and Reciproc blue, Odontology 107 (2019) 96-102. https://doi.org/10.1007/s10266-018-0364-3.

[19] E. Schäfer, C. Diez, W. Hoppe, J. Tepel, Roentgenographic investigation of frequency and degree of canal curvatures in human permanent teeth, Journal of endodontics 28 (2002) 211-216.

[20] S.W. Schneider, A comparison of canal preparations in straight and curved root canals, Oral surgery, Oral medicine, Oral pathology 32 (1971) 271-275. https://doi.org/10.1016/0030-4220(71)90230-1.

[21] C. Prati, F. Zamparini, A. Spinelli, G.A. Pelliccioni, C. Pirani, M.G. Gandolfi, Secondary root canal treatment with reciproc blue and K-File: radiographic and ESEM-EDX analysis of dentin and root canal filling remnants, Journal of Clinical Medicine 9 (2020) 1902. https://doi.org/10.3390/jcm9061902

[22] V. Franco, C. Fabiani, S. Taschieri, A. Malentacca, M. Bortolin, M. Del Fabbro, Investigation on the shaping ability of nickel-titanium files when used with a reciprocating motion, Journal of endodontics 37 (2011) 1398-1401. https://doi.org/10.1016/j.joen.2011.06.030.

[23] G. Rossi-Fedele, H.M.A. Ahmed, Assessment of root canal filling removal effectiveness using micro–computed tomography: a systematic review, Journal of endodontics 43 (2017) 520-526. https://doi.org/10.1016/j.joen.2016.12.008.

[24] T.-F. Alakabani, V. Faus-Llácer, I. Faus-Matoses, C. Ruiz-Sánchez, Á. Zubizarreta-Macho, S. Sauro, V. Faus-Matoses, The efficacy of rotary, reciprocating, and combined non-surgical endodontic retreatment techniques in removing a carrier-based root canal filling material from straight root canal systems: a micro-computed tomography analysis, Journal of clinical medicine 9 (2020) 1989. https://doi.org/10.3390/jcm9061989.

[25] I. Bago, G. Plotino, M. Katić, M. Ročan, M. Batinić, I. Anić, Evaluation of filling material remnants after basic preparation, apical enlargement and final irrigation in retreatment of severely curved root canals in extracted teeth, International endodontic journal 53 (2020) 962-973. https://doi.org/10.1111/iej.13287

[26] D. Kırıcı, S. Demirbuga, E. Karataş, Micro–computed tomographic assessment of the residual filling volume, apical transportation, and crack formation after retreatment with Reciproc and

Reciproc Blue Systems in curved root canals, Journal of endodontics 46 (2020) 238-243. https://doi.org/10.1016/j.joen.2019.11.003.

[27] A.G. Limoeiro, A.H. Braitt, A.S. Machado, C.E. Bueno, C.E. Fontana, L.G. Freire, R.T. Lopes, A. De Martin, Micro-computed tomography evaluation of filling material removal by three reciprocating systems with different thermal treatments, Giornale Italiano di Endodonzia 35 (2021). https://doi.org/10.32067/GIE.2021.35.01.07.

[28] B.C. Sağlam, E. Çiçek, M.M. Koçak, S. Koçak, B.H. Kivanç, Apical transportation during removal of root canal filling with different retreatment systems, The International Journal of Artificial Organs 39 (2016) 541-545.

[29] V. Faus-Llácer, R.L. Pérez, I. Faus-Matoses, C. Ruiz-Sánchez, Á. Zubizarreta-Macho, S. Sauro, V. Faus-Matoses, Efficacy of removing Thermafil and GuttaCore from straight root canal systems using a novel non-surgical root canal re-treatment system: a micro-computed tomography analysis, Journal of Clinical Medicine 10 (2021) 1266. https://doi.org/10.3390/jcm10061266.

[30] J.F. Siqueira Jr, I.N. Rôças, D. Ricucci, M. Hülsmann, Causes and management of post-treatment apical periodontitis, British dental journal 216 (2014) 305-312. https://doi.org/10.1038/sj.bdj.2014.200.

[31] B.M. Crozeta, F.C. Lopes, R. Menezes Silva, Y.T.C. Silva-Sousa, L.F. Moretti, M.D. Sousa-Neto, Retreatability of BC Sealer and AH Plus root canal sealers using new supplementary instrumentation protocol during non-surgical endodontic retreatment, Clinical Oral Investigations 25 (2021) 891-899. https://doi.org/10.1007/s00784-020-03376-4.

[32] I.L.L. Gomes, F.R.F. Alves, M.F. Marceliano-Alves, S.B. Silveira, J.C. Provenzano, L.S. Gonçalves, Canal transportation using Mani GPR or HyFlex NT during the retreatment of curved root canals: A micro-computed tomographic study, Australian Endodontic Journal 47 (2021) 73-80. https://doi.org/10.1111/aej.12470.

[33] A.A.R. Hashem, A.G. Ghoneim, R.A. Lutfy, M.Y. Foda, G.A.F. Omar, Geometric analysis of root canals prepared by four rotary NiTi shaping systems, Journal of endodontics 38 (2012) 996-1000. https://doi.org/10.1016/j.joen.2012.03.018.

[34] E. Karataş, H.A. Gündüz, D.Ö. Kırıcı, H. Arslan, M.Ç. Topçu, K.Y. Yeter, Dentinal crack formation during root canal preparations by the twisted file adaptive, ProTaper Next, ProTaper Universal, and WaveOne instruments, Journal of endodontics 41 (2015) 261-264.

[35] S. Singh, M.S.M. Abdul, U. Sharma, S. Sainudeen, C. Jain, J.T. Kalliath, An in vitro comparative evaluation of volume of removed dentin, canal transportation, and centering ratio of 2Shape, WaveOne Gold, and ProTaper Gold files using cone-beam computed tomography, Journal of International Society of Preventive & Community Dentistry 9 (2019) 481. https://doi.org/10.4103/jispcd.JISPCD_444_18.

[36] G. Plotino, N. Grande, L. Testarelli, G. Gambarini, Cyclic fatigue of Reciproc and WaveOne reciprocating instruments, International Endodontic Journal 45 (2012) 614-618. https://doi.org/10.1111/j.1365-2591.2012.02015.x.

[37] E. Berutti, G. Chiandussi, D.S. Paolino, N. Scotti, G. Cantatore, A. Castellucci, D. Pasqualini, Effect of canal length and curvature on working length alteration with WaveOne reciprocating files, Journal of endodontics 37 (2011) 1687-1690. https://doi.org/10.1016/j.joen.2011.09.014.

[38] B. Aydın, T. Köse, M. Çalışkan, Effectiveness of HERO 642 versus Hedström files for removing gutta-percha fillings in curved root canals: an ex vivo study, International endodontic journal 42 (2009) 1050-1056. https://doi.org/10.1111/j.1365-2591.2009.01624.x

[39] K. Romeiro, A. de Almeida, M. Cassimiro, L. Gominho, E. Dantas, N. Chagas, C. Velozo, L. Freire, D. Albuquerque, Reciproc and Reciproc Blue in the removal of bioceramic and resin-based sealers in retreatment procedures, Clinical oral investigations 24 (2020) 405-416. https://doi.org/10.1007/s00784-019-02956-3

[40] J.C. Pinto, M.M.B. Pivoto-João, C.G. Espir, M.L.G. Ramos, J.M. Guerreiro-Tanomaru, M. Tanomaru-Filho, Micro-CT evaluation of apical enlargement of molar root canals using rotary or reciprocating heat-treated NiTi instruments, Journal of Applied Oral Science 27 (2019).

[41] D. Zhao, Y. Shen, B. Peng, M. Haapasalo, Root canal preparation of mandibular molars with 3 nickel-titanium rotary instruments: a micro–computed tomographic study, Journal of endodontics 40 (2014) 1860-1864. https://doi.org/10.1016/j.joen.2014.06.023.

[42] E. Patel, C. Owen, The use of textural analysis to test the hardness and penetrability of three types of gutta percha cones when exposed to two endodontic solvents, South African Dental Journal 71 (2016) 346-350.