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Apical Transportation and Centering Ability of Trunatomy, Edmax, and Reciproc Blue in Curved Mesiobuccal Canals of Mandibular Molars

Nazanin Zargar [a], Babak Zandi [a], Yaser Safi [b], Mahgol Mehrabani [c*]

[a] Department of Endodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran; [b] Department of Oral and Maxillofacial Radiology, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran; [c] Department of Endodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran

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****Corresponding author***: Department of Endodontics, School of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.

E-mail: mahgolmehrabani@yahoo.com

Introduction: This study compared apical transportation and centering ability of TruNatomy, EDMax, and Reciproc Blue in curved mesiobuccal canals of mandibular molars. **Materials and Methods:** This *ex vivo* study was conducted on curved (20-40 degrees) mesiobuccal canals of 60 mandibular molars. The teeth were randomly assigned to 4 groups (n=15) for instrumentation of the mesiobuccal canals with (I) TruNatomy, (II) EDMax, (III) Reciproc Blue, and (IV) Reciproc Blue+R-Pilot. Cone-beam computed tomography (CBCT) scans were obtained before and after instrumentation. Changes in canal wall thickness in mesiodistal (MD) and buccolingual (BL) directions were assessed at 1, 2, 3, and 4 mm from the apex using OnDemand software. Data were analyzed by the Kruskal-Wallis, Bonferroni, Friedman, and Fisher's exact tests (alpha=0.05). **Results:** TruNatomy showed significantly lower transportation than Reciproc Blue and EDMax in the apical, middle, and coronal thirds (P<0.05). Reciproc Blue and EDMax had no significant difference in transportation (P>0.05). Using the R-Pilot glider had no significant effect on transportation (P>0.05). Canal transportation was not significantly different within each group at four distances from the apex (P>0.05). TruNatomy showed significantly higher centering ability than Reciproc Blue+R-Pilot in the BL dimension at 3 mm from the apex (P<0.05). **Conclusion:** TruNatomy showed significantly lower canal transportation than Reciproc Blue and EDMax at all distances from the apex. The files had no significant difference in centering ability except at 3 mm in BL dimension, where TruNatomy had significantly higher centering ability than Reciproc Blue+R-Pilot.

Keywords: Canal Transportation; Centering Ability; Root Canal Therapy

Introduction

Mechanical preparation of the root canal system is performed to eliminate microorganisms and necrotic pulp residues from the root canal system, and create a conical shape for enhanced and more efficient irrigation of the root canal and its subsequent three-dimensional obturation [1]. Complete cleaning of the root canal system is a key step in root canal therapy, and is highly important for a successful treatment due to the anatomical complexities of the root canals [2].

Nickel-titanium (NiTi) files are superior to stainless-steel (SS) hand files in preserving the main canal path, especially in curved canals [3]. Nonetheless, the initial NiTi files were hard and susceptible to damage due to rotational and torsional fracture [4].

Root canal preparation is more challenging in curved canals, since the files have a greater tendency to deviate from the original canal path. Canal transportation is a common procedural error that may occur during the preparation of curved canals. Canal transportation in the apical third impedes optimal root canal cleaning; thus, debris and microorganisms remain in the root canal system and impair the integrity of obturation and a perfect seal [5]. Apical transportation changes the position of the apical foramen iatrogenically. It may harm the root structure integrity, decrease tooth resistance to fracture, or lead to root canal perforation when using larger files [6, 7], which can bring about numerous problems and result in eventual treatment failure [1, 8]. Changed root canal anatomy and straight shaping of the canal can cause irreversible problems such as apical transportation, compaction of debris and dentin chips in the canal and ledge formation, deviation from the original canal path, excessive removal of dentin from the furcation area and creation of a tear drop pattern at the canal end, apical perforation, or file fracture [9].

It has been reported that the apical third is the most challenging region of the root canal for cleaning and shaping while preserving the original canal path [10, 11].

Despite the attempts to maximize the success rate of root canal treatment, an ideal protocol has yet to be introduced [12]. SS files have a satisfactory performance in straight canals; however, they can cause procedural errors such as zipping, perforation, transportation, and ledge formation in severely curved canals. Also, their application is time-consuming, and several files and drills are required to accomplish a root canal treatment [13-16]. Thus, flexible NiTi files were introduced for the preparation of severely curved canals while preserving the original canal path. Their flexibility is 2 to 3 times that of SS files, and they are also resistant to fracture [17]. Also, due to the difficult use and time-consuming nature of hand files, NiTi rotary systems were introduced to minimize the risk of procedural errors [18, 19]. An ideal file should be flexible and easily reach the working length in curved canals, must have optimal shear force, and should be resistant to fracture [20]. To date, the canal transportation and centering ability of many file systems have been previously evaluated. However, to the best of the authors' knowledge, the canal transportation and centering ability of EDMax in comparison with TruNatomy have not been previously assessed. Thus, this study aimed to compare the centering ability and apical transportation of TruNatomy, EDMax, and Reciproc Blue with and without R-Pilot glider in curved mesiobuccal canals of mandibular molars using cone-beam computed tomography (CBCT).

Materials and Methods

This *ex vivo* study was conducted on curved mesiobuccal canals of 60 mandibular molars extracted for purposes not related to this study. The study protocol was approved by the ethics committee of the university (IR.SBMU.DRC.REC.1402.108).

Eligibility criteria

The inclusion criteria were curved mesiobuccal canals of extracted mandibular molars with 20-40-degree curvature, closed apices, no internal/external root resorption, no cracks, no root caries, and no root canal calcification.

The exclusion criteria were canals with two curvatures, incomplete roots [21], root length < 19 mm, and teeth with file fracture in the canal or perforation during the treatment process.

Sample size

The sample size was calculated to be 15 in each group (a total of 60) using the one-way ANOVA feature of PASS software (PASS version 21; NCSS, Kaysville, Utah, USA), assuming $\alpha=0.05$, $\beta=0.2$, study power of 80%, mean and standard deviation values extracted from a previous study [22], and an effect size of 0.514.

Specimen preparation

A total of 60 eligible mandibular first molars were cleaned from debris, calculus, and tissue residues and disinfected by immersion in 5.25% sodium hypochlorite (Golrang, Babol, Iran) for 48 h. The coronal caries was removed, and the teeth were clinically inspected under a microscope with magnification to ensure no external root resorption, no root caries, and no cracks. Access cavities were prepared by using a fissure bur (Brasseler, Savannah, USA), and were examined by an explorer to ensure direct access to the mesiobuccal canal. Next, a #10 K-file was introduced into the canal, and the teeth underwent radiography (radiovisiography) to measure the root canal curvature by using Schneider's method [23]. Teeth with 20-40 degree curvature [24] of the mesiobuccal canals were selected for the study.

The access cavity was filled with 5.2% sodium hypochlorite, the canal path was initially opened with a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland), and then another #10 K-file was used for working length determination. The file was introduced into the canal until its tip was visible at the apex; 1 mm was subtracted from this length to determine the working length. Severely calcified or very large canals (larger than a #15 K-file) were excluded.

The tooth crowns were then mounted in wax while the roots were exposed in the air to have the highest contrast (coronal mounting). To do so, 4 cylinders were fabricated with a 5 cm diameter and 2.5 cm height, and the wax was poured into one side of the cylinder to seal one end of it. Before setting the wax, tooth crowns were mounted in wax towards the buccal surface, and the buccal and mesial sides were marked on the cylinders (Figure 1). The teeth underwent CBCT in a Smart3DX CBCT scanner (Largev, Beijing, China) with the exposure settings of 100 kV, 9.5 mA, 50 μm voxel size, and 5×8 cm field of view in Denture Base mode.

OnDemand software (Cybermed, Yuseong-gu, Daejeon, Korea) was used for the measurements. The teeth underwent CBCT before and after instrumentation, and the distance between the external root surface and the internal root canal wall was measured at the mesial (M1), distal (D1), buccal (B1), and lingual (L1) at 1, 2, 3, and 4 mm from the apex [25, 26].

Figure 1. Coronal mounting of the specimens

Root canal preparation

The teeth were randomly assigned to 4 groups (n=15) to undergo root canal instrumentation as follows:

Group 1: TruNatomy (Dentsply Sirona, Ballaigues, Switzerland): A conservative access cavity was prepared such that the canal orifices were evident. Next, the coronal 2/3 of the canal was negotiated by a #10 K-file in the presence of lubricant and irrigant. Next, TruNatomy Orifice Modifier was used at 500 rpm and 1.5 N/cm torque in the coronal 2-3 mm of the canal in the presence of irrigant and with a maximum of 2-3 up-and-down pecking movements. The coronal third of the canal was shaped by repeating this movement several times. The root canals were irrigated, and the file flutes were cleaned after using each file. Patency was maintained by using a #10 K-file. Next, TruNatomy glider file #17/2% was used with 2-3 up-and-down pecking movements with 2-5 mm penetration depth in the presence of irrigant. Patency was ensured by using a #10 K-file. Next, the Prime file #26/4% operating at 500 rpm with 1.5 N/cm torque was used in the presence of 5.25% sodium hypochlorite, with 2-3 up-and-down pecking movements and 2-5 mm penetration depth. This movement was repeated until reaching the working length. Root canal irrigation was performed with 2 mL of 5.25% sodium hypochlorite and 2 mL of sterile saline with a 25-mm 30-gauge double side-vented needle (Endo Top, Hangzhou, China). The files were regularly cleaned, and patency was ensured.

Group 2: EDMax (Neolix, Évron, France): After access cavity preparation and using a #10 K-file to negotiate the canal path, #10 and #20 opener files were used for passive instrumentation of the coronal third at 500 rpm and 1.5 N/cm torque with pecking movements. Brushing of the canal walls was performed as instructed by the manufacturer in the presence of 5.25% sodium hypochlorite. The crown-down preparation technique was adopted in this group. Next, #15/3% glider file was used to create a glide path. The file was used passively in the presence of irrigant. After using each file, debris was removed, the root canal was irrigated, and patency was ensured until the glider file reached the working length. Subsequently, #20/6% followed by #25/6% Shaper files were used, similar to the glider in the presence of irrigant and by ensuring patency after using each file to the working length.

Group 3: Reciproc Blue (VDW, Munich, Germany): Access cavity was prepared, and a straight path to the coronal third was established. The endo-motor was adjusted on Reciproc All (VDW Gold Reciproc, Munich, Germany). Irrigant was injected into the access cavity and root canals. After introducing the file through the orifice, it was moved with pecking in-and-out movements with no more than 3 mm penetration depth with slight apical pressure. After three movements, the file was removed, cleaned, and reused. After each time of using the file, the root canal was rinsed with 5.2% sodium hypochlorite, and patency was ensured. This process was repeated until the file reached the working length.

Group 4: Reciproc Blue+R-Pilot: In this group, before root canal instrumentation with R25 file (as explained for group 3), the first R-Pilot file was used to create a glide path. The glider file was also used with the Reciproc All feature of the endo-motor. The file was used with a maximum of three pecking movements with 3 mm penetration depth in the presence of irrigant. After the glider file reached the working length, R25 size of Reciproc Blue was used for canal shaping as explained earlier.

Postoperative CBCT

After root canal instrumentation, the teeth were mounted in the wax molds prepared earlier and underwent CBCT. To assess canal transportation on CBCT scans, the Gambill method was used [15]. Accordingly, the lowest dentin thickness in each axial section (1, 2, 3, and 4 mm from the apex) at the mesial (M2), distal (D2), buccal (B2) and lingual (L2) surfaces of the prepared teeth was measured using OnDemand software (Cybermed, Yuseong-gu, Daejeon, Korea) (Figure 2).

Canal transportation was calculated using the following formulae:

Canal transportation in mesiodistal (MD) direction: (M1-M2)-(D1-D2)

Canal transportation in buccolingual (BL) direction: (B1-B2)-(L1-L2)

The absolute value of apical transportation was calculated and reported.

The following formula was used to assess centering ability (*e.g.*, the ability of an instrument to remain centered in the canal) [27]:

Canal centering in the BL dimension: $\frac{l2-l1}{b2-b1}$

Canal centering in the MD dimension: $\frac{d2-d1}{m2-m1}$

The closer the value to 1 or equal to 1, the higher the centering ability of the instrument would be.

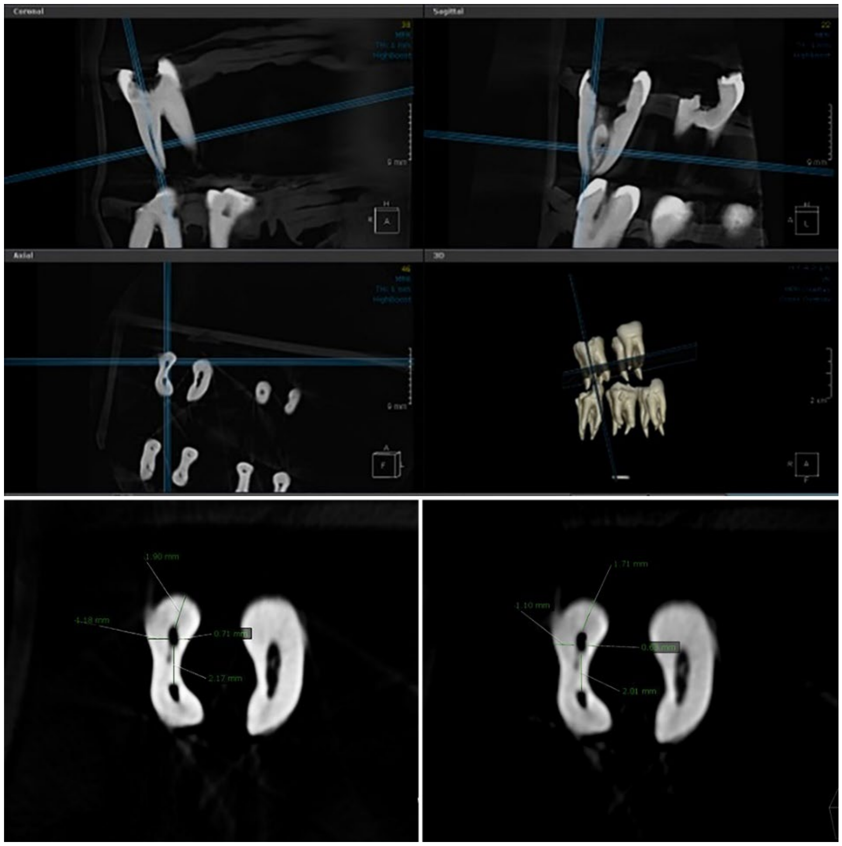

Figure 2. Assessment of canal transportation using OnDemand software

Statistical analysis

The Shapiro-Wilk test was used to assess the normality of data distribution. Since the data were not normally distributed ($P<0.05$), the four groups were compared by the Kruskal-Wallis test. Within-group comparisons were made by the Friedman test, while pairwise comparisons were conducted by the Bonferroni test. One-way ANOVA was used for the variables with normal distribution. Also, the Pearson Chi-square test or Fisher's exact test was used to compare the presence/absence of apical transportation and centering ability and their direction (mesial/distal/center or buccal/lingual/center). All statistical analyses were carried out using SPSS version 26 (SPSS, IL, USA) at a 0.05 level of significance.

Results

All the prepared root canals in all four groups showed apical transportation in MD and BL directions. Tables 1 and 2 show the mean apical transportation in MD and BL directions in the four groups.

Comparison of MD and BL transportation among the study groups at different levels from the apex

At 1 mm from the apex: The mean MD transportation in TruNatomy was significantly lower than that in Reciproc Blue (P=0.045). Also, the mean BL transportation in TruNatomy was significantly lower than that in EDMax (P=0.002). TruNatomy caused significantly lower transportation than Reciproc Blue (P=0.001).

At 2 mm from the apex, MD transportation in the TruNatomy group was significantly lower than that in the Reciproc Blue group (P=0.001). Also, MD transportation in the TruNatomy group was significantly lower than that in the Reciproc Blue+R-Pilot group (P=0.000). BL transportation in the TruNatomy group was significantly lower than that in all other groups ($P<0.05$).

At 3 mm from the apex, MD transportation in the TruNatomy group was significantly lower than that in the EDMax group (P=0.022). Also, MD transportation in the TruNatomy group was significantly lower than that in the Reciproc Blue (P=0.001). BL transportation in the TruNatomy group was significantly lower than that in all other groups ($P<0.05$).

At 4 mm from the apex, MD transportation in the Reciproc Blue+R-Pilot group was significantly lower than that in the EDMax group (P=0.013). Also, TruNatomy showed significantly lower MD transportation than the EDMax group (P=0.024). BL transportation in the TruNatomy group was significantly lower than that in the Reciproc Blue (P=0.000) and Reciproc Blue+R-Pilot (P=0.028) groups. No other significant differences were found ($P>0.05$).

Centering ability

Tables 3 and 4 present the mean centering ability of the four groups in MD and BL directions at different distances from the apex.

Comparison of BL and MD centering ability among the groups at different distances from the apex

No significant difference was noted in MD or BL direction among the groups at 1 mm, 2 mm, and 4 mm from the apex. At 3 mm from the apex, TruNatomy showed significantly higher BL centering ability than Reciproc Blue+R-Pilot (P=0.05).

Within-group comparisons

Related-samples Friedman's two-way ANOVA by ranks showed no significant within-group difference in BL or MD transportation or centering ability when different levels from the apex were compared (P>0.05).

Discussion

This study compared the centering ability and apical transportation of TruNatomy, EDMax, and Reciproc Blue with and without R-Pilot glider in curved mesiobuccal canals of mandibular molars using CBCT. CBCT is commonly used for research purposes [28-32] due to its non-destructive nature, high accuracy, and 3D visualization of anatomical structures [33]. The results showed that TruNatomy caused significantly lower transportation than Reciproc Blue and EDMax. Reciproc Blue and EDMax had no significant difference in transportation. Also, TruNatomy showed significantly higher centering ability than Reciproc Blue+R-Pilot in BL dimension at 3 mm from the apex.

TruNatomy (Dentsply Sirona) is a novel rotary file with a unique design made of heat-treated NiTi alloy [28]. It is available in three different sizes of small (#20/4%), original size (#26/4%), and medium size (#36/4%). According to the manufacturer, the three shaping instruments of TruNatomy enable better dentin debridement due to their specific design. The NiTi wire used in this system has a maximum diameter of 0.8 mm, instead of the 1.2 mm wires used in other NiTi rotary systems. It has an eccentric parallelogram design, and its heat-treated wire increases its flexibility [29]. Thus, it is believed that TruNatomy can optimally preserve the root canal anatomy and minimize the risk of procedural errors such as canal transportation [29].

Table 1. Mean (SD) of apical transportation in MD direction in the four groups

Group	1 mm	2 mm	3 mm	4 mm
TruNatomy	0.04 (0.04)	0.02 (0.02)	0.02 (0.02)	0.09 (0.20)
EDMax	0.14 (0.18)	0.06 (0.06)	0.07 (0.05)	0.16 (0.16)
Reciproc Blue	0.09 (0.04)	0.10 (0.07)	0.10 (0.07)	0.15 (0.10)
Reciproc Blue+R-Pilot	0.10 (0.07)	0.10 (0.07)	0.06 (0.03)	0.05 (0.08)
Total	0.09 (0.11)	0.07 (0.07)	0.06 (0.05)	0.11 (0.15)

Table 2. Mean (SD) of apical transportation in the BL direction in the four groups

Group	1 mm	2 mm	3 mm	4 mm
TruNatomy	0.03 (0.02)	0.02 (0.02)	0.02 (0.03)	0.04 (0.10)
EDMax	0.27 (0.31)	0.20 (0.22)	0.15 (0.18)	0.11 (0.16)
Reciproc Blue	0.19 (0.13)	0.15 (0.15)	0.11 (0.11)	0.24 (0.18)
Reciproc Blue+R-Pilot	0.15 (0.16)	0.17 (0.11)	0.16 (0.09)	0.11 (0.12)
Total	0.16 (0.20)	0.13 (0.16)	0.11 (0.13)	0.12 (0.16)

Table 3. Mean (SD) of centering ability of the four groups in the MD direction at different distances from the apex

Group	1 mm	2 mm	3 mm	4 mm
TruNatomy	0.62 (0.19)	0.64 (0.17)	0.63 (0.20)	0.62 (0.26)
EDMax	0.60 (0.24)	0.70 (0.21)	0.52 (0.32)	0.56 (0.26)
Reciproc Blue	0.64 (0.17)	0.65 (0.19)	0.58 (0.28)	0.60 (0.26)
Reciproc Blue+R-Pilot	0.55 (0.23)	0.55 (0.26)	0.69 (0.10)	0.78 (0.21)
Total	0.60 (0.21)	0.64 (0.21)	0.61 (0.24)	0.64 (0.26)

Table 4. Mean (SD) of centering ability of the four groups in the BL direction at different distances from the apex

Group	1 mm	2 mm	3 mm	4 mm
TruNatomy	0.58 (0.28)	0.74 (0.22)	0.76 (0.21)	0.80 (0.16)
EDMax	0.54 (0.21)	0.55 (0.27)	0.67 (0.32)	0.72 (0.26)
Reciproc Blue	0.54 (0.21)	0.67 (0.24)	0.70 (0.25)	0.56 (0.23)
Reciproc Blue+R-Pilot	0.56 (0.27)	0.53 (0.22)	0.51 (0.21)	0.66 (0.25)
Total	0.56 (0.24)	0.62 (0.25)	0.66 (0.26)	0.69 (0.24)

Reciproc Blue has the same back-and-forth motion and kinematics as the Reciproc with similar design, size, and geometry. However, it is manufactured by a novel thermal process, which changes its molecular structure, and is therefore, much more flexible than Reciproc and is more resistant to torsional fatigue. It has lower surface microhardness and has a prebend potential. Its manufacturer claims that Reciproc Blue can be used in severely curved canals without requiring a glidepath [34].

EDMax is the most recent rotary system produced by Neolix, manufactured through electric discharge machining, which prevents the formation of microcracks in the file and confers unique properties such as a smooth core and a hard and rough surface, yielding NiTi files with soft power. The EDMax files are made of highly flexible NiTi alloy, with high fracture resistance, which can be pre-curved and optimally preserve the root canal anatomy. Their hard and abrasive surface enables effective brushing of the walls; this system is suitable for endodontic treatment and retreatment.

The present results showed no significant difference among the four systems in MD centering ability at different levels from the apex. In the BL direction, the centering ability of TruNatomy was significantly superior to that of Reciproc Blue+R-Pilot at 3 mm from the apex, but no other significant differences were found. This result was in agreement with the findings of Kabil *et al.* [35]. They also showed inferior centering ability of Reciproc Blue compared with TruNatomy. In the current study, Reciproc Blue showed lower centering ability in the BL dimension than TruNatomy, but the difference did not reach statistical significance. Thus, significantly lower centering ability of Reciproc Blue+R-Pilot than TruNatomy was probably because of the combination of reciprocal movement with the use of two consecutive files. Also, Kabil *et al.* [35] reported that apical transportation in Reciproc Blue was significantly higher than that in other groups. Similarly, TruNatomy caused significantly lower apical transportation than Reciproc Blue in almost all sections and both BL and MD dimensions (except at 4 mm from the apex in the MD dimension) in the present study. In contrast to the present results, Eren and Sezer [36] found no significant difference between TruNatomy and Reciproc Blue in the amount of residual dentin in mandibular molar root canals. This difference may be attributed to the difference in taper of gliders in WaveOne Gold (#15/2%) and Reciproc Blue (#12.5/4%).

In the present study, TruNatomy caused significantly lower BL and MD transportation than EDMax in almost all sections. To the best of the authors' knowledge, canal transportation and centering ability of EDMax have not been previously evaluated. However, Kumar *et al.* [22] indicated significantly lower transportation by TruNatomy compared with HyFlex EDM, which was in line with the present results. But García-Castañeda *et al.* [37] used micro computed tomography and found no significant difference in shaping ability of TruNatomy with HyFlex EDM and two other file systems. This difference is probably because they used mandibular premolars with long oval-shaped canals, while the mesiobuccal canals of mandibular molars with an almost round shape and a smaller size were evaluated in the present study, which are more prone to file deviation from the original path. In general, canal shape is an important parameter in the occurrence of apical transportation.

EDMax and Reciproc Blue had no significant difference in apical transportation in the current study, which was in agreement with the results of Ravichandran *et al.*, [30] who compared WaveOne Gold, ProTaper Universal, and HyFlex EDM regarding apical transportation. WaveOne Gold is somehow similar to Reciproc Blue, and HyFlex EDM is somehow similar to EDMax in terms of file sequence, type of movement, and fabrication process. Another study reported a similar level of transportation by WaveOne Gold and Reciproc Blue, confirming their similarity [38]. Nonetheless, in a study by Ravichandran *et al.*, [30] the mean transportation in both groups was < 0.1 mm, which was considered acceptable; whereas, in the present study, the mean BL transportation caused by Reciproc Blue at 4 mm distance, and the mean BL transportation at 1- and 2-mm distances caused by EDMax were greater than 0.1 mm, which may be considered unacceptable according to Ravichandran *et al.* [30]. The reason may be the difference in the sequence of files used in the two studies, since in using HyFlex EDM, instrumentation is terminated by file #25/0% while in EDMax, #25/6% is the final file used, increasing the risk of transportation. Furthermore, although WaveOne Gold has a reciprocation movement similar to Reciproc Blue, they have differences in file sequence. The WaveOne Gold glider has 2% taper, while that of EDMax has 4% taper, increasing the risk of transportation. Additionally, Ravichandran *et al.* [30] did not standardize the canals in terms of curvature.

In the present study, no significant difference was found in canal transportation and centering ability between Reciproc Blue with and without R-Pilot glider, which was in agreement with the results of Vorster *et al.* [31] who found no significant difference in canal transportation in using WaveOne Gold with/without three different gliders. In contrast, Keskin *et al.* [34] showed that using a glider with Reciproc Blue significantly decreased canal transportation and improved centering ability. This difference may be because they used resin blocks containing S-shaped canals. Also, they used #16/2% ProGlider while #12.5/4% R-Pilot was used in the present study, and a higher taper may increase the risk of transportation. Furthermore, a previous study showed that the ProGlider file (Dentsply Maillefer, Ballaigues, Switzerland) was significantly better than the ScoutRace rotary instrument (FKG Dentaire, La Chaux-de-Fonds, Switzerland) regarding transportation at a level of 2 mm from the apex in buccopalatal direction [39]. Moreover, in the evaluation of ProTaper Next, WaveOne Gold, and Reciproc Blue in simulated curved resin canals, there were no statistical differences in canal transportation between them [40].

In the current study, within-group comparisons revealed no significant difference in transportation in any group. Kim *et al.* [41] reported that TruNatomy caused maximum transportation in coronal sections; although the highest transportation was also noted at 4 mm from the apex in the present study, the difference was not significant. The same was observed in the EDMax group. No previous study is available regarding transportation caused by EDMax. However, previous studies on file systems similar to EDMax, such as ProTaper Next, reported significantly higher transportation in coronal sections [42], probably due to eccentric rectangular cross-section and brushing movement. Transportation was also insignificantly higher in coronal sections in the Reciproc Blue group, which can be due to its single-file use with 8% taper. Using a glider before the shaping file decreased transportation in coronal sections compared with apical sections, which was similar to the findings of previous studies [35, 38]. Another previous study showed that canal centrality and transportation were similar at coronal, middle, and apical cross-sections in the RaCe (FKG Dentaire, LaChaux-de-Fonds, Switzerland) and Af f-one (Dental Fanta, Shanghai, China) rotary systems [43].

Assessment of transportation and centering ability at 1- and 2-mm distances from the apex was a strength of this study since previous studies mainly assessed 3-, 6-, and 9-mm distances from the apex, while transportation is more common in more apical areas. Also, canal cleaning at 1 mm from the apex is highly important.

Ex vivo design was a limitation of this study, which limits the generalizability of the findings to the clinical setting. Lack of previous studies on EDMax for comparison was another limitation.

Future *in vivo* and clinical studies are required to obtain more generalizable results. Also, the efficacy of EDMax in comparison with other files should be compared in other root canals with various shapes and forms. Furthermore, the effect of the magnitude of apical transportation and centering ability on the treatment outcome should be investigated.

Conclusion

TruNatomy showed significantly lower canal transportation than Reciproc Blue and EDMax at all distances from the apex. The files had no significant difference in centering ability except at 3 mm in BL dimension, where TruNatomy had significantly higher centering ability than Reciproc Blue+R-Pilot.

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