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SHAPING ABILITY OF SINGLE ROTARY AND RECIPROCATING FILE SYSTEMS WITH DIFFERENT ACCESS CAVITY DESIGNS USING CONE BEAM COMPUTED TOMOGRAPHY

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ABSTRACT

Aim: to evaluate the use of CBCT to assess the effects of various access cavity designs on the canal transportation of root canals in human premolars that have been produced with a single rotary and reciprocating file system.

Materials and Methods: Six groups of sixty mature single-canal premolars were randomly selected. In Group 1, traditional access cavity design (TECs) were performed and canals were prepared with HyFlex/EDM file (TAC/ HyFlex), Group 2: Conservative access cavity design with HyFlex EDM (CAC/HyFlex), Group 3: Traditional access cavity design with WaveOne Gold (TAC/ WOG), Group 4: Conservative access cavity design with WaveOne Gold (CAC/ WOG), Group 5: Traditional access cavity design with TruNatomy (TAC/ TRN) and Group 6: Conservative access cavity design with TruNatomy (CAC/ TRN). To calculate root canal transportation, CBCT imaging was done before and after root canal preparation.

Results: The TRN file had the lowest canal transportation, whereas the WOG group had the greatest value. The difference between the WOG and TRN and HyFlex groups was statistically significant (P≤ 0.0001). HyFlex and TRN did not significantly differ from one another (p=0.674). It was found that, CAC recorded a considerably higher canal transportation than TAC regardless of the instrumentation file systems used, with significant differences at the apical and middle thirds and a non-significant value (p=0.373) at the coronal third.

KEYWORDS: Conservative access cavities, Canal transportation, HyFlex EDM, Traditional endodontic cavities , TruNatomy, WaveOne Gold.

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INTRODUCTION

A crucial step of a successful nonsurgical root canal treatment is endodontic access cavity preparation [1]. The goal of traditional access cavity (TAC) preparation is to allow direct, straight-line access to the pulp chamber by completely de-roofing the pulp chamber and any dentinal protrusions. It is based on designs that were first proposed by Black in 1908 and modified by Ingle in 1965 [2]. Although this technique allows for unrestricted access to the apical foramen and root canal orifices, the substantial loss of the structure of the tooth lowers the tooth's fracture resistance and makes it more prone to fracture under functional loads because of increased cuspal flexure [3-5].

Clark and Khademi [6] developed the idea of minimally invasive access cavity preparation to overcome these limitations. As much of the tooth structure as possible is preserved using this conservative method, especially the pericervical dentin, which has been demonstrated to increase fracture resistance [7-10]. Though they have shown superior results in preserving tooth integrity, conservative or constricted endodontic access cavities (CAC) may potentially increase the risk of inefficient root canal instrumentation and other procedural mistakes [5,9,11].

Root canal instrumentation, a critical step in root canal therapy, preserves the root canal's original structure, including the curvature and apical foramen. But because both rotary and manual instruments tend to straighten, procedure errors such root canal transportation can result from coronal interference, which causes the endodontic instrument to act on the exterior wall surface of the root canal curvature. Thus, to increase flexibility, new rotary file system designs and technologies have been introduced, such as R phase and M wire, heat technology, and controlled memory, cross-sectional designs, cutting edges, taper, and additional characteristics [12].

Since electrical discharge machining and controlled memory (CM) treatment have been shown to greatly improve flexibility and resilience to cycle fatigue, Ni-Ti rotary instrument generations with more flexibility and cutting efficiency have been introduced as HyFlex(HyFlex/EDM) (Coltene Whaledent AG, Altstatten, Switzerland). By switching from a triangular cross section at the shaft side, which provides more flexibility and fatigue resistance, to a rectangular cross section at the tip, which yields higher torsional resistance, HyFlex/EDM, the only instrument currently on the market made with electrical discharge machining, has led to a unique design [13, 14].

In 2020, Dentsply introduced the TruNatomy (TRN) files, which advocate for conservative endodontic access cavities. According to a unique heat treatment, this file system is made from 0.8 mm NiTi wire rather than the 1.2 mm Ni-Ti wire utilized to make the majority of files. The post-manufacturing thermal procedure used to create these files results in an instrument with extremely elastic Ni-Ti metal qualities and resistance to file fatigue [14, 15].

In comparison to traditional nickel titanium or M Wire, Because the metal has less memory, the files may appear slightly bent when extracted from a curved root canal due to the new wire's incredibly elastic properties. Three different sizes of TRN-shaping files are available: small (20/0.04 taper), prime (26/0.04 taper), and medium (36/0.03 taper). These files include a variable regressive taper and an off-center parallelogram square cross-section shape [14, 16].

As instruments and alloys continued to evolve, more modern file systems were improved. One such system is WaveOne Gold (WOG), a single-file system with reciprocal movement that alternates between 170° counterclockwise and 50° clockwise movement [17]. The unique heat treatment technique used after production is what gives WOG instruments their distinctive gold look. Repetitive heating and cooling of raw metal enhances its strength and flexibility in addition to giving it a golden hue [18].

For a precise and reliable endodontic diagnosis, sectional pictures are provided by the three-dimensional imaging method known as cone-beam computed tomography (CBCT). A diagnostic tool for measuring the amount of dentin removed during root canal instrumentation [19, 20].

Improved imaging tools like CBCT, very flexible equipment, and using of illumination and magnification all contributed to the progression of cutting smaller access cavities [21]. Because coronal interferences with CACs are thought to increase the operative obstacles during canal instrumentation, which may result in root canal transportation, while it is vital to move modern endodontic therapy toward a conservative worldview, it is also critical to allow appropriate endodontic access in order to accomplish optimal shape [22].

To attempt to close this gap, the current work compares and assesses several methods of access cavity preparation in conjunction with various single file systems, with an emphasis on how these methods affect canal transportation using CBCT.

MATERIALS AND METHODS

Sample size calculation:

Considering previous studies, comparing TECs and CECs [23, 24] , both of which had 10 teeth per group, the sample size was determined. Thus, with a research power of 80% and an alpha (α) level of 0.05, the minimum anticipated sample size was 10 each group, for a total of 60 samples.

Sample selection and grouping:

After the approval of a research ethical committee of Faculty of Dentistry, Tanta University, no #R-END-10-24-3146, 60 mature, intact human mandibular first premolars that were extracted for periodontal or orthodontic purposes from patients ages 20 to 40 were chosen. They were kept in 0.9% saline solution at 4°C until they were needed. The teeth were nearly the same length and had a degree of curvature that ranged from 25 to 35 degrees [25].

Schneider's method[26], which entailed radiographing teeth buccolingually and measuring the angle of curvature with two lines, was employed to ascertain the curvature's degree. The canal's long axis was paralleled by the first line, and the point where the canal began to diverge from the tooth's long axis was where the first and second lines met. When these two lines connect, an acute angle known as the Schneider angle is created, which indicates the canal curvature angle mesio-distally (α). Fig.1

Fig. (1) Schneider's method : radiographing teeth buccolingually and measuring the angle of curvature with two lines,

Based on the file systems and access cavity design, six equal experimental groups were randomly allocated coded teeth.

(n = 10) as follows:

Group 1: Traditional access cavity design with HyFlex EDM (TAC/ HyFlex/EDM)

Group 2: Conservative access cavity design with HyFlex EDM (CAC/ HyFlex/EDM)

Group 3: Traditional access cavity design with WaveOne Gold (TAC/WOG)

Group 4: Conservative access cavity design with WaveOne Gold (CAC/ WOG)

Group 5: Traditional access cavity design with TruNatomy (TAC/ TRN)

Group 6: Conservative access cavity design with TruNatomy (CAC/ TRN)

The teeth in each group were arranged in rows and fixed halfway up in transparent auto polymerizing acrylic resin (Acrostone, Dental and Medical Supplies, Cairo, Egypt) according to the guidelines provided by the manufacturer. The teeth were scanned using CBCT (Scanora 3D Soredex, Helsinki, Finland) prior to instrumentation. The machine's detector had a voxel size of 0.25 mm, and the X-ray tube used to scan the samples had a focal spot size of 0.5 mm, a target angle of 5 degrees, a current intensity of 16 mA, and a kilovoltage of 85 Kvp. In order to scan a field of view (FOV) of 7.5 cm x 14.5 cm x 14.5 cm (height, width and depth respectively), the scanning time was 10 seconds of pulsed exposure, which leads to an effective exposure time of 2.5 seconds.

Endodontic Access Cavity Preparation:

As for Group 1,3 and 5, traditional endodontic access cavity (TAC) was prepared using a no. 2 round carbide bur and diamond burs (Dentsply Maillefer, Baillagues, Switzerland) placed in a high-speed contra-angle handpiece (NSK, Japan) under water cooling. With a bur located mesiodistally and oriented along the tooth's long axis, the upper third of the lingual inclination of the facial cusp served as the first point of entrance. Using a tapered cylinder diamond bur, the pulp chamber's roof was removed by expanding the cavity mesiodistally and buccolingually. For straight line access, a portion of the pericervical dentin was removed.

For Group 2, 4 and 6, A portion of the chamber roof and lingual shelf were preserved when the conservative endodontic access cavity (CAC) was expanded apically after being accessible 1 mm buccal to the central fossa. This was done using no.2 round carbide bur with a high-speed contra-angle handpiece under water cooling.

All canals diameter were standardized by selecting roots fitting initial apical file #15 K-type (Dentsply Sirona Endodontics, Switzerland). Canals that were smaller or larger than this diameter weren't used. Each canal's working length (WL) was calculated by subtracting 1mm from the length of the K-type file size #10 at the apical foramen [27].

Biomechanical preparation:

Root canal instrumentation was performed utilizing X SmartTM Plus motor (Dentsply Maillefer, Baillagues, Switzerland) in accordance with the manufacturer's instructions for each system. 25/~ Both group 1 and group 2 canals were shaped using the HyFlex/EDM one file system (Coltene Whaledent AG, Altstatten, Switzerland). The files were run at 500 rpm and 2.5 Ncm of torque. up to four root canals could be shaped with each file.

Groups 3 and 4 were prepared using WOG (Dentsply, Maillefer, Switzerland), In the X-smart Plus motor's reciprocating WOG mode, the primary file (25/0.07) was utilized in a slow, reciprocating pecking motion in and out until the determined working length. The file was gently pushed inside using strokes of 3 mm amplitude, following the manufacturer's instructions.

Regarding groups 5 and 6, the TruNatomy Prime files (#26/0.04) (Dentsply Sirona, Ballaigues, Switzerland) were used to instrument the canals in accordance with the manufacturer's instructions. The canals were shaped using TRN and the following instrument sequence: TruNatomy Prime (26/0.04) file, Orifice Modifier (20/0.08), and TruNatomy Glider (17/0.02). Three vertical motions were carried out with all the files set to 500 rpm and 1.5 Ncm of torque.

Using 30-gauge side-vented irrigating endodontic needles (NaviTip, Ultradent, South Jordan, UT, USA), 10 mL of 2.5% sodium hypochlorite solution (Clorox Co., 10th of Ramadan, Egypt) was used to irrigate each root canal. To remove smear layer, 1 mL of 17% EDTA (Pulpdent Corp., Watertown, MA) was used. Two mL of saline and two mL of 2.5% sodium hypochlorite were then used as a final irrigation, and paper points were employed to dry the area.

Following instrumentation, teeth were scanned a second time using the same standards as pre-instrumentation scanning. The software Ondemand 3D Application (Cybermed Inc. Tustin, CA, USA) automatically completed superimposition, fusing the pre and postoperative images to provide the highest level of accuracy.

Evaluation of canal transportation:

The apical end of each root in each group was marked with cut lines at 3 mm (mid-apical level), 6 mm (mid-middle level), and 9 mm (mid-coronal level) on the axial view of the fused image CBCT scan. Use the following formula to find canal transportation: (a1-a2) - (b1-b2). Here, a1 denotes the shortest distance between the root's mesial edge and the un-instrumented canal's mesial edge, b1 the shortest distance between the root's distal edge and the un-instrumented canal's distal edge, a2 the shortest distance between the instrumented canal and the root's mesial edge, and b2 the shortest distance between the instrumented canal's distal edge and the root's distal edge[28]. (Fig. 2)

This formula states that there is no canal transportation if the score is zero, that the canal is carried to the distal side if the score is positive, and that the canal is transferred to the mesial if the score is negative [28, 29].

Statistical analysis

The data was expressed using the mean and standard deviation. At a significance level of P < 0.05, a two-way ANOVA was employed for statistical analysis using SPSS software version 20 (SPSS Inc., Chicago, USA). Multiple pairwise comparisons were then conducted using the post hoc Tuckey test.

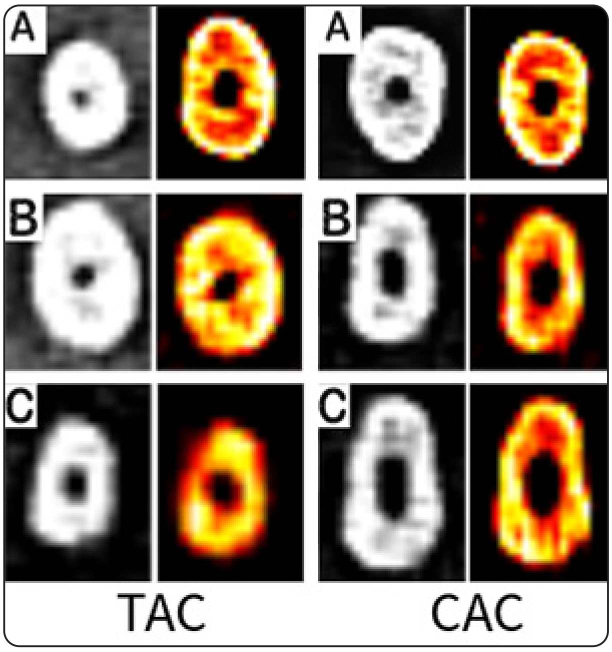

Fig. (2) Representative CBCT images of axial view for TAC and CAC to evaluate transportation before and after instrumentation at 3 (A), 6 (B) and 9 mm (C).

RESULTS

The descriptive information and mean canal transportation comparison for each group at the apical, middle, and coronal levels are shown in Table 1. The three root canal levels showed a statistically significant difference in the mean canal transportation values (p <0.001). Group 5 (TAC/TRN) had the lowest mean canal transportation values, while group 4 (CAC/WOG) had the highest mean values. With a statistically significant difference between the three-thirds in all groups, the coronal level had the highest canal transportation value when comparing the root levels in each group, while the apical level had the lowest value overall.

The TRN file had the lowest canal transportation (0.040 ± 0.019) when comparing the three tested file systems, irrespective of the tested root canal level and access cavity design. In contrast, the WOG group had the highest value (0.205 ± 0.088), and the difference between the WOG and TRN and HyFlex groups was statistically significant (P < 0.0001). However, TRN and HyFlex did not differ significantly (p=0.674). (Table 2)

It was discovered that the design of the access cavity had a significant impact on canal transportation because, as table 3 shows, CAC recorded a significantly higher canal transportation than TAC regardless of the instrumentation file systems used, with significant differences at the apical and middle thirds and a non-significant value (p=0.373) at the coronal third.

TABLE (1)

Transportation	Group 1 TAC/ HyFlex	Group 2 CAC/ HyFlex	Group 3 TAC/WOG	Group 4 CAC/WOG	Group 5 TAC/TRN	Group 6 CAC/TRN	ANOVA	
	Mean± SD	Mean± SD	Mean± SD	Mean± SD	Mean± SD	Mean± SD	F	P-value
Apical	0.023 ± 0.003$^{a, A}$	0.032 ± 0.003$^{b, A}$	0.072 ± 0.007$^{c, A}$	0.196 ± 0.003$^{d, A}$	0.017 ± 0.004$^{e, A}$	0.022 ± 0.003$^{a, e, A}$	3018.572	<0.001*
Middle	0.045 ± 0.005$^{a, B}$	0.052 ± 0.003$^{a, B}$	0.131 ± 0.038$^{b, B}$	0.289 ± 0.030$^{c, B}$	0.035 ± 0.005$^{a, B}$	0.042 ± 0.011$^{a, B}$	234.221	<0.001*
Coronal	0.064 ± 0.003$^{a, C}$	0.075 ± 0.004$^{a, C}$	0.246 ± 0.030$^{b C}$	0.295 ± 0.048$^{c, C}$	0.057 ± 0.007$^{a, C}$	0.068 ± 0.005$^{a, C}$	206.518	<0.001*
F	311.556	341.509	99.868	28.212	151.771	98.730		
P-value	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*		

Within the same raw, groups with the same lowercase were not statistically significant.
Within the same column, groups with different uppercase were statistically significant.
****Means statistically significant value.***

TABLE (2)

Total Groups	HyFlex			WOG			TRN			ANOVA		TUKEY'S Test		
	Mean	±	SD	Mean	±	SD	Mean	±	SD	F	P-value	HyFlex vs WOG	HyFlex vs TRN	WOG vs TRN
Transportation	0.048	±	0.018	0.205	±	0.088	0.040	±	0.019	184.647	<0.001*	<0.001*	0.674	<0.001*

****Means statistically significant value.***

TABLE (3)

Transportation	Group						T-Test	
	TAC			CAC				
	Mean	±	SD	Mean	±	SD	t	P-value
Apical	0.037	±	0.025	0.083	±	0.081	-2.979	0.004*
Middle	0.070	±	0.049	0.128	±	0.118	-2.478	0.016*
Coronal	0.122	±	0.091	0.146	±	0.111	-0.897	0.373

****means statistically significant value.***

DISCUSSION

Endodontic access cavity preparation is one of the most important stages of root canal therapy[30]. Pulp tissue remnants, that might serve as a microbial habitat, should be able to be removed with proper access[31]. Furthermore, removing coronal interferences makes it easier to determine root canal orifices [32] and opens the door to disinfecting irrigant solutions, increasing instrument efficiency and preventing mishaps [33].

With traditional endodontic cavities, straight-line access to the apical foramen or first canal curvature is possible [34]. The pericervical dentine (PCD), which is 4 mm apical and coronal to the alveolar crest, is among the substantial amounts of healthy dentine removed by this endodontic access cavity design. This could make the tooth weaker and more prone to breaking [33]. To ensure that the maximum amount of dental tissue is preserved, minimally invasive endodontic cavities have been proposed, which deviates from the overall fundamental principles of TAC [1,35].

Maintaining the root canal curvature's natural shape is necessary for sustained success of the root canal procedure, just as important as protecting the dentin [36]. Throughout the preparation process, endodontic instruments should stay centralized in the root canal [37]. If they are not, canal transportation may occur, resulting in improper dentine removal. Additionally, there is a considerable danger of straightening the initial canal curvature and creating ledges in the dentine wall [38].

Because curved canals pose a greater challenge to equipment, they are frequently employed as specimens in research studies [39]. This study employed severely curved canals to provide a more realistic assessment of the performance of various instrument systems [39, 40].

Because premolar anatomy varies with small cervical region of mandibular premolars, single canal premolars were chosen for the study. Additionally, because premolars have a higher concentration of masticatory forces, which makes them more susceptible to fracture following root canal therapy, minimally invasive endodontics in premolars is extremely important [41].

Schneider's approach was used to record the canal curvature angle, which was standardized to be between 21 and 39 degrees[26] because preparation flaws like canal transportation could likely result from this canal morphology[16]. Because CBCT is reliable and provides accurate three-dimensional characterization of the root canal anatomy, it was employed in this investigation to evaluate root canal transportation [12]. Furthermore, both before and after instrumentation, CBCT can be used to identify and assess the amount and direction of canal deviation[42].

Three root canal levels; three, six, and nine millimeters from the apex were ultimately selected. These measurements represented the root canals' apical, middle, and coronal thirds, that may have curves and are highly vulnerable to iatrogenic accidents [16, 43].

Canal transportation is caused by a number of factors, including as the instrument's operating mode, additional heat treatments applied during production, and geometrical features [44,45]. The working efficiency of rotary endodontic instruments during biomechanical preparation coud be enhanced by heat treatment process of NiTi alloys. As a result, several endodontic tools (TRN, WOG, and HyFlex/EDM) composed of distinct NiTi alloys were selected for this study.

Apical preparation size of 0.25 mm was chosen for all file systems, and a comparable size of 0.26 mm for TRN and 0.25 mm for HyFlex/EDM and WOG were chosen because Paque et al. [46] suggested that for evaluating the shaping capabilities of various root canal file systems, the same apical preparation diameters be used. It is actually more effective to remove debris and disinfect the root canal with a larger apical preparation size [47]. However, the effectiveness of the 25 apical size group in reducing bacteria did not differ significantly from that of the other groups with greater apical diameters, according to a prior study by Akhlaghi et al. [48]. Additionally, when apical size increases, the file's flexibility reduces, raising the risk of canal transportation [49].

Through the use of minimally invasive root canal shaping, TRN was created with the goal of maintaining the high occlusal strength of teeth that have had endodontic treatment. TRN's regressive taper (0.04), two cutting edges, and unique heat treatment give the TRN file system more flexibility, permitting the file to adhere to the canal's natural curve. Additionally, its off-centered parallelogram cross sectional design appears to enable the shaping of a larger canal surface when compared to concentric instruments with the same cross-sectional area. These factors may be responsible for TRN's lowest canal transportation in comparison to the other two file systems with both access cavity designs. Additionally, this would result in a more advantageous distribution of stress during instrumentation [12, 16, 50].

The distinctively thin design of that rotary file system can be explained by the fact that the Ni-Ti wire of TRN has a 0.8 mm design rather than the 1.2 mm design that is often utilized by more rotating Ni-Ti file systems [36, 51].

TRN is thought to protect the tooth's integrity and the root canal's basic anatomy because of all these qualities. These findings were consistent with a study by Kumar et al. [52], which discovered that the TRN system has the least amount of canal transportation when compared to the HyFlex/EDM and ProTaper Gold systems. Additionally, TRN demonstrated noticeably less canal transportation than WOG and ProTaper Gold at the apical and middle canal thirds, according to Kim et al. [36]

The current TRN study's findings were in line with those of Pit et al., who discovered that TRN produced more conservative preparations than ProTaper gold and Reciproc blue because it required less tooth material removal and maintained the canal's original shape during the preparatory phase of the endodontic treatment [53]. Also, the results of the current TRN study were consistent with those of Kabil et al., who demonstrated that very slight canal transit in the distal direction was generated by XPS and TRN instruments [54].

Due to the inverse link between canal transportation and instrument tapering, WOG was found to have the highest transportation mean [55]. In contrast to the other two tested instruments, where the TRN file has a consistent 4% taper throughout, primary WOG instrument has an 8% taper over the first 3 mm, while the HyFlex/EDM taper begins at 0.08 from D1 to D4 and decreases to 0.04 in the remaining file length [56], which may help to explain the WOG finding.

This is consistent with an earlier study that demonstrated that taper plays a role in determining shaping ability [57, 58]. The more taper in the apical region compared to similar files of the same size, the higher the degree of transportation and the less flexible the file [59].

The results of this analysis were in agreement with those of Shaheen and Elhelbawy's investigation, which discovered that WOG recorded more canal transportation than TRN and XP-Endo Shaper [16]. WOG was lower than TRN and ProTaper Ultimate in maintaining canal shape and pericervical dentin, according to a study by Ribeiro et al. [60], which further supports the taper parameter's significant impact on treatment outcomes.

The results of the current investigation contradicted those of Abdullah et al. and Singh et al., who demonstrated that WOG system outperformed the evaluated systems in improved performance, decrease canal aberrations, and shaping ability[61,62]. It was challenging to compare the contradicting results, though, and this could be explained by variations in the systems and methodologies used.

In addition, HyFlex demonstrated less transportation than WOG across all cross-sectional levels, independent of access design. The increased flexibility of the HyFlex file may be the cause of this observation, which is not surprising. The construction of significantly curved root canals may benefit more from the use of instruments with increased flexibility [63]. Compared to traditional NiTi and M-wire instruments of comparable diameters and tapers, HyFlex files are more flexible because of CM technology [64, 65]. Differentiate it from WOG with higher taper in addition to reducing the taper to 4% toward the coronal region with varying cross section [66].

This agreed with Turkistani et al. [67] who reported that HyFlex demonstrated less canal transportation than proTaper Next. Kumar et al. coordinate the current research result and discovered that HyFlex had less transportation than TRN without significant difference apically [52]. The advantage of the controlled memory effect, which keeps the file in the canal's shape even when it is out of it, may assist to explain it. This can be attributed in responsibility for preventing procedural mistakes including perforations, ledge development, and transportation. These files are highly beneficial in cases involving curved canals because to their exceptional flexibility and reduced taper [56].

At the three root levels, it was seen that TAC groups outperformed CAC groups with less transportation significantly in apical and middle thirds regardless the file system utilized. The absence of direct access and coronal interferences made instrumentation more difficult, which caused additional pecking motions to be needed to attain the working length and excessive instrument pressure against the outer portion of the root canal curvature[68].

The results of this study demonstrated that the shaping outcome in terms of transportation was influenced by the type of access cavity. These outcomes concur with those of Alovisi et al. [69], who demonstrated that canal transportation was noticeably higher in CECs than in TECs even when using CM equipment. Similar findings were seen in a study by Rover et al. [70], where even with M-Wire Ni-Ti technology, canal transportation was significantly greater for the CEC group in the palatal canal of upper teeth at 7 mm from the apical end than for the TEC group. Research has shown that CECs negatively impact the native canal architecture, especially in mandibular molars, regardless of used file system [71, 72].

Bayoumi et al. found that in their study, teeth with CECs prepared with HyFlex EDM showed statistical significantly highest transportation median, with no significant difference between both groups in centering ability [68].

Otherwise, these results were in conflict with those of Wang et al.'s study [73], which concluded that the design of the endodontic access cavity had no effect on the non-instrumented canal area, canal transportation, or centering ratio. This could be because they employed a different approach, instrumenting the buccal canals of maxillary first molars using the ProTaper Gold File system and evaluating the results using Micro-CT.

Consistent with the findings of Gu et al., [74] the current investigation discovered an overall tendency of increased canal transportation size in the coronal direction. In particular, they discovered that heat-treated NiTi instruments, such as WaveOne (M-wire), HyFlex CM, V Taper 2H (CM-wire), and Twisted Files (R-phase), displayed more transportation at coronal than at apical curvatures.

The mean root canal transportation was lowest in all groups at the 3 mm cross sectional level, followed by 6 mm and 9 mm. The heat treatment, which raised the phase transformation temperature, may be the cause of the lowest mean root canal transportation, which was 3 mm across all groups. For HyFlex, the Austenite finish temperature is from 47°C to 55°C [75], whereas, for TRN the austenite phase was obtained at 35˚C and at 60˚C [12], and for WOG it is ranged from 40˚C-60˚C [76] suggesting that, in clinical settings, these devices are primarily in the martensite or R-phase.

The results of the present study are in accordance with Ewis et al. [77] and Shaheen and Elhelbawy. [16] and Turkistani et al. [67] who found that TRN, WOG and HyFlex showed higher canal deviation at the coronal level whereas the apical level recorded the lowest value.

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