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SHAPING ABILITY OF THREE NICKEL-TITANIUM SYSTEMS IN CONTINUOUS AND RECIPROCATION MOTION USING CONE BEAM COMPUTED TOMOGRAPHY IN VITRO STUDY

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ABSTRACT

Introduction: Endodontic preparation in curved and narrow root canals has always been difficult because the prepared canal tends to deviate from its natural axis. Because of their increased shape memory, super elasticity, and cutting efficiency, nickel titanium rotary instruments provide acceptable treatment of curved canals in less time. Recently various single file systems with various metallurgy and designs have been developed to prepare the root canals using either continuous rotation or reciprocation motion. **Aim:** To compare canal transportation and centering ability in curved root canals after instrumentation with two different single file systems (*XP-Endo Shaper, WaveOne Gold*) in continuous rotation and reciprocation motion respectively and compared with one well-assessed full-sequence rotary NiTi system (*ProTaper NEXT*) using cone-beam computed tomography (CBCT). **Materials and Methods:** Forty-five human permanent mandibular first molars with mesiobuccal canal curvatures between 20° and 35° were used in this study after removal of distal root. They were divided into three groups (n=15) according to the instrumentation file system. Samples were fixed into acrylic resin block and were scanned before and after preparation using cone-beam computed tomography (CBCT). Scanned images were then superimposed and accessed to determine canal transportation and centering ability at three different levels (apical, middle, and coronal)..Data was statistically analyzed one way ANOVA and followed by Duncan multiple range tests (DMRTs) to further assess differences between different treatment groups. **Results:** XP-Endo Shaper always has the lowest mean of transportation which was significant with ProTaper Next at 3mm and 9mm and significant with WaveOne Gold and at 9mm from the apex. Also, XP-Endo Shaper showed the highest centering ratio, which was not significant with WaveOne Gold or ProTaper Next at any of the three levels. However, regardless levels of the canal for overall centering ratio, XP Endo Shaper was the highest statistically significant from ProTaper Next and not significant with WaveOne gold. **Conclusion:** The findings from the current study suggested that Single file systems are efficient and safe, to prepare severely curved canals. Not only file motion that affects root canal transportation other factors may play a role between different filing systems such, the design of the file and instrument manufacturing alloy.

INTRODUCTION

During endodontic treatment the achievement of an ideal preparation is a hard task in curved root canals. The curvature of the canal is considered to be the pre-eminent risk factor for procedural errors enlisting ledging, zipping, and transportation. *Cimis et al* [1] stated that 46% of curved canals have varying degrees of apical transportation subsequent to instrumentation. Transportation occurs due to the tendency of endodontic instruments to straighten the root canal during the chemo-mechanical preparation[2]. The structural durability of the tooth following endodontic therapy is directly proportional to the remaining dentin thickness. The aggressive instrumentation of the root canal structure results in loss of dentin which may eventually weaken the tooth [3].

The introduction of nickel-titanium (NiTi) rotary files to endodontics, almost two decades ago, has changed the way of root canal preparations, enabling more complicated root canal systems to be shaped with fewer procedural errors [4]. Nickel-titanium has a lower modulus of elasticity (lower stiffness) and a very large capacity for elastic (recoverable) deformation in comparison to stainless-steel instruments. These characteristics suggest that files made from nickel-titanium should be superior for the instrumentation of curved root canals when compared with stainless steel files [5]. That is, the greater flexibility possessed by nickel titanium files should allow instrumentation to be completed with less changes to the canal shape.

Though, fracture of rotary NiTi instruments remains an inadvertent incident during clinical use [6, 7]. Beside variations in the design of NiTi instruments, manufacturers have introduced several proprietary manufacturing procedures including thermal, mechanical, and surface treatment to improve the mechanical properties of NiTi alloys, in order to produce instruments with enhanced resistance to fracture and increased flexibility.

Instead of full rotation, the reciprocating NiTi rotary instruments have movements in which clockwise and counterclockwise degrees of rotation are not equal. The reciprocation theory of canal preparation has led to development of the fourth generation of NiTi rotary instruments. The use of a single file technique to achieve a thorough cleaning and shaping goals at this phase was another success which was also derived from the reciprocating philosophy in cleaning and shaping the root canal systems [8].

Recently single file shaping technique simplified the instrumentation protocol while reducing the working time and cost, improve safety of the shaping procedure reduce risk of instrument fracture and cross contamination. The single file systems can be used either in a reciprocal motion or in continuous rotation.

However, the shaping efficiency of all single files with different heat-treatment NiTi alloy and different rotation and reciprocation motion was not studied enough in curved root canals to assess their effectiveness against the rotary full sequence NiTi files.

Therefore, this study was conducted to assess the effect of different rotary NiTi single-file systems used in continuous rotation and reciprocating movements on canal transportation and canal centering ability and compared it with well-assessed full-sequence rotary NiTi system using CBCT scanning.

The null hypothesis tested was that there is no difference between rotation and reciprocation single files systems in comparison with rotary full sequence NiTi flie system regarding canal transportation and centering ability in curved root canals.

MATERIALS AND METHODS

This study was approved by research ethical committee, Faculty of Dentistry, Suez Canal University (approval no 36/2017).

I. Sample size calculations:

To evaluate and compare canal transportation, centering ability in curved root canals after instrumentation with single file systems*;* XP-endo Shaper (Rotation) and WaveOne Gold (Reciprocation) versus full-sequence rotary ProTaper NEXT system, the results were statistically analyzed using one-way analysis of variance (ANOVA), followed by a post hoc test. A minimum total sample size of 45 samples was sufficient to detect the effect size of 0.61, with a power (1-β=0.95) at a significance probability level of $p \leq 0.05$. According to sample size calculations, there is a 95 % chance of correctly rejecting the null hypothesis of no significant effect of the interaction with 15 sample for each group. The sample size was calculated according to G*Power software version 3.1.9.7.

II. Samples selection:

A total of forty-five unidentified human permanent mandibular first molar extracted due to periodontal or prosthodontic reasons were collected. Teeth were placed in 2.5% NaOCl for one hour to disinfect the teeth surface and dissolve organic debris on root surfaces. The external surfaces were scraped with a curette to remove the residual tissue, then calculus was removed with ultrasonic scaler. Preoperative periapical radiographs were taken to inspect the mesial roots and to determine the angle of root curvature according to Schneider's method[9]. Inclusion criteria were the following:

- Complete root formation.
- No internal root calcification.
- No internal or external root resorption.
- Mesiobuccal canal curvatures between 20° and 35°.
- Mesial roots with 2 separate mesiobuccal and mesiolingual canals (Type III Weine classification). Teeth were stored in saline solution until use.

III. Samples preparation:

The pulp chambers of the teeth were accessed using a round diamond bur (BR31, Mani Inc., Japan) mounted in a high-speed hand piece with air and water cooling then diamond taper stone (TF13, Mani Inc., Japan) was used to refine the access walls and obtain convenience form. The meisobuccal canals were localized and explored with a size 10 K-file (M. access,Dentsply Maillefer, Ballaigues, Switzerland) .

The buccal surfaces of teeth were marked with black permanent marker pen. Distal roots with the respective part of the crown were sectioned buccolingually using diamond disk (Anyang City Kangda Dental Abrasives Co., China) mounted in a low-speed hand piece with cooling and discarded.

Mesial roots with the respective part of the crown were shortened to standardize the length of ≃ 16mm by using diamond disk mounted in a low-speed hand piece with cooling leaving cervical part of the crown to provide conditions similar to the clinical situation. Then the working length of the roots was determined by introducing k-file size #15 (M. access, Dentsply Maillefer, Ballaigues, Switzerland) till it was seen flushed with apex, then the file was removed, and its length was measured, by subtraction 1mm from the measured length to obtain the working length. Samples were coded and stored in saline solution until use.

IV. Randomization and coding:

Forty-five folded papers containing the codes were packed in opaque sealed envelopes. The allocator chose one of envelopes for each sample and opened it by assistant supervisor. Forty-five samples were placed in resin block according to their codes, each group was represented in block by 15 samples each. Three folded papers containing group names (1,2.3) and another 3 folded papers containing tested files (*XP-Endo Shaper, WaveOne Gold, ProTaper NEXT*) name were packed in opaque sealed envelopes. Allocator chose one envelope from each group to match files with groups (**Figure 1**).

Fig. (1) Representative photograph showing coding of all samples after working length determination.

V. Resin block construction:

In order to standardize the position and angulation of pre-operative and post-operative scans all samples were embedded into acrylic resin block. The root apices were sealed with wax to preserve the apical foramen from resin penetration then roots were fixed by mounting them in transparent auto-polymerizing acrylic resin (Acrostone cold cure, Acrostone Dnetal And Medical Sup., Cairo, Egypt) mixed according to the manufacturer's instructions in a custom-made silicon mold (10 cm x 10 cm).The roots were arranged in 9 columns and 5 rows so that their long axes were parallel to the long axis of the mold with the buccal surface of all the samples facing the same direction. A metal ball was inserted into the resin at the buccal side to enable the orientation of the canal during scanning. Samples (teeth) were arranged according to their codes with letters and numbers for ease of identification (**Figure 2**).

Fig. (2) Representative photograph showing roots fixed in the acrylic resin block.

VI. Pre-instrumentation scanning:

All roots were scanned using cone beam computed tomography (Scanora 3Dx, Soredex, USA). The images were captured at 85 kvp and 15 mA and exposure time 3 seconds with resolution of 0.25 voxels (high resolution) to detect canal shape before instrumentation.

VII. Root Canal Preparation:

A glide path was created using #15 K file, samples in the resin block were randomly divided into 3 equal groups (n = 15 canals per group) according to the type of instrument used in each group as follows (each group made of 3 columns and 5 rows). Randomization was done using (http://www.random.org/) net program.

Group 1*: XP-Endo Shaper* (FKJ Dentaire SA, Switzerland): where roots were mechanically prepared using XP-endo shaper with Econnect Endomotor (Changzhou Eighteeth Medical Technology Co., Ltd., China) set at 800 rpm and 1Ncm torque.

Group 2: *Wave one Gold* (Dentsply Maillefer, Ballaigues, Switzerland)***:*** where roots were mechanically prepared using Wave One Gold primary file with Econnect Endomotor set at reciprocation motion 150 counterclockwise, 30 clockwise rotations.

Group 3: *ProTaper Next* (Dentsply Maillefer, Ballaigues, Switzerland)*:* where roots were mechanically prepared using ProTaper Next files X1 (17/04) then X2 (25/06) in rotation motion with Econnect Endomotor set at 300 rpm and 2Ncm torque.

Freshly prepared 2.5% Sodium hypochlorite (NaOCl) (Egyptian Company for Household Cleaners Clorox, Egypt) was mused as an irrigant during the instrumentation procedure in all groups after each three in and out movements (pecks) all roots were flushed with 3 ml of NaOCl and at the end of instrumentation with 6 ml with total volume of 15 ml per each sample using 30-gauge needle tips (Steri. Irrigation Tips, DiaDent Group International, Chungcheongbuk-do, Korea) inserted into the canal without binding at 14mm depth.

VIII. Post-instrumentation scanning

The root canals were scanned after mechanical preparation using CBCT, similarly to the pre-instrumentation scanning protocol. Pre- and Post-instrumentation scans were superimposed using On-Demand 3D software program to evaluate the degree of transportation as well as the centering ability of the tested instruments (**Figure 3**).

IX. Methods of evaluation:

Three cross-sections were selected for each specimen. The first corresponded to the area located 3 mm, from the apex, (apical third), the second 6 mm (middle third) and the third 9 mm (cervical third) from the root apex. The shortest distance from the canal wall to the external root surface was measured in the mesial and distal directions for the mesiobuccal root canal. The distance was measured on the reconstructed 2-dimensional cross-sectional images using the measure length tool. Measurements were recorded before and after instrumentation.

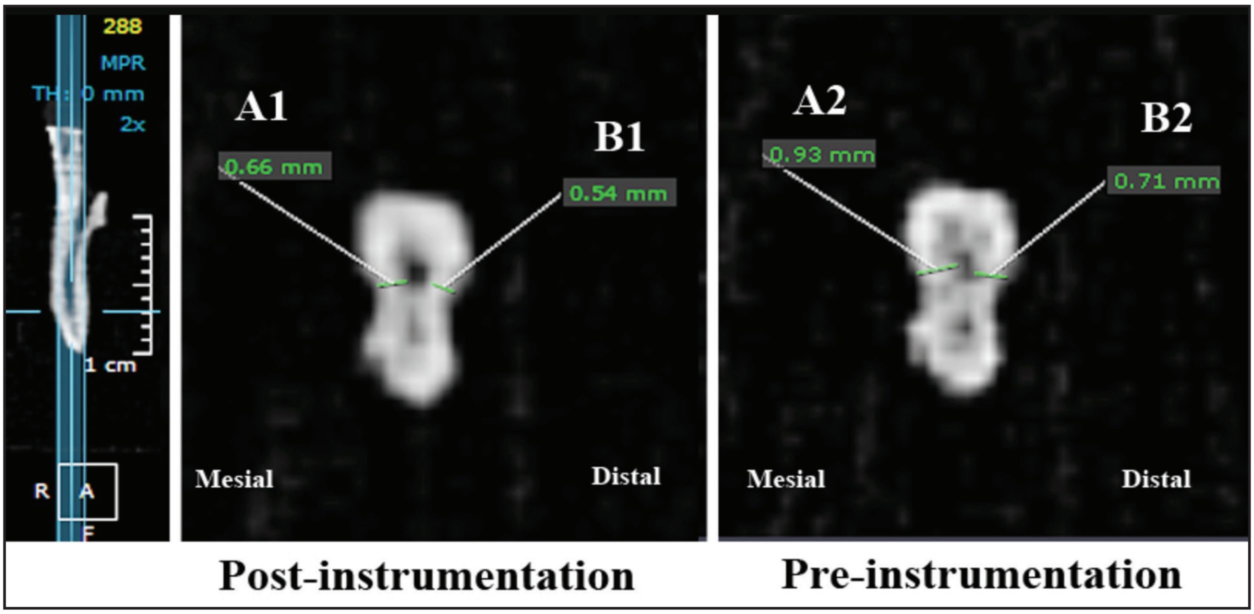

Fig. (3) Representative Photomicrograph showing Pre- and Post- instrumentation scans and superimposition of them using On-Demand 3D software program.

The degree of transportation:

Degree of transportation at each level was calculated according to the formula provided by *Gambill et al* [10]

Canal transportation (CT) = (A1–A2) – (B1–B2)

Regarding the transportation direction, CT equal to 0 (zero) denoted lack of transportation, a negative value denoted transportation towards the distal direction, and a positive value denoted transportation towards the mesial direction.

The canal centering ratio:

Canal centering ratio at each level was calculated according to the formula provided by *Gambill et al* [10]

Centralization ability ratio = (A1–A2) / (B1–B2) or (B1–B2) / (A1–A2)

The formula was selected in such a manner that the lowest of the results acquired through the difference should be the numerator.

A result equal to 1.0 signified perfect centralization. When the value was closer to zero, it denoted that the instrument had lower capacity to maintain itself in the central axis of the canal.

Where: A1: is the shortest distance from the mesial edge of the root to the mesial edge of the uninstrumented canal. **A2**: is the shortest distance from the mesial edge of the root to the mesial edge of the instrumented canal. **B1**: is the shortest distance from the distal edge of the root to the distal edge of the uninstrumented canal. **B2**: is the shortest distance from the distal edge of the root to the distal edge of the instrumented canal.

Statistical analysis:

Statistical analyses were performed using the computer software SPSS for Mac OS version 23.0 (Statistical package for social Science, Armonk, NY: IBM Corp.) at significance level of 0.05.

All data were handled, organized in tables and figures using Microsoft excel 2016. Data were checked for normality using Shapiro-Wilk normality test at 0.05 to check whether the data is parametric or nonparametric. Accordingly, data were parametric according to Shapiro-Wilk normality test and Kolmogorov Smirnov ($p<0.05$) (Xu, 2017). The collected data were checked for outliers, outliers were treated as missing values using SPSS.

Descriptive statistics were calculated in the form of Mean ± standard error and standard deviation. Data were analyzed for descriptive statistically both graphical and numerical description.

One-way analysis of variance (ANOVA) was used to compare between different tomogram levels (apical, middle, and cervical) in root canal transportation and centering ability at different group. One way ANOVA was also used to assess the difference between three treatment groups (XP Endo Shaper, Wave One Gold and ProTaper NEXT) at significance of 0.05 and 0.01. Analysis of variance (ANOVA) were followed by Duncan multiple range tests (DMRTs) to further assess differences between different treatment groups.

RESULTS

The degree of root canal transportation

There was no statistically significant difference between WaveOne Gold and ProTaper Next at three tested levels. However, XP-Endo Shaper always showed the lowest mean values of transportation which was significant with ProTaper Next at 3mm and 9mm and significant with WaveOne Gold at 9mm from the apex (**Table 1**).

Table (1) *Descriptive statistic of degree of root canal transportation in all sections (levels apical, middle, cervical) and all over the canal between different treatment groups (WaveOne Gold, XP Endo Shaper, and ProTaper NEXT) the mean ± standard deviation (SD). Difference between treatment groups was assessed by one-way ANOVA at 0.05.*

Canal level	Groups			P value
	1 XP-Endo Shaper	**2 WaveOne Gold**	**3 ProTaper Next**	
	Mean ± SD	Mean ± SD	Mean ± SD	
Apical (3mm)	$0.044^{X} \pm 0.025^{B}$	$0.087^{X} \pm 0.074^{AB}$	$0.098^{XY} \pm 0.065^{A}$	**0.036***
Middle (6mm)	$0.056^{XY} \pm 0.042^{A}$	$0.095^{X} \pm 0.084^{A}$	$0.079^{X} \pm 0.062^{A}$	**0.410NS**
Cervical(9mm)	$0.089^{Y} \pm 0.065^{B}$	$0.181^{Y} \pm 0.09^{A}$	$0.140^{Y} \pm 0.067^{A}$	**0.007****
P value	**0.039***	**0.005****	**0.049***	
Degree of transportation in all levels	0.063 ± 0.050^{B}	0.121 ± 0.092^{A}	0.104 ± 0.068^{A}	0.002**

NS; non-significant at p-value>0.05

** Significant at p<0.05; ** highly significant at p<0.01; *** very high significant at p<0.001*

Means with different letters "A,B" are significantly different within same row however different letters "X,Y" are significantly different within same columns at p<0.05 according to Duncan's Multiple Range Comparisons Test (DMRTs).

Regarding transportation all over the canal XP Endo Shaper was significantly different from WaveOne Gold and ProTaper Next, however, WaveOne Gold was non-significantly different from ProTaper Next (**Table 1**).

Regarding root canal level our results showed that preparing the canal with XP-Endo Shaper created degree of transportation at the cervical section, showed the highest mean value of canal transportation, followed by middle level and the lowest values recorded in apical level. Cervical level was significantly different from apical one however, the middle level was not significantly different from either apical or cervical.

In WaveOne Gold group the cervical section showed the significantly highest mean value of canal transportation. However, there was no statistically significant difference in canal transportation between middle and apical. While in ProTaper Next group the degree of transportation in cervical level was significantly different from middle one. However, the apical level was not significantly different from middle or cervical (**Table1**).

The comparison of the directions of root canal transportation in each level between the three tested groups showed that both WaveOne Gold and ProTaper Next groups had transportation towards mesial direction of the curvature while the samples in XP Endo Shaper group remained centered. at apical level (3-mm). While at the middle level (6-mm) WaveOne Gold showed transportation towards the distal direction while both XP Endo Shaper and ProTaper Next groups remained centered. At the cervical level (9-mm from the apex) the canal samples in all the experimental groups showed the same distal directed transportation tendency. The highest mean value was recorded was ProTaper Next group followed by WaveOne Gold and the lowest was XP Endo Shaper (**Figure 4**).

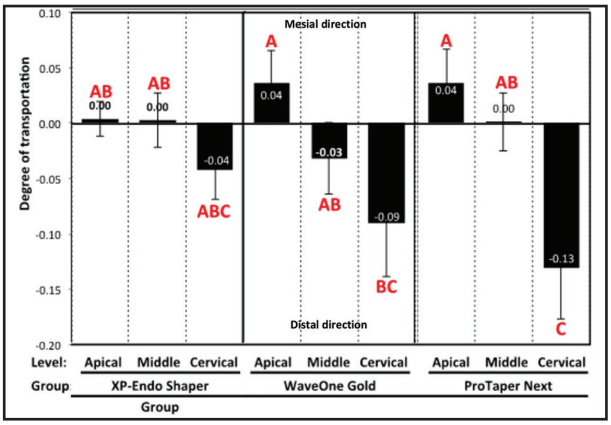

Fig. (4) Bar chart comparing directions of root canal transportation in each level between the three tested groups. Means with different letters are significantly different at p<0.05 according to Duncan's Multiple Range Comparisons Test (DMRTs).

The canal centering ratio

There was no significant difference among different groups at any level (Apical, Middle, and Cervical) (**Table 2**).

Regarding centering ratio all over the canal XP Endo Shaper has the highest mean value of centering ratio with no significant with WaveOne gold or ProTaper Next which has the lowest mean value (**Table 2**).

Regarding root canal level within each group XP Endo Shaper, WaveOne gold and ProTaper Next centering ratio showed no statistically significant difference among the different root levels (**Table 2**).

Table (2) *Descriptive statistic of degree of canal centing ratio in all sections (levels apical, middle, cervical) and all over the canal between different treatment groups (WaveOne Gold, XP Endo Shaper, and ProTaper NEXT) the mean ± standard deviation (SD). Difference between treatment groups was assessed by one-way ANOVA at 0.05.*

Canal level	Groups			P value
	XP-Endo Shaper	**WaveOne Gold**	**ProTaper Next**	
	Mean ± SD	Mean ± SD	Mean ± SD	
Apical (3mm)	0.609±0.256	0.581±0.283	0.438±0.324	**0.344NS**
Middle (6mm)	0.587±0.282	0.521±0.251	0.506±0.342	**0.725NS**
Cervical (9mm)	0.579±0.205	0.390±0.298	0.425±0.289	**0.138NS**
P value	**0.941 NS**	**0.168 NS**	**0.760 NS**	
Centering ratio in all levels	0.592±0.244	0.497±0.283	0.456±0.314	0.072

NS; non-significant at p-value>0.05

** Significant at p<0.05; ** highly significant at p<0.01; *** very high significant at p<0.001*

Means with different letters are significantly different at p<0.05 according to Duncan's Multiple Range Comparisons Test (DMRTs).

DISCUSSION

The aim of root canal treatment is to clean and shape the canals adequately. The shape of the prepared canals should provide a space for the irrigating solution to optimize the eradication of microorganisms. The prepared shape should also provide sufficient space for obturation. Sodium hypochlorite and rotary NiTi file systems are frequently used to accomplish these goals[11]. *Schneider*[9] underlined the importance of maintaining the apical foramen and maintaining the original canal curvature while presenting a flare-shaped root canal from apical to coronal. A constantly tapering funnel form with the largest diameter at the orifice and the smallest diameter at the terminal is the best canal design for gutta-percha filling and irrigation [12].

From 1990s until now, NiTi rotary instruments have undergone revolutionary changes in terms of the construction and as a result physical characteristic of the NiTi instrument. Additionally, there have been significant changes to the design, shape, and number of instruments used. The goal of changing and enhancing these tools is to create a NiTi rotary instrument that effectively cuts and removes the dentin while also being resistant to fracture even in the most difficult narrow, curved root canals [8]. Another reason for changing and enhancing NiTi rotary files is to make the cleaning and shaping process easier, utilize fewer instruments, and maintain the original shape of the prepared root canals [13].

The fourth generation of NiTi rotary instruments has been developed based on the reciprocation theory of canal preparation. Another success derived from the reciprocating philosophy in cleaning and shaping the root canal systems was the use of a single file to accomplish cleaning and shaping goals[8].

The concept of reciprocating motion based on balanced force technique was introduced by Yared, and single file F2 ProTaper instrument in a reciprocating motion was proposed to use for the preparation of curved root canals [14]. This dynamic helps to keep the instrument centered in the root canal by keeping the cutting force equivalent on both the concave and convex sides of the curve [15]. Manufacturers recently concentrated their efforts on enhancing the properties of the NiTi alloy in addition to the other modifications that previously stated [16, 17].

The temperature-dependent microstructure phases of NiTi alloy are austenite, martensite, and R-phase [18]. Austenitic NiTi is tough and hard, whereas martensitic and R-phase NiTi are flexible and easily deformed. The compositions of the three phases influence the mechanical properties of NiTi [19]. At room temperature, the conventional NiTi alloy is primarily in the austenite phase. Thermomechanical treatments could keep the alloy in the martensite phase, R-phase, or mixed phase by changing the transformation temperature and thus changing the alloy's properties [16, 18].

The WaveOne Gold system replaces the WaveOne single-file system. WaveOne Gold files are designed with a variable taper parallelogram-shaped cross-section has two cutting edges which are in contact with the canal wall, alternating with an off-centered cross section where only one cutting edge contacts the canal wall. It rotates in a reciprocal motion, with preset values set by the manufacturer of clockwise/counter clockwise angles. Counter-clockwise which is greater than the clockwise allows the file to progress apically while the latter disengages the file and eliminates file binding. WaveOne Gold, when introduced was claimed to have an increased elasticity owing to its metallurgical developments in gold-wire heat treatment. The gold process is a post-production procedure that involves heating and slowly cooling ground NiTi files. From a technical standpoint, heat treatment changes the transformation temperatures (austenitic start and austenitic finish), which improves the instrument properties. While this process gives the file its distinctive gold finish, it also significantly improves its strength and flexibility over its predecessor [20].

The XP-Endo Shaper is a single-file system with a continuous rotary movement and rectangular cross section. The MaxWire alloy technology used to create this file gives it superelasticity and shape memory properties [21]. With apical diameter of 0.27 mm and initial taper of .01, the XP-endo Shaper expands once inside the canal, achieving a taper of at least .04. When exposed to body temperature (35°C), the martensite phase of the file converts to the austenite phase, and the taper increases to 0.04 due to the molecular memory of the A phase [22]. Thanks to the Booster Tip (BT), the XP-endo Shaper benefits from a unique geometry, having six cutting edges at the tip. The BT tip respects the trajectory of the canal, whilst removing more material with each pass.

Protaper Next is a multiple file system that employs the concept of multiple progressive tapers. On a single file concept, each file presents an increasing and decreasing percentage tapered design [23]. This design minimizes contact between the cutting flutes of the instrument and the dentine wall, lowering the possibility of taper lock (screw-in effect) at the same time, it improves flexibility and efficiency [24]. Another advantage of this system is that the instruments are made of M-wire rather than traditional nickel titanium alloy. When compared to similar instruments made from conventional nickel titanium alloys, M-wire alloy could reduce cyclic fatigue by 400%. [25]. The additional metallurgical benefit contributes to more flexible instruments, increased safety, and decrease fracture [7]. PTN has an off-centered rectangular cross-sectional design that allows for debris removal in a coronal direction, allowing for more space around the flutes of the instrument and improving cutting efficiency through continuous blade contact with the surrounding dentin wall.

In the current study different two single file systems (*XP-Endo Shaper, WaveOne Gold*) were used in continuous rotation and reciprocation motion respectively and compared with one well-assessed full-sequence rotary NiTi system (*ProTaper NEXT*) using cone-beam computed tomography (CBCT) to evaluate canal transportation and centering ability in curved root canals after instrumentation.

Mesiobuccal canals of extracted first mandibular molars were chosen because testing file systems in natural dentin under realistic conditions is thought to be more beneficial than testing in standardized artificial canals [26].

Also, the mesiobuccal canals of mandibular molars have an accentuated curvature, they were chosen for this study. [27]. The curvature of the roots has been initially acknowledged by simply estimating the angle of the curve and then categorizing roots as straight (5° and less), moderately (10° to 20°) or severely (>20°) curved [28]. In this study the angle of curvature was severely curved ranged from 20° to 35° according to Schneider's technique [9], because endodontic preparation in curved root canals has always been a challenge, due to the tendency of the prepared canal to deviate from its natural axis [29].

Mesial roots with the respective part of the crown were shortened to leave the cervical part of the crown in which the interference of cervical dentin projections would create tensions on the files during canal instrumentation to simulate clinical conditions [27].

Three levels (ie, 3, 6, and 9 mm from the root apex) were chosen representing the apical and middle thirds of root canal, in which curvatures mostly exist and are highly susceptible to iatrogenic mishaps, and cervical third respectively in which strip perforation may exist [30].

Two parameters were selected to assess the shaping ability of the instruments tested in this study: (1) Apical transportation, which can endanger efficient root canal sealing, thereby reducing the treatment outcomes, and (2) maintenance of canal centering, which is basic in preparing curved canals [31].

Cone beam computed tomography (CBCT) was used to evaluate shaping ability of tested file systems it is the most used method today because it does not necessitate the destruction of the specimen, is reproducible, allows the capture of multiple images, and provides detailed information about the root canal before, during, and after biomechanical preparation [27, 32, 33, 34]. The evaluation of centering ability and canal transportation is facilitated by CBCT examination of preoperative and postoperative images of the root canal cross-section [35]. Furthermore, pre-, and postoperative CBCT scans can be precisely superimposed to the nearest voxel so that volumes and areas can be easily computed and compared using customized computer software Moreover, CBCT scanning is noninvasive and, therefore, multiple scans can be performed on the same specimen [36].

Regarding the results of the present study, all tested rotary systems resulted in canal transportation at all examined levels. Also results showed no statistically significant difference between WaveOne Gold and ProTaper Next at three tested levels. However, XP-Endo Shaper always showed the lowest mean of transportation which was significant with ProTaper Next at 3mm and 9mm and significant with WaveOne Gold at 9mm from the apex.

This result came in accordance with **Alrahabi and Alkady** [37] who stated that there was no significant difference in apical transportation between Wave One and ProTaper Next, which may be due to the similar design of these systems. Also, this result came in accordance with **Yuan** *et al* [38], who found that there was no significant difference in canal transportation values between Wave One and ProTaper Next both at the coronal and middle thirds. However, in contradiction to the current study, they found WO showed larger values of transportation compared with PTN at the apical third. This may be due to the specific heat treatment of WaveOne Gold which makes it have 80% greater flexibility than that of WaveOne [39].

Also, result was not consistent with **Kamha** *et al* [40], who found that, transportation was higher in ProTaper Next than WaveOne Gold in all levels (cervical, middle and coronal) with no significant difference between them at the apical and coronal parts of the canal. But, in the middle part, there was a significant difference between them. This difference in results may be due to different methodology as in our study we chose 3 fixed points 3mm from apex (apical), 6mm from apex (middle) and 9mm from apex (coronal) but in their study they chose 3 mm from the apex (apical), 3mm from the canal orifice (coronal), and mid-way between the two measurements (middle).

Our results came in agreement with **Poly** *et al* [41] and **Shukri** *et al* [42], who found that XP Endo Shaper resulted in less canal transportation than WaveOne Gold. The great results of the XP Endo Shaper can be attributed to its Adaptive Core technology, thanks to which it can expand while preserving the original canal anatomy and curvature [43]. Standard rotary files, despite their flexibility or surface treatment, can be all classified as ‘‘nonadaptive core’’ instruments. They instrument the canals to a rounded uniform shape without adaption to the individual variations of each canal. On the other hand, the XP Shaper is manufactured from a MaxWire alloy and has a tip size of ISO #27 with a 0.01 taper across the length of the instrument. Upon exposure to body temperature (35°C), the martensite phase of the file converts to the austenite phase, and the taper increases to 0.04 according to the molecular memory of the austenite phase [24]. This makes the file effectively clean and shapes the canal walls in 3 dimensions in both longitudinal and cross-sectional directions. Also, these results come in agreement with **Yanes** *et al* [44], who found that XP Endo Shaper showed significantly less canal transportation when compared with reciprocation systems. Regarding the superior results of XP Endo Shaper it showed the lowest statistically significant mean of transportation all over the canal , while the Wave One Gold and ProTaper Next instruments produced highest mean of transportation, with no statistically significant difference between them. These results came in agreement with of **Hassan** *et al* [45] and **Ozturk** *et al* [46], which may be due to the increasing tendency of canal transportation as the diameter of the files increases. As there is an inverse relationship between instrument tapering and canal transportation [47]. The primary Wave One Gold instrument has a 7% taper and showed the highest mean of transportation followed by ProTaper Next X2 file with 6% taper and XP Endo Shaper with an initial 1% taper along its whole length, which expands to a final 4% taper.

On other hand, this result came in disagreement with *Alfadley et al*[21], who found that in terms of canal transportation, there were no significant differences between XP Endo Shaper and Wave One Gold at the three levels. Also, this may be due to that their study was performed on simulated resin canal blocks with a J-shaped canal and the methodology of measuring canal transportation was different.

In this study all systems showed transportation smaller than 0.3 mm, which according to *Wu et al*[48] apical canal transportation smaller than 0.3 mm would have minimum impact on the prognosis of the endodontic treatment.

In this study, the direction of transportation of rotary NiTi instruments was generally towards outer aspect of the curve at the apical third. These findings were consistent with several studies that have reported that there was a greater tendency for transportation to the external side of the curvature (mesial direction) at the apical third, as a result of the increased pressure exerted on this area when instruments are inserted into the apical third of a curved canal [27, 49, 50, 51]. However, the XP Endo Shaper system maintained the best rate of shaping among the inner/outer walls over the entire length of the canal, this could be attributed to the difference in taper and design of booster tip that lead the file into the pre-established glide path ensuring precise guidance and centering of the instrument.

These results of the current research also came in agreement with *Poly et al* [41] who found that root canals instrumented with either WaveOne gold or XP Endo Shaper were not statistically significant in canal centering ratio at 3mm and 5mm from apex also XP Endo Shaper showed the higher centering ratio. And at 7mm from apex XP Endo Shaper showed the statistically significant highest mean centering ratio. Independent of the alloy, the flexibility and the stiffness of a file change as the file size and the core diameter increase as well as the instrument taper [52]. This suggests that the smaller size and taper of the XPS (27/.01) could lead to better-centered canal preparation than the WOG Primary (25/.07).

These results were also in consistent with *Kamha et al* [40] who found that, the percentage of centric canals after instrumentation was higher in Wave One Gold group followed by Wave One group, ProTaper Next group and the least percentage was ProTaper Universal group with no significant difference between them at the apical and coronal parts of the canal.

Canal transportation and centering ratio were only measured on three levels (3,6 and 9 mm from apex) which considered limitation of current study. Furthermore, the angle of curvature was between 20° and 35°different range of angles could give different results.

Within limitation of the present study XP Endo Shaper produced less canal transportation than WaveOne Gold and ProTaper NEXT, so the null hypothesis was rejected. Further studies are recommended to determine preparation time and evaluation of the volume of removed dentine by each file system during preparation. Also, more studies to investigate XP Endo Shaper shaping ability with other file systems and In-vivo studies to evaluate those files in clinical conditions using CBCT.

CONCLUSIONS

Based on the results and within the limitations of the present study, we concluded that:

1. Single file systems are efficient and safe, to prepare severely curved canals.
2. Not only file motion that affect root canal transportation other factors may play a role between different filing systems such, the design of the file and instrument manufacturing alloy.
3. XP Endo Shaper, WaveOne Gold and ProTaper NEXT can be used to shape severely curved canals as they showed the ability to maintain the original canal shape.
4. XPEndo Shaper produce less canal transportation than WaveOne Gold and ProTaper NEXT.

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