ORIGINAL RESEARCH

Effect of Glide Path and Coronal Flaring on the Centering Ability and Transportation of Root Canals: Micro-CT *In Vitro* Study

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Abstract

Aim: To compare the effect of glide path and coronal flaring on the centering ability and transportation in curved canals prepared by different NiTi instruments using micro-CT.

Materials and methods: The mesiobuccal canal of 48 extracted mandibular molars was selected and divided into two groups of 24 each according to the type of instrument used, either Race Evo or EdgeSequel. Each group was further divided into three subgroups: Group I: without glide path and coronal flaring (control); Group II: with glide path and without coronal flaring; Group III: with glide path and coronal flaring. Following access opening and working length determination, coronal flaring and glide path were done in the required groups. The canals were then prepared according to the assigned instruments and assessed using micro-CT at 3, 5, and 7 mm of the root canal. Data of pre- and postoperative measurements were statistically analyzed using SPSS.

Results: The mean value of centering ability was 0.39 (SD 0.36) while the mean value of transportation ability was 0.002 (SD 0.153). Transportation and centering ability did not vary significantly among the tested groups of rotary instruments. Comparison of centering and transportation among root canal instrumentation groups at 3, 5, and 7 mm showed no statistical significance ($p > 0.05$).

Conclusion: No significant difference was found among the tested groups regarding transportation and centering ability.

Clinical significance: This study provided data on the effect of glide path and coronal flaring on the centering ability and transportation on curved canals prepared by Race Evo and EdgeSequel. Coronal flaring and glide path did not affect the centering ability and transportation.

Keywords: Centering ability, Coronal flaring, Glide path, Micro-CT, Transportation.

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Introduction

Using of nonflexible instruments to shape a curved canal can lead to several errors, such as divert the canal away from the original axis, lead to canal transportation, apical zipping, canal ledges, strip perforations, and instrument separation. Flexible instruments, for example nickel titanium (NiTi) instruments, were introduced commercially to overcome many drawbacks, one of which is that they are considered to significantly reduce procedural errors.[1]

Anatomical changes by the instruments could cause many complications that could interfere with the treatment results, including perforations. Rotary instruments used in endodontic treatment play a significant role in successful cleaning, chemo-mechanical disinfection, and shaping.[2] These newer devices are used to achieve a smooth gliding path and coronal flaring, which is essential for achieving good shaping and cleaning of the root canal.[3]

The endodontic glide path is a smooth radicular tunnel from canal orifice to apical constriction. A secured glide path is a significant indicator that bigger files can reproduce another smooth passage.[4] Numerous studies have compared the centering ability, transportation, and ability to maintain the canal anatomy using different hand and rotary glide path files by various methodologies.[5–7]

Utilization of rotary glide path files has resulted in mixed results, with some studies favoring their use while others rejecting them. It was reported that the use of rotary glide path files preserved the original canal anatomy and caused fewer canal aberrations and transportations than K-files.[8] However, other studies found that glide path preparation failed to prevent apical transportation in curved canals.[9,10]

Coronal flaring has been defined as a pre-enlargement of the root canal up to its terminus using hand or rotary files to a tip size at least equal to that of the first rotary instrument's tip used.[11] The primary purpose of coronal flaring is to minimize the torsional stress on the file when engaging within the root canal.[12]

Gliding path and coronal flaring, if correctly done, can be assessed by the two essential parameters of centering ability and transportation to evaluate the shaping ability of the instruments. Any newer devices introduced commercially, and if they are to be evaluated for their efficiency for creating gliding path and coronal flaring, need to be evaluated based on these two parameters. Centering ability is the instrument's ability to reduce constraints

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and remain centered in the canal even when the root canals are straight. The canal transportation caused by the instrument is also considered to assess how much the instrument helps keep the original anatomy.[13]

There are various means by which the assessment of these two parameters of canal shaping can be done, including microscopy, leakage tests, and digital imaging.[14] Nevertheless, micro-computed tomography (micro-CT) is the most advanced and efficient method, wherein the roots are scanned and three-dimensional images are reconstructed, which allow for thorough assessment without altering the original anatomy.[15]

Since the inception of NiTi for the manufacturing of endodontic instruments, several newer rotary instruments have been introduced. Recently, two heat-treated NiTi instruments were introduced: EdgeSequel (EdgeEndo, New Mexico, USA) and Race Evo (FKG, Le Crêt-du-Locle, SWISS). To the best of our knowledge, there have not been any previous studies that have evaluated the effect of glide path and coronal flaring together on the centering ability and transportation using these rotary NiTi systems. Therefore, the present study was undertaken to assess the effect of glide path and coronal flaring on the centering ability and transportation in curved canals prepared by different NiTi instruments using micro-CT.

The null hypothesis was that there will be no significant difference in the centering ability and transportation among the tested groups.

Materials and Methods

Ethical Approval

The research was registered at Riyadh Elm University, Riyadh, KSA, with an IRB approval FPGRP/2020/506.

Sample Power Calculation

Sample power was calculated using the G-Power sample power calculator (UniversitatKiel, Kiel, Germany). Using 5% as the margin of error, 95% confidence interval, and power of 80%, a total sample size of 48 with eight samples per group was determined. By using G-power, the effect size was calculated using similar method (5% margin of error and 95% confidence interval) for a sample size of 48; the estimated effect size is 0.434 or 43.4%.

Specimen Selection and Preparation

The mesiobuccal canal (MB) of 48 extracted mandibular molars was selected and divided into two groups of 24 each according to the type of instrument used, either Race Evo or EdgeSequel. Teeth were extracted mainly for periodontal reasons. The following inclusion criteria were used to select the teeth: permanent mature teeth, separated canals, the range of canal curvature is between 20° and 40° (Schneider 1971), and sound teeth. On the other hand, the following cases were excluded: teeth with more than one apical foramen, teeth with root resorption, teeth with previous treatment or endodontic therapy, and fractured teeth.

Grouping

The selected teeth were divided into two groups ($N = 24$) based on the instrument to be used, Race Evo (Group I) or EdgeSequel (Group II). Each group was further subdivided into three subgroups ($n = 8$) based on the procedure:

- **Group I-a:** Race Evo
- **Group I-b:** Race Evo with glide path
- **Group I-c:** Race Evo with both glide path and coronal flaring
- **Group II-a:** EdgeSequel
- **Group II-b:** EdgeSequel with glide path
- **Group II-c:** EdgeSequel with both glide path and coronal flaring

Access Opening and Working Length Determination

The specimens were disinfected in 1% sodium hypochlorite (NaOCl), rinsed with distilled water, and stored in 0.1% hyaluronate solution. Access opening was performed initially using a round bur size 4 (Brasseler, Georgetown, USA) followed by Endo Z bur (Dentsply-Maillefer, Tulsa, OK). The pulp chamber was irrigated with a 2.5% NaOCl solution. Working length was determined by using a #10 K-file (Dentsply-Maillefer, Tulsa, USA), wherein the file was inserted through the canal until it was visualized at the apical foramen, and then reduced by 1 mm. A #15 k-file was subsequently used for initial instrumentation (Dentsply-Maillefer, Tulsa, USA).

Coronal Flaring

An SX (EdgeEndo, New Mexico, USA) file was used on an X-Smart endodontic engine (Dentsply-Maillefer, Tulsa, USA) at the suggested setting (300–350 rpm, 3 N cm). RC Prep (Premier, Muskogee, USA) was used as a lubricating agent. Coronal flaring was done for Groups I-c and II-c.

Glide Path

A Glide Path file (EdgeEndo, New Mexico, USA) was used on an X-Smart endodontic engine (Dentsply-Maillefer, Tulsa, USA) at the suggested setting (300–450 rpm, 3 N cm) to smoothen the radicular tunnel from canal orifice to apical constriction. RC Prep (Premier, Muskogee, USA) was used as a lubricating agent. Glide path was done for Groups I-b, I-c, II-b, and II-c.

Coronal Flaring and Glide Path

In these groups, coronal flaring was done, followed by a glide path as described earlier. Coronal flaring and glide path were done for Groups I-c and II-c.

Chemo-mechanical Preparation

A single operator with knowledge and experience in all the systems used performed all the root canal instrumentations. One group of teeth were instrumented with EdgeSequel size 30, taper 4% speed 300–450 rpm, and torque 3 N cm. The other group of teeth were instrumented using Race Evo size 30, taper 4%, speed 800–1000 rpm, and torque 1.5 N cm. Both systems were operated using the endodontic engine (X-Smart, Dentsply Maillefer) in continuous motion. Sodium hypochlorite at a concentration of 2.25% was used for irrigation using Endo-Eze irrigator tips with 27 gauge (Ultradent, South Jordan, USA). RC Prep was used as a lubricating agent. Files that were used for a tooth were discarded and fresh files used for each subsequent tooth.

Micro-CT Analysis

Pre- and postscans for each sample were performed by individually securing it with polyvinyl siloxane and mounting it in a polyethene plastic container to establish an identical position for repeated scanning. Samples were then positioned on the micro-stage inside the specimen chamber. Scans were acquired using the Bruker SkyScan 1,172 high-resolution micro-CT (Bruker SkyScan, Kontich, Belgium). The scanner configuration used was 95 kV voltage, 104 µA anode current, 158 ms exposure time, 25 µm image pixel size, Al 0.5 mm, 0.3 rotation step for 360° angle, frame averaging of four for improved signal-to-noise ratio, and random movement of eight minimized ring artefacts. A flat-field correction was performed before the scanning procedure to correct variations in the camera pixel sensitivity.

After the scanning, a reconstruction of the projected images was performed using N-Recon©, program version 1.6.9.4 (Bruker Skyscan, Kontich, Belgium), to produce a reconstructed cross-sectional image. Numerical parameters needed to establish the best image results were checked and adjusted. A ring artefact reduction of 5 for nonuniformity of the background image taken by the X-ray camera; 25% beam hardening compensation to prevent the specimen from appearing artificially denser at or near its surface, and less dense at its central parts; and a smoothing of 2 using Gaussian kernel were applied. A 16-bit TIF format was the choice for saving the images because of the variety of densities comprising the specimen. Preoperative data for all groups are listed in Table 1.

Calculation of Transportation and Centering Ability

The extent and direction of canal transportation were determined according to a technique proposed by Gambill et al.[16] A comparison was made between the images of the preinstrumented and instrumented canals, measuring the shortest distance from the edge of the canal to the edge of the tooth in both mesial and distal directions (Fig. 1).

The transportation (T) calculation was obtained using the formula:[16]

$$T = (M1 - M2) - (D1 - D2)$$

where $M1$ is the shortest distance from the root's mesial aspect to the periphery of the pre-instrumented canal; $M2$ is the shortest distance from the root's mesial aspect to the periphery of the postinstrumented canal; $D1$ is the shortest distance from the root's distal aspect to the periphery of the preinstrumented canal; $D2$ is the shortest distance from the root's distal aspect to the periphery of the post-instrumented canal.

Based on this formula, a $T = 0$ result indicates no transportation. A positive result ($T > 0$) indicates transportation towards the mesial (outer) aspect of the root. A negative ($T < 0$) indicates transportation toward the distal (furcal) aspect of the root.

The mean centering ratio (C) is a measure of the instrument's ability to stay centered in the canal. The centering ability of different instruments was subsequently calculated using the formula:[16]

$$C = (M1 - M2)/(D1 - D2) \text{ if } (D1 - D2) > (M1 - M2)$$

or

$$C = (D1 - D2)/(M1 - M2) \text{ if } (M1 - M2) > (D1 - D2)$$

Based on this formula, a $C = 1$ result indicates perfect centering ability. However, the closer the result was to zero the worse the centering ability of the instrument.

Levels of Assessment

The assessment was done at three levels of the root canal at 3-, 5-, and 7-mm coronal to the apex.

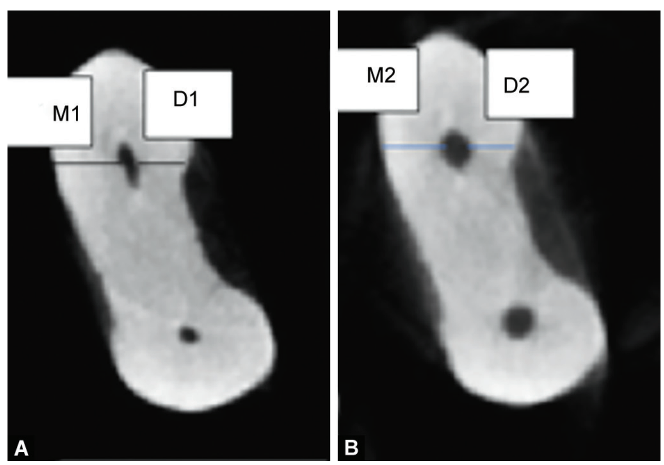
Statistical Analysis

Descriptive statistics were presented using mean and standard deviation. The comparison between transportation and centering ability among the distance and the performed root canal instrumentation was calculated using one-way ANOVA test. *Post-hoc* test was also performed using Tukey-HSD test. A p-value cut-off point of 0.05 at 95% CI used to determine statistical significance. Normality test (i.e., data homogeneity) has been calculated using Kolmogorov-Smirnov test as well as Shapiro Wilk test. Data follow normal distribution. Therefore, parametric tests were applied. All data analyzes were performed using Statistical Packages for Software Sciences (SPSS) version 21 (IBM Corporation, New York, USA).

Results

For all groups, the measure of centering ability had a mean of 0.392 (SD 0.355) while the measure of transportation ability had a mean of 0.002 (SD 0.153).

Transportation in the group of EdgeSequel with both glide path and coronal flaring (0.04 ± 0.12) was the highest. On the other hand, transportation in the groups of Race Evo with both glide path and coronal flaring (−0.01 ± 0.13) and EdgeSequel (0.01 ± 0.15) was the least. However, the comparison between root canal instrumentation



Figs 1A and B: (A) Pre-instrumentation and (B) Post-instrumentation micro-CT images with markings showing points of measurements used for determination of canal transportation and centering ability

Table 1: Preoperative data (mean ± SD) for all groups

Group	*Root canal volume (mm³)*	*Root canal length (mm)*	*Apical diameter (mm)*	*Root curvature (°)*
Race Evo	1.85 ± 0.95	13.25 ± 0.93	0.24 ± 0.02	28.23 ± 1.84
Race Evo with glide path	1.86 ± 0.59	12.55 ± 1.25	0.22 ± 0.02	29.17 ± 1.95
Race Evo with both glide path and coronal flaring	1.76 ± 0.51	12.98 ± 0.98	0.25 ± 0.02	28.02 ± 2.12
EdgeSequel	1.83 ± 0.98	12.73 ± 1.24	0.27 ± 0.03	29.24 ± 1.85
EdgeSequel with glide path	1.91 ± 0.84	13.08 ± 0.99	0.23 ± 0.02	30.02 ± 2.07
EdgeSequel with both glide path and coronal flaring	2.07 ± 0.76	12.68 ± 0.92	0.24 ± 0.03	29.33 ± 1.85

in transportation ability did not vary significantly across the groups ($p = 0.484$) (Table 2).

The comparison of root canal instrumentation performed in centering ability was shown in Table 3. It was found that the measurements of centering ability were not significantly different across root canal instrumentations ($p = 0.331$). The group of Race Evo with both glide path and coronal flaring (0.45 ± 0.35) and the group of EdgeSequel with both glide path and coronal flaring (0.45 ± 0.37) show higher centering ability than the other groups.

Comparison of centering and transportation among root canal instrumentation groups at all assessment levels did not reach statistical significance ($p > 0.05$). The highest centering ability was found in the groups of EdgeSequel at 3 mm (0.59 ± 0.27) and EdgeSequel with glide path at 5 mm (0.59 ± 0.42). The least centering ability was found in the group of Race Evo with glide path at 5 mm (0.26 ± 0.21). Values of transportation varied from 0.01 in the groups of EdgeSequel with both glide path and coronal flaring at 5 and 7 mm to −0.18 ± 0.34 in the group of EdgeSequel with glide path at 7 mm (Table 4).

Based on the aim of the study, it could be inferred that glide and coronal flaring had no effect on the centering ability and transportation in curved canals prepared by two NiTi instruments using micro-CT.

Table 2: Comparison of root canal instrumentation performed in transportation ability

Root canal instrumentation	*Transportation Mean ± SD*	*p value**
Race Evo	0.03 ± 0.16	0.484
Race Evo with glide path	−0.02 ± 0.12	
Race Evo with both glide path and coronal flaring	−0.01 ± 0.13	
EdgeSequel	0.01 ± 0.15	
EdgeSequel with glide path	−0.02 ± 0.22	
EdgeSequel with both glide path and coronal flaring	0.04 ± 0.12	

**p* value has been calculated using one-way analysis of variance test

Table 3: Comparison of root canal instrumentation performed in centering ability

Root canal instrumentation	*Centering ability Mean ± SD*	*p value**
Race Evo	0.31 ± 0.34	0.331
Race Evo with glide path	0.31 ± 0.35	
Race Evo with both glide path and coronal flaring	0.45 ± 0.35	
EdgeSequel	0.43 ± 0.31	
EdgeSequel with glide path	0.40 ± 0.39	
EdgeSequel with both glide path and coronal flaring	0.45 ± 0.37	

**p* value has been calculated using one-way analysis of variance test

Discussion

After the root canal shaping procedures, the noncentral root canal preparation and the insufficient or excessive instrumentation of the tooth structure may have adverse effects on the prognosis.[17] For this reason, assessing the quality of root canal preparation is of significant importance for selecting the appropriate file system. Mesiobuccal canal was chosen in this research based on a previous study,[18] as it is usually more curved than other canals.

To our knowledge, there are currently no existing studies that compared the effect of glide path and coronal flaring on the centering ability and transportation prepared by different NiTi instruments, making it difficult to compare the current study's results directly with others. This study's findings are expected to provide new information in the field of endodontics. Transportation and centering ability may vary at different root canal levels and the current study has analyzed this to assess the instrument's performance at different levels (3, 5, 7 mm).

Though there are many methods available to assess these components, Micro-CT analysis is currently considered the gold standard, which permits noninvasive analysis of changes in the canal morphology, surface area, and volume and identification of the unprepared area, and is far better than the other methods available till-date.[19] This high-resolution tomography with its improved technique has been used by various studies for the assessment over the other methods. Meanwhile, micro-CT imaging is considered to generate accurate, high-resolution, and fully quantitative data, allowing easy 3D assessment of the root canal system and measurement of canal changes. It also avoids the potential of a radiographic or photographic transfer error.[20] The utilization of micro-CT in the current study is well justified, wherein the preinstrumented and postinstrumented images of the same sample were combined utilizing advanced matching and comparison features during micro-CT analysis to obtain fully measurable images, as what was done in a previous study.[21]

The results obtained from the present study determined that the glide path and coronal flaring did not significantly affect the tested files' transportation and centering ability. Moreover, there was no statistically significant difference between the files

Table 4: Comparison of root canal instrumentation performed at different levels

Level	*Assessment*	*RE Mean ± SD*	*RE/GP Mean ± SD*	*RE/GP CF Mean ± SD*	*ES Mean ± SD*	*ES/GP Mean ± SD*	*ES/GP CF Mean ± SD*	*p value**
3 mm	Centering	0.30 ± 0.23	0.34 ± 0.32	0.49 ± 0.62	0.59 ± 0.27	0.33 ± 0.35	0.40 ± 0.32	0.631
	Transportation	0.03 ± 0.09	0.06 ± 0.09	0.02 ± 0.09	0.06 ± 0.08	0.04 ± 0.12	0.04 ± 0.09	0.963
5 mm	Centering	0.51 ± 0.31	0.26 ± 0.21	0.56 ± 0.19	0.27 ± 0.27	0.59 ± 0.42	0.58 ± 0.43	0.124
	Transportation	0.02 ± 0.11	−0.04 ± 0.14	−0.03 ± 0.15	−0.03 ± 0.19	0.08 ± 0.08	0.01 ± 0.13	0.572
7 mm	Centering	0.27 ± 0.38	0.35 ± 0.39	0.39 ± 0.21	0.46 ± 0.34	0.31 ± 0.47	0.42 ± 0.35	0.909
	Transportation	−0.13 ± 0.12	0.08 ± 0.11	−0.11 ± 0.09	−0.03 ± 0.18	−0.18 ± 0.34	−0.01 ± 0.07	0.441

RE, Race Evo group; RE/GP, Race Evo with glide path group; RE/GP/CF, Race Evo with glide path and coronal flaring group; ES, EdgeSequel group; ES/GP, EdgeSequel with glide path group; ES/GP/CF, EdgeSequel with glide path and coronal flaring group; **p* value has been calculated using one-way analysis of variance test of RaceEvo and EdgeSequel. Automated glide path preparation produces significantly less canal transportation and more preservation of the original canal anatomy than hand glide path preparation.[22] Van der Vyver et al. showed that One-G (MicroMega, Besancon, France) and ProGlider (Dentsply Sirona, Pennsylvania, USA) were significantly more centered at the apical, mid-root, and coronal levels than K-files.[23] A recent study showed that mechanical glide path preparation with ProGlider and PathFile (Dentsply Sirona, Pennsylvania, USA) rotary systems followed by WaveOne (Dentsply Sirona, Pennsylvania, USA) showed significantly less canal transportation than the use of K-files followed by the same system.[24] These findings confirmed that rotary files in the glide path produced transportation less than hand files; therefore, rotary glide path files were used in this study. Various studies have reported that the file systems' kinematics affects the changes that the files created within root canals during shaping procedures. In a study by Gergi et al.,[25] TF Adaptive files (Kerr, California, USA) in continuous rotation motion produced better centering abilities and less transportation than the WaveOne and Reciproc (VDW, Munich, Germany) which are used in reciprocating motion.

A study was conducted to evaluate and compare the transportation and centering ability of the ProTaper Next system (Dentsply Sirona, Pennsylvania, USA) with and without glide path using ProGlider and reported no significant difference among the tested groups regarding the centering ratio.[18] Similarly, another study showed that the centering ability and transportation values of the Primary WaveOne Gold (Dentsply Sirona, Pennsylvania, USA) instrument with or without different glide paths were not significantly affected.[8] Another study has compared the shaping ability of different rotary and reciprocating nickel-titanium file systems with and without previous glide path preparation in simulated S-shaped canals, it was found that glide path preparation had no significant impact on canal straightening.[26]

The results of these studies, which are consistent with ours, could be explained based on the fact that the rotary files tested were all heat-treated and in the martensitic phase possessing shape memory. These files are already very flexible and have high centering ability that is why the glide path did not yield significant difference. Based on these findings, the null hypothesis of the research was accepted.

There are certain limitations in the current study. Instrumentation for all teeth was performed to a unified size and taper (30/4%), without taking in consideration the original size of the canal, which does not coincide with a real clinical scenario. Second, as with most *in vitro* studies, the results may not be directly applicable *in vivo*. Third, the image pixel size of the scanner used was a bit high (25 μm) which reduces the resolution. The amount of dentin removed can be significantly different depending on the scan resolution.[20] Lastly, increasing the sample size may give a better outcome.

Conclusion

Within the limitations of the study, it could be concluded that glide path and coronal flaring had no effect on the centering ability and transportation in curved canals prepared by two heat-treated NiTi files, namely, Race Evo and EdgeSequel. Moreover, there was no statistically significant difference with regard to centering ability and transportation among root canal instrumentation groups at 3, 5, and 7 mm.

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