EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

Vol. 69, 751:760, January, 2023

Print ISSN 0070-9484 • Online ISSN 2090-2360

EDJ

Conservative Dentistry and Endodontics

Submit Date : 02-09-2022 • Accept Date : 02-01-2023 • Available online: 1-1-2023 • DOI : 10.21608/edj.2023.160040.2237

COMPARATIVE ASSESSMENT OF APICAL TRANSPORTATION AND CENTERING ABILITY OF THREE NOVEL ROTARY NITI FILES: A CONE BEAM COMPUTED TOMOGRAPHY STUDY

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ABSTRACT

The objective of this study was to evaluate, the apical transportation and centering ability in mesial mandibular root canals after biomechanical preparation with 3 different NiTi rotary systems.

Twenty seven freshly extracted human mandibular first molar teeth were collected from the outpatient clinic of Oral and Maxillofacial Department, Faculty of Dentistry, Cairo University. Teeth were decoronated and the distal root of each tooth was resected at the furcation level using a safe sided diamond disc under coolant. The working length was adjusted to be 16mm. A K-file size #15 was confirmed to fit to the full working length. Mesial roots were vertically mounted halfway in autopolymerizing acrylic resin. All roots were scanned using CBCT to detect canal shape before instrumentation.Teeth were then divided into three groups (n=9) according to the type of the rotary instruments used in the root canal preparation and irrigated with 2.5% sodium hypochlorite solution before instrumentation.(Trunatomy group, protaper next group and M-Pro group). Post instrumentation tomograms were taken and the degree of canal transportation and centering ability ratio were calculated. Data were analyzed using one-way ANOVA followed by Tukey's post hoc test for intergroup comparisons. The significance level was set at $p<0.05$ within all tests. Regarding canal transportation,there was a significant difference between different files with Trunatomy having significantly lower value than other files ($p=0.014$). Regarding centering ability there was a significant difference between different files with M-pro having significantly lower value than other files ($p<0.001$).

Conclusion: From the findings of our present study, it was found that all systems were able to effectively shape curved root canals in terms of canal transportation and centering ability.

KEYWORDS: Apical transportation, Centering ability, Trunatomy, Protaper next, M-Pro

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INTRODUCTION

One of the most important steps in root canal therapy is the chemo mechanical preparation. Mechanical disinfection of the root canal system is done with instruments and irrigants. The traditional concept of enlarging the apical portion to a large sizes is changing with the improvements in armamentarium that are used for cleaning and shaping of the root canal system. Our main concern is to allow the irrigant to reach the most apical part of the canal with minimal dentine removal.

Chemo mechanical preparation of curved canals represents a challenge. Many systems are introduced to the market with different design features to allow for preparation of the root canals with minimal procedural errors and to achieve a predictable canal preparation. This is the most difficult objective to be achieved specially in curved canals this because the files usually tends to regain their straight shape. This usually leads to certain mishaps such as ledge, transportation and perforation [1]. The capability of our instrument to follow the original path of the canal during shaping is affected by the root canal morphology and the instrument's design (flexibility, taper, and the type of alloy) [2].

Root canal transportation is defined as the removal of dentine from the outer part of the curve at the apical third of the canal. This is due to the restoring forces of the files to their original shape during preparation. The ability of the instrument to stay centered within the canal is known as canal centering ability. This ability is an indication for an even distribution of dentine removal within our prepared root canals.[3]

ProTaper Next (PTN, Dentsply, Maillefer, Ballaigues, Switzerland) is a NiTi system which is manufactured from M-Wire to provide better cyclic fatigue and flexibility.[4] They have a rectangular off-centered design and progressive and regressive tapers. The variable taper will help to reduce contact between the file and the canal wall and hence reduce the taper lock and screw in effect..[5]

TruNatomy, is a NiTi heat-treated rotary system (TRN; Dentsply, Maillefer, Ballaigues, Switzerland), that was recently introduced into the market. The system has three different sizes, including small: #20, 0.04 taper; prime: #26, 0.04 taper; and medium: #36, 0.03 taper. The striking feature of the TRN files is slip shaping that allows larger space for debridement with preservation of dentine at the peri cervical area.

The manufacturer of TRN files claimed that it has higher fatigue resistance and it is more flexible. This is due to the off-centered parallelogram design and the special heat treatment.[6] It was claimed that TRN files have better conservation of the structural integrity of the root canal dentin and this is attributed to regressive tapers, instrument geometry, the slenderized pattern and the special heat-treatment of the alloy.[6,7]

M-PRO is a rotary system files with continuous taper and controlled memory wire. But there are no enough studies done yet on these files to evaluate its shaping characteristics.

The aim of our study is to evaluate, the apical transportation and centering ability in mesial root canals of mandibular molars after chemo mechanical preparation with 3 different NiTi rotary systems.

MATERIALS AND METHODS

Sample Size

A power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference between tested groups regarding transportation and centering ratio. By adopting an alpha (α) level of (0.05), a beta (β) of (0.2) (i.e. power=80%), and an effect size (f) of (0.651) calculated based on the results of a previous study [8] the minimum required sample size (n) was found to be (27) samples (i.e. 9 samples per group). Sample size calculation was performed using G*Power version 3.1.9.7

Sample selection

Twenty seven freshly extracted human mandibular first molar teeth were collected from patients of 20 to 40 years of age from the outpatient clinic of Oral and Maxillofacial Department, Faculty of Dentistry, Cairo University. Teeth were extracted due to periodontal or prosthodontic reasons.

The inclusion criteria were set to be: Teeth with mature root apices, type III root canal system in the mesial root and Mesiobuccal canal curvature was measured by ***Schneider's*** method to be between 20° & 35°. All the teeth were inspected with microscope for cracks and a radiograph was taken to verify the presence of type III root canal system in the mesial root, absence of any resorption or endodontic treatment. Teeth were then cleaned and stored in 0.9% saline solution (Egypt Otsuka Pharmaceutical Co., S.A.E) till use.

Samples Preparation:

Teeth were decoronated and the distal root was resected at the level of the furcation by a safe sided diamond disc (Dentsply Sirona, Ballaigues, Switzerland) under coolant. The working length was adjusted to be 16mm. Working length is confirmed by a K-file size #15 and a K-file size #20 was placed to verify that it could not reach the full working length.

Mesial roots were vertically mounted halfway in auto polymerizing acrylic resin (Acrostone, Dental & Medical Supplies, Cairo, Egypt) mixed according to the manufacturer's instructions in a plastic mold of dimensions (15cm X 15cm).

Vaseline was used to paint the internal surface of the mold to act as a separating medium. A piece of wax was used to seal the root apices and to prevent resin penetration into the apical foramen. To ensure standardization of the specimens during tomographic scanning, each root was placed in the unset acrylic resin such that its long axis was parallel to the long axis of the mold and with the buccal surfaces of all roots facing at the same direction. An amalgam filling was placed in each mold, to identify the buccal side.

Pre-Instrumentation Scanning:

All roots were scanned using CBCT, iCAT Next generation scanner (ISI, USA) with voxel dimension of 0.125mm, 120 kVp, 37.07 mAs, and 26.9 sec acquisition time to detect canal shape before instrumentation

Pre-Instrumentation measurement:

The OnDemand 3D software was used (Cybermed Inc, Seoul, South Korea) and the coronal and sagittal planes were adjusted so that the long axis of each root is aligned vertically.

Three tomograms were taken for each specimen. The first one is correspondent to the apical third (3mm from the apical end), the second one represents the middle third (6mm from the apical end), and the third one represents the coronal third (9mm from the apical end).

Dentin thickness was measured in the axial plane mesially, distally, buccally, and lingually, from the root canal border to the root surface border in each tomogram

Teeth were then divided into three groups (n=9) according to the type of the rotary system used to prepare the root canals: and irrigated with 2.5% sodium hypochlorite solution (Clorox, Egyptian company for house detergents, 10th of Ramadan, A.R.E) before instrumentation.

Trunatomy (Dentsply Sirona, Maillefer, Ballaigues, Switzerland)**:** All files were used according to the manufacturer's instructions (500 RPM/ 1.5 Ncm)

TRN orifice Modifier (20/0.08) was used in the coronal third only followed by TruNatomy Glider (17/0.02), and the Prime instrument (26/0.04). All the instruments were used with two to three gentle apical movements with an amplitude of 2-5mm. Then the glider and the prime instrument were used to prepare the canal to the full working length.

ProTaper Next File system (Dentsply Sirona, Ballaigues, Switzerland): Protaper Next SX was used for coronal flaring rotary followed by: X1 (#17/4) and finally X2 (#25/6) using X-Smart Endo Motor set at (300 RPM/ 2.5 N.cm) for PTN files.

M-PRO file system (Foshan stardent equipment co limited, Gungdon, China): M-PRO files were used following the manufacturer instructions at speed of 500 rpm and torque 3N.cm for file #18, and 1.5 N.cm for shaping and finishing files #20 and #25.

Each instrument was used to prepare three canals. All rotary files were operated in conjunctions with a gear reduction handpiece (16:1), powered by X-Smart Plus endodontic motor (Dentsply Sirona, Ballaigues, Switzerland). Copious amount of irrigation was used between each file (2ml of 5.25% NaOCl solution) by a side-vented needle and then, 3 ml of distilled water was used. 17% EDTA-gel was used as lubricant during root canal preparation.

Post-Instrumentation Scanning:

Each mold was rescanned, to obtain apical, middle, and coronal tomograms for each specimen, using CBCT, with same parameters mentioned in the pre-instrumentation imaging section.

- Post instrumentation tomograms were taken at the exact same distance from the apical end, as in pre-instrumentation imaging at 3,6 & 9 mm levels.

Evaluation Method:

- Two points were evaluated: Canal Transportation and Centering ability of the used file.
- Pre-and post-instrumentation scans were superimposed using the abovementioned software program to evaluate the degree of transportation as well as the centering ability of the tested instruments.

Canal Transportation:

Transportation in the root canal system was represented by the deviation in the axis (millimeters) after instrumentation, in comparison to the original axis of the canal before instrumentation. The degree of canal transportation was calculated according to the formula provided by Gambill et al (1996) [9]. The value used were the measurements of the shortest distance from the edge of the instrumented canal to the periphery of the root surface (mesially, distally, buccally, lingually), and comparing these measurements with the same measurements before canal instrumentation.

The formula used for calculation of canal transportation (CT):

Mesiodistally = (M1-M2) -(D1-D2)

Buccolingually = (B1-B2) -(L1-L2)

Where:

M1: refers to the shortest distance from the mesial edge of the root to the mesial edge of the uninstrumented canal.

M2: refers to the shortest distance from the mesial edge of the root to the mesial edge of the instrumented canal.

D1: refers to the shortest distance from the distal edge of the root to the distal edge of the uninstrumented canal.

D2: refers to the shortest distance from the distal edge of the root to the distal edge of the instrumented canal.

B1: refers to the shortest distance from the buccal edge of the root to the buccal edge of the uninstrumented canal.

B2: refers to the shortest distance from the buccal edge of the root to the buccal edge of the instrumented canal.

L1: refers to the shortest distance from the lingual edge of the root to the lingual edge of the uninstrumented canal.

L2: refers to the shortest distance from the lingual edge of the root to the lingual edge of the instrumented canal.

The result zero meant no transportation, positive results indicated (mesial/buccal) transportation, and negative results indicated (distal/lingual) transportation.

Centering Ability

The mean centering ratio is the ability of the instrument to be centered within the root canal during preparation.

Centering ability ratio was calculated using the same values obtained during the measurement of transportation according to the formula introduced by ***Gambill et al* (1996)**[9]:

Mesiodistally: (M1-M2)/(D1-D2) or (D1-D2)/(M1-M2)

Buccolingually: (B1-B2)/(L1-L2) or (L1-L2)/(B1-B2)

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 a lower capacity to maintain itself in the central axis of the canal.

Statistical analysis:

The numerical data were presented as mean and standard deviation (SD) values. Shapiro-Wilk's test was used to test for normality. Homogeneity of variances was tested using Levene's test. Data showed parametric distribution and variance homogeneity and were analyzed using one-way ANOVA followed by Tukey's post hoc test for intergroup comparisons and repeated measures ANOVA followed by Bonferroni post hoc test for intragroup comparisons. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.1.1 for Windows.

RESULTS

Results of inter and intragroup comparisons for transportation were presented in table (1) showed that for mesiodistal measurements at 9 mm from the apex there was a significant difference between different files with Trunatomy showing significantly higher values than M-pro ($p=0.018$). For other distances from the apex, the difference was not statistically significant ($p>0.05$). Overall, there was a significant difference between different files with Trunatomy showing significantly lower values than other files ($p=0.014$). For Trunatomy, there was a significant difference between values measured at different distances from the apex with value measured at 9 mm being significantly higher than value measured at 3 mm ($p=0.038$). For other files, the difference was not statistically significant ($p>0.05$).

For buccolingual measurements at 9 mm from the apex there was a significant difference between different files with Trunatomy showed significantly higher values than PTN ($p=0.036$). For other distances from the apex and overall, the difference was not statistically significant ($p>0.05$). For all files there was no significant difference between values measured at different distances from the apex ($p>0.05$).

Results of inter and intragroup comparisons for centering ratio presented in table (2) and figures from (5) to (8) showed that for mesiodistal measurements at 9mm and 6mm from the apex there was a significant difference between different files with M-pro having significantly lower value than other files at 9 mm ($p<0.001$) and then Trunatomy only at 6 mm ($p=0.016$). At 3 mm from the apex, the difference was not statistically significant ($p=0.094$). Overall, there was a significant difference between different files with M-pro showing significantly lower value than other files ($p<0.001$). For Trunatomy, there was a significant difference between values measured at different distances from the apex with value measured at 9 mm being significantly higher than values measured at other distances ($p=0.004$).

For other files, the difference was not statistically significant (p>0.05).

For buccolingual measurements at the three levels and overall there was a significant difference between different files with M-pro having significantly lower value than other files (p<0.001). For all files there was no significant difference between values measured at different distances from the apex (p>0.05).

TABLE (1) Inter and intragroup comparisons for transportation results

Measurement	*Distance from the apex*	*Transportation (Mean±SD)*			*p-value*
		Trunatomy	*PTN*	*M-pro*	
Mesiodistal	***9 mm***	0.07±0.05^{Aa}	-0.07±0.21^{ABa}	-0.06±0.18^{Ba}	**0.018***
	6 mm	0.00±0.16^{Aab}	-0.11±0.26^{Aa}	-0.11±0.18^{Aa}	**0.316**
	3 mm	-0.03±0.00^{Ab}	-0.07±0.16^{Aa}	-0.05±0.13^{Aa}	**0.588**
	p-value	**0.038***	**0.711**	**0.785**	
	Total	0.01±0.10^{A}	-0.08±0.21^{B}	-0.07±0.16^{B}	**0.014***
Buccolingual	***9 mm***	-0.11±0.08^{Ba}	0.03±0.24^{Aa}	-0.10±0.15^{ABa}	**0.036***
	6 mm	-0.05±0.13^{Aa}	-0.13±0.22^{Aa}	-0.10±0.07^{Aa}	**0.509**
	3 mm	-0.04±0.03^{Aa}	-0.19±0.28^{Aa}	-0.07±0.10^{Aa}	**0.850**
	p-value	**0.083**	**0.054**	**0.607**	
	Total	-0.07±0.09^{A}	-0.09±0.26^{A}	-0.09±0.11^{A}	**0.706**

Means with different upper and lowercase superscript letters within the same horizontal row and vertical column respectively are significantly different *significant (p<0.05)

TABLE (2) Inter and intragroup comparisons for centering ratio results

Measurement	*Distance from the apex*	*Centering ratio (Mean±SD)*			*p-value*
		Trunatomy	*PTN*	*M-pro*	
Mesiodistal	***9 mm***	1.22±0.33^{Aa}	0.85±0.30^{Aa}	0.41±0.28^{Ba}	**<0.001***
	6 mm	0.68±0.21^{Ab}	0.57±0.46^{ABa}	0.35±0.28^{Ba}	**0.016***
	3 mm	0.81±0.61^{Ab}	0.51±0.64^{Aa}	0.39±0.30^{Aa}	**0.094**
	p-value	**0.004***	**0.084**	**0.852**	
	Total	0.90±0.47^{A}	0.64±0.50^{A}	0.38±0.28^{B}	**<0.001***
Buccolingual	***9 mm***	1.01±0.40^{Aa}	1.21±0.31^{Aa}	0.18±0.13^{Ba}	**<0.001***
	6 mm	0.96±0.16^{Aa}	1.11±0.11^{Aa}	0.29±0.23^{Ba}	**<0.001***
	3 mm	1.04±0.00^{Aa}	1.08±0.11^{Aa}	0.27±0.25^{Ba}	**<0.001***
	p-value	**0.675**	**0.237**	**0.278**	
	Total	1.00±0.25^{A}	1.13±0.20^{A}	0.25±0.21^{B}	**<0.001***

Means with different upper and lowercase superscript letters within the same horizontal row and vertical column respectively are significantly different *significant (p<0.05)

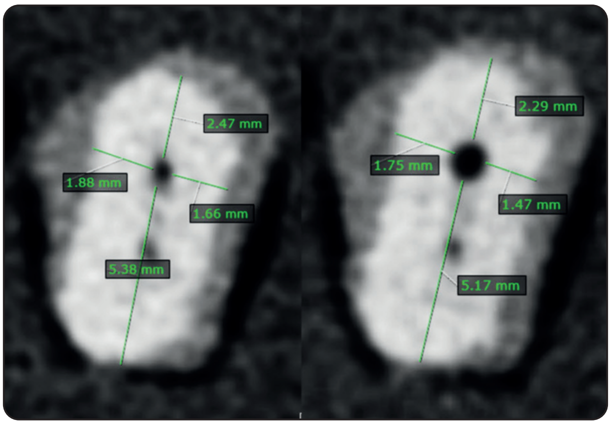

Fig. (1) Axial Cross section of the root showing Pre- and post instrumentation results

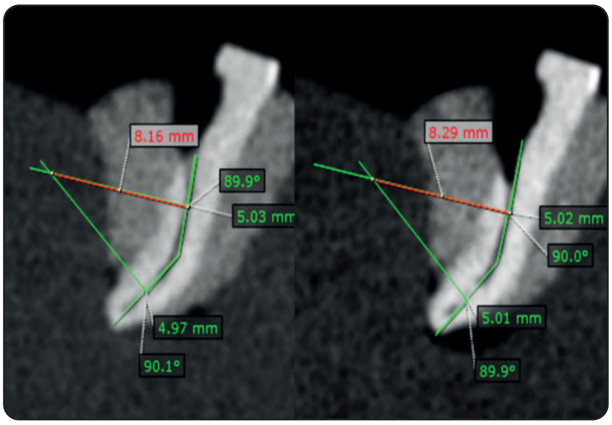

Fig. (2) CBCT showing the effect of the rotary instruments on the radius of curvature of the root canal

DISCUSSION

Complex root canal anatomy has always presented a challenge to successful endodontic therapy, through creating a continuous tapered form [10], while preserving the original canal anatomy [11].

The purpose of this study was to compare the shaping ability of new NiTi rotary instruments (Trunatomy, Protaper Next and Mpro) in terms of canal transportation and centring ratio in the mesiobuccal root canals of mandibular molars.

Protaper Next rotary NiTi file system was chosen as the comparator in the present study, as it is a system that has been used successfully and can be used as a reference technique for comparison. It is well-known for its ability in preparing curved root canals with minimal transportation [12], producing well centered preparations [13] and shaping the root canals with sufficient flare and without excessive removal of dentin.

In the present study, natural teeth were used as an experimental models to simulate real clinical condition and instrument performance in natural canals.

Mesiobuccal root canals of extracted mandibular molars were utilized as the mesial roots are usually curved, with the greatest curvature in the mesiobuccal root canals. Moreover, mesiobuccal root canals also shows curvature in the buccolingual plane that cannot be detected by radiographs. So, mesiobuccal root canals usually show more significant root canal transportation on instrumentation than other canals [14].

The crowns were resected at the level of CEJ to remove any coronal interference that may alter the operator authority over the file during preparation [15].

Working length of all samples was adjusted to 16mm to avoid greater length of the roots and complicated access to the cavity, that have an impact on the final results [16].

The size of apical preparation in all samples was set to #25 and #26. This was in accordance to the recommendation of the manufacturers, who reported that size #25 is designated for narrow and curved canals. It was important to standardize the diameter of apical preparation, as larger files cause more canal transportation due to the decrease of instrument flexibility [17]. Concerning the taper of the preparation, the final root canal taper of Trunatomy was 0.04 Protaper Next group and MPro group was 0.06.

Recently, the manufacturers of Ni-Ti rotary systems recommends that apical preparation should be kept as narrow as possible while increasing root canal taper. This will help to minimize instrumentation mishaps and provide an easier and more efficient obturation [18].

Cone beam computed tomography (CBCT) was chosen as the evaluation method our study. It has been widely used in the research filed of endodontics, and has proved to be an accurate, reliable and reproducible method of measuring dentin thickness and volume of root canals.

Shaping ability was assessed in terms of two parameters; Canal transportation and centering ability. These are important parameters to be examined on studying shaping ability of endodontic files, as they greatly affect the outcome of root canal treatment.

In the present study, root canal transportation and centering ability were assessed at 3,6 & 9mm from the apical end of the root. The first level (3 mm from the apical end) represents the apical third where elbows and zips often develops [19]. While, second and third levels, at 6 and 9mm from the apical end, represents the middle and coronal thirds respectively, where stripping may occur [20].

There are several instrument-related factors that are believed to affect canal transportation including: instrument design (degree of taper, cross sectional design, radial lands, and cutting non-cutting tip design), metallurgy of NiTi alloy of the instrument, movement kinematics, and instrumentation technique (previous creation of glide path, coronal pre-flaring, and size of apical preparation).

Before studying canal transportation with respect to horizontal levels and direction of transportation, it is important to remind of the progressive taper feature of ProTaper Next system, which has limited the cutting action of each file to a specific region of the root canal. SX is designed to flare and relocate root canal orifice, X1, X2 and X3 were used to prepare apical part of the canals.

Concerning the results of canal transportation in the present study, there was no statistically significant difference found among the three systems in buccolingual direction. While, in the mesiodistal direction Trunatomy showed significant difference from the other two systems. This was in agreement with the findings of **Dalia et al 2020** [15], **Elnagy and Elsaka 2016** [21] and **Hatice et al 2021** [22]. However, the results of the present study were in disagreement with the findings of **Abdulrahman et al 2018** [23]. This could be attributed to the differences in methodologies between studies, as the latter study used simulated resin blocks as experimented models, different range of curvatures for the included samples and different evaluation methods.

It was reported by Wu et al 2000 [24] that apical transportation more than 0.3mm can compromise the apical seal of the endodontic treatment. The values of apical transportation in our present study were much lower than this limit, which indicates the ability of both systems to perform proper apical preparations, with acceptable transportation that does not compromise the apical seal.

At the apical level, the comparison is being held between the PTN (X2) file (which dominantly shapes the apical part of root canal in the present study) and Mpro file 25. Both files have same tip diameter (0.25mm), same degree of taper at the first 3mm from the tip (8%), similar cross-sectional design (modified convex triangle), in addition to the modified noncutting tips of both instruments.

Similarly, at the middle level, there was no significant difference between PTN and M-Pro systems. The middle third of root canals in the PTN group, is dominantly prepared using the (X1) file, and progressively enlarged up to (X2) file. Both Mpro file, as well as (X2) PTN file have same degree of taper at this region (shaft diameter of both of them, at 5mm from the apex, is equal to 0.55 mm). In addition, both systems have similar cross-sectional designs at this level; modified convex triangle. This similarity in instrument design can explain the insignificant difference between both systems at this level.

Correspondingly, at the coronal level there was no significant difference between PTN and M-Pro systems. This could be attributed to the same degree of taper 0.04 of both PTN and Mpro file [18].

Concerning the results of centering ability, the difference was statistically insignificant at the three levels of root canals, in both mesio-distal and bucco-lingual directions as well as the total centering ratios. This agreed with the findings of previous authors **Elnagy and Elsaka 2016** [21] and **Jussaro et al 2017** [25].

The design of TN file includes a special heat-treated wire, uses a 0.8 mm NiTi wire instead of 1.2 mm NiTi wire, and is operated at a higher speed. Prime file that was used in our experiment has a tip size of 26 with a 0.04 taper. Prime TN was compared with the PTN X2 (size 25 and taper 0.06) knowing it has a different taper. However, other reports in the literature have also compared the cyclic fatigue resistance of files with different tapers. TruNatomy shaping file has an off-centered parallelogram cross-sectional design [26]; it might be speculated that this design compared with PTN rectangular cross section and the TF equilateral triangular cross section could contribute to the higher cyclic fatigue resistance of the TN files. In addition, the fact that the TruNatomy file is made of a thin NiTi wire (0.8 mm) might have resulted in increasing cyclic fatigue resistance [27]

CONCLUSION

From the findings of our present study, it was found that all systems were able to effectively shape curved root canals in terms of canal transportation and centering ability. All systems were able to prepare curved root canals with angles of curvature ranging between 25-35° with minimal acceptable transportation, produce well centered preparations, as well as preparing root canals with sufficient flare and without excessive removal of dentin.

REFERENCES

1. Guelzow A, Stamm O, Martus P, Kielbassa AM. Comparative study of six rotary nickel-titanium systems and hand instrumentation for root canal preparation. Int Endod J. 2005;38(10):743-52.
2. Camara AC, Aguiar CM, Figueiredo JA. Assessment of the deviation after biomechanical preparation of the coronal, middle, and apical thirds of root canals instrumented with three Hero rotary systems. J Endod 2007;33:1460–1463.
3. Kandaswamy D, Venkateshbabu N, Porkodi I, Pradeep G. Canal-centering ability: An endodontic challenge. J Conserv Dent. 2009;12:3–9.
4. Elnaghy AM. Cyclic fatigue resistance of ProTaper Next nickel-titanium rotary files. Int Endod J. 2014;47(11):1034-9. doi: 10.1111/iej.12244.
5. Ruddle CJ. The ProTaper endodontic system: geometries, features, and guidelines for use. Dent Today. 2001; 20(10):60- 7.
6. Van der Vyver PJ, Vorster M, Peters OA. Minimally invasive endodontics using a new single-file rotary system. Int Dent– African ed. 2019;9(4):6-20.
7. Riyahi MA, Bashiri A, Alshahrani K, Alshahrani S, Alamri HM, Sudani DA. Cyclic Fatigue comparison of TruNatomy, Twisted File, and ProTaper Next Rotary Systems. Int J Dent. 2020;2020:3190938. doi:10.1155/2020/3190938.
8. Mookhtiar M., Hussain. "Comparative Evaluation of Canal Transportation and Centering Ability of Different Generations Of Niti Files Systems Using Cbct: An In Vitro Study." (2019).
9. Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. J Endod. 1996 Jul;22(7):369-75.
10. V J Fornari, Yara Teresinha Corrêa Silva Sousa, J R Vanni and Manoel Damião de Sousa-NetoHistological evaluation of the effectiveness of increased apical enlargement for cleaning the apical third of curved canals International Endodontic Journal 43(11):988-94.
11. S Drukteinis, V Peciuliene, P M H Dummer, J Hupp · Shaping ability of BioRace, ProTaper NEXT and Genius nickel-titanium instruments in curved canals of mandibular molars: a MicroCT study. Int Endod J, 2019 Jan;52(1):86-93.
12. Hatice Yalniz 1, Mehrdad Koohnavard 2, Aysenur Oncu 2, Berkan Celikten 2, Ayse Isil Orhan 3, Kaan Orhan.

Comparative evaluation of dentin volume removal and centralization of the root canal after shaping with the ProTaper Universal, ProTaper Gold, and One-Curve instruments using micro-CT. J Dent Res Dent Clin Dent Prospects.2021;15(1):47-52.

13. Jussaro Alves Duque, Marco Antonio Hungaro Duarte, Lyz Cristina Furquim Canali, Rafaela Fernandes Zancan, Rodrigo Ricci Vivan, Ricardo Affonso Bernardes, Clovis Monteiro Bramante. Comparative Effectiveness of New Mechanical Irrigant Agitating Devices for Debris Removal from the Canal and Isthmus of Mesial Roots of Mandibular Molars. J Endod . 2017 Feb;43(2):326-331.

14. Frank Paqué 1, Daniel Ganahl, Ove A Peters. Effects of root canal preparation on apical geometry assessed by micro-computed tomography. J Endod 2009 Jul; 35(7):1056-9.

15. Dalia Yacoub Girgis, Hany Samy Sadek, Nehal Nabil Roshdy. Comparative Assessment of the Shaping and Cleaning Abilities of M-Pro and Revo-S versus ProTaper Next Rotary Ni-Ti Systems (An In Vitro study). Advanced Dental Journal 2020,2:4:162-176.

16. Abeer M Marzouk 1, Angie G Ghoneim. Computed tomographic evaluation of canal shape instrumented by different kinematics rotary nickel-titanium systems. J Endod. 2013 Jul;39(7):906-9.

17. Lan Zhang, Hong-xiaLuo, Xue-dongZhou,, HongTan,, Ding-ming Huang: The Shaping Effect of the Combination of Two Rotary Nickel-Titanium Instruments in Simulated S-Shaped Canals. JEndod Volume 34, Issue 4, April 2008, Pages 456-458.

18. Arvaniti IS1, Khabbaz MG. Influence of root canal taper on its cleanliness: a scanning electron microscopic study. Journal of Endodontics, 01 Jun 2011, 37(6):871-874.

19. F S Weine 1, R F Kelly, P J Lio. The effect of preparation procedures on original canal shape and on apical foramen shape. J Endod 1975 Aug;1(8):255-62.

20. M Abou-Rass, A L Frank, D H Glick .The anticurvature filing method to prepare the curved root canal. J Am Dent Assoc 1980 Nov;101(5):792-4.

21. Elnaghy AM, Elsaka SE.Mechanical properties ofProTaper Gold nickel-titanium rotary instruments. International Endodontic Journal,49, 1073–1078, 2016.

22. Hatice Yalniz, Mehrdad Koohnavard, Aysenur Oncu, Berkan Celikten, Ayse Isil Orhan, and Kaan Orhan. Comparative evaluation of dentin volume removal and centralization of the root canal after shaping with the ProTaper Universal, ProTaper Gold, and One-Curve instruments using micro-CT. J Dent Res Dent Clin Dent Prospects. 2021 Winter; 15(1): 47–52.

23. Abdulrahman Abdullah Al-Dhbaan, Mohammad A Al-Omari, Shibu Thomas Mathew, Mohammad Abdul Baseer. Shaping ability of ProTaper gold and WaveOne gold nickel-titanium rotary file in different canal configurations .Saudi Dent J . 2018: 8(3), 202-207.

24. M K Wu, P R Wesselink, R E Walton. Apical terminus location of root canal treatment procedures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. . 2000 Jan;89(1):99-103.

25. Jussaro Alves Duque, Marco Antonio Hungaro Duarte, Lyz Cristina Furquim Canali, Rafaela Fernandes Zancan, Rodrigo Ricci Vivan, Ricardo Affonso Bernardes, Clovis Monteiro Bramante. Comparative Effectiveness of New Mechanical Irrigant Agitating Devices for Debris Removal from the Canal and Isthmus of Mesial Roots of Mandibular Molars. J Endod . 2017 Feb;43(2):326-331.

26. Van der Vyver PJ, Vorster M, Peters OA. Minimally invasive endodontics using a new single-file rotary system. Int Dent – African ed. 2019;9:6–20.

27. Ruba Mustafa, Taher Al Omari, Suhad Al-Nasrawi, Rami Al Fodeh, Alaa Dkmak, Julfikar Haider. Evaluating In Vitro Performance of Novel Nickel-Titanium Rotary System (TruNatomy) Based on Debris Extrusion and Preparation Time from Severely Curved Canals. J Endod 2021 Jun;47(6):976-981.