ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642

Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL

Official Publication of Ain Shams Dental School

June 2024 • Vol. 34

Comparison of the Shaping Ability and Cutting Efficiency of Three Different Rotary Nickel-Titanium Systems (An In Vitro Study)

Safinaz Othman Ahmed[1], Medhat Taha El-Faramawy[2], Sarah Hossam Fahmy[3]

Aim: The aim of the study was to compare the shaping ability and cutting efficiency of Neolix Neoniti with Hyflex EDM and Protaper NEXT.

Material and Methods: Thirty human mandibular permanent molars having curvature of about 20°- 40° were selected for the study. The teeth were randomly divided into 3 groups (n=10): Group 1: Protaper NEXT; Group 2: Hyflex EDM; Group 3: Neoniti. Mesiobuccal canals of mesial roots were prepared with the three systems according to manufacturer's instruction. Cone beam computed tomography (CBCT) scanning was done to all canals pre- and post- instrumentation to evaluate shaping ability of the three tested systems. To evaluate cutting efficiency, A custom made device was made and 30 plexiglas plates were used. The exact depth of the Plexiglas plate cut in one minute was then measured for all tested groups. Data were statistically analyzed using One-way ANOVA to compare between different groups, followed by Tukey's Post Hoc test for multiple comparisons.

Results: All three systems functioned very similarly regarding canal transportation, centering ability and changes in canal curvatures when used in moderately curved canals. After root canal instrumentation, there was insignificant difference in shaping ability among groups (P>0.05). There was, however, a significant difference in the cutting efficiency between the three systems (P<0.05) where Hyflex EDM showed higher cutting efficiency with respect to Protaper NEXT and Neoniti.

Conclusion: The triangular cross-sectional design and EDM technology resulted in superior cutting efficiency of the file.

Keywords: Shaping Characteristics, Neolix Neoniti, Protaper Next, Hyflex EDM, cutting ability, Cone beam computed tomography.

1. MSc student at Endodontic Department, Faculty of Dentistry, Ain Shams University, Cairo, Egypt.
2. Professor at Endodontic Department, Faculty of Dentistry, Ain Shams University, Cairo, Egypt.
3. Associate Professor at Endodontic Department, Faulty of Dentistry, Ain Shams University, Cairo, Egypt

Corresponding author: Safinaz Othman Ahmed, email: Drsafinazothman@hotmail.com

Introduction

The purposes of biomechanical preparation of the root canal system are to eradicate microorganisms and necrotic pulp tissue from the rootcanal walls, and aid in the appropriate irrigation and fillingof the root canal system.[1] Ideally, Mechanical instrumentation should produce continuous conical tapering preparation, while preserving the anatomy and original canal curvature and maintaining the foramen size as minimal as practically feasible.[1]

Avoiding canal transportation and aberrations as zips, ledges, and perforations poses a major challenge to clinicians, especially in narrow and curved canals.[2]

For more than a half-century, Stainless steel instruments have been used in endodontics because of their high fracture resistance and high cutting efficiency, however owing to their stiffness, they tend to straighten curved root canals. [3]

Nowadays, a number of improvements in manufacturing technologies and thermo-mechanical treatment resulted in enhancement of microstructure of Nickel-Titanium alloys which in turns, achieved the ideal requirements of canal shaping.[4] Electric Discharge Machining EDM was used to produce The Neoniti (Neolix, châtres-la-Forêt, France), which is a newly introduced single file rotary system, manufactured from the heat-treated wire alloy which provides these files with cyclic fatigue resistance and controlled memory, improving their canal-preservation properties. In addition, The EDM technology produces a rough surface, which improved their abrasiveness and cutting efficiency.[5 6, 7]

Similarily The Hyfkex EDM (Coltene/ Whaledent, Altstatten, Switzerlan) is a new version of the HyFlex CM system, made with a control memory (CM) wire. However, unlike HyFlex CM, They are the first system to be manufactured by a special manufacturing technology; Electric Discharge Machining (EDM) and a variable cross-sectional design, which gives the file increased cyclic fatigue resistance, greater safety and flexibility which is imperative for preserving the original canal anatomy.[7, 8]

The Protaper Next (PTN; Dentsply Sirona, Ballaigues, Switzerland) created from M-wire heat-treated alloy, was reported to increase their flexibility and resistance to cyclic fatigue.[9] Their off-centered cross-section gives the files asymmetrical swaggering rotary motion enhancing their canal shaping efficiency and provide more cross- sectional space for improved cutting efficiency of root canal in comparison to ProTaper Universal rotary system which has a centered mass and axis of rotation.[10]

Modifications in instrument design, metallurgical properties and surface also aim to improve instrument's cutting efficiency which is a decisive parameter when evaluating the performance of rotary systems during root canal instrumentation as it reflects the removal of infected dentin and affects the capability of the operator to shape the root canals safely.

The present study aimed at assessing and comparing the shaping ability and cutting efficiency of Neoniti, Hyflex EDM and Protaper NEXT rotary systems. The null hypothesis is that there is no difference in shaping ability and cutting efficiency between the three tested file systems during canal instrumentation.

Materials and Methods

Shaping ability

Sample Size Calculation

The statistical calculation of sample size was done using G* Power Program utilizing α-type error of 0.5 and β- type error of 0.8 and N2/N1 ratio of 1. The mean and standard deviation were taken from previous comparable studies.[11, 12] Ethics committee approval number FDASU-RecEM012116 from ethical committee Faculty of Dentistry, Ain Shams University.

Selection and preparation

Thirty human permanent mandibular molars with mature apices, no apparent root resorption and having curvature of about 20°-40° were selected for the study.

The samples were accessed using round bur size #2 (Mani, Tochijo, Japan) and Endo-Z bur. Mesio-buccal canals were located, and teeth were de- coronated at the level of the cementoenamel junction using EndoAccess burs under copious irrigation to obtain approximate of 16 mm root lengths for all samples. Mesial roots were marked with indelible marker pen near Mesio- buccal surface, and distal roots were then resected.

Teeth were then placed vertically in a silicone impression material to mark their orientation during scanning. (Figure 1)

The specimens were randomly assigned to 3 groups (n=10). Group 1: Protaper Next X2. Group 2: Hyflex EDM (One file). Group 3: Neonlix Neoniti.

Figure 1: Picture, showing sample embedded in Silicon blocks.

Sample Instrumentation

Cleaning and shaping were done in a crowndown technique, with a steady and slow in and out pecking movement. After three pecks, the flutes of the files were cleaned and re-inserted, the process was repeated until the entire working length was reached. For each canal preparation, a new file was used. Recapitulation was periodically done using #10 K-file. Irrigation was done with 3 ml of 2.5% sodium hypochlorite solution using a 30-gauge side-vented needle (Fanta, China) before and during instrumentation in a manual irrigation technique. Saline was used as a final rinse for the root canals. Canals were dried with paper points.

Group I: ProTaper NEXT

Protaper NEXT Orifice opener XA file (19/.035) followed by X1 file (17/.04) were used, then Protaper NEXT X2 file (25/0.06) (Dentsply, Tulsa Dental, Tulsa, OK, USA) was used to shape mesiobuccal canal till working length in a crown-down technique. The E-connect pro endomotor (Eighteeth, Changzhou, China) was set according to manufacturer instructions; rotational speed 300 rpm and 2.5 Ncm torque.

Group II: Hyflex EDM

25/.12 orifice opener file was used followed by glide path file 10/.05 at 300 rpm and at a torque of up to 1.8 Ncm, then HyFlex EDM (25/~) OneFile (Coltene Whaledent, OH, USA), was used according to the manufacturer's guidelines, to shape the root canal up to the full working length with the crown- down technique; a rotational speed of 500 rpm, and 2.5N cm torque.

Group III: Neoniti

Mesiobuccal canals in this group was prepared using C1 Orifice opener file (25/.12), then Neoniti A1 #25 (25/0.06) (Neolix, Châtres-la-Forêt, France) was used at 500 rpm and 1.5 N cm as recommended by the manufacturer to the full working length in a crown-down manner.

Method of evaluation of shaping ability

All roots were scanned before and after instrumentation using cone beam computed tomography (Planmeca ProMax, Planmeca Oy, Helsinki, Finland) with endo mode. After acquisition, data were exported and transferred in DICOM format. Planmeca Romexis viewer software was used for analysis.

Change in Canal Curvature measurements.

The preoperative and the post operative degree of canal curvature was calculated according to Schneider's method[13] (Figure 2).

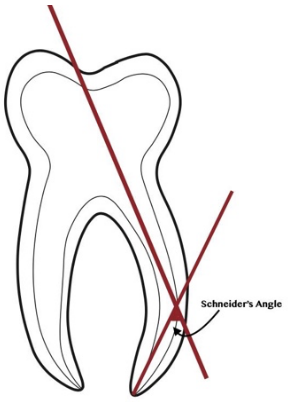

Figure 2: An Illustration, showing Schneider's method for determination of angle of curvature.

Centering ability and Degree of transportation Measurement

The dentin thickness was measured preoperatively and post operatively at 3 cross-sectional planes for each sample: 3mm from the root apex, 6mm from the root apex, 9 mm from the root apex.

The shortest distance from the internal root boundary to the external root boundary was measured mesially and distally. (Figure 3,4)

The centering ability at each cross-sectional plane was measured according to Gambil et al. equation $(X_1-X_2)/(Y_1-Y_2)$,[14] and the degree of transportation at each cross-sectional plane was measured as follows: $(X_1-X_2)-(Y_1-Y_2)$[15 1617] where:

X_1 refers to the shortest distance from the mesial external root surface to the mesial wall of un-instrumented canal.

Y_1 refers to the shortest distance from the distal external root surface to the distal wall of un-instrumented canal.

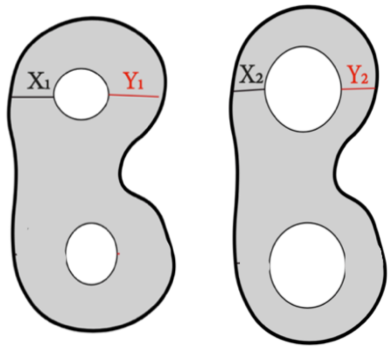

Figure 3: A schematic figure, showing the cross-section of the canal; X1, X2 and Y1, Y2 are wall width before and after canal preparation respectively.

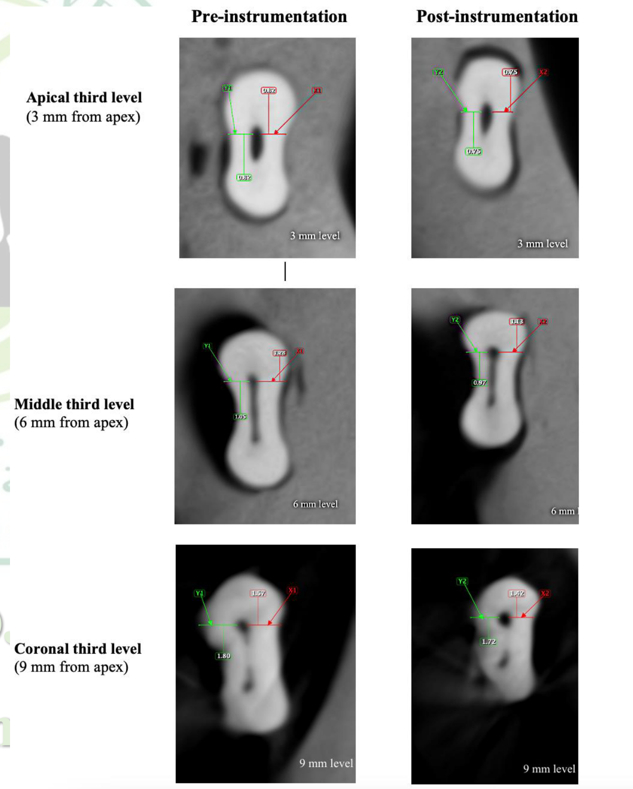

Figure 4: Cone beam CT scans showing axial sections of pre- and post- instrumentation dentin thickness at multiple levels

X_2 refers to the shortest distance from the mesial external root surface to the mesial wall of instrumented canal

Y_2 refers to the shortest distance from the distal external root surface to the distal wall of instrumented canal.

For centering ability and according to the formula, A ratio close to or equal to 1 at any given cross section plane would suggest a high centering ability.[14]

A zero outcome would suggest the lack of canal transportation, however positive or negative outcomes would suggest distal or mesial canal transportation, respectively.[14]

Cutting efficiency

Selection and preparation

The statistical calculation of sample size was done using G Power Program utilizing α-type error of 0.5 and β- type error of 0.8 and N2/N1 ratio of 1. Thirty Plexiglas blocks (30 x 30 x 2 mm) were used, Each Plexiglas block will be utilized to evaluate 1 instrument from the 3 tested groups.

A specifically designed device (Figure 5) was made to test the cutting efficiency of the three systems.[18,19] It comprised of a main frame connected to a movable plastic support for the handpiece.

Figure 5: Picture, showing the custom-made device for measuring cutting efficiency of the three rotary systems.

The Plexiglas plates used to test the cutting efficiency of the files, was contained in a stainless-steel. A fixed 150 gram weight was attached to a moving device connected to the dental hand-piece, to push the instrument towards the block in an accurate and reproducible way. On the 2-mm-thick Plexiglas, a notch of 1 mm in width and depth was laser-cut to prevent instrument slippage off the smooth plexiglas surface.[19]

The tested systems were allocated into 3 groups (n=10). Each group consisted of 10 plexiglas plates. One plate was utilized to evaluate 1 instrument from each system. Group I: consisted of 10 Plexiglas plates were prepared using Protaper NEXT X_2 (25/0.06). Group II: consisted of 10 Plexiglas plates were prepared using Hyflex EDM OneFile (25/0.08). Group III: consisted of 10 Plexiglas plates were prepared using Neoniti A_1 (25/0.06).

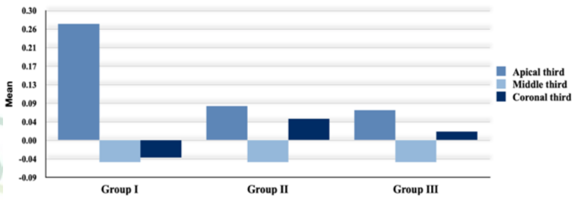

Figure (6): Bar, showing degree of transportation in all groups regarding all sectional planes

Sample instrumentation

Torque and speed were kept constant for all the tested systems to eliminate variables. To prevent instrument deflection when the weight is placed, the cutting efficiency was evaluated 14 mm from the instruments tip.[18]

Method of evaluation of cutting efficiency

Each instrument underwent testing in a unidirectional linear cutting motion and the depth of grooves they created determined their cutting efficiency.[18] The exact depth of the Plexiglas plates cut in one minute was measured in millimeters for all tested groups. The 1 mm notch was deducted from the length obtained.[18]

Statistical analysis

Statistical analysis was performed with SPSS 20® (Statistical Package for Social Science, IBM, USA.), Graph Pad Prism® (Graph Pad Technologies, USA) and Microsoft Excel 2016 (Microsoft Co-operation, USA). All quantitative data were explored for normality by using Shapiro Wilk and Kolmogorov Normality test and presented as means and standard deviation (SD) values. Comparison between different groups by using ONE WAY ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons. The levels of significance were set at (P≤ 0.05).

Results

Overall, all three systems proved to be relatively safe and efficient during root canal therapy maintaining original canal anatomies. Despite having no statistically significant difference in canal transportation, Neoniti and Hyflex EDM showed lower transportation than PTN at apical third level. (Figure 6)

Regarding centering ability, Neoniti and Hyflex EDM showed more conservative enlargement than PTN in middle third of canal, however these differences were insignificant (P>0.05)(Figure 7)

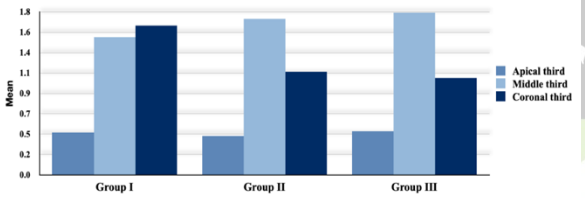

Figure (7): Bar, showing centering ability in all groups regarding all sectional planes

As for cutting efficiency, Hyflex EDM exhibited statistically better cutting efficiency when compared to the other two systems; Protaper NEXT and Neoniti where no significant difference was detected between them *(Figure 8)*

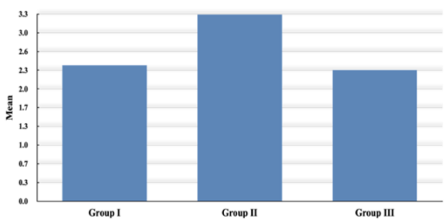

Figure (8): Bar, showing centering ability in all groups regarding all sectional planes

Discussion

One of the most crucial stages of endodontic treatment is cleaning and shaping of the root canal system.[20] The fracture incidence of Nickel-Titanium instruments during canal instrumentation pushed the innovation of different designs and heat treatment of their alloys such as M-wire, R-Phase, CM-wire, to optimize their microstructure and their mechanical performance. Improvements in mechanical properties of endodontic files focused on properties like, cutting efficiency, flexibility and fracture resistance.

The ability of the instrument to advance into the root canal and remove dentin is directly correlated with its cutting efficiency. Furthermore, cutting efficiency affects fracture resistance by producing less torsional stresses and so, less risk of torsional fractures.[21] The use of the newly introduced single file system has been widely encouraged, as it reduces the time for mechanical canal preparation and enhances the efficiency of canal shaping while reducing workload of the dentists and patient's pain.[22]

The aim of this study was, to compare the newly introduced single-file system Neoniti A_1, produced using a recently developed wire-cut electrical discharge machining technique (EDM) which is a non-contact machining technique that allow accurate material removal via high frequency electrical sparks, with minimum production of mechanical stresses on the file,[23] with Hyflex EDM One File system, which is also a single file system and has been selected for this study as a benchmark. ProTaper NEXT was chosen as it has been the gold standard in endodontics for many years.

In the present study, Distal roots were resected to get clearer CBCT scans.[24] Schneider's method was used to measure the angle of curvature.[13] Many studies suggested Schneider's method to measure angle of curvature because of its reliability, predictability and production of minimum errors during root canal obturation.[22, 25]

The cutting efficiency of the three rotary systems was assessed based on the maximum penetration depth of instrument. Different materials were used as substrate to measure the cutting efficiency, including extracted teeth, Plexiglas blocks, molded epoxy resin, Poly methyl methacrylate, and Bovine bone.[26] In our study, Plexiglas plates made from the same material were used instead of natural teeth to overcome the variable hardness and water content of dentin that could affect results. Nonetheless, Plexiglas lacks the same mechanical properties as dentin and the motion simulated by the testing apparatus did not replicate the process of root canal instrumentation.[19]

A 1 mm notch was laser cut on the Plexiglas to prevent instrument slippage off the Plexiglas plates. The specially designed testing device together with Plexiglas plates eliminate variability and ensure consistent conditions enabling direct comparisons of the cutting performance of various instruments.[27] Each instrument was used once on each block, as a previous study has reported that cutting efficiency is modified after use and that there is no way to guarantee that the files will remain as efficient as feasible after use.[28]

The results of the current study indicated no significant difference between the three systems regarding the change in angle of curvature, degree of transportation and centering ability. There was, however, a significant difference in the cutting efficiency between the three systems.

No significant difference was found between tested groups regarding change in canal curvature, which concurs with the results of previous research by Forghani et al. [29] and Madani et al. [30] where differences between Protaper instruments and Neoniti were insignificant regarding change in angle of canal curvature. A possible explanation for these results is that the amount of canal transportation was similar in all three systems.

Canal transportation was evident in every tested system in all tested levels. Apical transportation ought to be below 0.3 mm to ensure a sufficient seal of the root canal filling at the apex.[31] All canal transportation values recorded for the tested instruments were below 0.3 mm and so indicate that they are capable of preparing canals without violating the apical seal. At Apical third, Neoniti and Hyflex EDM showed lower transportation than PTN. However, these differences were small and insignificant. Canal transportation was comparable between all groups in all cross- sectional planes, this could be explained considering the similarity in manufacturing process (EDM) between Hyflex EDM and Neoniti. Also, Neoniti also has a constant taper design (0.06) which produces less canal straightening than progressive tapered files. [32] In addition, Hyflex EDM is made from CM wire and has a variable cross-sectional design which renders the file more flexible and conform better to the canal shape.[7 8] Protaper Next has an offset design which allows swaggering motion, with reduced screwing effect and minimum contact between the file and the dentin. Transportation was toward the mesial side apically, and towards the distal side in the middle third in most canals.

These results agree with previous studies carried out by Ramadan et al. [24] , Ronquete et al.[33] and Turkistani et al. [34] when there was no statistically significant difference between Hyflex EDM and Protaper NEXT in all tested sections. Hussien et al.[35] and Madani et al.[30] also reported no significant difference regarding canal transportation between Neoniti single file and Protaper NEXT instruments, they explained that this is due to improved flexibility and cutting performance of Neoniti, which maintained the original canal curvature while effectively removing debris.

Concerning the results of the centering ability in the present study, although no significant difference was detected amongst the tested groups, Neoniti and Hyflex EDM revealed more conservative enlargement than PTN in middle third of canal. This might be related to the taper design of Neoniti; having a constant taper of 0.06 along whole length of the file and the fact that the middle third section of the tooth coincides with the greatest taper of Protaper NEXT files.[34] In addition to that, Neoniti files and Hyflex EDM files are manufactured by a newly developed EDM technology, which results in superior flexibility when compared to Protaper NEXT. Furthermore, Neoniti files are subjected to proper heat treatment that leads to increased flexibility, and Hyflex EDM are made of CM wire, giving them more flexibility than traditional NiTi and M-wire instruments (as PTN) of similar sizes and taper.[36, 37]

Protaper NEXT, however, produced more centered preparation at coronal third than Hyflex EDM and Neoniti, which showed the worst centering capability than the other two systems. Although these differences were small and not significant, they could be linked to the homothetic rectangle cross-section of the Neoniti file, circumferential brushing motion of the file in the coronal section, sharp cutting edges and the flutes' abrasive property.[20] In addition, Protaper NEXT and Hyflex EDM have variable taper with least taper at shaft of the file (0.04) compared to the (0.06) constant taper design of Neoniti file system, which might explain why they showed better centering ability than Neoniti file system at the canal coronal level.

These results are in line with a previous study conducted by Turkistani et al.[34] where no significant difference in centering ability were noted between Protaper NEXT and Hyflex EDM in all tested levels except middle third where Hyflex EDM resulted in a more centered preparation. Ramadan et al.[24] , Ronquete et al. [33] compared Protaper NEXT and Hyflex EDM and results also showed insignificant difference between the two groups overall and at each level. Hussein et al.[35], Madani et al.[30] compared centering ability of Protaper NEXT and Neoniti and observed no significant difference between the tested groups. In addition, Kumar et al.[38] when comparing remaining dentin thickness following mechanical preparation revealed no statistically significant difference between Hyflex EDM and Neoniti file systems at three different levels in both mesiodistal and buccolingual direction. Rubio et al.[39] also concluded that Neoniti, Hyflex EDM and Protaper NEXT obtained comparable results regarding root canal anatomy preservation.

Regarding the results of cutting efficiency measurements, the three rotary systems differed significantly from one another. Hyflex EDM showed a statistically significant increase in cutting efficiency when compared to the other two systems. Unfortunately, these results couldn't be compared with already published data as no relevant studies with the same methodology were found in the review of literature. The findings in this study could be attributed to the electric discharge machining (EDM) technology used in the manufacture of Hyflex EDM files, according to the manufacturer this method employs spark erosion to toughen the surface of the NiTi file producing sharp cutting edges, inherent abrasiveness that leads to quicker root canal preparation, enhanced flexibility and superior cutting efficiency.[5, 6] In addition to that, Hyflex EDM files have variable cross section design along their length with a shift from quadratic apically to trapezoidal in the middle then triangular coronally[4041]. Protaper NEXT and Neoniti, however, have a constant rectangular cross-sectional design along their length and the observation is that instruments having a triangular cross-section are associated with an enhanced cutting efficiency and this has been confirmed in previous studies. [27, 42, 43]

Conclusion

Within the limitations of the study, it was determined that all three systems: Protaper NEXT, Hyflex EDM and Neoniti, functioned very similarly regarding canal transportation, centering ability and changes in canal curvatures when used in moderately curved canals . The triangular cross-sectional design and EDM technology resulted in superior cutting efficiency of the file.

References

1. Schilder H. Cleaning and shaping the root canal. *Dent Clin North Am*. 1974;18(2):269-296.
2. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. *J Endod*. 2004;30(8):559-567. doi:10.1097/01.don.0000129039.59003.9d
3. Craig RG, Peyton FA. Physical properties of stainless steel endodontic files and reamers. *Oral Surgery, Oral Medicine, Oral Pathology*. 1963;16(2):206-217. doi:10.1016/0030-4220(63)90034-3
4. Shen Y, Zhou H min, Zheng Y feng, Peng B, Haapasalo M. Current Challenges and Concepts of the Thermomechanical Treatment of Nickel-Titanium Instruments. *J Endod*. 2013;39(2):163-172. doi:10.1016/j.joen.2012.11.005
5. Gergi R, Arbab-Chirani R, Osta N, Naaman A. Micro–Computed Tomographic Evaluation of Canal Transportation Instrumented by Different Kinematics Rotary Nickel-Titanium Instruments. *J Endod*. 2014;40(8):1223-1227. doi:10.1016/j.joen.2014.01.039
6. Adel M, Tofangchiha M, Rashvand E, et al. Comparison of the Efficacy of NeoNiTi, ProTaper, and Reciproc Files in the Retreatment of Curved Root Canals: a CBCT Assessment. *Acta Stomatol Croat*. 2022;56(4):351-362. doi:10.15644/asc56/4/2
7. Khandagale PD, Shetty PP, Makandar SD, et al. Evaluation of Cyclic Fatigue of Hyflex EDM, Twisted Files, and ProTaper Gold Manufactured with Different Processes: An In Vitro Study. *Int J Dent*. 2021;2021:7402658. doi:10.1155/2021/7402658
8. Elashiry MM, Saber SE, Elashry SH. Comparison of Shaping Ability of Different Single-File Systems Using Microcomputed Tomography. *Eur J Dent*. 2020;14(1):70-76. doi:10.1055/s-0040-1701393
9. Ye J, Gao Y. Metallurgical Characterization of M-Wire Nickel-Titanium Shape Memory Alloy Used for Endodontic Rotary Instruments during Low-cycle Fatigue. *J Endod*. 2012;38(1):105-107. doi:10.1016/j.joen.2011.09.028
10. Das S, Pradhan PK, Lata S, Sinha SP. Comparative evaluation of dentinal crack formation after root canal preparation using ProTaper Next, OneShape, and Hyflex EDM. *J Conserv Dent*. 2018;21(2):153-156. doi:10.4103/JCD.JCD_219_17
11. Turkistani AK, Gomaa MM, Shafei LA, Alsofi L, Majeed A, AlShwaimi E. Shaping ability of HyFlex EDM and ProTaper next rotary instruments in curved root canals: A micro-CT study. *Journal of Contemporary Dental Practice*. 2019;20(6):680-685. doi:10.5005/jp-journals-10024-2579
12. Kamal M, Mobarak A, Mahmoud S. EVALUATION OF CANAL TRANSPORTATION AND CENTERING ABILITY OF HYFLEX EDM, SMARTTRACK X3 AND PROTAPER NEXT ROTARY FILE SYSTEMS USING CBCT (IN-VITRO STUDY). *Alexandria Dental Journal*. 2023;47(4):15-15. doi:10.21608/adjalexu.2022.273600
13. Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol*. 1971;32(2):271-275. doi:10.1016/0030-4220(71)90230-1
14. Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *J Endod*. 1996;22(7):369-375. doi:10.1016/S0099-2399(96)80221-4
15. Gergi R, Rjeily JA, Sader J, Naaman A. Comparison of canal transportation and centering ability of twisted files, Pathfile-ProTaper system, and stainless steel hand K-files by using computed tomography. *J Endod*. 2010;36(5):904-907. doi:10.1016/j.joen.2009.12.038
16. Iqbal MK, Floratos S, Hsu YK, Karabucak B. An in vitro comparison of Profile GT and GTX nickel-titanium rotary instruments in apical transportation and length control in mandibular molar. *J Endod*. 2010;36(2):302-304. doi:10.1016/j.joen.2009.10.021
17. Nazari Moghadam K, Shahab S, Rostami G. Canal transportation and centering ability of twisted file and reciproc: a cone-beam computed tomography assessment. *Iran Endod J*. 2014;9(3):174-179.
18. Rubini AG, Plotino G, Al-Sudani D, et al. A new device to test cutting efficiency of mechanical endodontic instruments. *Medical Science Monitor*. 2014;20:374-378. doi:10.12659/MSM.890119

19. Plotino G, Giansiracusa Rubini A, Grande NM, Testarelli L, Gambarini G. Cutting efficiency of reciproc and waveone reciprocating instruments. *J Endod*. 2014;40(8):1228-1230. doi:10.1016/j.joen.2014.01.041
20. Kuzekanani M, Sadeghi F, Hatami N, Rad M, Darijani M, Walsh LJ. Comparison of Canal Transportation, Separation Rate, and Preparation Time between One Shape and Neoniti (Neolix): An In Vitro CBCT Study. *Int J Dent*. 2021;2021:1-6. doi:10.1155/2021/6457071
21. Di Giuseppe I, Di Giuseppe D, Malagnino VA, Silla EP, Somma F. Conditioning of root canal anatomy on static and dynamics of nickel-titanium rotary instruments. *G Ital Endod*. 2015;29(2):58-64. doi:10.1016/j.gien.2015.08.004
22. Othman Ahmed J, Abdel Aziz T, el-gendy A. Shaping Ability of Three Different Rotary Nickel Titanium Systems An In Vitro Study. *Ain Shams Dental Journal*. 2024;33(1):156-163. doi:10.21608/asdj.2023.243436.1190
23. Daneshmand S, Farahmand Kahrizi E, Abedi E, Abdolhosseini MM. Influence of Machining Parameters on Electro Discharge Machining of NiTi Shape Memory Alloys. *Int J Electrochem Sci*. 2013;8:3095-3104.
24. Kamal M, Mobarak A, Mahmoud S. EVALUATION OF CANAL TRANSPORTATION AND CENTERING ABILITY OF HYFLEX EDM, SMARTTRACK X3 AND PROTAPER NEXT ROTARY FILE SYSTEMS USING CBCT (IN-VITRO STUDY). *Alexandria Dental Journal*. 2023;47(4):15-15. doi:10.21608/adjalexu.2022.273600
25. Pangica AM, Biclesanu C, Florescu A. Methods for Evaluation of Root Canal Curvatures. In: ; 2013:159-162. doi:10.1007/978-3-642-34197-7_41
26. Medhat Kataia M, Kataia EM. Cutting efficiency of different cross sectional design protaperrotary instruments-in-vitro study. *Journal of Innovations in Pharmaceuticals and Biological Sciences* . 2016;3:116-122. www.jipbs.com
27. Schäfer E, Oitzinger M. Cutting Efficiency of Five Different Types of Rotary Nickel–Titanium Instruments. *J Endod*. 2008;34(2):198-200. doi:10.1016/j.joen.2007.10.009
28. Schafer E. Effect of sterilization on the cutting efficiency of PVD-coated nickel-titanium endodontic instruments. *Int Endod J*. 2002;35(10):867-872. doi:10.1046/j.1365-2591.2002.00586.x
29. Forghani M, Hezarjaribi M, Teimouri H. Comparison of the shaping characteristics of Neolix and Protaper Universal systems in preparation of severely-curved simulated canals. *J Clin Exp Dent*. 2017;9(4):e556-e559. doi:10.4317/jced.53476
30. Madani Z, Soleymani A, Bagheri T, Moudi E, Bijani A, Rakhshan V. Transportation and centering ability of neoniti and protaper instruments; A CBCT assessment. *Iran Endod J*. 2017;12(1):43-49. doi:10.22037/iej.2017.09
31. WU M, FAN B, WESSELINK P. Leakage Along Apical Root Fillings in Curved Root Canals. Part I: Effects of Apical Transportation on Seal of Root Fillings. *J Endod*. 2000;26(4):210-216. doi:10.1097/00004770-200004000-00003
32. Yang GB, Zhou XD, Zheng YL, Zhang H, Shu Y, Wu HK. Shaping ability of progressive versus constant taper instruments in curved root canals of extracted teeth. *Int Endod J*. 2007;40(9):707-714. doi:10.1111/j.1365-2591.2007.01296.x
33. Ronquete V, Martin AS de, Zuim K, et al. Microtomographic Evaluation of Canal Centralization and Dentine Removal after Canal Preparation with Two Rotary Systems: HyFlex EDM and ProTaper Next. *Eur J Dent*. 2022;16(03):663-668. doi:10.1055/s-0041-1739440
34. Turkistani AK, Gomaa MM, Shafei LA, Alsofi L, Majeed A, AlShwaimi E. Shaping ability of HyFlex EDM and ProTaper next rotary instruments in curved root canals: A micro-CT study. *Journal of Contemporary Dental Practice*. 2019;20(6):680-685. doi:10.5005/jp-journals-10024-2579
35. Hamdy Hussien Y, Nabil Roshdy N, Galal Ghoniem A. Assessment of the Shaping Abilities of 2Shape, Neolix and Pro Taper Next Rotary Systems: A Comparative In vitro study. *Acta Scientific Dental Sciences*. 2020;4(4):71-78. doi:10.31080/ASDS.2020.04.0814
36. Testarelli L, Plotino G, Al-Sudani D, et al. Bending Properties of a New Nickel-Titanium Alloy with a Lower Percent by Weight of Nickel. *J Endod*. 2011;37(9):1293-1295. doi:10.1016/j.joen.2011.05.023
37. Gomaa MA, Osama M, Badr AE. Shaping ability of three thermally treated nickel-titanium systems in S-shaped canals. *Australian Endodontic Journal*. 2021;47(3):435-441. doi:10.1111/aej.12496
38. Kumar T, Mittal S, Keshav V, Kaur R, Maakhni E. A comparative evaluation of remaining dentin thickness following biomechanical preparation of teeth using different rotary file systems: An in vitro study. *Journal of Conservative Dentistry*. 2022;25(1):32. doi:10.4103/jcd.jcd_373_21
39. Rubio J, Zarzosa JI, Pallarés A. Comparison of Shaping Ability of 10 Rotary and Reciprocating Systems: an In Vitro Study with AutoCAD. *Acta Stomatol Croat*. 2017;51(3):207-216. doi:10.15644/asc51/3/4

40. Yılmaz K, Uslu G, Özyürek T. In vitro comparison of the cyclic fatigue resistance of HyFlex EDM, One G, and ProGlider nickel titanium glide path instruments in single and double curvature canals. *Restor Dent Endod*. 2017;42(4):282-289. doi:10.5395/rde.2017.42.4.282

41. Raouf A, Ali M, Elzahar S, Hassan R. Cone-Beam Computed Tomographic Analysis of Shaping Ability of XP Shaper, TRUshape, and Hyflex EDM. *Journal of International Dental and Medical Research*. 2021;14:60-66.

42. SCHAFER E. Effect of Physical Vapor Deposition on Cutting Efficiency of Nickel-Titanium Files. *J Endod*. 2002;28(12):800-802. doi:10.1097/00004770-200212000-00002

43. Felt RA, Moser JB, Heuer MA. Flute design of endodontic instruments: its influence on cutting efficiency. *J Endod*. 1982;8(6):253-259. doi:10.1016/S0099-2399(82)80335-X