EUROPEAN ENDODONTIC JOURNAL

ORIGINAL ARTICLE

Analysis of Force and Torque with XP Shaper and OneCurve Systems During Shaping of Narrow Canals

Ahmed JAMLEH, Abdulmohsen ALFADLEY, Nasser ALGHOFAILI, Hani JAMLEH, Khalid Al FOUZAN

ABSTRACT

Objective: The purpose of this laboratory-based study was to compare the shaping forces and torques developed by the XP Shaper (FKG Dentaire SA, La Chaux-de-fonds, Switzerland) and OneCurve (Micro-Mega, Besancon, France) systems during shaping of narrow canals.

Methods: Mandibular premolars with a single canal were divided equally into two groups; XP Shaper and OneCurve (n=16 each). In both groups, the canals were shaped with XP Shaper file (30/01) or OneCurve file (25/O6) that was inserted three times until it reached the canal length. The tooth was surrounded by water under controlled simulated intracanal temperature throughout the experiment. The inward and outward peak forces and the peak torques were recorded and analyzed statistically using the Mann-Whitney test. The shaping times were analyzed using Student's t-test. The significance level was set at 5%.

Results: In both groups, the developed forces in both directions and the torques increased with the successive insertions of the file. In the two groups, the inward peak forces ranged from 0.33 to 3.12 N, while the outward peak forces ranged from 0.09 to 1.96 N. In the three insertions, the XP Shaper showed significantly lower peak forces in both directions. The peak torque developed in both groups ranged from 0.12 to 1.52 N.cm. XP Shaper had significantly lower torque values in all the insertions than OneCurve. The XP Shaper system was able to completely shape the canals in 33.4 seconds while the OneCurve system was able to completely shape the canals in 32.8 seconds.

Conclusion: The XP Shaper system showed favorably lower force and torque values during canal shaping compared with the OneCurve system.

Keywords: Canal shaping, force, OneCurve, torque, XP Shaper

Please cite this article as: Jamleh A, Alfadley A, Alghofaili N, Jamleh H, Al Fouzan K. Analysis of Force and Torque with XP Shaper and OneCurve Systems During Shaping of Narrow Canals. Eur Endod J 2020; 2: 123-7

From the Department of Restorative and Prosthetic Dental Sciences (A.J. ✉ aojamleh@gmail.com, A.A., K.A.F.) College of Dentistry, King Saud bin Abdulaziz University for Health Sciences, National Guard Health Affairs, Riyadh, Kingdom of Saudi Arabia; King Abdullah International Medical Research Centre (A.J., A.A., K.A.F), National Guard Health Affairs, Riyadh, Kingdom of Saudi Arabia; King Abdulaziz Dental Center (N.A.), National Guard Health Affairs, Riyadh, Kingdom of Saudi Arabia; Department of Electrical Engineering (H.J.), Jordan University, Amman, Jordan

Received 01 December 2019, Accepted 08 April 2020

Published online: 14 May 2020
DOI 10.14744/eej.2020.96967

HIGHLIGHTS

- This study provided data on the vertical forces and torques induced during the shaping of narrow canals with XP Shaper and OneCurve systems.
- The two systems shaped the canals with different vertical forces and torques.
- XP Shaper file had lower vertical forces and torques compared to that induced with the OneCurve file.

INTRODUCTION

Thorough debridement of the complex root canal system is paramount to the success of endodontic therapy (1). While chemical cleaning aims to remove all organic substances including pulpal tissues, microbial biofilms, and toxic byproducts, the mechanical shaping is necessary to develop a continuously tapering canal that allows for the optimal delivery of irrigating solutions, intracanal medicaments, and three-dimensional obturation of the root canal system (1). Historically, stainless steel files were used to perform canal shaping during nonsurgical root canal treatment. Nowadays, nickel-titanium (NiTi) rotary files are widely used to shape the root canals owing to their increased flexibility, rapid and centered canal preparation, safer preparation of curved canals, improved cutting efficiency, superior torsional resistance, and improved treatment outcome (2, 3). In spite of all of these advantages, a main limitation of NiTi files is the risk of intracanal file fracture as a result of fatigue. Fatigue is one mechanism of instrument failure which might fracture due to torsion, ductility, shear or other types of forces and deformations. Cyclic fatigue develops when the file rotates in a curvature, producing alternating cycles of compression and tension until fracture occurs. Torsional failure occurs when the torque from contact between the file and root canal wall exceeds the file's torsional strength (2).

The use of rotary file systems was reported to induce less shaping force but more torque than the manual stainless steel files (4, 5). Past studies revealed that the force and torque exerted on the tooth during canal shaping directly affected the file fatigue (6-9) as well as the root canal wall (10). Moreover, it has been shown that force and torque during canal shaping are directly proportional (6). These parameters are known to be influenced by many factors such as the motion kinematics, contact area between the file and the canal walls, file geometry and preoperative canal volume (7-9, 11).

New systems have been introduced to simplify shaping procedure, reduce mechanical stress, and shape the canal quickly (12). In addition, significant improvement in NiTi files' production contributed to increased safety and efficiency of canal shaping, including changes in the design, alloy treatments, and motion kinematics of NiTi files (11). These advancements played a key role in the evolvement of single NiTi systems, where canal shaping is completed with one file. It is noteworthy that single-file systems do not compromise canal cleanliness, compared with the conventional multi-file systems (12, 13). Furthermore, the use of a single NiTi file reduces cost and shaping time (14).

XP Shaper (FKG Dentaire SA, La Chaux-de-fonds, Switzerland) is a single-file system that is made with MaxWire technology (15). The file has an apical diameter of 0.30 mm and a fixed taper of 1%. It has a triangular cross-section, six-blade tip, and booster tip that allow starting to shape the canal after a manual glide path of at least size 15. Upon exposure to body temperature (35ºC), the martensite phase of the file converts to the austenite phase, and this enables the file to shape the canal to a taper of 8% because of a "snake" shape (15-17).

OneCurve system (Micromega, Besancon, France) is another single-file system that is used in continuous rotation. It was introduced as the evolution of OneShape file with the same tip size (#25), taper (6%), and a variable cross-section along the file. It is made from heat-treated NiTi alloy (C. Wire) (18). The different manufacturing process has shown improved mechanical properties of the OneCurve file, compared to OneShape file (19). Its cross-section varies from a triangular-shaped at the file tip to S-shaped near the shaft. The manufacturer claims that this variable cross-section can respond to the need for efficient shaping while respecting the initial root canal anatomy (18).

Several experiments and protocols have been proposed to study the forces and torques generated during canal shaping with different rotary systems (7-9, 20-26). However, the force and torque developed with the XP Shaper system have not been studied before. Hence, this in vitro study was conducted to determine the force and torque generated during the canal shaping using the XP Shaper and compare them with that developed with the OneCurve. The null hypothesis is that there would be no difference between the XP Shaper and OneCurve systems in terms of force and torque during canal shaping.

MATERIALS AND METHODS

The design of the study was implemented according to the guidelines of the Ethics Committee of King Abdullah International Medical Research Center and in accordance with the principles of the Declaration of Helsinki.

Teeth Selection

Mandibular premolar teeth were taken from a pool of extracted human teeth. Facial and proximal views were obtained with a digital radiograph to select teeth with mature roots, narrow canals, and curvature of less than 10 degrees.

Sample size calculation was conducted using a 5% significance level and 80% power to detect a minimum load difference of 0.70 N between the 2 systems. The common standard deviation within a group was assumed to be 0.60 N. The result showed that at least 13 teeth should be included in each group.

Mounting of Teeth

The tooth apex was covered with wax to avoid penetration of resin into the root canal, and the whole root was embedded in a mixed acrylic resin (DuraLay; Reliance Dental Mfg Co, Worth, IL). After the resin was set, the teeth were decoronated to a level that kept 15-mm root length to standardize the samples. The periodontal ligament was not simulated in this study in order to investigate pure forces on the internal root canal wall caused by the tested file systems (5).

The canal length was determined as 1 mm short of the major apical foramen (14 mm). The narrow root canal was verified by placing a size 15 K-file (Dentsply Sirona) that would bind no less than 3 mm from the canal length (27). Otherwise, the tooth was excluded. According to these criteria, 32 teeth with single canals were chosen for this study.

Force and Torque Measurements

A force gauge (M5-20 Advanced Digital Force Gauge; Mark-10 Corporation, Long Island, NY) with a force capacity for 100 N and torque gauge (TT01 torque Gauge; Mark-10 Corporation, Long Island, NY) with a torque capacity for 115 N.cm were used in this experiment.

The force gauge device was secured above the torque gauge device between the four pins in a standing position. Afterward, the tooth assembly was firmly set on a fixed stage at the top of the force gauge so that the tooth was exactly centered to ensure axial measurements. The tooth assembly was surrounded with water inside a small tank under controlled simulated intracanal temperature (35±1ºC), as confirmed by a thermocouple device (Fig. 1).

The forces in two directions (inward and outward) and the torques were simultaneously measured and presented separately on two personal computers using MESUR™ Lite software (Mark-10 Corporation, NY, USA). The inward force represented the force required to introduce the file into the canal, and the outward force represented the force developed when the file was pulled from the canal. The positive torque was measured.

Root Canal Shaping

After the establishment of a manual glide path with size 15 K-file, the teeth were randomly assigned to two experimental groups (n=16) according to the NiTi system used for canal shaping; XP Shaper and OneCurve systems.

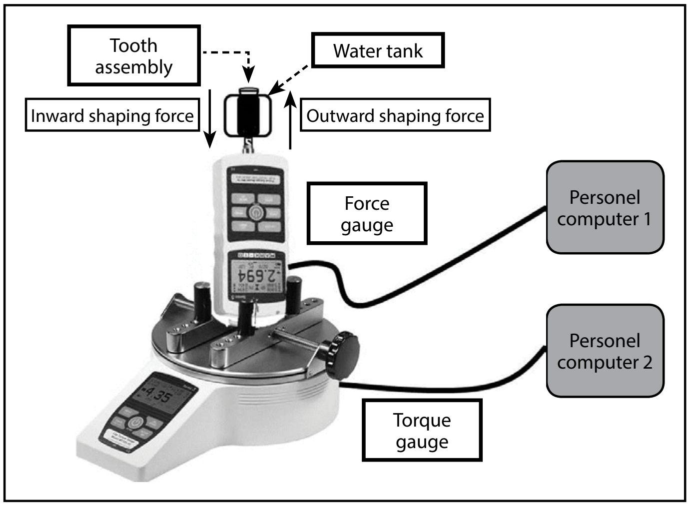

Figure 1. Schematic drawing of the experimental set-up. The force gauge and torque gauge devices (Mark-10 Corporation) were used for recording shaping forces and torques, respectively. The data are presented separately on two separate PCs using MESUR Lite software (Mark-10 Corporation)

In a pilot study, the measured torques of the tested files during shaping narrow canals did not exceed 2.5 N.cm. This made the use of X-Smart Plus (Dentsply Sirona) in both groups possible with the torque set at the upper limit (4 N.cm).

Before the canal shaping, the root canal was filled with 1% sodium hypochlorite, and the force and torque gauges were zeroed. The XP Shaper file was operated at a speed of 800 rpm and the OneCurve file was used at a speed of 300 rpm. The file was inserted gently with in-and-out movements. The canal shaping was performed with three insertions until the file reached the canal length. The tooth was excluded and replaced with another one if its canal received more or less than three insertions. After each file insertion, the flutes of the file were cleaned with a gauze, canal patency was confirmed with a size 10 K-file, and the root canal was irrigated with a 2 ml of 1% NaOCl. Each file was used to shape four canals or until evidence of deformation or fracture was noted. The canals from both groups were shaped alternately and gently by a single operator who had training on using the experimental systems. The stand was placed beside the tooth assembly for hand support. With this, the canal shaping was performed with a controlled "in-out" movement.

The shaping time, which included the total active instrumentation, irrigation and recapitulation, was recorded. The force and torque data were expressed in Newton (N) and N.cm, respectively. The gauge devices measured data every 0.1 seconds.

Data Analysis

Differences between the inward and outward forces and peak torque values of the three shaping insertions in the two systems were tested for statistical significance using Mann-Whitney U-test. The shaping times were analyzed using Student's t-test. The significance level was set at 5%.

RESULTS

Tables 1 and 2 show the descriptive data of shaping time, axial inward and outward shaping peak forces and peak torque for each system.

The forces in both directions and the torques increased with the successive file insertions. The inward and outward peak forces of the XP Shaper ranged from 0.33 to 0.89 N and from 0.09 to 0.76 N, respectively. Whilst in the OneCurve, they ranged from 1.50 to 3.12 N and from 1.16 to 1.96 N, respectively. In the three insertions, the XP Shaper showed significantly lower peak forces in both directions (P<0.001).

XP Shaper had significantly lower torque values in all the insertions than OneCurve (P<0.001) where the peak torques have reached 0.46 and 1.52 N.cm, respectively.

The XP Shaper and OneCurve shaped the canals completely in 33.4 and 32.8 seconds, respectively (P=0.7). No file fracture nor visible deformation has taken place throughout the experiment.

TABLE 1. Descriptive data (Mean±standard deviation) of shaping time and peak shaping forces values for each insertion in the tested systems

		Shaping force (N)					
		First insertion		Second insertion		Third insertion	
Group	Shaping time (second)	Inward force	Outward force	Inward force	Outward force	Inward force	Outward force
XP Shaper (n=16)	33.42±3.35	0.33±0.23	0.09±0.21	0.45±0.37	0.44±0.35	0.89±0.48	0.76±0.38
OneCurve (n=16)	32.84±4.84	1.50±0.57	1.16±0.43	2.03±0.74	1.56±0.53	3.12±.91	1.96±0.82
P-value	0.7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

TABLE 2. Descriptive data (Mean±standard deviation) of peak torques values for each insertion in the tested systems

	Maximum torque (N.cm)		
Group	First insertion	Second insertion	Third insertion
XP Shaper (n=16)	0.12±0.11	0.24±0.17	0.46±0.19
OneCurve (n=16)	0.61±0.26	0.89±0.34	1.52±0.48
P-value	<0.001	<0.001	<0.001

DISCUSSION

This laboratory-based study was conducted to investigate the performance of two single-file systems (XP shaper and OneCurve) in terms of force and torque induced during the shaping of narrow canals. In this experiment, no file fracture or deformation was observed in both groups. It is notable that the forces and peak torques created by the XP Shaper file in the three insertions were lower than that induced with OneCurve file. The different findings might be attributed to many factors including the alloy treatment, rotational speed, file design and file-wall contact (8, 22, 26). The OneCurve system is made of heat-treated C-Wire with a different taper and variable cross sections along the file (18). The XP Shaper file is made of MaxWire alloy which makes it react in a favorable way to changes in temperature; once surrounded by the intracanal temperature, the file can accommodate the canal anatomy (15). Thus, the experiment was conducted under simulated intracanal temperature to make the study more clinically relevant. The XP Shaper system rotates at a higher speed than the OneCurve system (800rpm Vs. 300rpm). A previous study showed that rotating the file at higher speed generates less force and torque (22), which is consistent with our results. Moreover, the XPS file's snake shape design presents a triangular cross-section with size 30 and 1% taper compared with the larger taper of the OneCurve file. Nonetheless, the XP Shaper file can prepare the canal in 3 dimensions (3D) to size 30 and 6%±2% taper in the apical and middle thirds (17). Despite the limited contact area between the XP Shaper file and the root canal wall, the resultant preparation size is considered larger than what OneCurve file can create. This makes XP Shaper a promising design to shape the canal gently. The need for 3D canal shaping and the emphasis placed on less invasive treatments have increased in recent years. Proper and safe cleaning and shaping of root canals depend on the mechanical behavior of endodontic files (28). In a clinical setting, it has been shown the higher the apical force, the more torque will be generated that will create excessive stress on the file, followed by deformation and possible fracture (23, 29). The force directly influences the file's cyclic fatigue and torsional failure, which might result in file fracture (6, 9). Moving the file deeper into the root canal requires higher forces (20, 26) and this will generate more torque resulting in the file locking at or near its tip (30). Dane et al. (10) investigated the effect of torque on the root canal wall and found that canal shaping at high-torque settings induced more dentinal cracks than at low-torque settings. On the other hand, the resultant force and torque induce strain on the root canal walls, leading to the development of dentinal defects (27, 31, 32). Therefore, gentle shaping with low apical force, low torque and low stress is required (23).

It is reported that shaping a narrow canal with a single file without pre-shaping with smaller files generates a large contact surface with the dentin walls, resulting in high stresses on the file as well as the root canal walls (27). In a previous study, the WaveOne and WaveOne Gold single file systems generated a force that exceeded 6.4 N (26). However, the forces generated with XP Shaper and OneCurve did not exceed 0.9 N and 3.1 N force, respectively, which is also much lower than the shaping peak force induced by any tested multi-file system in the literature (7-9, 20-24). Moreover, the manufacturers of XP Shaper and OneCurve recommend setting the torque at 1 N.cm and 2.5 N.cm, respectively, to avoid file fracture (15, 18). This experiment showed that the mean peak torque generated in shaping narrow canals with XP Shaper did not exceed 0.5 N.cm, and the mean peak torque in OneCurve did not exceed 1.5 N.cm. This means that the shaping procedure remained well within the safety torque values of the files and can be used to shape at least four narrow canals using the shaping technique described in this experiment. Recent studies reported that the tested system safely shaped curved root canals with minimal canal transportation in the apical region and relatively centered shapings (33, 34).

This screwing-in effect is considered unfavorable since it might cause over-instrumentation because of the unwanted file penetration beyond the apex (31). The XP Shaper induced almost less than one-third of the outward force induced with OneCurve in each insertion. Having the snake shape design limits the engagement of XP Shaper file inside the canal to one or two points of contact at any given cross-section, which will, in turn, reduce the "screwing-in" effect.

Recently, the XP Shaper file has been investigated in many aspects that showed improved cyclic fatigue, reduced debris extrusion, less instrumentation time, better canal cleanliness, and no formation of the dentinal defect, compared to other commercially available file systems (16, 35-37). The present results identify another benefit of the low force and torque required to shape a root canal using the XP Shaper system. Given that shaping a canal with XP Shaper can result in a canal with #30 size and 6%±2% taper with only a single file, this might confirm its effectiveness for shaping a canal with it (17).

The results of this study must be taken with caution since there are limitations that must be considered. The axial force and torque may be influenced by the operator, tooth position, and root canal dimensions. Canal curvature plays an important role in measuring the force and torque by sensors located at the base of the tooth. In this case, measurement can be performed properly in straight canals. However, measurements in curved canals might lead to errors because sensors should be positioned differently (20). Furthermore, efforts were strictly undertaken to limit any variable that might appear in the experimental setup and to maintain consistent and gentle pressure on the files. Thus, the selected canals were identified as narrow and straight canals with standardized lengths. They were shaped by only one operator who is trained to use the tested systems. Furthermore, each tooth was placed centered on a fixed stage on the top of the force gauge and in a standing position simulating a position of a mandibular tooth to measure the pure force and torque developed along the long axis of the tooth. The canals from both groups were alternately shaped to avoid operator bias. Besides that, a stand was assembled at what the operator's hand was placed to be above the upper level of the root. Future studies are needed to assess these parameters in detail.

CONCLUSION

In short, the two systems shaped the canals with different forces and torques. The XP Shaper system favorably imposed lower forces and torques compared with the OneCurve system.

Disclosures

Conflict of interest: The authors deny any conflict of interest.

Ethics Committee Approval: The research design was reviewed and approved by the Ethics Committee of King Abdullah International Medical Research Center.

Peer-review: Externally peer-reviewed.

Financial Disclosure: This work was supported by a research grant (RC18/187/R) from King Abdullah international medical research center and National Guard Health Affairs, Riyadh, Kingdom of Saudi Arabia.

Authorship contributions: Concept – A.J., A.F.; Design – A.J., A.F.; Supervision – A.J., A.F., K.F.; Funding - A.F.; Materials - None; Data collection &/or processing – A.J., A.F., N.G., H.J.; Analysis and/or interpretation – A.J., A.F., N.G., H.J., K.F.; Literature search – A.J., A.F., N.G.; Writing – A.J., A.F., H.J., K.F.; Critical Review – A.J., A.F., H.J., K.F.

REFERENCES

1. Hülsmann M, Peters OA, Dummer PM. Mechanical preparation of root canals: Shaping goals, techniques and means. Endod Topics 2005; 10(1):30–76. [CrossRef]
2. Glossen CR, Haller RH, Dove SB, del Rio CE. A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-Flex endodontic instruments. J Endod 1995; 21(3):146–51. [CrossRef]
3. Cheung GS, Liu CS. A retrospective study of endodontic treatment outcome between nickel-titanium rotary and stainless steel hand filing techniques. J Endod 2009; 35(7):938–43. [CrossRef]
4. Htun PH, Ebihara A, Maki K, Kimura S, Nishijo M, Tokita D, et al. Comparison of torque, force generation and canal shaping ability between manual and nickel-titanium glide path instruments in rotary and optimum glide path motion. Odontology 2020; 108(2):188–93. [CrossRef]
5. Bürklein S, Stüber JP, Schäfer E. Real-time dynamic torque values and axial forces during preparation of straight root canals using three different endodontic motors and hand preparation. Int Endod J 2019; 52(1):94–104. [CrossRef]
6. Gambarini G. Cyclic fatigue of ProFile rotary instruments after prolonged clinical use. Int Endod J 2001; 34(5):386–9. [CrossRef]
7. Peters OA, Peters CI, Schönenberger K, Barbakow F. ProTaper rotary root canal preparation: assessment of torque and force in relation to canal anatomy. Int Endod J 2003; 36(2):93–9. [CrossRef]
8. da Silva FM, Kobayashi C, Suda H. Analysis of forces developed during mechanical preparation of extracted teeth using RaCe rotary instruments and ProFiles. Int Endod J 2005; 38(1):17–21. [CrossRef]
9. Schrader C, Peters OA. Analysis of torque and force with differently tapered rotary endodontic instruments in vitro. J Endod 2005; 31(2):120–3.
10. Dane A, Capar ID, Arslan H, Akçay M, Uysal B. Effect of Different Torque Settings on Crack Formation in Root Dentin. J Endod 2016; 42(2):304–6.
11. Çapar ID, Arslan H. A review of instrumentation kinematics of engine-driven nickel-titanium instruments. Int Endod J 2016; 49(2):119–35.
12. Bürklein S, Benten S, Schäfer E. Shaping ability of different single-file systems in severely curved root canals of extracted teeth. Int Endod J 2013; 46(6):590–7. [CrossRef]
13. Capar ID, Ertas H, Ok E, Arslan H, Ertas ET. Comparative study of different novel nickel-titanium rotary systems for root canal preparation in severely curved root canals. J Endod 2014; 40(6):852–6. [CrossRef]
14. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. Int Endod J 2008; 41(4):339–44. [CrossRef]
15. FKG Dentaire SA. XP-endo Shaper: Simplify your endo. The one-file system. Available at: https://www.fkg.ch/products/endodontics/canal-shaping-and-cleaning/xp-endo-shaper. Accessed Mar 25, 2020.
16. Bayram HM, Bayram E, Ocak M, Uygun AD, Celik HH. Effect of ProTaper Gold, Self-Adjusting File, and XP-endo Shaper Instruments on Dentinal Microcrack Formation: A Micro-computed Tomographic Study. J Endod 2017; 43(7):1166–9. [CrossRef]
17. Azim AA, Piasecki L, da Silva Neto UX, Cruz ATG, Azim KA. XP Shaper, A Novel Adaptive Core Rotary Instrument: Micro-computed Tomographic Analysis of Its Shaping Abilities. J Endod 2017; 43(9):1532–8. [CrossRef]
18. One Curve – MICRO-MEGA. Available from: https://micro-mega.com/shaping/one-curve?lang=en. Accessed Mar 25, 2020.
19. Serafin M, De Biasi M, Franco V, Angerame D. In vitro comparison of cyclic fatigue resistance of two rotary single-file endodontic systems: OneCurve versus OneShape. Odontology 2019; 107(2):196–201. [CrossRef]
20. Peters OA, Barbakow F. Dynamic torque and apical forces of ProFile.04 rotary instruments during preparation of curved canals. Int Endod J 2002; 35(4):379–89. [CrossRef]
21. Diop A, Maurel N, Oiknine M, Patoor E, Machtou P. A novel platform for in vitro analysis of torque, forces, and three-dimensional file displacements during root canal preparations: application to ProTaper rotary files. J Endod 2009; 35(4):568–72. [CrossRef]
22. Bardsley S, Peters CI, Peters OA. The effect of three rotational speed settings on torque and apical force with vortex rotary instruments in vitro. J Endod 2011; 37(6):860–4. [CrossRef]
23. Glavičić S, Anić I, Braut A, Miletić I, Borčić J. Vertical force and torque analysis during mechanical preparation of extracted teeth using hand ProTaper instruments. Aust Endod J 2011; 37(2):51–5. [CrossRef]
24. Jamleh A, Alfouzan K. Vertical Load Induced with Twisted File Adaptive System during Canal Shaping. J Endod 2016; 42(12):1811–4. [CrossRef]
25. Kwak SW, Ha JH, Cheung GS, Kim HC, Kim SK. Effect of the Glide Path Establishment on the Torque Generation to the Files during Instrumentation: An In Vitro Measurement. J Endod 2018; 44(3):496–500. [CrossRef]
26. Jamleh A, Alfadley A, Alfouzan K. Vertical Force Induced with WaveOne and WaveOne Gold Systems during Canal Shaping. J Endod 2018;44 (9):1412–5. [CrossRef]
27. Jamleh A, Komabayashi T, Ebihara A, Nassar M, Watanabe S, Yoshioka T, et al. Root surface strain during canal shaping and its influence on apical microcrack development: a preliminary investigation. Int Endod J 2015; 48(12):1103–11. [CrossRef]
28. Lopes HP, Elias CN, Vieira MV, Siqueira JF Jr, Mangelli M, Lopes WS, et al. Fatigue Life of Reciproc and Mtwo instruments subjected to static and dynamic tests. J Endod 2013; 39(5):693–6. [CrossRef]
29. Gambarini G. Rationale for the use of low-torque endodontic motors in root canal instrumentation. Endod Dent Traumatol 2000; 16(3):95–100.
30. Nalla RK, Kinney JH, Ritchie RO. On the fracture of human dentin: is it stress- or strain-controlled?. J Biomed Mater Res A 2003; 67(2):484–95.
31. Adorno CG, Yoshioka T, Suda H. Crack initiation on the apical root surface caused by three different nickel-titanium rotary files at different working lengths. J Endod 2011; 37(4):522–5. [CrossRef]
32. Jamleh A, Adorno CG, Ebihara A, Suda H. Effect of nickel titanium file design on the root surface strain and apical microcracks. Aust Endod J 2016; 42(1):25–31. [CrossRef]
33. Razcha C, Zacharopoulos A, Anestis D, Mikrogeorgis G, Zacharakis G, Lyroudia K. Micro-Computed Tomographic Evaluation of Canal Transportation and Centering Ability of 4 Heat-Treated Nickel-Titanium Systems J Endod 2020; 46(5):675–681. [CrossRef]
34. Alfadley A, Alrajhi A, Alissa H, Alzeghaibi F, Hamadah L, Alfouzan K, Jamleh A. Shaping Ability of XP Endo Shaper File in Curved Root Canal Models. Int J Dent 2020;2020:4687045. [CrossRef]
35. Lacerda MFLS, Marceliano-Alves MF, Pérez AR, Provenzano JC, Neves MAS, Pires FR, et al. Cleaning and Shaping Oval Canals with 3 Instrumentation Systems: A Correlative Micro-computed Tomographic and Histologic Study. J Endod 2017; 43(11):1878–84. [CrossRef]
36. Keskin C, Inan U, Guler DH, Kalyoncuoğlu E. Cyclic Fatigue Resistance of XP-Endo Shaper, K3XF, and ProTaper Gold Nickel-titanium Instruments. J Endod 2018; 44(7):1164–7. [CrossRef]
37. Uslu G, Özyürek T, Yılmaz K, Gündoğar M, Plotino G. Apically Extruded Debris during Root Canal Instrumentation with Reciproc Blue, HyFlex EDM, and XP-endo Shaper Nickel-titanium Files. J Endod 2018; 44(5):856–9.