A study to compare the efficiency of different instrumentation systems for cleaning oval-shaped root canals (An in vitro study)

Tay H. Kadhom, B.D.S. [1]
Walid N. Al-Hashimi, B.D.S., M.Sc. [2]

ABSTRACT

Background: Proper cleaning and shaping of the whole root canal space have been recognized as a real challenge, particularly in oval-shaped canals.This in vitro study was conducted to evaluate and compare the efficiency of different instrumentation systems in removing of dentin debris at three thirds of oval-shaped root canals and to compare the percentage of remaining dentin debris among the three thirds for each instrumentation system.
Materials and methods: Fifty freshly extracted human mandibular molars with single straight oval-shaped distal root canals were randomly divided into five groups of ten teeth each. Group One: instrumentation with ProTaper Universal hand instruments, Group Two: instrumentation with ProTaper Universal rotary instruments, Group Three: instrumentation with Revo-Srotary instruments, Group Four: instrumentation withTwisted rotary files and Group Five: instrumentation with Self-Adjusting Files (SAF). Sodium hypochlorite (3%) was used as an irrigant for all groups. After canals preparation, the roots were split longitudinally and photographed with a professional digital camera. The images of root sections were then magnified to 100x and the percentage of remaining dentin debris calculated for the apical, middle and coronal thirds by dividing the pixels occupied by debris at each third by the total pixels representing the entire area of the canal using Adobe Photoshop CS6. Data were analyzed statistically by ANOVA and LSD at 1% and 5% significant levels.
Results: Both ProTaper hand and ProTaper rotary files resulted in significantly cleaner canals than Revo-S and Twisted rotary files at the middle and coronal thirds. The Self-Adjusting Files produced significantly cleaner canals at the three thirds than all the other groups. The coronal and middle thirds showed a greater amount of remaining dentin debris than the apical third for all groups except a non-significant difference found between the apical and middle thirds in SAF group.
Conclusion: The Self-Adjusting Files allowed more efficient cleaning of oval-shaped root canals than hand and rotary instruments.
Key words: Dentin debris, oval-shaped root canals, Self-Adjusting File. (J Bagh Coll Dentistry 2013; 25(1):49-55).

INTRODUCTION

One of the major procedural steps in endodontic treatment is to thoroughly removedebris, pulp tissue, and microorganisms from the root canal system by means of chemomechanical preparation [1].

A funnel-shaped canal with a circular base is not the common configuration inrootcanal anatomy. Recently, cross-sectional root canal configurations havebeen classified as round, oval, long oval, flattened, or irregular. A high prevalence of oval and long oval root canals even in the apical root canal portion has been reported. According to Wu et al.[2], the prevalence of oval root canals in the apical third of human teeth is generally about 25%; in some groups of teeth such as mandibular incisors and maxillary second premolars the prevalence is greater than 50%, and in distal roots of mandibular molars the prevalence is 25%–30%[3].

In canals with these anatomical conditions, hand and rotary instruments working in reaming motionhave been reported to leave untouched fins or recesses. In addition to harboring remnants of pulp tissue or bacterial biofilms, such recesses might also be packed with dentin chips generated and pushed therein by rotating instruments. Packed debris can interfere with the quality of obturationand, in infected root canals, can harbor bacteria to serve as a potential source of persistent infection [4].

The Self-Adjusting File (SAF) (ReDent-Nova, Ra'anana, Israel) has been devised with the purpose of sidestepping some of the limitations of Nickel-Titanium (NiTi) rotary instruments. During its operation, the file is designed to adapt itself to the shape of the root canal, both longitudinally and cross-sectionally, providing a three-dimensional adaptation. Rather than machining a central portion of the root canal into a round cross section, the SAF is claimed to maintain an oval canal as an oval canal with slightly larger dimensions. Hence, SAF system has the potential to be particularly advantageous in promoting cleaning and shaping of oval-shaped canals [5].

(1) M.Sc. student, Department of Conservative Dentistry, College of Dentistry, University of Baghdad.
(2) Professor, Department of Conservative Dentistry, College of Dentistry, University of Baghdad.

In this in vitro study, different instrumentation systems were used and the cleaning efficiency was evaluated and compared to find which system is more preferable for instrumentation of oval-shaped canals.

MATERIALS AND METHODS

Fifty freshly extracted human mandibular molar teeth with single straight oval-shaped distal root canals collected from different specialized dental centers were used in this study.

Immediately after extraction, bone, calculus, stains and soft tissues on the tooth surface were removed manually with cumine scaler[6]. The teeth were then stored in 10% formalin solution to provide disinfection until use and in saline solution during the experiment [7].

Carious tissues (when present) were removed with a low speed carbide round bur and preparation of standard access cavities performed with a high speed cylindrical diamond bur using ample water cooling[8].The distal root canals controlled visually for oval shape at the canal orifice.With aid of a digital vernier and permanent black marker, tooth length was standardized to 18 mm from the anatomic apex by cutting off part of the crown (decoronation) perpendicular to the long axis of the tooth using double-faced diamond disc with straight handpiece under water-cooling to eliminate coronal interferences and to prevent the introduction of confounding variables that might contribute to variations in the preparation procedures [9-13] and to establish a flat surface that served as a stable reference position to facilitate length measurement of the canal,instrumentation and penetration of irrigant needles[13-16].Using a marker and double-faced diamond disc with straight handpiece under water-cooling, the mesial roots of all teeth were separated at the furcation area perpendicular to the long axis of the root in order to prevent superpositions in the mesio-distal direction and to facilitate manipulation of the samples [14, 17]. Buccolingual and mesiodistal diagnostic radiographs of each tooth were taken to confirm the presence of a single oval canal with type I morphology [13], fully formed mature apex and no signs of internal resorption, or calcification.

The working length was calculated by subtracting 1 mm from the length at which a #10 K-file was just visible with 20x magnification in the apical foramen [12, 13].With aid of tray adhesive, the teeth were mounted in surgical tubes filled with silicon impression material to within 1mm apical to the cemento-enamel junction [9, 10 18].

The teeth were randomly divided into five groups according to the instrumentation system used with ten teeth each. The root canal preparation was performed according to the manufacturer's instructions of the instrumentation system used in each group.

Group One: Manual Instrumentation with ProTaper Universal Hand System (Dentsply-Maillefer, Ballaigues, Switzerland), SX was inserted to pre-enlarge the coronal two-thirds of the canals, after which they were prepared with S1, S2, F1, F2, F3 and F4 at the full working length [19, 20]. These instruments were used according to the Manual ProTaper Handle Motion.

Group Two: Rotary Instrumentation with ProTaper Universal Rotary System (Dentsply-Maillefer, Ballaigues, Switzerland), SX was fed into the canal with a brushing outstroke motion away from the furcation area for two thirds of its blade length. S1 and S2 were used with a brushing outstroke action until the full working length was reached. F1, F2, F3 and F4 were used in sequence with pecking motions (non-brushing motions) until reaching the full working length. All ProTaper Universal rotary files were inserted into root canals in a continuous in-and-out movement with a suitable force; they were never forced apically. Files were used in a torque-controlled electric micromotor (Endo-Mate DT, NSK, Japan) with a 16:1 reduction contra-angle handpiece using recommended torque of (2.0 N/cm) and rotation speed of (300 rpm) [10, 17, 21, 22].

Group Three: Rotary Instrumentation with Revo-S Classic Rotary System (Micro-Mega, Besançon, France), SC1 file was used to about two-thirds of the working length of the canal with slow and unique downward movement in a free progression and without pressure. SC2 file was used to the full working length of the canal with a progressive 3 wave movement (up and down movement). SU file was used to the full working length of the canal with a slow and unique downward movement in a free progression and without pressure. AS30, AS35, AS40, files were used to the full working length of the canal. The AS instruments were used with slow and unique downward movement and without apical pressure, after using the SU. The files were rotated at a constant recommended rotation speed of (300 rpm) and recommended torque of (0.8 N/cm) using a 16:1 reduction contra-angle handpiece powered by a torque-controlled electric micromotor(Endo-Mate DT).

Group Four: Rotary Instrumentation with Twisted Files Rotary System (SybronEndo, Orange, CA, USA), TF .08/25 was taken into the canal until it engaged dentin and then withdrew immediately. The step was repeated with the same TF file until the full working length was achieved. TF .06/30 was taken into the canal until it engaged dentin and then withdrew immediately. The step was repeated with the same TF file until the full working length was achieved. TF .06/35 and TF .04/40 were then taken to the full working length. The Twisted Files were rotated freely as entered the canal, advanced with a single continuous and controlled motion until the files engaged dentin, and then withdrew; they were never forced apically. The files were rotated at a constant recommended rotation speed of (500 rpm) and recommended torque of (2.0 N/cm) using a 16:1 reduction contra-angle handpiece powered by a torque-controlled electric micromotor(Endo-Mate DT).

During root canal instrumentation, irrigation was performed using a 5 mL luer lock disposable plastic syringe with a 28-gauge Max-I-Probe side-vented endodontic irrigation needle placed passively into the canal, to 2 mm from the working length without bindingafter initial instrumentation to allow easy back flow of the irrigating solution. A two mL of 3% freshly prepared sodium hypochlorite (NaOCl) solution was used after each instrument size, leaving the canal filled with irrigant between each instrument. Canals then received a final irrigation of eight mL of the same solution after root canal instrumentation. Finally, the canals were dried with ProTaper absorbent paper points size #F4and the access opening was sealed with a moist cotton pellet and temporary filling to block the entry of debris during sectioningand prevent contamination of the root canal space[16, 18, 23].

Group Five: Root Canal Instrumentation with the Self-Adjusting File System (Figure 1), a SAF 1.5 mm was inserted into the canal while vibrating and was delicately advanced apically with an intermittent in-and-out hand movement of about 3-5 mm amplitude until it reached the predetermined working length. A pecking motion of 3-5 mm allowing rotation of the file when not in contact with the canal walls; this permitted the file to slide into the canal until resistance was met. This technique allowed various paths of insertion when the asymmetrically tipped file was introduced into the canal. Each SAF was operated for 4 minutes per canal with continuous irrigation.The SAF was operated by using a 1:1 reduction contra-angle low-speed handpiece(Gentle-Power Lux 20LP; KaVo, Biberach, Germany)adapted with a reciprocating trans-line (in-and-out) vibrating handpiece head(RDT3, ReDent-Nova) at a frequency of 83.3 Hz. The electric micromotor (X-Smart, Dentsply, Tulsa Dental) rotation speed was set at (5,000 rpm), and a recommended torque of (1.0 N/cm) which resulted in an in-and-out operation of 5,000 vibrations per minute with an amplitude of 0.4 mm. The head produces a rotational motion at 80 rpm when the file is unrestricted, and it transforms the rotational motion generated by the motor into an apico-coronal motion of 0.4 mm. This movement combined with intimate contact along the entire circumference and length of the canal and the slightly rough surface of the file removed a layer of dentin with a filing motion (abrasion action). Continuous irrigation with 3% sodium hypochlorite (NaOCl) was applied throughout the procedure at a flow rate of 5 mL/min using a special irrigation device (VATEA peristaltic pump, ReDent-Nova) that was connected to a free-rotating irrigation hub on the file via a silicone tube. The canals were dried with ProTaper absorbent paper points size #F4 and the access opening was sealed with a moist cotton pellet and temporary filling to block the entry of splattering cutting debris during sectioning and prevent contamination of the canal walls [3, 12, 13].

Before sectioning, a permanent black marker was used to draw guiding lines horizontally at the cemento-enamel junction and longitudinally along the buccal and lingual surfaces of the distal roots. A double-faced diamond disc with straight handpiece then used for preparation of horizontal and longitudinal grooves under water cooling at the marks previously determined, preserving the inner shelf of dentine surrounding the canal. The crowns and roots were split by placing a surgical chisel in thegrooves and with slight pressure striking the chisel with a smallmallet. The longitudinal section of each root with ≤ 180° of the canal circumference was selected for study. The sections with > 180° of canal circumference would possibly interfere with total canal visualization during photography[24, 25].

The chosen sections of the split roots were photographed by using a 7-megapixelNikon D40 professional digital camera (Nikon Corp., Tokyo, Japan) at a 1:1 setting and saved in a computer as TIFF images with maximum resolution of 2000-3000 pixels. The images were then imported into Adobe Photoshop CS6(Adobe Systems Incorporated,San Jose, California, USA) and enlarged to 100x the original size. The root canal area was divided into three equal thirds (Apical, Middle and Coronal) from the apical constriction to the canal orifice with aid of superimposing lines. The remaining debris in each canal was traced and the total number of pixels occupied by the debris was reported by using the histogram function in the software program. The outline of the canal was then traced and the same feature of the software reported the total pixels occupied by the canal. Percentage of the remaining debris was calculated by dividing the pixels of debris by the total pixels representing the entire area of the canal. Percentage of remaining debris was calculated for the apical, middle and coronal thirds for each canal [24, 25].

The data were collected and analyzed using SPSS (Version 18) for statistical analysis. One-Way Analysis of Variance (ANOVA) test and Least Significant Difference (LSD) test were used to determine whether there is a statistical difference among the groups and within group at different thirds with a significance level of $P \leq 0.05$.

Figure 1: Self- Adjusting File (SAF) system components.

RESULTS

The mean values (±SD) for the percentage of dentin debris remaining in the **Apical**, **Middle** and **Coronal** thirds of root canals for five instrumentation systems are shown in Table1 and Figure 2.

The comparison between the five instrumentation systems in removing of dentin debris at each third

One-way ANOVA test showed that there was a highly significant difference among all groups at all thirds ($P< 0.01$). By performing the least significant difference (LSD)test, at the apical third, no significant differences were found among ProTaper hand instruments, ProTaper rotary instruments, Revo-s rotary instruments and Twisted rotary files and highly significant differences were found between Self-Adjusting Files and all the other four groups. At the middle and coronal thirds, no significant difference was found between ProTaper hand and ProTaper rotary instruments, highly significant differences were found between ProTaper hand instruments and both Revo-s instruments and Twisted files, also highly significant differences were found between ProTaper rotary instruments and both Revo-s instruments and Twisted files, no significant difference was found between Revo-s instruments and Twisted files and highly significant differences were found between Self-Adjusting Files and all the other four groups.

The percentage of dentin debris remaining at three difference thirds for each instrumentation system

At ProTaper Hand, ProTaper Rotary, Revo-S and Twisted File groups, highly significant differences were found between apical third and both middle and coronal thirds and highly significant difference was found between middle and coronal thirds. At Self-Adjusting File group, no significant difference was found betweenapical and middle thirds and highly significant differences were found between both apical and middle thirds and coronal third.

Table 1: Descriptive statistical analysis for the percentage of dentin debris remaining at three thirds (Apical, Middle and Coronal) for five instrumentation systems

Thirds	Tested groups	N	Mean	±SD
Apical	ProTaper Hand	10	1.1260	0.08178
	ProTaper Rotary	10	1.0749	0.08488
	Revo-S	10	1.1274	0.09961
	Twisted File	10	1.1395	0.10538
	SAF	10	0.5333	0.07305
Middle	ProTaper Hand	10	2.0326	0.09900
	ProTaper Rotary	10	2.0405	0.09226
	Revo-S	10	2.3086	0.27426
	Twisted File	10	2.2915	0.13740
	SAF	10	0.5985	0.10834
Coronal	ProTaper Hand	10	2.6805	0.19229
	ProTaper Rotary	10	2.6672	0.28932
	Revo-S	10	3.2187	0.09755
	Twisted File	10	3.1457	0.10042
	SAF	10	0.8298	0.08058

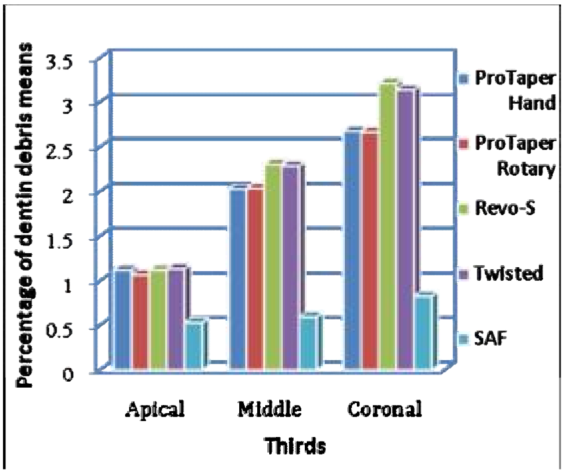

Figure 2: Bar chart showing means percentage of dentin debris remaining.

DISCUSSION

The main objective of chemomechanical instrumentation is the total elimination of infected pulp tissue from the root canal. Thus, proper cleansing of the canal space is considered essential for success in endodontics. To achieve these objectives, pulpal remnants as well as debris and the smear layer produced by instrumentation procedures must be removed from the root canal walls. Mechanical instrumentation establishes an adequate canal shape, allowing easy access of irrigating solutions to the entire canal space and adequate obturation[26]. Anatomic complexities might represent physical constraints that pose a serious challenge to adequate root canal instrumentation and disinfection. An example includes the cross sectional root canal configuration, which has been classified as oval [4].

The efficiency of the five instrumentation systems at apical third:

The superior cleaning efficiency of SAF in this study are in agreement with De-Deus et al. [11], who found that there was significantly greater residual pulp tissue left after ProTaper system instrumentation versus SAF instrumentation (21.4% vs. 9.3%, $P < 0.05$) at the 1-5 mm apical levels of oval-shaped root canals, the SAF-treated canals had a more evident preparation of the buccal and/or lingual recesses due to:

(1) the SAF ability toadapt itself to the cross-section of the canal and

(2) the continuous irrigation.

The results of this study disagreed with Paranjpe et al.[12], who found no significant difference between ProTaper Rotary and SAF in the amount of dentin debris at 1mm apical level of oval shaped root canals as well as ProTaper showed statistically less debris than SAF at 3 mm apical level, this might be related to differences in the method of measurement, the authors used SEM method in which the measurements were limited to 1 and 3 mm apical levels only, whereas in the present study, the evaluation was made for the entire apical third by using digital image morphometric analysis method.

The efficiency of the five instrumentation systems at middle and coronal thirds:

The results of this study showed that ProTaper instruments resulted in cleaner canals at the middle and coronal thirds than Revo-S and Twisted File. The explanations for these results could probably be attributed to (1)The sharp cutting edges of the convex triangular cross-sectional design of ProTaper instruments and a flute design that combines multiple tapers within the shaft up to 19%, whereas Revo-S and TF instruments used in this study had a constant taper of a maximum 6% and 8%, respectively. Therefore, Revo-S and TF removed smaller amounts of dentin in both middle and coronal thirds of the canals compared with ProTaper, and this may compromise the irrigation control and upward debris removal. Fayyad and Elgendy[27] found that ProTaper showed a greater amount of removed dentin than TF, especially for the middle and coronal thirds in the mesiodistal direction and for the middle third in the buccolingual direction.

(2) ProTaper Rotary shaping files (SX, S1, and S2) were used with brushing action against the buccal and lingual walls, so that a greater amount of instrumented areas created, which allowed better penetration of the irrigant and superior upward debris elimination, whereas Revo-S and Twisted File were used with pecking motion (non-brushing motion) according to the individual manufacturer instructions of each system. Zmener et al. [28] stated that in oval-shaped canals, nickel-titanium instruments used only in a rotary motion and without lingual and buccal pressure tend to partially remove tooth structure leaving untouched areas on the opposite walls. The cutting efficiency and the ability to clean root canal walls are dependent on the inherent design of the instrument and the dynamics used during instrumentation.

Metzger et al.[29] showed that the SAF resulted in cleaner canals walls than ProTaper rotary files for the coronal and midroot portions of the root canal. The difference was also pronounced in the apical third, in which rotary files failed to adequately clean the canal. These findings are in accordance with the results of this study. Also the results of the present study are in agreement with Paqué et al. [30] and De-Deus et al. [22], who stated that the use of SAF in canals adjacent to isthmuses and oval canals resulted in much less hard-tissue debris accumulation and uninstrumented recesses cleaner of tissue debris, respectively than when ProTaper rotary files were used. The authors attributed these results either to avoiding rotary motion in the canals, which most probably caused debris packing when rotary files were used, or because of the continuous irrigation that was applied through the hollow file throughout the procedure or both. The mode of action of the SAF may also have contributed to the results. Rotary files have a rotating cutting edge that cuts off dentine particles that may be packed into the isthmus or uninstrumented recesses of oval canals. The SAF on the other hand works like sandpaper: its delicately rough surface comes in close contact with the canal walls with a light pressure produced by the compressed lattice attempting to regain its original form. The in-and-out vibration that is generated by the special handpiece head serves as the motion required to remove material from the canal walls. Dentine is removed as a thin powder that is continuously suspended and carried out by the flow of the irrigant.

The percentage of dentin debris remaining at three difference thirds for each instrumentation system:

The results of comparison the apical, middle and coronal thirds for Rotary systems in this study coincide with Taha et al.[7], who found that in the apical third of oval canals, Rotary NiTi gave the best results with regard to canal cleanliness, also the apical third showed the least uninstrumented canal surfaces followed by middle and coronal thirds, respectively. The explanations of these results might be attributed to that (1) The oval shape of the canal is mostly present in the coronal and middle parts of the root, and this shape taper toward a rounder shape apically[2, 6, 7].Paqué et al. [30] reported that when rotary files are used in canal with a round cross section, the dentine particles that are cut from the canal wall are carried coronally by the flutes of the file, in a manner similar to that of a common mechanical spiral drill. This removal is apparently less effective when the file has no dentine wall on one side, as is the case of a canal adjacent to an isthmus or oval canals. Rather than being carried coronally or being contained and packed in the file's flute space, the debris was most probably actively packed into the area with the least resistance, namely into the isthmuses or similar recesses in case of oval canals. It is conceivable to hypothesize that dentine particles were actively packed into soft-tissue remnants in these isthmuses and recesses, thus resulting in composite debris of dentine particles embedded in soft-tissue remnants, which was resistant to the common syringe-and-needle irrigation.

(2) The rotating movement of NiTi instruments, their superelasticity, and their self-centering properties result in a nonselective cutting action along the walls of the root canal. In other words, the rotating movement of these instruments tends to maintain the instrument in the center of the canal, with the result that not all areas are being instrumented [31]. Rödig et al. [23]found that the flexibility of the NiTi instruments did not allow the operator to force them into the buccal and lingual extensions of the middle and coronal sections of oval root canals. The instruments frequently produced a circular bulge in the canal whilst the buccal and lingual extensions remained unprepared. Root canal cleanliness was not good with much remaining debris and smear layer in the unprepared extensions.

The results of this study are in conflict with Zmener et al.[28], who observed that no significant differences in remaining debris were found between 1, 5, 10 mm levels from the working length of oval-shaped canals for the NiTi rotary instrumentation, this might be attributed to differences in the type of rotary instruments and the method of measurement; the author used rotary instruments with radial lands and SEM method for analysis of instrumented walls only and uninstrumented areas were excluded from evaluation, also areas selected for measurements were limited to 1, 5 and 10 mm levels.

In the SAF group, the apical and middle thirds showed statistically better canal cleanliness than the coronal third, this could be related to the canal anatomy in which the oval shape become more pronounced in the coronal third and the use of 1.5 mm file size.

REFERENCE

1. Paqué F, Balmer M, Attin T, Peters OA. Preparation of oval-shaped root canals in mandibular molars using nickel titanium rotary instruments: A micro-computed tomography study. J Endod 2010; 36:703-7.
2. Wu MK, R'Oris A, Barkis D, Wesselink PR. Prevalence and extent of long oval canals in the apical third. Oral Surg Oral Med Oral Pathol Oral RadiolEndod 2000; 89:739-43.
3. Paqué F, Peters OA. Micro-computed tomography evaluation of the preparation of long oval root canals in mandibular molars with the Self-Adjusting File. J Endod 2011; 37:517-21.

4. SiqueiraJr, Alves FRF, Almeida BM, de Oliveira JCM, Rôças IN. Ability of chemomechanical preparation with either rotary instruments or Self-Adjusting File to disinfect oval-shaped root canals. J Endod 2010; 36:1860-5.
5. Metzger Z, Teperovich E, Zary R, Cohen R, Hof R. The Self-Adjusting File (SAF). Part 1: Respecting the root canal anatomy; a new concept of endodontic files and its implementation. J Endod 2010a; 36:679-90.
6. Malur MH, Goud M. A preliminary analysis in the preparation and obturation of oval canals. J ClinExp Dent 2011; 3(3):189-92.
7. Taha NA, Ozawa T, Messer HH. Comparison of three techniques for preparing oval-shaped root canals. J Endod 2010; 36:532-5.
8. Bernardes RA, Rocha EA, Duarte MAH, Vivan RR, de Moraes IG, Bramante AS, de Azevedo JR. Root canal area increase promoted by the EndoSequence and ProTaper systems: Comparison by computed tomography. J Endod 2010; 36:1179-82.
9. De-Deus G, Garcia-Filho P. Influence of the NiTi rotary system on the debridement quality of the root canal space. Oral Surg Oral Med Oral Pathol Oral RadiolEndod 2009; 108:71-6.
10. De-Deus G, Barino B, Zamolyi RQ, Souza E, Fonseca A, Fidel S, Fidel RAS. Suboptimal debridement quality produced by the single-file F2 ProTaper technique in oval-shaped canals. J Endod 2010; 36:1897-900.
11. De-Deus G, Souza EM, Barino B, Maia J, Zamolyi RQ, Reis C, Kfir A. The Self-Adjusting File optimizes debridement quality in oval-shaped root canals. J Endod 2011; 37:701-5.
12. Paranjpe A, Gregorio de C, Gonzalez AM, Gomez A, Herzog DS, Pina AA, Cohenca N. Efficacy of the Self-Adjusting File System on cleaning and shaping oval canals: A microbiological and microscopic evaluation. J Endod 2012; 38(2):226-31.
13. de Gregorio C , Paranjpe A, Garcia A, Navarrete N, Estevez R, Esplugues EO, Cohenca N. Efficacy of irrigation systems on penetration of sodium hypochlorite to working length and to simulated uninstrumented areas in oval shaped root canals. IntEndod J 2012; 45(5):475-81.
14. Plotino G, Grande NM, Falanga A, Giuseppe ILD, Lamorgese V, Somma F. Dentine removal in the coronal portion of root canals following two preparation techniques. Int Endod J 2007; 40: 852-8.
15. Fornari VJ, Silva-Sousa YTC, Vanni JR, Pécora JD, Versiani MA, Sousa-Neto MD. Histological evaluation of the effectiveness of increased apical enlargement for cleaning the apical third of curved canals. IntEndod J 2010; 43:988-94.
16. Howard RK, Kirkpatrick TC, Rutledge RE, Yaccino JM. Comparison of debris removal with three different irrigation techniques. J Endod 2011; 37(9):1301-5.
17. ÇelikÜnal G, Maden M, Savgat A, Orhan EO. Comparative investigation of 2 rotary nickel-titanium instruments: ProTaper Universal versus ProTaper. Pathol Oral Radiol Endod 2009; 107:886-92.
18. Nielsen BA, Baumgartner JC. Comparison of the endovac system to needle irrigation of root canals. J Endod 2007; 33:611- 5.
19. Huang QL, Zhang XQ, Deng GZ, Huang SG. SEM evaluation of canal cleanliness following use of ProTaper hand-operated rotary instruments and stainless steel K-files. The Chinese J Dent Res 2009; 12 (1):45-9.
20. Li KZ, Gao Y, Zhang R, Hu T, Guo B. The effect of a manual instrumentation technique on five types of premolar root canal geometry assessed by micro-computed tomography and three-dimensional reconstruction. BMC Medical Imaging 2011, 11:14.
21. Wu J, Lei G, Ming Y, Yu Y, Yu J, Zhang G. Instrument separation analysis of multi-used ProTaper Universal rotary system during root canal therapy. J Endod 2011; 37:758-63.
22. De-Deus G, Barino B, Marins J, Magalhães K, Thuanne E, Kfir A. Self-Adjusting File cleaning-shaping-irrigation system optimizes the filling of oval-shaped canals with thermoplasticized gutta-percha. J Endod 2012; 38(6):846-9.
23. Rödig T, Hülsmann M, Muhge M, Schafers F. Quality of preparation of oval distal root canals in mandibular molars using nickel-titanium instruments. IntEndod J 2002; 35:919-28.
24. Sabins RA, Johnson JD, Hellstein JW. A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. J Endod 2003; 29:674-8.
25. Munley PJ, Goodell GG. Comparison of passive ultrasonic debridement between fluted and nonfluted instruments in root canals. J Endod 2007; 33:578-80.
26. Zmener O, Pameijer CH, Serrano SA, Hernandez SR. Cleaning efficacy using two engine-driven systems versus manual instrumentation in curved root canals: A scanning electron microscopic study. J Endod 2011; 37:1279-82.
27. Fayyad DM, Elgendy AAE. Cutting efficiency of twisted versus machined nickel-titanium endodontic files. J Endod 2011; 37:1143-6.
28. Zmener O, Pameijer CH, Banegas G. Effectiveness in cleaning oval-shaped root canals using Anatomic Endodontic Technology, ProFile and manual instrumentation: A scanning electron microscopic study. IntEndod J 2005; 38:356-63.
29. Metzger Z, Teperovich E, Cohen R, Zary R, Paque F, Hulsmann M. The Self-Adjusting File (SAF). Part 3: Removal of debris and smear layer – A scanning electron microscope study. J Endod 2010; 36:697-702.
30. Paqué F, Al-Jadaa A, Kfir A. Hard-tissue debris accumulation created by conventional rotary versus Self-Adjusting File instrumentation in mesial root canal systems of mandibular molars. IntEndod J 2012; 45(5):413-8.
31. Plotino G, Grande NM, Sorci E, Malagnino VA, Somma F. Influence of a brushing working motion on the fatigue life of NiTi rotary instruments. IntEndod J 2007; 40:45-51.