



The Open Dentistry Journal

Content list available at: www.benthamopen.com/TODENTJ/

DOI: 10.2174/1874210601812010189



REVIEW ARTICLE

Influence of File Motion on Shaping, Apical Debris Extrusion and Dentinal Defects: A Critical Review

Victor Feliz Pedrinha, Juliana Melo da Silva Brandão, Oscar Faciola Pessoa and Patrícia de Almeida Rodrigues*

School of Dentistry, Federal University of Pará, Pará, Brazil

Received: November 23, 2017

Revised: December 21, 2017

Accepted: February 06, 2018

Abstract: Advances in endodontics have enabled the evolution of file manufacturing processes, improving performance beyond that of conventional files. In the present study, systems manufactured using state of the art methods and possessing special properties related to NiTi alloys (*i.e.*, CM-Wire, M-Wire and R-Phase) were selected. The aim of this review was to provide a detailed analysis of the literature about the relationship between recently introduced NiTi files with different movement kinematics and shaping ability, apical extrusion of debris and dentin defects in root canal preparations. From March 2016 to January 2017, electronic searches were conducted in the PubMed and SCOPUS databases for articles published since January 2010. *In vitro* studies performed on extracted human teeth and published in English were considered for this review. Based on the inclusion criteria, 71 papers were selected for the analysis of full-text copies. Specific analysis was performed on 45 articles describing the effects of reciprocating, continuous and adaptive movements on the WaveOne Gold, Reciproc, HyFlex CM and Twisted File Adaptive systems. A wide range of testing conditions and methodologies have been used to compare the systems. Due the controversies among the results, the characteristics of the files used, such as their design and alloys, appear to be inconsistent to determine the best approach.

Keywords: Endodontic files, Endodontically treated teeth, Kinematics, Nickel-titanium, Root canal preparation, Root canal therapy.

1. INTRODUCTION

Nickel-titanium (NiTi) files were introduced in the manufacturing process in 1988 [1] to avoid unwanted changes in the morphology of root canals caused by stainless steel files. These files have shown a significant increase in flexibility, enabling the development of rotational automated systems and improving efficiency in root canal shaping [2].

Recently, a thermomechanical procedure appropriate for nitinol, an alloy component, aiming to produce super-elastic NiTi wires that can be used to manufacture endodontic files with improved fatigue resistance [3] was developed; the wires are collectively called M-Wire NiTi (Dentsply Tulsa, OK, USA). VDW (Munich, Germany), the company that produces the Reciproc system, uses M-Wire technology to manufacture NiTi files that use reciprocating movements [4]. The WaveOne Gold system (Dentsply Maillefer, Ballaigues, Switzerland) maintains the same file as the WaveOne reciprocating system but has modified dimensions and geometry. The file has a parallelogram-shaped cross-section with 2 cutting edges. The manufacturing process consists of a thermal treatment performed repeatedly by heating and slow cooling, resulting in a golden file [5].

Another change in NiTi alloys has been developed to increase the efficiency and flexibility of rotating files, as occurs in the files of the HyFlex Controlled Memory (CM) system (Coltene Whaledent, Cuyahoga Falls, OH, USA), containing a smaller percentage of nickel than other systems [6]. The reduction of nickel content generates a metal that is softer, *i.e.*, exhibits lower hardness [7]. The processing of these files also affects the metal properties, such as the thermal changes that occur during the manufacturing of the HyFlex CM file, which results in a martensitic metal phase. The martensitic phase is a more flexible form of yarn that results in greater elasticity and resistance to cyclic fatigue [8].

* Address correspondence to this author at the School of Dentistry, Federal University of Pará, Augusto Corrêa Street, Guamá, Belém, Pará, Brazil; Tel: (+55) 91-98134-7899; E-mail: patsilesouza@uol.com.br

In the adaptive motion Twisted File Adaptive (TFA) system (Sybron, Orange, CA, USA), the NiTi alloy is manufactured by R-Phase technology. This system presents a lower degree of apical transport and greater centralization of the canal; in addition, the system maintains the path in the apical third of severely curved proximal surface canals [9].

Because the kinematic effects of preparation systems affect the quality of endodontic treatment, a system in which better clinical results are obtained through biomechanical preparation techniques is expected. Advances in endodontics have enabled the evolution of file manufacturing processes, improving performance beyond that of conventional files. In the present study, systems manufactured using state of the art methods and possessing special properties related to NiTi alloys (*i.e.*, CM-Wire, M-Wire and R-Phase) were selected. The aim of this study was to review the articles including *in vitro* studies performed only in extracted human teeth and involving automated systems with files produced by NiTi alloys found in the Reciproc, WaveOne Gold, HyFlex CM and Twisted File Adaptive systems and their possible differences with respect to shaping ability and formation of apical debris and dentinal defects.

2. SEARCH METHODOLOGY

Between March 2016 and January 2017, 2 independent researchers searched the electronic bibliographic databases MEDLINE/PubMed and SCOPUS (ELSEVIER) for *in vitro* studies performed on extracted human teeth (in English language). The study was complemented with a search of citations from relevant articles on the subject. Searches in the MEDLINE/PubMed database did not have filters or limits applied; filters were used to restrict the searches in SCOPUS (ELSEVIER) to articles concerning dentistry.

The electronic searches resulted in the identification of 736 articles (396 from PubMed and 340 from SCOPUS), which were exported to the Mendeley Desktop software program in database groups. The abstracts were first screened to eliminate articles that clearly failed to meet the search criteria. Based on the inclusion criteria, 71 papers were selected for the analysis of full text copies. Specific analysis was performed on 45 articles, describing the effects of reciprocating, continuous and adaptive movements on the WaveOne Gold, Reciproc, HyFlex CM and Twisted File Adaptive systems. The articles were required to describe *in vitro* studies on automated systems with respect to one of the following subjects: shaping, the apical extrusion of debris or the formation of dentinal cracks.

The exclusion criteria pertained to publication type and excluded reviews, editorials, opinions, technical articles, guidelines, comment articles, animal studies, artificial or simulated canals, studies on deciduous dentition, and studies evaluating systems through endodontic retreatment. Combinations of the terms used in the search are described in Figs. (1-3).

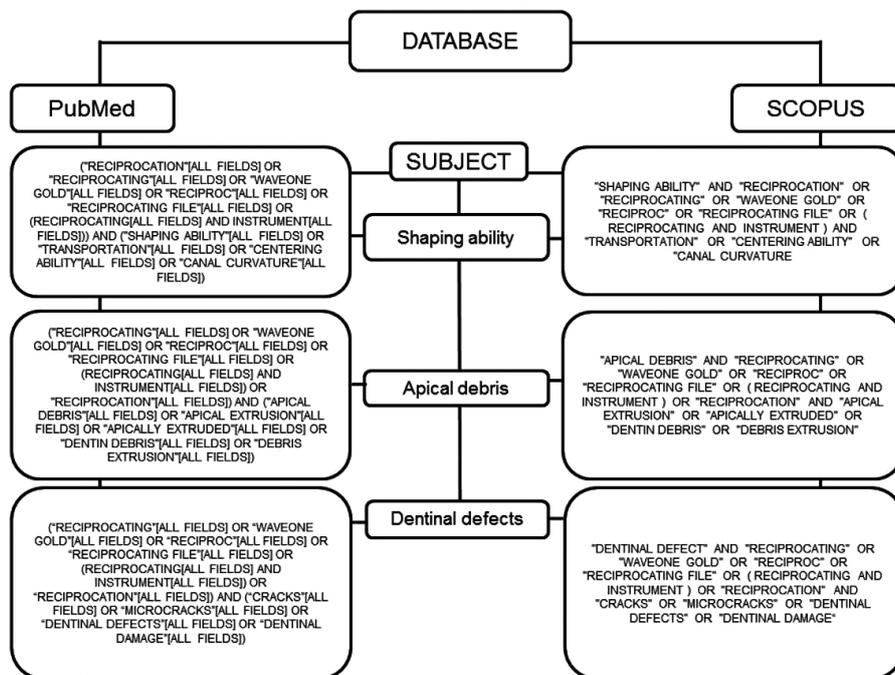


Fig. (1). Combination of terms used for database search related to the WaveOne Gold and reciproc systems.

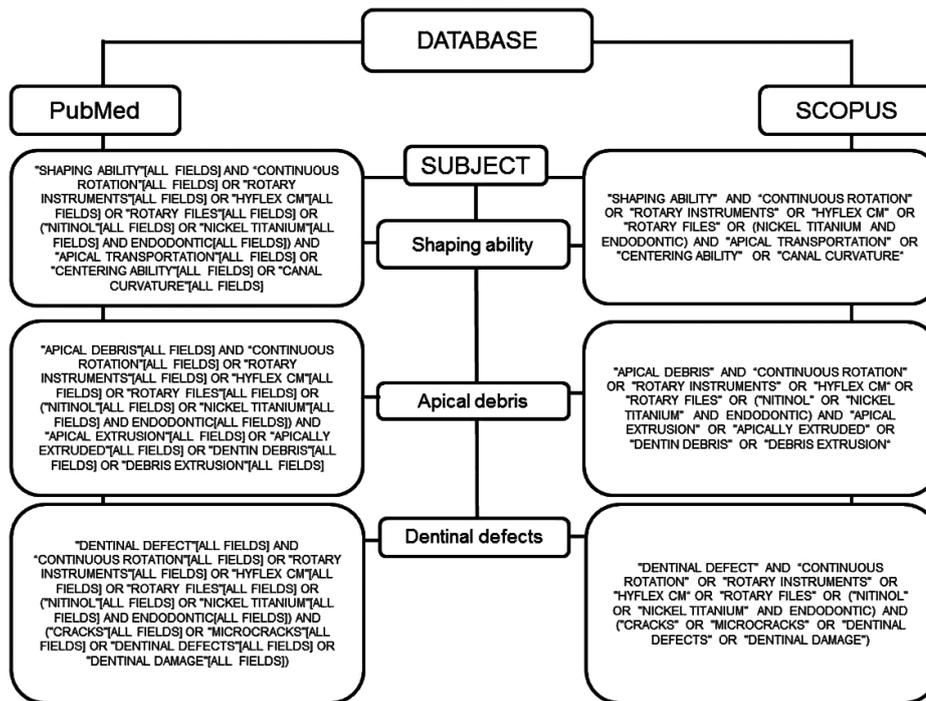


Fig. (2). Combination of terms used for database search related to the HyFlex CM system.

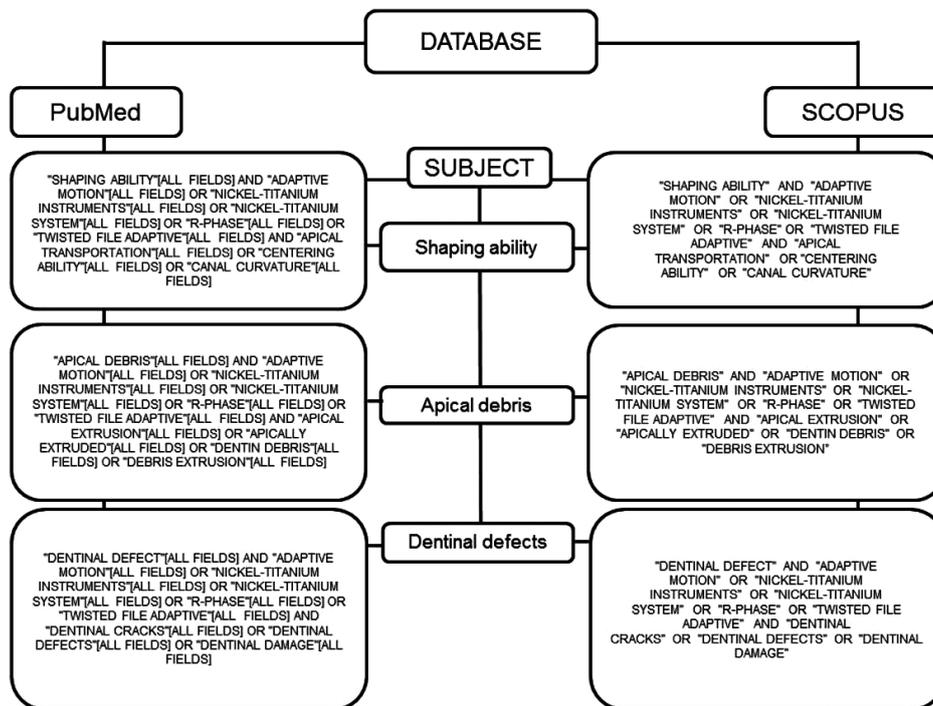


Fig. (3). Combination of terms used for database search related to the Twisted File adaptive system.

From selected studies, the following data were extracted and included in the review: sample size or type, type of files used, kinematics, and methods used for obtaining and evaluating results (shaping ability, amount of apical debris and dentinal cracks).

3. LITERATURE REVIEW

The literature review was organized into three sections: (I) comparative shaping ability for canal transport; (II) comparative studies of apical extrusion of debris; and (III) comparative studies of the formation of dentinal defects, featuring biomechanical preparations carried out by automated systems. The types of movement were investigated in these studies, and their characteristics are described in Tables 1, 2 and 3.

Table 1. Summary of characteristics of the studies about shaping ability.

Author	Type of Sample	Number of Canals	File Used	Kinematics	Methods	Results (Transportation)
Marceliano-Alves <i>et al.</i>	Mn molar 10° - 20° curvature	64	Reciproc WaveOne Twisted File HyFlex CM	R R CR CR	μCT	Reciproc and WaveOne > Twisted File and HyFlex CM
Saber <i>et al.</i>	Mn molar 20° - 45° curvature	60	Oneshape Reciproc WaveOne	CR R R	Radiographic	Oneshape > Reciproc and WaveOne
Simpsy <i>et al.</i>	Mn molar 25° - 35° curvature	45	HyFlex CM WaveOne ProTaper	CR R CR	CBCT	ProTaper > WaveOne > HyFlex
Dhingra <i>et al.</i>	Mn molar (curvature not mentioned)	120	Oneshape Reciproc WaveOne	CR R R	CBCT	Oneshape > WaveOne and Reciproc
Bürklein <i>et al.</i>	Human teeth (type not mentioned) 25° - 35° curvature	80	Mtwo Reciproc F360 OneShape	CR R CR CR	Radiographic	No significant difference
Hwang <i>et al.</i>	Mx molar 20° - 45° curvature	45	Mtwo Reciproc	CR and R R	μCT	Mtwo RC > Mtwo R and WaveOne
Bürklein <i>et al.</i>	Human teeth (type not mentioned) 25° - 39° curvature	80	Mtwo ProTaper Reciproc WaveOne	CR CR R R	Radiographic	No significant difference
Ramazani <i>et al.</i>	Mn molar 20° - 40° curvature	64	K-File Mtwo Reciproc	MI CR R	CBCT	Mtwo > Reciproc
Nabavizadeh <i>et al.</i>	Mx molar 25° - 35° curvature	60	Reciproc BioRace	R CR	Radiographic	Reciproc > BioRace
Navós <i>et al.</i>	Mx molar 20° - 40° curvature	60	ProTaper MTwo Reciproc	CR CR R	CBCT	No significant difference
Moazzami <i>et al.</i>	Mn molar 15° - 30° curvature	45	Neoniti Reciproc	CR R	CBCT	Reciproc > Neoniti
Ahmetoglu <i>et al.</i>	Mx molar CV - 20° - 45° CP - 0° - 10° curvature	90	Self-Adjusting File Revo-S Reciproc	CR CR R	μCT	Reciproc > Self-Adjusting File and Revo-S
Gergi <i>et al.</i>	Mn molar 25° - 35° curvature	48	Reciproc WaveOne Twisted File Adaptive	R R AM	μCT	Reciproc and WaveOne > Twisted File Adaptive
Pedulla <i>et al.</i>	Mn molar 25° - 35° curvature	64	Mtwo Twisted File Adaptive	CR and AM CR and AM	μCT	No significant difference
Gergi <i>et al.</i>	Mn molar 25° - 35° curvature	48	Reciproc WaveOne Twisted File Adaptive	R R AM	μCT	Reciproc and WaveOne > Twisted File Adaptive
Capar <i>et al.</i>	Mn molar 20° - 40° curvature	120	Oneshape ProTaper Universal ProTaper Next Reciproc WaveOne Twisted File	CR CR CR R R AM	CBCT	No significant difference

Mn, mandible; Mx, maxillar, VC, vestibular canal; PC, palatine canal; MI, manual instrumentation; AM, adaptive movement; CR, continuous rotation; R, reciprocation; CT, computed tomography; CBCT, cone beam computed tomography.

Table 2. Summary of characteristics of the studies about apical debris.

Author	Type of Samples	Number of Canals	File Used	Kinematics	Irrigant	Results
Karatas <i>et al.</i>	Mn premolar	80	ProTaper Gold WaveOne Gold ProTaper Universal WaveOne	CR R CR R	Distilled water	ProTaper Universal > WaveOne, ProTaper Gold and WaveOne Gold
Burklein <i>et al.</i>	Mn incisor	80	Reciproc F360 OneShape Mtwo	R CR CR CR	Distilled water	Reciproc > F360, OneShape and Mtwo
Kucukyilmaz <i>et al.</i>	Mn premolar	45	Reciproc OneShape ProTaper ProTaperNext	R CR CR CR	Distilled water	No significant difference
Nevares <i>et al.</i>	Mn premolar	60	Reciproc WaveOne HyFlex CM	R R CR	NaOCl	Reciproc > WaveOne > HyFlex CM
Surakanti <i>et al.</i>	Mn premolar	60	ProTaper Hyflex WaveOne	CR CR R	Distilled water	WaveOne and ProTaper > HyFlex CM
Capar <i>et al.</i>	Mn premolar	60	ProTaper Universal ProTaper Next Twisted File Adaptive HyFlex CM	CR CR AM CR	Distilled water	ProTaper Universal and HyFlex CM > ProTaper Next and Twisted File Adaptive
Kirchhoff <i>et al.</i>	Mn incisor	48	ProTaper Next WaveOne Twisted File Adaptive	CR R AM	Distilled water	No significant difference
Karatas <i>et al.</i>	Mn incisor	72	Twisted File Adaptive	R CR	Distilled water	R > CR
Bürklein <i>et al.</i>	Mn incisor	80	Reciproc WaveOne Mtwo ProTaper	R R CR CR	Distilled water	WaveOne and Reciproc > Mtwo and ProTaper
Arslan <i>et al.</i>	Mx incisor	45	Reciproc	R CR	Distilled water	CR > R
De-Deus <i>et al.</i>	Mn molar	48	ProTaper WaveOne Reciproc	CR R R	Distilled water	ProTaper > WaveOne and Reciproc
Cakici <i>et al.</i>	Mn molar	80	ProTaper Gold ProTaper Universal ProTaper Next Reciproc	CR CR CR R	Distilled water	ProTaper Universal and HyFlex CM > ProTaper Gold and Reciproc
Uzun <i>et al.</i>	Mn premolar	60	WaveOne Reciproc SafeSider Typhoon ProTaper Universal Mtwo	R R R CR CR CR	Distilled water	Mtwo, ProTaper Universal, Typhoon, SafeSider and WaveOne > Reciproc
Lu <i>et al.</i>	Anterior teeth (type not mentioned)	80	Reciproc WaveOne BLX ProTaper	R R CR CR	Saline solution	BLX and ProTaper > Reciproc and WaveOne
Nayak <i>et al.</i>	Mn premolar	60	Reciproc WaveOne Oneshape	R R CR	Distilled water	Reciproc and Waveone > Oneshape
Silva <i>et al.</i>	Mn premolar	60	ProTaper Universal ProTaper Next WaveOne Reciproc	CR CR R R	Distilled water	ProTaper Universal > ProTaper Next, WaveOne and Reciproc
Topçuoğlu <i>et al.</i>	Mn premolar	60	Vortex Blue K3XF Reciproc ProTaper Next	CR CR R CR	Distilled water	K3XF and Reciproc > Vortex Blue and ProTaper Next

(Table 4) *contd....*

Author	Type of Samples	Number of Canals	File Used	Kinematics	Irrigant	Results
Kuřtarcı <i>et al.</i>	Mn premolar	90	Reciproc Revo-S Twisted File Adaptive	R CR AM	Distilled water	No significant difference

Mn, mandible; Mx, maxillar; MA, adaptive movement; RC, continuous rotation; R, reciprocation.

Table 3. Summary of characteristics of the studies about dentinal defects.

Author	Type of Samples	Number of Canals	File Used	Kinematics	Methods	Results
Coelho <i>et al.</i>	Mn molar	160	ProFile TRUShape WaveOne Gold	CR CR R	Led transillumination	No significance difference
Ustun <i>et al.</i>	Mn incisor	120	K-File ProTaper Universal ProTaper Next Reciproc	MI R and CR CR R	SEM	No significance difference
Gergi <i>et al.</i>	Mn molar	180	Reciproc WaveOne Twisted File Adaptive	R R CR and R	SEM	Reciproc > WaveOne and Twisted File Adaptive
Jalali <i>et al.</i>	Mn premolar	100	Reciproc ProTaper Universal Mtwo	R CR CR	SEM	Mtwo and ProTaper Universal > Reciproc
Karatař <i>et al.</i>	Mn incisor	75	ProTaper Universal ProTaper Next WaveOne Twisted File Adaptive	CR CR R AM	SEM	ProTaper Universal and WaveOne > ProTaper Next and Twisted File Adaptive
Karatař <i>et al.</i>	Mn incisor	105	Twisted File Adaptive	CR/R/AM	SEM	RC and Adaptive Movement > R
Aydin <i>et al.</i>	Mn premolar	70	Reciproc WaveOne Twisted File Adaptive	R R AM	SEM	No significance difference
De-Deus <i>et al.</i>	Mn molar	20	ProTaper Next Twisted File Adaptive	CR R	μ CT	No formation of dentinal defects
Zhou <i>et al.</i>	Mn premolar and molar	280	WaveOne Protaper Universal Twisted File Twisted File Adaptive	R CR CR AM	SEM	WaveOne and ProTaper Universal > Twisted File and Twisted File Adaptive
De-Deus <i>et al.</i>	Mn molar	30	Reciproc WaveOne BioRace	R R CR	μ CT	No significance difference
Bürklein <i>et al.</i>	Mn incisor	100	Mtwo ProTaper Reciproc WaveOne	CR CR R R	SEM	WaveOne and Reciproc > Mtwo and ProTaper

Mn, mandible; Mx, maxillar; MI, manual instrumentation; AM, adaptive movement; CR, continuous rotation; R, reciprocating; CT, computed tomography; CBCT, cone beam computed tomography; SEM, scanning electron microscopy.

4. SHAPING ABILITY

One of the main objectives of biomechanical preparation is to promote the modeling of root canals, ensuring conicity with crown-apex tapering, such that the original shape of the canal is maintained. However, in curved canals, procedural errors such as apical transport and zips are common during this stage [10]. The elasticity of NiTi rotary files allows clinicians to conduct the desired form of taper root canal therapy with a reduced tendency for transport [11].

Based on peer-reviewed articles, it can be affirmed that all publications used curved canals in laboratory experiments; the angle of curvature of the roots varied between 10 and 45 degrees in most proximal surfaces of the molars. With respect to the efficiency of systems and the techniques developed for preparing canals and determining apical transports, several methods were used to compare the shape of the canals before and after preparation, such as the radiographic overlay method, cone beam computed tomography (CBCT) and micro-computed tomography (μ CT).

Among the studies that showed significant differences in transport values, comparative analyses before and after preparation were mostly performed by the μ CT evaluation method [9, 12 - 15], followed by studies that used CBCT [16

- 19] and finally, by studies that used radiographic evaluation methods pre- and post-instrumentation through computer image analysis programs [20, 21]. The high precision of three-dimensional (3D) analysis of root canal systems in experimental procedures is significant in justifying image comparison by μ CT as the more sensitive methodology for measuring transport values. In endodontic studies, μ CT analysis is performed by direct comparison of canal system images before and after biomechanical preparation through computer programs that are capable of presenting 2D and 3D morphological data of the root canals [22].

In the 5 articles [23 - 25] that were reviewed, kinematics showed no statistically significant differences in relation to transport values in the apical third; in 3 of the articles, no statistically significant differences were observed between continuous and alternate rotation kinematics. One article showed no significant difference about transport in the apical third between systems of continuous rotation and adaptive motion [26]; furthermore, no significant differences between the 3 types of kinematics were observed [27].

Four articles involving systems with alternate motion presented results indicating greater transport values than those of continuous rotation systems [12, 14, 17, 21]; in contrast, 5 articles [15, 16, 18 - 20] indicated greater transport values for continuous systems than for alternate motion systems. Regarding the articles that demonstrated higher values of apical transport for systems with alternating rotation, teeth treated with the Reciproc system were associated with significant increases in the area, perimeter and diameter of the main canal relative to systems of continuous rotation and adaptive movement. Some authors related the design of the file to the cutting ability of dentinal walls, particularly for the Reciproc system, which presents an S-shaped cross-section and sharp cutting edges. The design of the file together with the reciprocating movement increases the cutting efficiency of Reciproc files. In these articles [12, 14, 17, 21], root canals were modeled by selected files with similar sizes and tapers in the different comparative groups (file size 25 and 0.08 taper).

On the other hand, based on the results obtained in articles concerning apical transport, the smaller transport values obtained for alternate movement systems compared with continuous motion systems ($P < 0.05$), particularly for the Reciproc system, can be justified by the movement performed at rotation angles of 150° counterclockwise and 30° clockwise; because the rotation in the direction of the cut is greater than that in reverse, the file moves toward the apex. This reciprocal motion decreases the pressure on the tool and reduces the risk of cyclic fatigue caused by tension and compression, in addition to maintaining the centralization of the canal [15, 16, 18 - 20]. Moreover, M-Wire technology confers greater flexibility to these files because of the low modulus of elasticity [28].

Two articles [9, 13] compared alternate and adaptive systems; lower values were obtained for the TFA system. According to Gergi *et al.* [9, 13], the TFA system presented the lowest transport values in 2 articles that comparatively evaluated the Reciproc and WaveOne reciprocating systems in addition to the TFA adaptive system by μ CT. The TFA system uses a combination of continuous rotation and alternate movements, in which continuous rotation is used when the amount of pressure exerted on the file is minimal and reciprocal movement is used when the dentin has an applied load. The manufacturers claim that this adaptive technology and twisted file design increases flexibility and allows the file to adjust torsion forces inside canals, depending on the amount of pressure that is exerted. The adaptive movement is based on a patented algorithm that produces changes in motion in accordance with the loads that are applied to the file through the walls of the canal. This patented algorithm adapts to different conditions based on the amount of pressure on the file when it is not under pressure and will rotate continuously clockwise without anticlockwise motion, but when the file is subjected to pressure loads, the alternating angles vary, 370° clockwise and 20° to 50° counterclockwise, based on the load applied to the file [9, 13, 29].

With an apical preparation diameter similar to the values reported in other studies, the TFA system demonstrated that it could produce significantly less transport, followed by the WaveOne and Reciproc systems. The combination of adaptive movement and the flexibility of the files is proposed as the reason for the modeling results obtained for the TFA system [30].

5. APICAL EXTRUSION OF DEBRIS

During root canal shaping, dentin scrapings, pulp tissue fragments, necrotic tissue, and microorganisms or irrigating agents can be eliminated from periodontal tissues [31]. Apical extrusion of infected debris may have the potential to disrupt the balance between microbial aggression and protection of the host, resulting in episodes of periapical inflammation and flare-ups after surgery [32]. While all staging techniques cause apical extrusion of debris, the amount of debris extrusion in the periapical region may vary depending on the method used [33].

All articles examined in this review presented experiments involving the apical extrusion of debris. Two articles did not show statistically significant differences regarding the comparative amounts of debris in reciprocating systems in evaluating continuous rotation in lower premolars [34] and adaptive movement in mandibular incisors [35].

Five articles obtained significant differences using anterior teeth; in 2 of these articles, the Reciproc system resulted in a greater amount of debris than that generated by continuous rotational systems [36, 37]. Another article he first 3 mm of the workpiece, which decrease showed that continuous systems produced a greater amount of debris than reciprocating systems such as Reciproc and WaveOne [38]. Two articles used only one type of file in 2 alternate and continuous rotational kinematic mechanisms with the Reciproc and TFA systems [39, 40]. According to Ahn *et al.*, these two studies excluded the effect of file design, indicating controversial results [41].

With respect to premolars, 8 articles showed significant differences in their results. In only 1 article [40] addressing apical debris, the WaveOne Gold (WOG) system presented better results than the conventional WaveOne (WO) system and continuous rotation systems such as the ProTaper and ProTaper Universal Gold systems. Because of the absence of further studies on WOG, performing a comparative analysis is difficult; however, some differences between WOG and WO files should be highlighted.

WOG “primary” files have a taper of 0.07, while primary files in a conventional WO system have a taper of 0.08. This discrepancy may be responsible for the greater flexibility of WOG files presenting a parallelogram design with one or two cutting edges depending on the location along the file. The WO system presents a cross-sectional triangular design that can result in a smaller screwing effect and higher cutting efficiency. These differences in cross-section, *i.e.*, the taper and the flexibility of the files, may be responsible for the low amount of apical debris generated by WOG files [40].

The HyFlex CM system showed low amounts of extrusion of debris in reciprocating systems in 2 articles [42, 43]; this finding can be explained by the HyFlex CM system’s slightly convex triangular cross-section, while the Reciproc system exhibits higher cutting efficiency [42]. Articles indicate that differences in conicity between files may influence debris extrusion [42, 43]. Reciproc R40 (0.06 taper) and WaveOne Large (0.08 taper) files have a constant taper within the first 3 mm of the workpiece, which decreases to D16, while the HyFlex CM system has a continuous taper of 0.04. The greater contact at the tip of the WaveOne and Reciproc files may promote greater extrusion of debris compared with that of the HyFlex CM system due to the greater wear of the dentin walls, which was not observed in the abovementioned articles [42, 43]. However, compared with the adaptive motion TFA system, the HyFlex CM files showed more debris extrusion in which deformities were observed on all files used for up to 3 single canals, which after the preparation, 80% of the HyFlex CM files were deformed. Another condition pointed as the cause of debris extrusion, was the files deformation, leading to the unwinding of their spirals, as observed in the HyFlex CM system [44].

Two articles compared continuous rotation systems with the WaveOne and Reciproc alternating systems and demonstrated lower extrusion about reciprocating or alternating files [45, 46]. Topçuoğlu *et al.* [47] and Nayak *et al.* [48] indicated that the Reciproc system results in more extrusion of debris than some continuous rotation systems.

Three articles on molars were selected for this review. In these articles, the Reciproc system showed lower apical extrusion of debris [49, 50]; however, in the study by Kuştarıcı *et al.*, there was no statistically significant difference between the Reciproc and TFA systems evaluated in premolars [51].

Because the number of *in vitro* studies is limited and many have submitted conflicting results, more studies are required. The WOG system suggests efficiency, but only one manuscript has addressed the subject to date. HyFlex CM files have demonstrated less extrusion than Reciproc files; however, the TFA system suggests better performance than HyFlex CM files. Reciproc files showed lower extrusion in six studies, while in four others, these results were contradicted.

6. FORMATION OF DENTINAL DEFECTS

Dentinal defects can propagate to a vertical root fracture and, in most cases, lead to tooth extraction. These fractures have a multifactorial etiology, and some authors attribute this condition to excessive biomechanical preparation, excessive removal of dentin during the widening of the canal and after preparation, the amount of remaining coronal structure, types of parafunction and excessive force during the filling of the root canal [52].

One can speculate that when using only a file for preparation, more stress will be generated during the

instrumentation mechanics than when using canal preparation systems with string files. Thus, it is inferred that the incidence of defects can increase under these conditions compared with that observed in preparations using the complete sequence of rotational systems [53].

According to this review, 11 articles on dentinal defects were eligible; among these, 4 showed no statistically significant differences between continuous rotational and reciprocating systems [54 - 56]. One article showed no significant difference between a reciprocating system and the TFA system [57]. Only one article showed the absence of defects through image analysis by μ CT [58].

The TFA system showed the best results in 3 articles when compared with only reciprocating systems [59] or with continuous systems and reciprocating systems [60, 61]. In 1 article [62], this system was evaluated by performing three types of kinematic assessments, in which alternating movement yielded better results with respect to the formation of defects in dentine. In these articles, adaptive movement is indicated as a cause of the decrease in the tension caused by the walls of the root canals, particularly in the apical third, resulting in less crack formation [59 - 62]. The variation in the taper of the files is also considered as a contributing factor in the formation of dentin defects. Karatas *et al.* [61], WaveOne Primary and ProTaper F2 files caused greater crack formation at the 3 mm level of the apical third. The WaveOne Primary file has a taper of 0.08 in its apical portion which decreases to 0.055 for the remainder of the working length. Likewise, ProTaper F2 has a taper of 0.08 in the apical portion. However, the ProTaper Next X2 and TF Adaptive SM2 files feature a taper of 0.06. The greater conicity of the F2 and WaveOne Primary files in the apical portion may have led to greater crack formation [61].

Two articles are controversial. Jalali *et al.* [63] observed lower defect formation in a dental group instrumented with the Reciproc system, while for the same system, Bürklein *et al.* [54], obtained less satisfactory results relative to those obtained for the Mtwo (Sweden & Martina, Padova, Italy) and ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) systems with continuous rotation. Thus, in these cases again, the file taper and the kinematics employed by each of them, interfere to obtain different results.

CONCLUSION

Various NiTi files with different designs produced by different manufacturing methods have been introduced in dentistry. These files provide many advantages over conventional files, such as increased flexibility and improved efficiency in root canal shaping. Considering the three categories reviewed (shaping ability, extrusion of debris, and dentinal defects or cracks), in comparing shaping results based on the apical transport value, μ CT was determined to be the methodology that yielded the most significantly different results between the kinematic methods. With respect to shaping ability, the TFA system yielded the best results in 2 studies compared with reciprocating systems developed by the same author. For apical extrusion of debris in premolars, the WOG system presented better performance than the WaveOne system, which performs reciprocating kinematics, and the ProTaper Universal and ProTaper Gold systems, which perform rotational kinematics. The TFA adaptive motion system yielded better results than HyFlex CM files with respect to debris extrusion. In molars, the Reciproc system presented better results than continuous rotation systems. Regarding the shortcomings of the various systems, the TFA system presented lower values with respect to the formation of dentinal defects in three studies, with comparisons made between reciprocating and continuous systems. Because of the variation in the results, the characteristics of the files, such as their design and the wires used, appear to be inconsistent to determine the best approach. In addition, laboratory studies are limited when comparing the kinematics of the systems.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

None declared.

REFERENCES

- [1] Walia HM, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of nitinol root canal files. *J Endod* 1988; 14(7): 346-51. [http://dx.doi.org/10.1016/S0099-2399(88)80196-1] [PMID: 3251996]
- [2] Fife D, Gambarini G, Britto Lr Lr. Cyclic fatigue testing of ProTaper NiTi rotary instruments after clinical use. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2004; 97(2): 251-6. [http://dx.doi.org/10.1016/j.tripleo.2003.08.010] [PMID: 14970785]
- [3] Berendt CJ. Method of preparing Nickel Titanium Alloy for use in manufacturing instruments with improved fatigue resistance. united states patent US patent 2010; 7648599.
- [4] 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): 105-7. [http://dx.doi.org/10.1016/j.joen.2011.09.028] [PMID: 22152631]
- [5] Webber J. Shaping canals with confidence: WaveOne GOLD Single-File Roots 2015; 1: 34-40.
- [6] Zinelis S, Eliades T, Eliades G. A metallurgical characterization of ten endodontic Ni-Ti instruments: assessing the clinical relevance of shape memory and superelastic properties of Ni-Ti endodontic instruments. *Int Endod J* 2010; 43(2): 125-34. [http://dx.doi.org/10.1111/j.1365-2591.2009.01651.x] [PMID: 20078701]
- [7] Gao Y, Gutmann JL, Wilkinson K, Maxwell R, Ammon D. Evaluation of the impact of raw materials on the fatigue and mechanical properties of ProFile Vortex rotary instruments. *J Endod* 2012; 38(3): 398-401. [http://dx.doi.org/10.1016/j.joen.2011.11.004] [PMID: 22341083]
- [8] 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): 1293-5. [http://dx.doi.org/10.1016/j.joen.2011.05.023] [PMID: 21846552]
- [9] 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): 1223-7. [http://dx.doi.org/10.1016/j.joen.2014.01.039] [PMID: 25069937]
- [10] 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): 904-7. [http://dx.doi.org/10.1016/j.joen.2009.12.038] [PMID: 20416443]
- [11] Peters OA. Current challenges and concepts in the preparation of root canal systems: A review. *J Endod* 2004; 30(8): 559-67. [http://dx.doi.org/10.1097/01.DON.0000129039.59003.9D] [PMID: 15273636]
- [12] Marceliano-Alves MF, Sousa-Neto MD, Fidel SR, et al. Shaping ability of single-file reciprocating and heat-treated multifile rotary systems: A micro-CT study. *Int Endod J* 2015; 48(12): 1129-36. [http://dx.doi.org/10.1111/iej.12412] [PMID: 25400256]
- [13] Gergi R, Osta N, Bourbouze G, Zgheib C, Arbab-Chirani R, Naaman A. Effects of three nickel titanium instrument systems on root canal geometry assessed by micro-computed tomography. *Int Endod J* 2015; 48(2): 162-70. [http://dx.doi.org/10.1111/iej.12296] [PMID: 24717063]
- [14] Ahmetoglu F, Keles A, Simsek N, Ocak MS, Yologlu S. Comparative evaluation of root canal preparations of maxillary first molars with self-adjusting file, reciproc single file, and revo-s rotary file: A micro-computed tomography study. *Scanning* 2015; 37(3): 218-25. [http://dx.doi.org/10.1002/sca.21202] [PMID: 25737430]
- [15] Hwang YH, Bae KS, Baek SH, et al. Shaping ability of the conventional nickel-titanium and reciprocating nickel-titanium file systems: A comparative study using micro-computed tomography. *J Endod* 2014; 40(8): 1186-9. [http://dx.doi.org/10.1016/j.joen.2013.12.032] [PMID: 25069930]
- [16] Simpsy GS, Sajjan GS, Mudunuri P, Chittam J, Prasanthi NN, Balaga P. Shaping ability of reciprocating motion of WaveOne and HyFlex in moderate to severe curved canals: A comparative study with cone beam computed tomography. *J Conserv Dent* 2016; 19(6): 578-82. [http://dx.doi.org/10.4103/0972-0707.194028] [PMID: 27994323]
- [17] Moazzami F, Khojastepour L, Nabavizadeh M, Seied Habashi M. Cone-beam computed tomography assessment of root canal transportation by neoniti and reciproc single-file systems. *Iran Endod J* 2016; 11(2): 96-100. [PMID: 27141215]
- [18] Ramazani N, Mohammadi A, Amirabadi F, Ramazani M, Ehsani F. *In vitro* investigation of the cleaning efficacy, shaping ability, preparation time and file deformation of continuous rotary, reciprocating rotary and manual instrumentations in primary molars. *J Dent Res Dent Clin Dent Prospect* 2016; 10(1): 49-56. [http://dx.doi.org/10.15171/joddd.2016.008] [PMID: 27092215]
- [19] Dhingra A, Ruhil N, Miglani A. Evaluation of single file systems reciproc, oneshape, and WaveOne using cone beam computed tomography - An *in vitro* study. *J Clin Diagn Res* 2015; 9(4): ZC30-4. [PMID: 26023639]
- [20] Saber SE, Nagy MM, Schäfer E. Comparative evaluation of the shaping ability of ProTaper Next, iRaCe and Hyflex CM rotary NiTi files in severely curved root canals. *Int Endod J* 2015; 48(2): 131-6.

- [http://dx.doi.org/10.1111/iej.12291] [PMID: 24697590]
- [21] Nabavizadeh M, Abbaszadegan A, Khojastepour L, Amirhosseini M, Kiani E. A comparison of apical transportation in severely curved canals induced by reciproc and BioRaCe systems. *Iran Endod J* 2014; 9(2): 117-22. [PMID: 24688580]
- [22] Sinibaldi R, Pecci R, Somma F, Della Penna S, Bedini R. A new software for dimensional measurements in 3D endodontic root canal instrumentation. *Ann Ist Super Sanita* 2012; 48(1): 42-8. [PMID: 22456014]
- [23] Navós BV, Hoppe CB, Mestieri LB, Böttcher DE, Só MV, Grecca FS. Centering and transportation: *in vitro* evaluation of continuous and reciprocating systems in curved root canals. *J Conserv Dent* 2016; 19(5): 478-81. [http://dx.doi.org/10.4103/0972-0707.190008] [PMID: 27656071]
- [24] 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. [http://dx.doi.org/10.1111/iej.12037] [PMID: 23240965]
- [25] Bürklein S, Hinschitzka K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne *versus* Mtwo and ProTaper. *Int Endod J* 2012; 45(5): 449-61. [http://dx.doi.org/10.1111/j.1365-2591.2011.01996.x] [PMID: 22188401]
- [26] Pedullà E, Plotino G, Grande NM. Shaping ability of two nickel-titanium instruments activated by continuous rotation or adaptive motion: A micro-computed tomography study. *clin oral investig* 2016; 8: 2227-33.
- [27] 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. [http://dx.doi.org/10.1016/j.joen.2013.10.010] [PMID: 24862716]
- [28] Kim HC, Kwak SW, Cheung GS, Ko DH, Chung SM, Lee W. Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in reciprocation motion: Reciproc *versus* WaveOne. *J Endod* 2012; 38(4): 541-4. [http://dx.doi.org/10.1016/j.joen.2011.11.014] [PMID: 22414846]
- [29] Altunbas D, Kutuk B, Kustarci A. Shaping ability of reciprocating single-file and full-sequence rotary instrumentation systems in simulated curved canals. *Eur J Dent* 2015; 9(3): 346-51. [http://dx.doi.org/10.4103/1305-7456.163221] [PMID: 26430361]
- [30] Zhao D, Shen Y, Peng B, Haapasalo M. Micro-computed tomography evaluation of the preparation of mesiobuccal root canals in maxillary first molars with Hyflex CM, Twisted Files, and K3 instruments. *J Endod* 2013; 39(3): 385-8. [http://dx.doi.org/10.1016/j.joen.2012.11.030] [PMID: 23402512]
- [31] Seltzer S, Naidorf IJ. Flare-ups in endodontics: I. Etiological factors. 1985. *J Endod* 2004; 30(7): 476-81. [http://dx.doi.org/10.1097/00004770-200407000-00005] [PMID: 15220641]
- [32] Siqueira JF Jr. Microbial causes of endodontic flare-ups. *Int Endod J* 2003; 36(7): 453-63. [http://dx.doi.org/10.1046/j.1365-2591.2003.00671.x] [PMID: 12823700]
- [33] Torabinejad M, Eby WC, Naidorf IJ. Inflammatory and immunological aspects of the pathogenesis of human periapical lesions. *J Endod* 1985; 11(11): 479-88. [http://dx.doi.org/10.1016/S0099-2399(85)80221-1] [PMID: 3913729]
- [34] Küçükyılmaz E, Savas S, Saygili G, Uysal B. Assessment of apically extruded debris and irrigant produced by different nickel-titanium instrument systems. *Braz Oral Res* 2015; 29: 1-6. [http://dx.doi.org/10.1590/1807-3107BOR-2015.vol29.0002] [PMID: 25387860]
- [35] Kirchhoff AL, Fariniuk LF, Mello I. Apical extrusion of debris in flat-oval root canals after using different instrumentation systems. *J Endod* 2015; 41(2): 237-41. [http://dx.doi.org/10.1016/j.joen.2014.09.023] [PMID: 25447504]
- [36] Bürklein S, Schäfer E. Apically extruded debris with reciprocating single-file and full-sequence rotary instrumentation systems. *J Endod* 2012; 38(6): 850-2. [http://dx.doi.org/10.1016/j.joen.2012.02.017] [PMID: 22595125]
- [37] Bürklein S, Benten S, Schäfer E. Quantitative evaluation of apically extruded debris with different single-file systems: Reciproc, F360 and OneShape *versus* Mtwo. *Int Endod J* 2014; 47(5): 405-9. [http://dx.doi.org/10.1111/iej.12161] [PMID: 23889673]
- [38] Lu Y, Chen M, Qiao F, Wu L. Comparison of apical and coronal extrusions using reciprocating and rotary instrumentation systems. *BMC Oral Health* 2015; 15: 92. [http://dx.doi.org/10.1186/s12903-015-0081-z] [PMID: 26251234]
- [39] Arslan H, Doğanay E, Alsancak M, Çapar ID, Karataş E, Gündüz HA. Comparison of apically extruded debris after root canal instrumentation using Reciproc® instruments with various kinematics. *Int Endod J* 2016; 49(3): 307-10. [http://dx.doi.org/10.1111/iej.12449] [PMID: 25809717]
- [40] Karataş E, Ersoy İ, Gündüz HA, Uygun AD, Kol E, Çakıcı F. Influence of instruments used in root canal preparation on amount of apically extruded debris. *Artif Organs* 2016; 40(8): 774-7.

- [http://dx.doi.org/10.1111/aor.12675] [PMID: 26814380]
- [41] Ahn SY, Kim HC, Kim E. Kinematic Effects of Nickel-Titanium instruments with reciprocating or continuous rotation motion: A systematic review of in vitro studies. *J Endod* 2016; 42(7): 1009-17.
[http://dx.doi.org/10.1016/j.joen.2016.04.002] [PMID: 27185740]
- [42] Nevaes G, Xavier F, Gominho L, et al. Apical extrusion of debris produced during continuous rotating and reciprocating motion. *Sci World J* 2015; 2015: 267264.
[http://dx.doi.org/10.1155/2015/267264] [PMID: 26543896]
- [43] Surakanti JR, Venkata RC, Vemisetty HK, Dandolu RK, Jaya NK, Thota S. Comparative evaluation of apically extruded debris during root canal preparation using ProTaper™, Hyflex™ and Waveone™ rotary systems. *J Conserv Dent* 2014; 17(2): 129-32.
[http://dx.doi.org/10.4103/0972-0707.128045] [PMID: 24778507]
- [44] Capar ID, Arslan H, Akcay M, Ertas H. An *in vitro* comparison of apically extruded debris and instrumentation times with ProTaper Universal, ProTaper Next, Twisted File Adaptive, and HyFlex instruments. *J Endod* 2014; 40(10): 1638-41.
[http://dx.doi.org/10.1016/j.joen.2014.04.004] [PMID: 25260737]
- [45] Uzun I, Güler B, Özyürek T, Tunc T. Apical extrusion of debris using reciprocating files and rotary instrumentation systems. *Niger J Clin Pract* 2016; 19(1): 71-5.
[http://dx.doi.org/10.4103/1119-3077.173715] [PMID: 26755222]
- [46] Silva EJ, Carapiá MF, Lopes RM, et al. Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. *Int Endod J* 2016; 49(7): 700-5.
[http://dx.doi.org/10.1111/iej.12503] [PMID: 26174577]
- [47] Topçuoğlu G, Topçuoğlu HS, Akpek F. Evaluation of apically extruded debris during root canal preparation in primary molar teeth using three different rotary systems and hand files. *Int J Paediatr Dent* 2016; 26(5): 357-63.
[http://dx.doi.org/10.1111/ipd.12208] [PMID: 26538300]
- [48] Nayak G, Singh I, Shetty S, Dahiya S. Evaluation of apical extrusion of debris and irrigant using two new reciprocating and one continuous rotation single file systems. *J Dent (Tehran)* 2014; 11(3): 302-9.
[PMID: 25628665]
- [49] Cakici F, Cakici EB, Küçükkekenci FF, Uygun AD, Arslan H. Apically extruded debris during root canal preparation using ProTaper Gold, ProTaper Universal, ProTaper Next, and RECIPROC instruments. *Int J Artif Organs* 2016; 39(3): 128-31.
[http://dx.doi.org/10.5301/ijao.5000480] [PMID: 27034317]
- [50] De-Deus G, Neves A, Silva EJ, et al. Apically extruded dentin debris by reciprocating single-file and multi-file rotary system. *Clin Oral Investig* 2015; 19(2): 357-61.
[http://dx.doi.org/10.1007/s00784-014-1267-5] [PMID: 24950606]
- [51] Kuştarıcı A, Er K. Efficacy of laser activated irrigation on apically extruded debris with different preparation systems. *Photomed Laser Surg* 2015; 33(7): 384-9.
[http://dx.doi.org/10.1089/pho.2015.3900] [PMID: 26154727]
- [52] Kim HC, Lee MH, Yum J, Versluis A, Lee CJ, Kim BM. Potential relationship between design of nickel-titanium rotary instruments and vertical root fracture. *J Endod* 2010; 36(7): 1195-9.
[http://dx.doi.org/10.1016/j.joen.2010.02.010] [PMID: 20630298]
- [53] Bürklein S, Tsotsis P, Schäfer E. Incidence of dentinal defects after root canal preparation: reciprocating *versus* rotary instrumentation. *J Endod* 2013; 39(4): 501-4.
[http://dx.doi.org/10.1016/j.joen.2012.11.045] [PMID: 23522545]
- [54] Coelho MS, Card SJ, Tawil PZ. Visualization enhancement of dentinal defects by using light-emitting diode transillumination. *J Endod* 2016; 42(7): 1110-3.
[http://dx.doi.org/10.1016/j.joen.2016.04.006] [PMID: 27178248]
- [55] Ustun Y, Aslan T, Sagsen B, Kesim B. The effects of different nickel-titanium instruments on dentinal microcrack formations during root canal preparation. *Eur J Dent* 2015; 9(1): 41-6.
[http://dx.doi.org/10.4103/1305-7456.149638] [PMID: 25713483]
- [56] De-Deus G, Silva EJ, Marins J, et al. Lack of causal relationship between dentinal microcracks and root canal preparation with reciprocation systems. *J Endod* 2014; 40(9): 1447-50.
[http://dx.doi.org/10.1016/j.joen.2014.02.019] [PMID: 25146030]
- [57] Aydin U, Aksoy F, Karataslioglu E, Yildirim C. Effect of ethylenediaminetetraacetic acid gel on the incidence of dentinal cracks caused by three novel nickel-titanium systems. *Aust Endod J* 2015; 41(3): 104-10.
[http://dx.doi.org/10.1111/aej.12097] [PMID: 25495951]
- [58] De-Deus G, Belladonna FG, Silva EJ, et al. Micro-CT Evaluation of non-instrumented canal areas with different enlargements performed by NiTi Systems. *Braz Dent J* 2015; 26(6): 624-9.
[http://dx.doi.org/10.1590/0103-6440201300116] [PMID: 26963207]
- [59] Gergi RM, Osta NE, Naaman AS. Dentinal crack formation during root canal preparations by the twisted file adaptive, Reciproc and WaveOne instruments. *Eur J Dent* 2015; 9(4): 508-12.
[http://dx.doi.org/10.4103/1305-7456.172634] [PMID: 26929688]

- [60] Karataş E, Gündüz HA, Kırıcı DO, Arslan H, Topçu MÇ, Yeter KY. Dentinal crack formation during root canal preparations by the twisted file adaptive, ProTaper Next, ProTaper Universal, and WaveOne instruments. *J Endod* 2015; 41(2): 261-4. [<http://dx.doi.org/10.1016/j.joen.2014.10.019>] [PMID: 25476974]
- [61] Zhou X, Jiang S, Wang X, Wang S, Zhu X, Zhang C. Comparison of dentinal and apical crack formation caused by four different nickel-titanium rotary and reciprocating systems in large and small canals. *Dent Mater J* 2015; 34(6): 903-9. [<http://dx.doi.org/10.4012/dmj.2015-197>] [PMID: 26632241]
- [62] Karataş E, Arslan H, Alsancak M, Kırıcı DO, Ersoy İ. Incidence of dentinal cracks after root canal preparation with twisted file adaptive instruments using different kinematics. *J Endod* 2015; 41(7): 1130-3. [<http://dx.doi.org/10.1016/j.joen.2015.02.029>] [PMID: 25843752]
- [63] Jalali S, Eftekhari B, Paymanpour P, Yazdizadeh M, Jafarzadeh M. Effects of reciproc, mtwo and protaper instruments on formation of root fracture. *Iran Endod J* 2015; 10(4): 252-5. [PMID: 26523141]

© 2018 Pedrinha *et al.*

This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International Public License (CC-BY 4.0), a copy of which is available at: (<https://creativecommons.org/licenses/by/4.0/legalcode>). This license permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.