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ORIGINAL ARTICLE

Scanning Electron Microscopic Evaluation of Root Canal Walls after shaping with Different Single-use Rotary Systems

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ABSTRACT

The aim of the present study was to investigate the cleaning efficacy of four new single-use rotary nickel–titanium (NiTi) systems. A total of 48 single-rooted freshly extracted teeth were divided into four groups. Root canals were shaped with the single-use NiTi systems (ProTaper Next, F360, OneShape and F6 SkyTaper) using 5.25% NaOCl and 17% ethylenediaminetetraacetic acid (EDTA) solutions. Specimens were fractured longitudinally and prepared for scanning electron microscopic (SEM) analysis at standard magnification of 2,500×. The presence/absence of debris smear layer and smear layer at coronal, middle, and apical third of each canal were evaluated using a five-step scale for scores. Numeric data were analyzed using Kruskal–Wallis and Mann–Whitney U statistical tests and significance was predetermined at $p < 0.05$. Analysis of variance test showed no significant differences among the NiTi systems ($p > 0.05$). The same results were assessed considering the smear layer scores. Analysis of variance confirmed that the apical third of the canal maintained a higher quantity of debris and smear layer after preparation of all the samples. All the single-use rotary NiTi systems left dentinal walls generally free of debris, even if a small amount of smear layer is visible, especially in the apical third of the root canal. All tested single-use systems seem to be effective in removing smear layer from root canals, if irrigating protocols are respected.

Keywords: Nickel—titanium, Scanning electron microscopic, Single-file systems, Single-use instruments, Smear layer.

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INTRODUCTION

Root canal treatment is based on cleaning, shaping, and sealing the root canal system.[1] The main objective is the elimination of microorganisms from the root canals and the prevention of recontamination after filling.[2-5] Irrigating solutions facilitate the disinfection and the debridement of the root canal, and therefore, they are considered to be essential for successful endodontic treatment.[6-10] Instruments alone cannot effectively eliminate bacteria from the root canal system,[11] and modern rotary instrumentation techniques may produce a large quantity of smear layer that covers all root canal walls.

In the last decades, many nickel-titanium (NiTi) rotary instruments have been introduced. All NiTi rotary instruments have been shown to produce moderate to heavy smear layer that need to be removed with the use of chemical solutions.[12,13] Chelating agents like ethylenediaminetetraacetic acid (EDTA) are currently used to remove the smear layer formed during preparation of the root canals.[14] The association of EDTA and NaOCl solutions is the gold standard in chemomechanical preparation of the root canals.[15,16] Ethylenediaminetetraacetic acid acts upon the inorganic components of the smear layer and decalcifies the peri- and inter-tubular dentin and leaves the collagen exposed. Subsequently, the use of NaOCl dissolves the collagen, cleaning the dentinal walls.[14] The combined use of irrigating solutions and rotary instruments decreases bacterial counts in the root canal when compared with standard instrumentation alone.[17] Several scanning electron microscopic (SEM) studies revealed that rotating files associated with EDTA and NaOCl irrigation leave dentin surfaces substantially free from smear layer.[18-20] The combination of NaOCl and EDTA favorable the removal of smear layer and the removal of a great portion of circumferential dentinal collagen and mineralized dentin from the surfaces of tubules, as confirmed by Foschi et al.[18] This means that absence of smear layer and presence of clean dentinal walls provide a reduction in bacterial count. At present, it is well known that mechanical NiTi instrumentation along with chemical cleaning greatly reduce the microorganisms remaining in the root canal system.[21-23] Total removal of smear layer facilitates the diffusion of the irrigants and the medications to the root canal system[24] and improves the adaptation of the filling materials to the root canal dentin, reducing apical and coronal microleakage of the root canal filling materials.[25]

Numerous attempts have been made to improve and to facilitate mechanical root canal preparation and different new NiTi systems are available to achieve this goal.[26] Actually, new single-use NiTi systems have been

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launched to make the root canal treatment easier (due to the reduction of the files necessary for complete root canal shaping) and safer (due to the reduction of stresses related to reuse, disinfecting procedures, and thermal cycles in autoclave).

OneShape, F360, Protaper Next, and F6 Skytaper are single-use systems made for continuous rotations. They are used with a conventional endodontic engine and discarded after use; they are considered single-file systems when only one file is necessary for complete shaping of the root canal or multiple-file systems when a sequence of instruments is used.[27]

The purpose of the present study was to investigate the cleaning efficacy of these different single-use rotary NiTi instruments. The amount of debris and the morphology of smear layer were parameters for the evaluation of the cleanliness of root canals. The null hypothesis of the study is that there is no significant difference in debris scores and smear layer scores between the three systems.

MATERIALS AND METHODS

A total of 48 single-rooted human teeth freshly extracted for periodontal reasons were selected for this study and placed in saline at room temperature immediately after extraction. The inclusion criteria are morphological similarity, single-canal roots, straight roots, absence of root decay, absence of previous endodontic treatment, root length of at least 13 mm, and apical diameter of at least #20. The crown of each tooth was removed at the level of the cementoenamel junction in order to obtain root segments similar in length. Two longitudinal grooves were prepared on the palatal/lingual and buccal surfaces of each root with a diamond bur used with a high-speed water-cooled handpiece to facilitate vertical splitting with a chisel after canal instrumentation. All the roots were randomly assigned to four experimental groups of 12 specimens each.

The same trained operator prepared all root canals. The glide path was created using hand stainless steel #08-10-15 K-files (MicroMega, Besancon, France) to create a glide path, and then, they were shaped with four different single-use NiTi rotary instruments:

Group I: ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland).

Group II: F360 (Komet Brasseler GmbH & Co., Lemgo, Germany).

Group III: OneShape (MicroMega, Besancon, France).

Group IV: F6 SkyTaper (Komet Brasseler GmbH & Co., Lemgo, Germany).

The instruments were used with the same digital torque-controlled endodontic engine (Endo Mate DT, NSK, Kanuma, Japan) in clockwise rotation with respect to the manufacturers' instructions and protocols.

The root canals of group I were prepared using the ProTaper Next system at 300 rpm and 2 N/cm torque. The instrumentation sequence was: First X1 (17/04) and then X2 (25/06). All instruments were used at working length (WL) with gentle in- and out-motion. For each root canal, a new set of ProTaper Next instruments was used.

The root canals of group II were prepared using the F360 system at 300 rpm and 1.8 N/cm torque. The instrumentation sequence was first red instrument (25/04) and then green instrument (35/04). All instruments were used at WL with gentle in- and out-motion. For each root canal, a new set of F360 instruments was used.

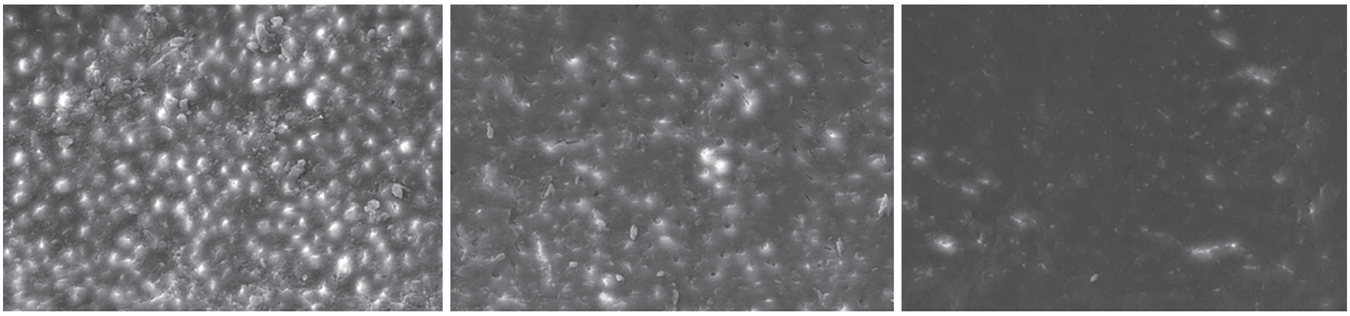
The root canals of group III were prepared using the OneShape system at 400 rpm and 4 N/cm torque. The instrument (25/06) was used at WL with gentle in- and out-motion. For each root canal, a new OneShape was used.

The root canals of group IV were prepared using the F6 SkyTaper system at 300 rpm and 2.2 N/cm torque. The instrument (25/06) was used at WL with gentle in- and out-motion. For each root canal, a new F6 was used.

Root canals were irrigated during instrumentation with 1 mL of 5.25% NaOCl and with 1 mL of 17% EDTA. After preparation, 4 mL of 17% EDTA was left *in situ* for 120 seconds followed by 1 mL of 5.25% NaOCl for 60 seconds as final rinse. The same manufacturer (Ogna Laboratori Farmaceutici, Muggiò, Italy) prepared the endodontic irrigating solutions. The irrigating solutions were frequently replaced to maintain their effectiveness. Small 27G endodontic needless (Kendall Monoject, Mansfield, MA, USA) allowed to reach the apical third with the reflux of irrigating solutions. At the end, all the canals were washed with ethanol for 30 seconds and dried with calibrated paper points (Absorbent Paper Points, Dentsply-Maillefer, Konstanz, Germany).

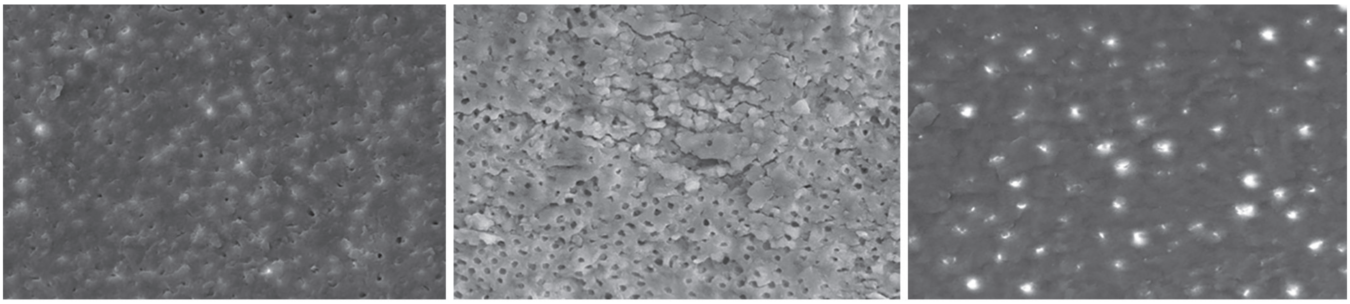
Each sample was dipped in liquid nitrogen immediately after canal preparation and split longitudinally into two halves with a stainless steel chisel. The sections were then prepared for SEM analysis. They were allowed to air-dry overnight in a desiccator at room temperature, sputter-coated with gold, and prepared for SEM analysis (EVO MA 10 Carl Zeiss SMT AG, Germany).

Scanning electron microscopic images were obtained at standard magnification of 2,500× (Figs 1 to 4). Six photomicrographs were taken in three different areas (coronal, middle, and apical third of the root canal). In a blind manner, three trained operators scored the presence or absence of debris and smear layer on the surface of the root canal at the coronal, middle, and apical portion of each canal. The rating system was proposed



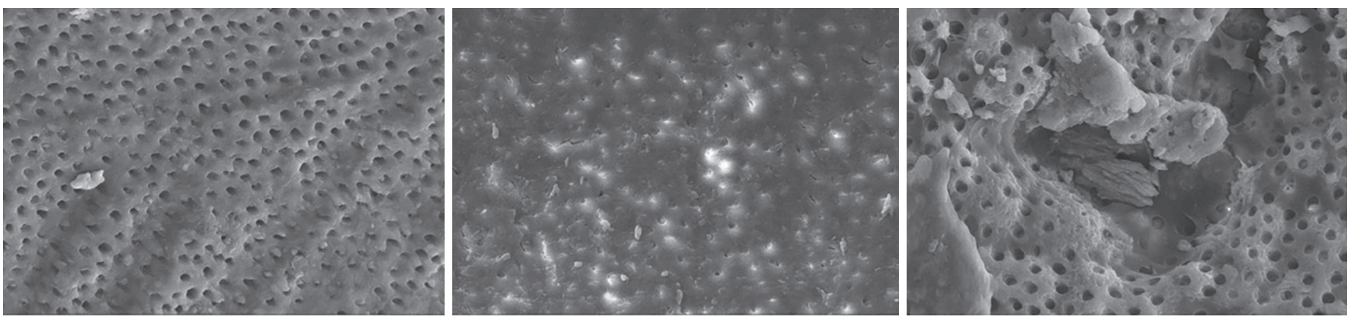
Coronal third　　Medium third　　Apical third

Fig. 1: Representative samples of SEMs of the root canal dentin surface instrumented with ProTaper Next (group I) at coronal, middle, and apical third of the root (magnification 2,500×)



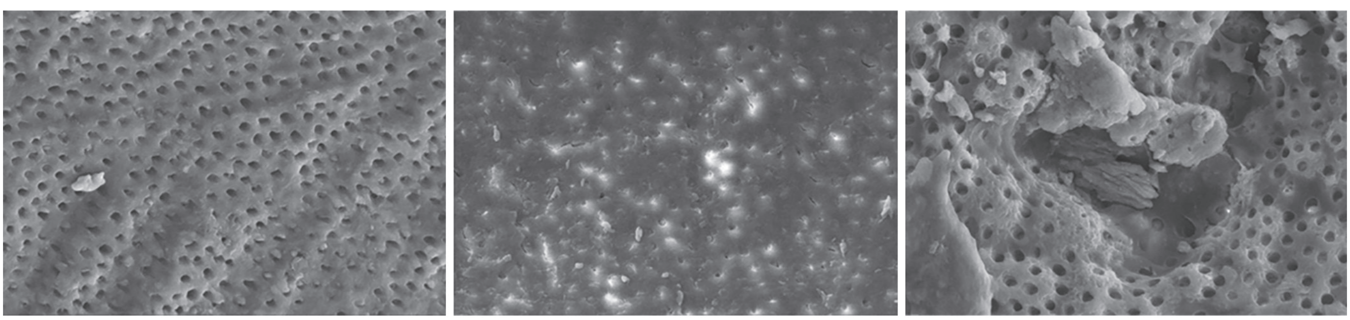
Coronal third　　Medium third　　Apical third

Fig. 2: Representative samples of SEMs of the root canal dentin surface instrumented with F360 (group II) at coronal, middle, and apical third of the root (magnification 2,500×)



Coronal third　　Medium third　　Apical third

Fig. 3: Representative samples of SEMs of the root canal dentin surface instrumented with OneShape (group III) at coronal, middle, and apical third of the root (magnification 2,500×)



Coronal third　　Medium third　　Apical third

Fig. 4: Representative samples of SEMs of the root canal dentin surface instrumented with F6 SkyTaper (group IV) at coronal, middle and apical third of the root (magnification 2,500×)

by Hulsmann et al,[28] and the criteria for the scoring are reported as follows:

Scores of the debris: Score 1: Clean root canal walls, only few small debris particles; score 2: Few small agglomerations of debris; score 3: Many agglomeration of debris covering less than 50% of the root canal walls; score 4: More than 50% of the root canal walls covered by debris; score 5: Complete or nearly complete root canal walls covered by debris.

Scores of the smear layer: Score 1: No smear layer, orifices of dentinal tubules open; score 2: Small amount of smear layer, some dentinal tubules open; score 3: Homogenous smear layer covering the root canal walls, only few dentinal tubules open; score 4: Complete root canal wall covered by a homogenous smear layer, no open dentinal tubules; score 5: Heavy, homogenous smear layer covering the entire root canal walls.

Statistical analysis was performed with Stata 12.0 software (Stata, College Station, TX, USA). Descriptive statistics for ordinal data, including the median, minimum, and maximum values, were calculated for all groups.

A nonparametric analysis of variance (Kruskal–Wallis ANOVA) and the *post hoc* Bonferroni test were applied to investigate significant differences among treatments and among the three thirds of the canals. Significance for all statistical tests was predetermined at $p < 0.05$.

RESULTS

Tables 1 and 2 report debris and smear layer scores for each group. With data about debris scores, the nonparametric ANOVA showed no significant differences among the instrument groups when no distinction within canal thirds was considered ($p > 0.05$). The nonparametric ANOVA applied among the three thirds of the canal showed significant differences between the coronal-middle third and the apical third ($p < 0.05$).

Similar results were obtained when data about smear layer scores were considered in the ANOVA (Tables 3 and 4).

DISCUSSION

The aim of endodontic therapy is to remove the vital or the necrotic tissue from the root canal system and to dissolve all dentin debris compacted along dentinal walls created by the action of endodontic instruments.[2,3] The presence of smear layer may affect the NaOCl to penetrate into the dentinal tubules, thus enhancing its bactericidal effect. Moreover, it may reduce the sealing efficiency of root canal sealers, acting as physical barrier interfering with adhesion to the canal walls.[4-7]

All NiTi rotary files produce moderate to heavy smear layer that need to be removed with the use of irrigating solutions. Chelating agents like EDTA are currently used to remove the smear layer formed during preparation of the root canals and the association with NaOCl solutions represents the gold standard in chemomechanical preparation of the root canals. Ethylenediaminetetraacetic acid acts upon the inorganic components of the smear layer and decalcifies the peri- and inter-tubular dentin and leaves the collagen exposed. Subsequently, the use of NaOCl dissolves the collagen, leaving the entrances of the dentinal tubules more open and exposed. For this reason, an irrigation regimen similar to the methodology proposed by Foschi et al[18] was used, with alternation of EDTA and NaOCl at each change of instrument.

The endodontic NiTi instruments have been evolved during the last two decades and underwent a revolution regarding design, geometry, and alloy in order to increase shaping/cutting ability and resistance to fracture.[29,30] Fourth- and fifth-generation files introduced some new

Table 1: Summary score of the debris

Groups	*Canal level*	*Score = 1*	*Score = 2*	*Score = 3*	*Score = 4*	*Score = 5*
PTN	Coronal	6	4	1	1	0
	Middle	7	4	1	0	0
	Apical	3	5	3	1	0
F360	Coronal	7	3	2	0	0
	Middle	8	2	2	0	0
	Apical	4	0	4	4	0
OS	Coronal	8	4	0	0	0
	Middle	7	4	1	0	0
	Apical	8	2	2	0	0
F6	Coronal	6	4	1	1	0
	Middle	7	3	2	0	0
	Apical	3	4	4	1	0

Table 2: Summary score of the smear layer

Groups	*Canal level*	*Score = 1*	*Score = 2*	*Score = 3*	*Score = 4*	*Score = 5*
PTN	Coronal	7	3	1	1	0
	Middle	5	1	5	1	0
	Apical	3	4	3	2	0
F360	Coronal	7	2	3	0	0
	Middle	8	1	2	1	0
	Apical	3	2	5	2	0
OS	Coronal	7	4	1	0	0
	Middle	8	3	1	0	0
	Apical	7	4	0	1	0
F6	Coronal	6	2	2	2	0
	Middle	5	2	4	1	0
	Apical	5	4	2	1	0

Table 3: Analysis of variance among instrument groups

	Debris			*Smear layer*		
	F360	*F6*	*OS*	*F360*	*F6*	*OS*
F6	1			1		
OS	0.175	0.322		0.378	0.220	
PTN	1	1	0.564	1	1	0.091

Table 4: Analysis of variance among canal thirds

	Debris		*Smear layer*	
	Apical	*Coronal*	*Apical*	*Coronal*
Coronal	0.009*		0.041*	
Middle	0.002*	1	0.032*	1

*Significant differences

concepts in endodontics like reciprocating movements, single file and single use. All the instruments used in this study belong to these generations. They are single-use files. It means that they have to be discarded at the end of the treatment; they cannot be sterilized (with no stresses related to chemical and thermal actions) and reused (with no stresses related to previous root canal treatments).

The aim of this study was to compare the cleaning effectiveness of these different single-use systems in order to assess differences (or not) between reciprocating single-file systems, rotating multiple-file systems, and rotating single-file systems.

All instruments were evaluated in accordance with the manufacturer's direction. All protocols' and instruments' operative sequences were respected. Irrigation procedures were standardized for all experimental groups. All root samples were shaped by the same trained operator.

The first single-use files introduced on the market were studied for reciprocating motion.[31] This movement consists of a counterclockwise (cutting direction) and a clockwise motion (release of the instrument), while the angle of the counterclockwise cutting direction is greater than the angle of the reverse direction. Although single-file reciprocating systems have been shown to offer advantages in root canal preparation, in literature, some doubts emerged regarding the accumulation of debris with a reciprocating motion. De-Deus et al[31] reported significantly greater debris accumulation using the single-file reciprocating ProTaper F2 technique when compared with the conventional ProTaper sequence in continuous rotation (Dentsply Maillefer, Ballaigues, Switzerland) in single-rooted lower incisors. Robinson et al[32] in 2013 showed that in canals with a high prevalence of isthmuses and protrusions, using traditional multiple-file rotary systems may be preferred over reciprocating files because it can yield cleaner canals with less debris accumulation. Similar results were assessed by Bürklein et al[33] in evaluating apical extrusion of debris after root canal shaping with Reciproc, F360 and OneShape *vs* MTwo. All systems caused apical debris extrusion; however, rotary instrumentation was associated with less debris extrusion when compared with reciprocal instrumentation. It means that reciprocating motion generates higher production of debris. The continuous forward motion of the rotary files enables constant exit of debris up the flute of the file. On the contrary, each backward motion of the reciprocating files might provide the opportunity for debris to build up along dentinal walls, in protrusions and isthmus areas. In addition, the reciprocating motion of the file may not allow the blade to cut into the dentin as cleanly, resulting in a burnishing-type effect and pushing debris into recesses and isthmuses.[33]

The reciprocating files may work against itself in extracting debris from the root canal. The continuous rotation favors upward elimination of debris and dentinal chips. For this reason, the newest single-use systems were developed for continuous rotation.

No significant differences emerged between the single-file rotating systems (OneShape and F6 Skytaper) and the multiple-file rotating systems (Protaper Next and F360). Even if a small amount of smear layer is visible, especially in the apical third, the main portion of debris is eliminated when irrigation protocols with NaOCl and EDTA are followed. Apart from an improved understanding and optimization of instrumentation, debris might be more effectively managed by postinstrumentation methods, such as ultrasonic cleaning, which showed superior debris removal.[32]

CONCLUSION

Dentistry is varying with induction of modern science to practice dentistry.[34] Within the limitations of this study, all tested single-use NiTi instruments made for continuous rotation seem to leave clean canal walls if irrigation protocols are followed (NaOCl + EDTA), even if a small amount of smear layer is visible especially in the apical third of the root canal. No significant differences emerged between single-file systems and multiple-file systems.

CLINICAL SIGNIFICANCE

Single-use systems seem to be effective in shaping root canal systems to remove smear layer from dentinal walls.

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REFERENCES

1. Torabinejad, M.; Walton, RE. Endodontics: principles and practice. 4th ed. St. Louis (MO): Saunders Elsevier; 2009.
2. Abou-Rass M, Piccinino MV. The effectiveness of four clinical irrigation methods on the removal of root canal debris. Oral Surg Oral Med Oral Pathol Oral Radiol 1982 Sep;54(3):323-328.
3. Briseño BM, Wirth R, Hamm G, Standhartinger W. Efficacy of different irrigation methods and concentrations of root canal irrigation solutions on bacteria in the root canal. Endod Dent Traumatol 1992 Feb;8(1):6-11.
4. Kaplan AE, Picca M, Gonzalez MI, Macchi RL, Molgatini SL. Antimicrobial effect of six endodontic sealers: an *in vitro* evaluation. Endod Dent Traumatol 1999 Feb;15(1):42-45.
5. Mickel AK, Nguyen TH, Chogle S. Antimicrobial activity of endodontic sealers on *Enterococcus faecalis*. J Endod 2003 Apr;29(4):257-258.

6. Brown JI, Doran JE. An *in vitro* evaluation of the particle flotation capability of various irrigating solutions. J Calif Dent Assoc 1975 Mar;3(3):60-63.
7. D'Arcangelo C, Varvara G, De Fazio P. An evaluation of the action of different root canal irrigants on facultative aerobic-anaerobic, obligate anaerobic, and microaerophilic bacteria. J Endod 1999 May;25(5):351-353.
8. Jeansonne MJ, White RR. A comparison of 2.0% chlorhexidine gluconate and 5.25% sodium hypochlorite as antimicrobial endodontic irrigants. J Endod 1994 Jun;20(6):276-278.
9. Jeansonne J Jr, Batista M, Fraga R, de Uzeda M. Antibacterial effects of endodontic irrigants on black-pigmented Gram-negative anaerobes and facultative bacteria. J Endod 1998 Jun;24(6):414-416.
10. Sundqvist G, Figdor D, Persson S, Sjögren U. Microbiologic analysis of teeth with failed endodontic treatment and the outcome of conservative retreatment. Oral Surg Oral Med Oral Pathol Oral Radiol 1998 Jan;85(1):86-93.
11. Shabahang S, Pouresmail M, Torabinejad M. *In vitro* antimicrobial efficacy of MTAD and sodium hypochlorite. J Endod 2003 Jul;29(7):450-452.
12. 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 Radiol 2009 Oct;108(4):e71-e76.
13. Rodig T, Hulsmann M, Kahlmeier C. Comparison of root canal preparation with two rotary NiTi instruments: ProFile .04 and GT Rotary. Int Endod J 2007 Jul;40(7):553-562.
14. Wadhwani KK, Tikku AP, Chandra A, Shakya VK. A comparative evaluation of smear layer removal with ethylenediaminetetraacetic acid in different states: a SEM study. Indian J Dent Res 2011 Jan-Feb;22(1):10-15.
15. Radcliffe CE, Potouridou L, Qureshi R, Habahbeh N, Qualtrough A, Worthington H, Drucker DB. Antimicrobial activity of varying concentrations of sodium hypochlorite on the endodontic microorganisms *Actinomyces israelii, A. naeslundii, Candida albicans* and *Enterococcus faecalis*. Int Endod J 2004 Jul;37(7):438-446.
16. Dagna A, Arciola CR, Florindi F, Scribante A, Saino E, Visai L, Poggio C. *In vitro* evaluation of antimicrobial efficacy of endodontic irrigants. Int J Artif Organs 2011 Sep;34(9):914-919.
17. Shuping GB, Orstavik D, Sigurdsson A, Trope M. Reduction of intracanal bacteria using nickel–titanium rotary instrumentation and various medications. J Endod 2000 Dec;26(12): 751-755.
18. Foschi F, Nucci C, Montebugnoli L, Marchionni S, Breschi L, Malagnino VA, Prati C. SEM evaluation of canal wall dentin following use of Mtwo and Protaper NiTi rotary instruments. Int Endod J 2004 Dec;37(12):832-839.
19. Pérez-Heredia M, Ferrer-Luque CM, González-Rodríguez MP. The effectiveness of different acid irrigating solutions in root canal cleaning after hand and rotary instrumentation. J Endod 2006 Oct;32(10):993-997.
20. Yang G, Wu H, Zheng Y, Li H, Zhou X. Scanning electron microscopic evaluation of debris and smear layer remaining following use of ProTaper and Hero Shaper instruments in combination with NaOCl and EDTA irrigation. Oral Surg Oral Med Oral Pathol Oral Radiol 2008 Oct;106(4):63-71.
21. Rollison S, Barnett F, Stevens RH. Efficacy of bacterial removal from instrumented root canals *in vitro* related to instrumentation technique and size. Oral Surg Oral Med Oral Pathol Oral Radiol 2002 Sep;94(3):366-371.
22. De Lima Machado ME, Bichels Sapia LA, Cai S, Martins GH, Nabeshima CK. Comparison of two rotary systems in root canal preparation regarding disinfection. J Endod 2010 Jul;36(7):1238-1240.
23. Dagna A, Arciola CR, Visai L, Selan L, Colombo M, Bianchi S, Poggio C. Antibacterial efficacy of conventional and single-use NiTi endodontic instruments: an *in vitro* microbiological evaluation. Int J Artif Organs 2012 Oct;35(10):826-831.
24. Economides N, Liolios E, Kolokuris I, Beltes P. Long-term evaluation of the influence of smear layer removal on the sealing ability of different sealers. J Endod 1999 Feb;25(2):123-125.
25. Karagöz-Küçükay I, Bayirli G. An apical leakage study in the presence and absence of the smear layer. Int Endod J 1994 Mar;27(2):87-93.
26. Peters OA, Gluskin AK, Weiss RA, Han JT. An *in vitro* assessment of the physical properties of novel Hyflex nickel-titanium rotary instruments. Int Endod J 2012 Nov;45(11):1027-1034.
27. Kumar SR, Gade V. Single file NiTi rotary systems. Int J Med and Dent Sci 2015;4 (Suppl 1):701-707.
28. Hulsmann M, Rummelin C, Schafers F. Root canal cleanliness after preparation with different endodontic handpieces and hand instruments: a comparative SEM investigation. J Endod 1997 May;23(5):301-306.
29. Haapasalo M, Shen Y. Evolution of Nickel-Titanium instruments: from past to future. Endod Topics 2013 Sep;29(1): 3-17.
30. Ruddle CJ, West JD, Machtou P. Fifth-generation technology in endodontic: the shaping movement. Roots 2014;1:22-28.
31. De-Deus G, Barino B, Zamolyi RQ, Souza E, Fonseca A Jr, Fidel S, Fidel RA. Suboptimal debridement quality produced by the single-file F2 ProTaper technique in oval-shaped canals. J Endod 2010 Nov;36(11):1897-1900.
32. Robinson JP, Lumley PJ, Cooper PR, Grover LM, Walmsley AD. Reciprocating root canal technique induces greater debris accumulation than a continuous rotary technique as assessed by three-dimensional micro-computed tomography. J Endod 2013 Aug;39(8):1067-1070.
33. 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 May;47(5):405-409.
34. Saini R. Ozone therapy in dentistry: a strategic review. J Nat Sc Biol Med 2011; 2:151-3.