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CLINICAL ARTICLE/ARTICOLO CLINICO

Apical preparation size after repetitive pecking to the working length using different endodontic file systems

Dimensione di preparazione apicale dopo ripetuti movimenti di preparazione alla lunghezza di lavoro utilizzando diversi sistemi endodontici

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Nickel—titanium;
Reciprocating files;
Rotary files;
Self-Adjusting File.

Abstract
Aim: The purpose of this study was to determine and evaluate the apical preparation size resulting from different pecking times to the working length (WL) with five different file systems. *Materials and methods:* Fifty standard simulated endodontic J-shaped blocks were instrumented using ProTaper NEXT (PTN), WaveOne (WO), WaveOne Gold (WOG), OneShape (OS) and the Self-Adjusting File (SAF) ($n = 10$) with different pecking times (1, 2 and 4) to the WL. For the SAF group, instrumentation was done till WL according to the time, i.e. 1, 3 and 4 min. On completion of each stage, silicone impression material was used to take canal impressions for comparison and evaluation of the apical size preparation, using a stereomicroscope. Two-way analysis of variance was applied to determine differences between groups and pecking times.

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Results: After four pecking times, a significant increase was observed in the apical diameter of four test groups compared to SAF ($P < 0.05$), which was not associated with increased apical preparation at all times.
Conclusion: A greater apical enlargement occurs with increasing pecking times; however, SAF instrumentation exhibits the minimum changes in the apical preparation after 1, 3 and 4 min. WO, WOG and OS are able to prepare the apical size similar to their tip at a single peck to the WL.

PAROLE CHIAVE
Dimensione di preparazione apicale;
Nichel-titanio;
Strumenti reciprocanti;
Strumenti rotanti;
Self-adjusting file.

Riassunto
Obiettivi: Lo scopo di questo studio è stato di determinare e valutare la dimensione della preparazione apicale risultante da diversi tempi di movimento alla lunghezza di lavoro con cinque diversi file system.
Materiali e metodi: Cinquanta blocchetti di resina endodontici standard con canali simulati a forma di J sono stati strumentati utilizzando ProTaper NEXT (PTN), WaveOne (WO), WaveOne Gold (WOG), OneShape (OS) e Self-Adjusting File (SAF) ($n = 10$) con numero di movimenti all'apice diversi (uno, due e quattro). Per il gruppo SAF, la strumentazione è stata eseguita fino alla lunghezza di lavoro in base al tempo, cioè 1 minuto, 3 minuti e 4 minuti. Al completamento di ogni fase, è stato utilizzato materiale per impronte in silicone per prendere l'impronta del canale per il confronto e la valutazione della preparazione della dimensione apicale, utilizzando uno stereomicroscopio. L'analisi della varianza a due vie è stata applicata per determinare le differenze statistiche tra i gruppi e i tempi di preparazione apicale.
Risultati: Dopo quattro movimenti all'apice, è stato osservato un aumento significativo nel diametro apicale nei quattro gruppi testati rispetto al SAF ($p < 0,05$), che non è stato associato ad un aumento della preparazione apicale in ogni momento.
Conclusioni: Si è rilevato un maggiore allargamento apicale con l'aumentare del numero di movimenti eseguiti all'apice; tuttavia, la strumentazione SAF mostra dei cambiamenti minimi nella preparazione apicale dopo 1, 3 e 4 minuti. WO, WOG e OS sono in grado di preparare la dimensione apicale simile alla loro punta effettuando un singolo movimento alla lunghezza di lavoro.

Introduction

Preservation of the integrity and location of apical canal anatomy is crucial during root canal preparation.[1] However, this is not always possible, because files have a tendency to straighten themselves inside the root canal.[2] As a result, over-preparation toward the outer curve in apical areas can occur. However, a root canal does not have a single curve and it changes in different planes of the root canal curvature.[3] Thus, the root canal preparation from curved root canals results in asymmetric dentin removal, which can lead to canal transportation (CT). CT increases the risk of iatrogenic damage, and prevents canals from being adequately cleaned, with the potential outcome of persistent apical lesions.[2]

Nickel–titanium (NiTi) instruments are widely used in endodontics[4] and their increased flexibility permits a safe mechanical preparation of curved canals. This has reduced the risk of possible iatrogenic errors compared with stainless instruments.[4] Nevertheless, it can still lead to an insufficient preparation of the apical area.[5,6] Apical size is necessary to be identified after canal preparation for a hermetic seal obturation.[7] NiTi instruments tend to straighten in the canal, which may cause apical transportation causing unintended apical preparation size.[8,9] Although manufacturers recommend a single peck to the working length, clinicians especially unexperienced, might tend to peck more times to the working length, even for retreatment or removal of intracanal medicament.

The ProTaper Next (Dentsply Sirona Endodontics, Ballaigues, Switzerland) is a multiple file system manufactured using m-wire with a quadrangular cross-section and an offset mass of rotation that (according to the manufacturer) reduces the file engagement during root canal preparation.

The recently introduced single-file instruments have considerably reduced root canal preparation time compared with multiple file systems, while maintaining the root canal anatomy.[10,11] The WaveOne and WaveOne Gold nickel-titanium (NiTi) file systems (Dentsply Sirona Endodontics, Ballaigues, Switzerland) are reciprocating single-file systems designed to shape the root canal completely. WaveOne is made from m-wire and WaveOne Gold from what is commercially known as gold-wire technology. In addition, the stress on the instrument is relieved through unequal bi-directional reciprocating motion, thereby increasing the resistance to cyclic fatigue in comparison with continuous rotary systems.[12]

The One Shape file system (Micro-Mega, Besancon Cedex, France) is also a NiTi single-file system used in continuous rotation. It has a triangular cutting edge in the apical part and a cross-section that progressively changes from 3 to 2

cutting edges between the apical and coronal parts. This is supposed to give the file an optimal cutting action causing less micro-cracks compared with conventional rotary systems.[13]

The Self-Adjusting File system (SAF) (ReDent-Nova, Ra'anana, Israel) is a single-file system that has a hollow lattice-like cylindrical structure with no metal core that scrubs the dentinal wall by vibrations. The hollow design allows the file to three dimensionally adapt to the root canal system[14] permitting continuous irrigation while simultaneously shaping the canal.[14,15]

A study by Jeon et al.[7] found no differences between two reciprocating files (WO and Reciproc) in apical enlargement after different pecking motions. However, to date, no study has evaluated the effect of different pecking times with 3 different motion systems. Thus, the purpose of this study was to evaluate and compare differences between different systems regarding apical enlargement after one, two and four pecking times to the working length (WL) and after 1 and 3 min with the SAF system. The null hypothesis tested was that there are no differences between systems regarding the size of the final apical preparation after different pecking times.

Materials and methods

Fifty standard simulated endodontic training blocks (ReDent-Nova, Ra'nana, Israel) with a J-shaped canal were used. These were divided into 5 groups according to the instruments used for canal preparation ($n = 10$):

Group 1: ProTaper Next X2 (Dentsply Sirona Endodontics, Ballaigues, Switzerland).
Group 2: WaveOne Primary (Dentsply Sirona Endodontics, Ballaigues, Switzerland).
Group 3: WaveOne Gold Primary (Dentsply Sirona Endodontics, Ballaigues, Switzerland).
Group 4: OneShape® (Micro Méga, Besançon, France).
Group 5: Self Adjusting File 1.5 mm (ReDentNova, Ra'nana, Israel).

A #10 K-file (Dentsply Sirona Endodontics, Ballaigues, Switzerland) was introduced in the canals in the acrylic block until it was visible at the apical foramen. The WL was determined by subtracting 0.5 mm from this measurement. A rubber stop for each file was fixed with cyanoacrylate adhesive (Loctite; Henkel, Düsseldorf, Germany) at the WL to accurately maintain it for every file. Hand instrumentation with K-files upto ISO #20 was performed in each block. Rotary preparation was performed according to the manufacturers' instructions for each system using an endodontic torque control motor (X-Smart Plus; Dentsply Sirona Endodontics, Ballaigues, Switzerland) for ProTaper Next, WaveOne, WaveOne Gold and OneShape file systems while the Endostation System (ReDentNova, Ra'nana, Israel) for the SAF.

For OneShape (25/0.06) and ProTaper NEXT, X1 (17/0.04) & X2 (25/0.06) were used in continuous rotation to the WL. WaveOne primary (25/0.08) and WaveOne Gold (25/0.07) were used in reciprocation with a pecking (in-and-out) motion until the WL. For the SAF group, the 1.5 mm diameter file was used in a light pecking-motion up to the WL for 1, 3 and 4 min. A single operator with previous experience in all systems performed the canal preparation.

Patency was confirmed with a #10 K-file after each pecking movement until the WL was reached, followed by copious irrigation with saline. Following the methodology from Jeon et al.,[16] a resin block and light body silicon impression (Aquasil, Dentsply Sirona Endodontics) material were used to make an impression of the prepared canal for evaluation. Impressions were made after the first, second and fourth repetitive pecking times to the WL. The apical 3 mm of the impression replicas were zoomed and focused to evaluate preparation size at the D_0 level under a stereomicroscope (Zeiss Stero Discovery V8, Carl Zeiss, Oberkochen, Germany.). A gutta-percha guage (Dentsply Sirona Endodontics, Ballaigues, Switzerland) was used before measuring any impression to calibrate the stereomicroscope and to have accurate measurements. In addition, ten simulated canal blocks were used as a control group and canal impressions were made without instrumentation to evaluate homogeneity and measurement accuracy. As there was a 0.5 mm uninstrumented canal from the working length, each impression was evaluated using this tapering end under the steriomicroscope for distortion immediately after removal of the material from the canal. If found, impressions were repeated until accuracy was achieved (Fig. 1).

The Shapiro—Wilk test was used to determine result distribution ($P = 0.0011$). As no normal distribution was observed, the non-parametric tests, Mann—Whitney *U*-test or the Kruskal—Wallis test, were used to evaluate differences among groups for the apical diameter of the canal preparation, with the number of peckings and the different systems being considered as two sources of variation. Significance was set at $P < 0.05$. Statistical analysis was performed using

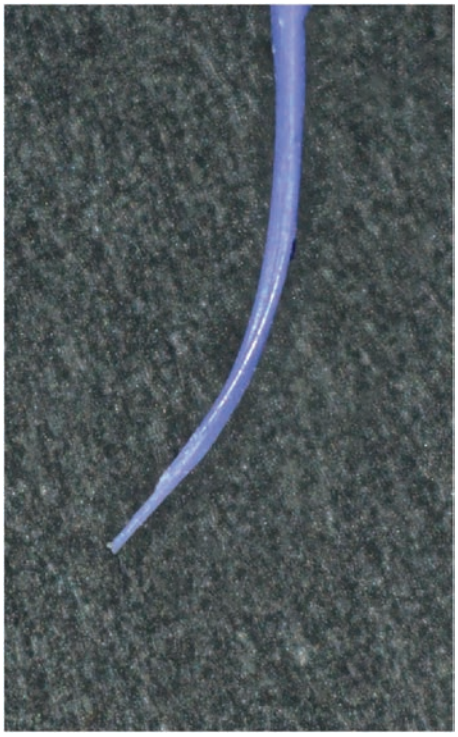

Figure 1 Impression after instrumentation verified by the tapering shape at the apex showing differences between uninstrumented and instrumented area.

Statgraphics Centurion XV software 15.2.06 (SPSS Inc., Chicago, IL).

Results

No instrument separation of any file occurred during the study. The apical diameter of the simulated canals was of 150 μm (D_0), which was confirmed by the impression replicas. Table 1 shows the median apical preparation size of the file systems used after the different number of pecking times to the WL.

The apical preparation with all the systems evaluated showed a statistically significant increase after every pecking movement to the WL ($P < 0.05$) (Table 1).

After one peck to the WL, no significant differences were observed in the apical preparation size between WO, WOG and OS ($P > 0.05$). Instrumentation with ProTaper Next resulted in a higher apical preparation, compared with WO, WOG and OS ($P < 0.05$).

After the second peck to the WL, no significant differences were observed in the apical preparation size between WO, WOG and OS ($P > 0.05$), and ProTaper Next instrumentation still resulted in an increased apical preparation ($P < 0.05$).

After the fourth peck to the WL, no significant differences were observed in the apical preparation size between PT Next, WOG and OS ($P > 0.05$), but instrumentation with WO resulted in a smaller apical preparation compared with the other systems ($P < 0.05$).

When comparing with the SAF, after 1 min of canal shaping to the WL, SAF resulted in an increased apical preparation size compared with the other systems after the first peck to the WL ($P < 0.05$), but in the second peck a significant difference was observed only with PT Next ($P < 0.05$) and not with other file systems ($P > 0.05$) (Table 1).

After 3 min, canal shaping with SAF produced an apical enlargement significantly higher as compared with all the other groups at the first, second and fourth peck to the WL ($P < 0.05$). (Table 1)

Canal preparation with SAF after 4 min resulted in an apical diameter preparation of 352.3 (±2.6 mm), similar to an ISO #35 as claimed by the manufacturer (Table 1).

Discussion

The main goals of root canal preparation are to clean and shape the root canal system with minimal procedural errors while maintaining the original canal configuration.[16,17] The alternating motion could be beneficial in the shaping of root canals by reducing the screwing effect.[18] This effect is often associated with the continuous rotary motion and may result in over instrumentation beyond the apical constriction, which sometimes causes apical transportation.[18] Although several studies have compared the efficacy and preparation sizes of reciprocating and rotary file systems,[7,17] to the author's knowledge no study has assessed and compared the apical preparation sizes after using different types of instruments by increasing the number of pecking times to the WL.

The purpose of this study was to evaluate the apical preparation size of five different file systems according to the number of pecking times (motions) to the WL. Four of the file systems evaluated, have an identical tip diameter of #25 (Wave One, WaveOne Gold, One Shape and ProTaper Next) but with differences in file design and movement. Both ProTaper NEXT and OneShape showed similar values after two and four pecking motions to the working length. However, instrumentation with PTN resulted in a larger apical preparation size. These differences may be due to the different cross sections of the systems themselves. Where two instruments reached the WL for the final preparation, significant differences were found after the first peck to the WL.

Capar et al.[11] compared 6 different systems, including continuous and reciprocating motion and concluded that all the systems produced straightening of canal curvature, but better results were observed with Reciproc R25 (VDW) file system. However, Jeon et al.[7] found no differences in apical size preparation between Waveone and Reciproc ($P < 0.05$). Thus, only WO was used for study comparison or for the single-file reciprocating system group. WaveOne Gold was included in the study due to its different cross section, alloy and that WaveOne being discontinued by the manufacturer. Similar results were obtained in our study after canal preparation with WO, which corroborates both our results and this methodology for comparison.

The results of different studies comparing the canal transportation with rotary and reciprocating files[11,19] conclude that there are no significant differences between systems and that the canal transportation was within the safety limit. Stern et al.[20] reported that use of PU instrument showed similar dentin removal with rotation or reciprocating motions. Significantly higher difference was found between WaveOne and WaveOne Gold in the 4th peck and interestingly WaveOne Gold had similar results to ProTaper Next in this section. It is important to note that ProTaper Next and WaveOne Gold have similar cross section but different taper and kinematics. It is not clear how the increase of apical preparation occurs from the file tip diameter, although with

Table 1 Mean size (μm) and standard deviation (SD) of the apical diameter after different pecking times of the different systems.

System	Number of pecking times or minutes to the WL				
	Single or 1 min SAF Mean ± SD (μm)	Double or 1 min SAF Mean ± SD (μm)	Double or 3 min SAF Mean ± SD (μm)	Four or 3 min SAF Mean ± SD (μm)	4 min SAF Mean ± SD (μm)
WaveOne	251 ± 3.53	271.05 ± 3.53	271.05 ± 3.53	285.95 ± 2.33	–
Waveone Gold	250.04 ± 5.64	270.04 ± 4.93[b]	270.04 ± 4.93[b]	299.23 ± 9.01	–
OneShape	251.1 ± 0.42	273.3 ± 9.05	273.3 ± 9.05	305.8 ± 5.23	–
Pro Taper NEXT	258.85 ± 2.05	277 ± 3.67	277 ± 3.67	303.45 ± 3.04	–
SAF	268.85 ± 3.74	268.85 ± 3.74	314.95 ± 1.20	314.95 ± 1.20	352.3 ± 1.83

regards to these studies it can be said that different cross sections of the file systems may be responsible rather than different kinematics.[11] However when comparing the single-file instruments (continuous rotation vs. reciprocation) in the present study (WO, WOG and OS), no differences were found in the apical size preparation after one or two pecking motions to the working length ($P > 0.05$). Nevertheless, canal instrumentation with OS resulted in a larger apical preparation after the fourth peck. Thus, it can be concluded that an alternating motion may be safer for apical size diameter when performing more than two pecking motions.

The SAF is also a single-file shaping system such as the WO, WOG and OS but the cross section, design and action are completely different. SAF adapts to the natural anatomy of the canal and shapes it by vertical scrubbing with simultaneous irrigation. Siqueira et al.,[21] comparing different file systems, including reciprocating, rotary and SAF, found no differences in root canal shaping ability. However, this study is difficult to understand since the authors compared different systems with a final apical preparation of #25 (Reciproc and Twisted files) with #35 (SAF 1.5 mm). As in our study, Siqueira et al.[21] used the smallest file tip in the system (1.5 mm of diameter) and according to the manufacturer, the final preparation size after 4 min of preparation would be an ISO #35. According to the findings of the present study the SAF was able to enlarge the apical diameter to an ISO 35 after 4 min of pecking time.

In the present study all the four files, except the SAF, have an ISO #25 available in their systems. The SAF does not have a # 25 file size. The smallest file of the SAF system has a tip diameter of 1.5 mm which produces an apical preparation size of ISO #35 after 4 min, according to the manufacturer. This fact limited the comparison between SAF and the other systems evaluated which is one of the limitations of this study. Thus, for a better comparison the apical preparations of the other systems were compared with 1 and 3 min of SAF preparation.

When preparing canals with WO and Reciproc (VDW) the apical preparation size increases with the increase in the number of peckings to the WL.[7] This is in agreement with the results in our study, where the four systems evaluated produced a statistical increase in the apical diameter ($P > 0.05$) under the same conditions after every pecking motion to the WL, except the SAF, which resulted in a similar apical preparation after different pecking motions to the WL. This may be due to the hollow lattice structure of the SAF, which prevents excessive cutting even after continuous pecking motions.

The use of simulated resin blocks allows standardization of degree, location and radius of root canal curvature in three dimensions.[1] Thus, a direct comparison of the final canal preparation can be obtained with different instruments. Furthermore, it also permits comparison with other studies. However, it should be noted that there is a difference in micro-hardness between dentin (35—40 kg/mm^2) and resin (20—22 kg/mm).[1] This is a limitation of the study as the results are not reproducible in clinical setting, rather just give an indication about the effect on the apical preparation size.

Although the impressions of the simulated resin block canals were taken with utmost care, they were repeated immediately if verified by the stereomicroscope to be distorted; retrieval of impression material from the canal may have produced errors affecting the results, which is another limitation of this study.

Canal transportation and deviation may readily occur during the shaping procedure, especially in curved canals, because of the file's tendency to revert to its original shape along with the reaction torque to the canal wall.[22] This mechanical phenomenon may occur particularly during repetitive pecking motions. Although apical enlargement has been proven to mechanically remove up to more than 90% of bacterial cells from the root canal,[23] in order to obtain a predictable apical preparation size, clinicians must avoid repetitive pecking motions and rather select a bigger instrument size for this purpose.

Conclusion

With the limitations of this study it can be concluded that WO, WOG and OS were able to prepare the apical size similar to their tip at a single peck and significant difference was found with ProTaper Next. SAF, even after 4 min of pecking time, produced the desirable size. Nevertheless, more number of pecking times may result in a larger diameter of the apical area than the file itself. Therefore, the clinician must be careful in choosing the appropriate system to prepare the canals and must confirm the apical gauge before obturating the canal space.

Clinical relevance

More number of pecking times may result in a larger diameter of apical area than the file itself. Clinicians must be careful in choosing appropriate system to prepare the canals and must confirm the apical gauge before obturating.

Conflict of interest

The authors deny any conflicts of interest.

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References

1. Hulsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: shaping goals, techniques and means. *Endod Top [Internet]* 2005;**10**(1):30—76. http://dx.doi.org/http://dx.doi.org/10.1111/j.1601-1546.2005.00152.x.
2. Peters OA, Ficd MS. Current challenges and concepts in the preparation of root canal systems: a review. *J Endod* 2004;**30**(8):559—67.
3. Cunningham CJ. A three-dimensional study of canal curvatures in the mesial roots of mandibular molars. *J Endod* 1992;**18**(6):294—300.
4. Pettiette MT, Olutayo Delano E, Trope M. Evaluation of success rate of endodontic treatment performed by students with stainless-steel k-files and nickel-titanium hand files. *J Endod* 2001;**27**(2):124—7.

5. Van der Vyver Peet JSMJ. Clinical guidelines for the use of ProTaper Next instruments (Part I). *Dent Trib* 2014;12—6.
6. Markvart M, Darvann TA, Larsen P, Dalstra M, Kreiborg S, Bjørndal L. Micro-CT analyses of apical enlargement and molar root canal complexity. *Int Endod J* 2012;**45**(3):273—81.
7. Jeon HJ, Paranjpe A, Ha JH, Kim E, Lee W, Kim HC. Apical enlargement according to different pecking times at working length using reciprocating files. *J Endod* 2014;**40**(2):281—4.
8. Wildey WL, Senia ES. Another look at root canal obturation. *Dent Today* 2002;**21**(3):68—73.
9. Wu MK, Fan B, Wesselink PR. Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. *J Endod* 2000;**26**(4):210—6.
10. Bürklein S, Hinschitza 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.
11. 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.
12. Topçuoğlu HS, Düzgün S, Aktı A, Topçuoğlu G. Laboratory comparison of cyclic fatigue resistance of WaveOne Gold, Reciproc and WaveOne files in canals with a double curvature. *Int Endod J* 2017;**50**(7):713—7.
13. Liu R, Hou BX, Wesselink PR, Wu MK, Shemesh H. The incidence of root microcracks caused by 3 different single-file systems versus the protaper system. *J Endod* 2013;**39**(8):1054—6.
14. Metzger Z, Teperovich E, Cohen R, Zary R, Paqué F, Hülsmann M. The self-adjusting file (SAF). Part 3: Removal of Debris and Smear Layer — A Scanning Electron Microscope Study. *J Endod* 2010;**36**(4):697—702.
15. 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* 2010;**36**(4):679—90.
16. Sonntag D, Delschen S, Stachniss V. Root-canal shaping with manual and rotary Ni-Ti files performed by students. *Int Endod J* 2003;**36**(11):715—23.
17. Yun HH, Kim SK. A comparison of the shaping abilities of 4 nickel-titanium rotary instruments in simulated root canals. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2003;**95**(2):228—33.
18. You SY, Kim HC, Bae KS, Baek SH, Kum KY, Lee W. Shaping ability of reciprocating motion in curved root canals: a comparative study with micro-computed tomography. *J Endod* 2011;**37**(9):1296—300.
19. Junaid A, Freire LG, Da Silveira Bueno CE, Mello I, Cunha RS. Influence of single-file endodontics on apical transportation in curved root canals: an ex vivo micro-computed tomographic study. *J Endod* 2014;**40**(5):717—20.
20. Stern S, Patel S, Foschi F, Sherriff M, Mannocci F. Changes in centring and shaping ability using three nickel-titanium instrumentation techniques analysed by micro-computed tomography (μCT). *Int Endod J* 2012;**45**(6):514—23.
21. Siqueira JF, Alves FRF, Versiani MA, Rôças IN, Almeida BM, Neves MAS, et al. Correlative bacteriologic and micro-computed tomographic analysis of mandibular molar mesial canals prepared by self-adjusting file, reciproc, and twisted file systems. *J Endod* 2013;**39**(8):1044—50.
22. Peters OA, Peters CI, Schönenberger K, Barbakow F. ProTaper rotary root canal preparation: effects of canal anatomy on final shape analysed by micro CT. *Int Endod J* 2003;**36**(2):86—92.
23. Siqueira JF, Lima KC, Magalhães FAC, Lopes HP, De Uzeda M. Mechanical reduction of the bacterial population in the root canal by three instrumentation techniques. *J Endod* 1999;**25**(5): 332—5.