Micro-CT evaluation of mesial canals preparation performed by two rotary NiTi systems in mandibular molars

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ABSTRACT

Objective: To evaluate the preparation quality and wear of the mesial and furcal walls by microCT, regarding the instrumentation of the mesial canals of mandibular molars. **Methods:** Thirty extracted human mandibular molars were scanned with microCT. The parameters analyzed of the images were: maintenance of the root canal centralization, extension and direction of the instrumentation deviation, quantity of dentin removed, minimal thickness of remaining dentin and the apical and total volumes before and after instrumentation. The teeth were divided into three groups (n = 10): Group 1: ProTaper Rotary instrumentation until F2; Group 2: Twisted file Rotary instrumentation with 25/.08 instrument; Group 3: Manual instrumentation (control). **Results:** There were no significant differences ($p > 0.05$) between the Rotary systems in relation to the instrumentation deviation. The cervical third presented the greatest quantity of instrumentation deviation when compared to the apical levels, and less quantity of remaining dentin, especially for danger zone. The systems wore more dentin in the furcal walls of the middle and cervical thirds. There were no differences between the groups regarding the quantity of dentin in the apical third. The apical and total volumes did not significantly increase after the preparation with the instrumentation in this study. **Conclusion:** The NiTi Rotary systems evaluated did not significantly increase the apical and total volumes of the root canals. The greatest instrumentation deviation occurred in the middle and cervical thirds for all the systems analyzed. For all groups analyzed, the quantity of remaining dentin was significantly reduced in the furcal direction of the middle and cervical thirds

Keywords: Root canal preparation. X-ray microtomography. Endodontics. Molar.

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Introduction

The cleaning and shaping of the root canal system are the main objectives of the biomechanical preparation. The pulp tissue remotion, elimination of microorganisms and its products in the root canal system and maintenance of the original trajectory must be achieved during the preparation.[23]

The complexity of the root canal system complicates the mechanical action of endodontic instruments,[2] whereas accidents can occur such as perforations, deviations and fracture of instruments, which many times determines the failure of endodontic treatments.[5,26]

Over the years, the search for a simple and more secure way to promote the amplification and obtainment of conical conformation has been under taken. The incorporation of NiTi alloy in the fabrication of endodontic instruments[26] proportioned new concepts and designs, such as alteration of the taper of the instruments and the instrumentation of curved canals utilizing continuous rotation. The use of rotary systems with NiTi instruments modified the concepts, techniques and manner in which to prepare the root canals.

As a consequence of the technological advancements in the development of materials, new generations of NiTi rotary systems are available, promising to be more efficient, secure and predictable. These different systems are characterized by the modification of the constant taper to the progressive and variable taper in the same instrument.[20] Another variation was the thermic treatment of the NiTi alloy, with the development of the R phase, which proportioned the development of NiTi twisted instruments.[11]

The analysis of the quality of the root canal preparation also suffered profound modifications with the introduction of computerized microtomography (microCT). The use of modern technologies have been emphasized by the possibility of utilizing and comparing the data collected from intact teeth, with the data collected after the preparation without destructing the sample.[10] The principal advantage in relation to the other methodologies for the evaluation of the root canal preparation is the capacity to demonstrate the detailed morphological characteristics of the root canal with precision and in a non invasive manner.[19] In addition, this technological method offers reproducible data in three dimensional form, which permits the evaluation of the volume of the root canal pre and post instrumentation.[19]

Meanwhile, the literature is scarce of studies that compare continuous rotary systems with different forms of manufacturing, tapers and designs in the quality and centralization of the root canal preparation, as well as the wear of the mesial and distal walls of the curved mesial canals of mandibular molars.

However, the present study aims to evaluate the quality and effects of the root canal instrumentation in curved mesial canals of mandibular molars performed by two NiTi rotary system: ProTaper and Twisted File. The null hypothesis tested is that there exist no differences between the quality of the root canal preparation and amplification between the two rotary systems.

Material and Methods

The project was approved by the Research Ethics Committee of the Bauru School of Dentistry (protocol #131/2010).

A hundred extracted human mandibular molars were radiographed to visualize and measure the degree of curvature of the mesial canal. The angle and radius of curvature were determined by the Schneider[25] and Pruett et al[18] methodologies, respectively and the standardization of the curvature was defined by the method of Schäfer and Lohmann.[22]

The selected teeth had canals with curvature angles between 20° and 35° and a radius of curvature less than 10 mm and lengths varying from 19 and 21 mm.

The coronal opening was performed and the root canals were catheterized with a #10 K-file (Dentsply-Maillefer, Ballaigues, Switzerland) until visualizing the instrument point at the apical foramen (AF) and the working length established 1 mm short of the AF.

To maintain the teeth in the same position during the microtomography, supports were fabricated in acrilic resin Peters, Schönenberger and Laib.[17]

For the pre and post operative evaluations of the root canals, a microCT Skyscan model 1076 (Skyscan, Kontich, Belgium) was utilized.

The images obtained were reconstructed from the different angle projections using an algorithm reconstruction of the NRecon software (Skyscan, Aartselaar, Belgium).

The teeth were grouped according to Yin et al.[28] and divided into 3 groups with 10 teeth each. For the sample selection, the type of pulp chamber floor,[9] 3D configuration of the internal anatomy[6] and the

number of canals and apical foramens were observed. The groups were divided as follows:

» Group I: ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland).The sequence of instrumentation was performed as follows: S1 and SX for the cervical preparation and S1, S2, F1 and F2 (25/.08) until the working length.

» Group II: Twisted File (SybronEndo, Orange, CA, USA). The sequence of instrumentation was performed as follows: 25/.08 and 25/.06 for the cervical preparation 25/.04, 25/.06 and 25/.08 until the working length.

» Group III – K flexofile (Dentsply Maillefer, Ballaigues, Switzerland). The sequence of instrumentation was performed as follows: #25 K-flexofile for the cervical preparation, #20 K-flexofile in the middle portion and #15 K-flexofile until the #25 K-flexofile in the working length and step back performed with the #30, #35 and #40 K-flexofile instruments.

During the preparation, the irrigating solution used was 2.5% NaOCl and the final irrigation with 3 mL of 17% EDTA and 5 mL of saline solution. For all the groups, the root canal catheterization was performed manually with a #15 K-file. The rotary NiTi instruments were used with a X-Smart electric motor (Dentsply Maillefer, Ballaigues, Switzerland).

Methodology for the evaluation of the results

After completing the preparation of the canals, the samples were positioned on the microtomography tray and new images were obtained utilizing the same parameters as the pre-operative phase.

The analyses were conducted in two stages. The first was bidimensional, where transversal sections were used for the measurement and comparison of the pre and post operative images, and the canal deviation, remaining root dentin thickness in 8 predetermined directions. The second stage was tridimensional, where the apical and total volumes of the root canals were measured before and after the root canal instrumentation. Five sections were obtained for the bidimensional analyses according to Bergmans et al.[1] The apical section were 2 mm short of the root apex and the coronal 2 mm below the root canal entrance. Three other sections were obtained from the division between the distance of the first and second sections divided by three.

The transversal section images were determined by the superposition, of pre- and post-sections images determined according to the alignment of the radicular internal and external surfaces of both images using DataViewer v.1.4.4 software (SkyScan, Kontich, Belgium). In sections images the center of each canal was also determined between mesiobuccal and mesiolingual position in the five sections. The pre and post images of each section were superimposed and the opacity of the post operative images were adjusted by 50%, and measuring the minimal remaining dentin thickness and the root canal deviation.

From the center of the root canal, four guide lines were sliced per canal, all in pairs, parallel in the same

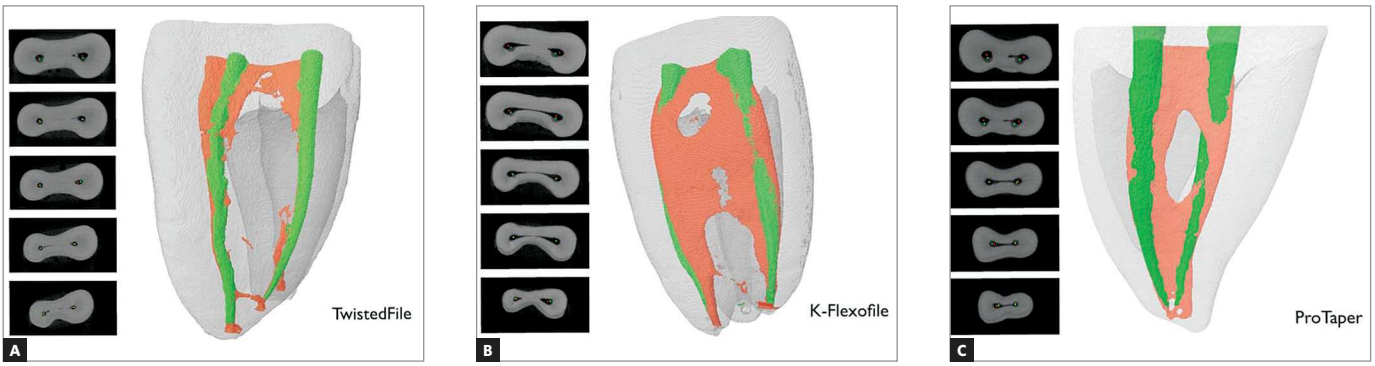

Figure 1. Reconstruction of microCT images in 3D. Representative images relating the mesial molar roots with the root canals instrumented by the systems: **A**) Twisted File, **B**) K-File and **C**) ProTaper. Green areas indicate where the instruments performed during the preparation. Areas in red show untouched portions by NiTi Rotary instruments with different systems.

direction (one in the mesiobuccal canal and one in the mesiolingual), with the exception of the line in the buccal-lingual direction. These guide lines in each canal were positioned so that each had an angle of 45° in each direction. This procedure was used to standardize the exact pre and post operative measurements. The images were exported in TIFF format and analyzed with Image J software (National Institute of Health, USA).

In each transversal section, eight measurements (in mm) were obtained from the remaining dentin of each canal before and after instrumentation. The comparison between the pre and post operative measurements indicated which region presented the most wear in each of five levels of the root canal.

Additionally, the quantity of removed dentin was measure by Rotary instruments in 8 directions of the 5 levels along the root canal using the formula: Dremoved = Dpre – Dpost).

The root canal deviation corresponded to the alteration of the central point of the canal after instrumentation. For this analysis, in each transversal section, a red marking was placed in the center of the root canal in the pre operative images and a green marking in the post operative images. The superimposing between the two markings (red and green) indicated the absence of root canal deviation. When the two markings were not superimposed, the distance between them were measured and used to quantify the root canal deviation (in mm) produced by each rotary system in accordance other studies.[12] The images were measured in the Image J software (National Institute of Health, USA).

The root canal volume (V), in mm^3, was calculated utilizing the 3D analysis tool of the CTan software. This measurement was obtained between the first apical millimeter and the second millimeter below the root canal bifurcation.

The apical volume (in mm^3) measurements were calculated by the measurements obtained between the first and third millimeter before the root canal apices, before and after the root canal preparation.

For the statistical analysis, the GraphPad Prism 5 (GraphPad Software Inc, La Jolla, CA, USA) program was used. The level of significance was set at $p < 0.05$. For the multiple comparisons between groups, the Kruskall-Wallis and Dunn's tests were used in each analyzed parameter. The Wilcoxon test was used for the comparison of the before and after the root canal preparation in each group and analyzed parameter.

Results

Table 1 presents the values of the minimal thickness of the remaining dentin pre and post instrumentation with NiTi rotary system in the 5 levels evaluated. Statistical significant differences were observed ($p < 0.05$) between the remaining dentin thicknesses, pre and post instrumentation in the fourth and fifth levels for the studied groups.

Table 2 presents the quantity of removed dentin (Dremoved = Dpre – Dpost) and the statistical differences by the Kruskall-Wallis and Dunn's tests ($p < 0.05$), with the median, minimum and maximum values of the root canal deviation after the root canal preparation by the different studied groups. There were no statistically significant differences ($p > 0.05$) between the groups. Regarding the comparison between the levels in the same group, statistical differences were found. The root canal deviation varied statistically between the different levels and was greater in the fifth level ($p < 0.05$).

The median, minimum and maximum values (mm^3) of the pre and post instrumentation volumes are presented in Table 3. There were no statistically significant differences between the pre and post instrumentation volumes after the root canal preparation for each group analyzed, as well as the total and apical volumes ($p > 0.05$). There were also no statistically significant differences in the comparison between the different groups analyzed ($p < 0.05$).

Table 1. Median, minimum and maximum values of the minimal quantity of remaining dentin in mm before and after root canal instrumentation.

Selection Level	ProTaper		Twisted File		K-Flexofile	
(apical-coronal)	Pre-thickness	Post-thickness	Pre-thickness	Post-thickness	Pre-thickness	Post-thickness
1	(apical-coronal)	0.61	0.78	0.78	0.7	0.61
	(0.14 - 1.18)	(0.14 - 1.14)	(0.44 - 1.21)	(0.44 - 1.21)	(0.15 - 1.45)	(0.14 - 1.03)
2	0.86	0.78	0.97	0.96	0.87	0.82
	(0.24 - 1.36)	(0.21 - 1.34)	(0.77 - 1.38)	(0.54 - 1.28)	(0.43 - 1.22)	(0.33 - 1.20)
3	0.9	0.8	1.03	0.98	0.91	0.77
	(0.64 - 1.42)	(0.54 - 3.66)	(0.72 - 1.36)	(0.45 - 1.36)	(0.70 - 1.22)	(0.55 - 1.15)
4	0.95	0.73	0.95	0.81	1.05	0.81
	(0.69 - 1.44)	(0.40 - 1.35)	(0.51 - 1.38)	(0.39 - 1.48)	(0.67 - 1.51)	(046 - 1.12)
5	0.99	0.72	1.02	0.71	1.05	0.88
	(0.73 - 1.61)	(0.32 -1.32)	(0.75 - 1.54)	(0.33 - 1.54)	(0.72 - 1.44)	(0.42 - 1.24)

Table 2. Number of specimens regarding the quantity of dentin removed in mm, pre and post root canal instrumentation. Median, minimum and maximum values (mm) regarding the root canal deviation.

Selection level (apical-coronal)		ProTaper				Twisted File				K-Flexofile			
		0-0.5mm (n)	0.6-1mm (n)	>1mm (n)	Canal deviation (mm)	0-0.5mm (n)	0.6-1mm (n)	>1mm (n)	Canal deviation (mm)	0-0.5mm (n)	0.6-1mm (n)	>1mm (n)	Canal deviation (mm)
1	Pre-	7	13	4	0.091	6	12	6	0.103	6	17	1	0.117
	Post-	7	13	4	(0.021–0.415)	6	14	4	(0.026–0.747)	11	12	1	(0.007–0.472)
2	Pre-	4	13	7	0.099	0	13	11	0.130	2	17	5	0.177
	Post-	4	15	5	(0.013–0.544)	0	16	8	(0.022–1.276)	4	17	3	(0.007–0.555)
3	Pre-	0	19	5	0.128[a]	0	10	14	0.162[a.b]	0	17	7	0.205[a]
	Post-	0	19	5	(0.007–0.733)	2	12	10	(0.006–1.459)	0	21	3	(0.007–0.707)
4	Pre-	0	14	10	0.246[a]	0	13	11	0.184[a]	0	10	14	0.320[b]
	Post-	2	20	2	(0.070–0.764)	2	16	6	(0.018–1.434)	1	19	4	(0.192–0.667)
5	Pre-	0	12	12	0.282	0	11	13	0.308	0	8	16	0.317
	Post-	2	16	6	(0.114–0.797)	3	16	5	(0.070–1.219)	2	19	3	(0.109–0.540)

Different letters in each column indicates statistical difference ($p<0.05$).

Table 3. Median, minimum and maximum values (mm^3) regarding the total and apical pre- and post-operative instrumentation volumes.

	ProTaper		Twisted File		K-Flexofile	
	Pre-	Post-	Pre-	Post-	Pre-	Post-
Total	6.05	8.38	5.62	8.61	4.26	6.65
	(2.92 - 9.58)	(5.87 - 11.44)	(4.0 - 13.46)	(5.34 - 15.43)	(2.81 - 9.62)	(5.49 - 13.38)
Apical	1.06	1.22	0.84	0.95	0.68	0.86
	(0.40 - 1.72)	(0.67 - 1.89)	(0.45 - 2.26)	(0.45 - 2.51)	(0.13 - 2.24)	(0.29 - 3.33)

Discussion

The objective of the root canal preparation is to obtain adequate cleaning and shaping of the root canal systems. The hypothesis tested was accepted, because there were no differences in the quality of preparation, dentin wear and changes in the total and apical volumes of the root canal between the groups tested.

An important fact when comparing different systems is the standardization of the samples. This variable was verified in the pre and post operative periods by the proposed method of the study, where the degree and radius of the curvature of the canals were measured.[13]

In the bidimensional analyses of the transversal sections, the levels were selected in accordance with other studies,[13] where the first level (apical) was standardize at 2 mm before the root apexes. The fifth level (cervical) was established 2 mm below the bifurcation, which corresponded to the level where the most wear of the distal wall of the mesial canal of the mandibular molars occurred during the root canal instrumentation.[30] The remaining three levels were obtained with the measurement of the distance between the first and fifth levels divided by three.[19]

With regards to the direction of the root canal deviations, eight directions were considered in relation to the four anatomical sides of the roots (mesial, distal, buccal and lingual), providing greater precision of the results, according to other studies.[8]

Three types of measurements were used to evaluate the deviation; root canal deviation, central axis alteration and the quantity of remaining dentin before and after instrumentation, verifying the wear promoted by the instruments.

In the comparison of the remaining dentin, the same tooth was used as a control, and no statistical reduction of the quantity of dentin was observed for any of the different instruments analyzed. This fact was confirmed by the absence of any significant deviation and by the absence of significant alterations of the apical volume after instrumentation. This can be explained by the large quantity of root canal area that was not touched by the instruments, due to the high prevalence of existing isthmuses that are usually found in the mesial roots of the mandibular molars,[28] and by the diameters of the instruments used, which probably were smaller than the anatomical diameter of the samples.

However, for the standardization of the volumetric statistic of the preoperative anatomy, the anatomical diameter was considered constant in order to establish a comparison, which may not correspond to the actual anatomy of the root canal, in which case every tooth has to be treated differently. In accordance with the observation of the preoperative apical volume analysis, the measurement of the last 2 millimeters were between 0.28 – 2.28 mm^3, demonstrating that the presence of constricted canals can be less prevalent than thought, in accordance with other studies.[24] In the present study, the root canal preparation in the working length was performed until the #25 instrument, which established a large area of the root canal, not instrumented. Another study presented a greater area of instrumentation and less remaining debris when the preparation was performed until the 40/.02 instrument.[4]

When considering the quantity of dentin wear, higher wear was observed on the external side of the curvature in the apical portion (Levels 1 and 2), principally for the ProTaper instrument, which corroborated with other studies.[7] Although the tendency for deviation had occurred, the remaining dentin thickness observed was not statistically different from the preoperative thickness, demonstrating that all groups were secure in the apical preparation. Another factor observed was the significant wear of the internal sides of the curvature performed by the ProTaper system and the highest measurement found was 0.013 mm which correspond 13 μm. This significance can be result of the high sensibility of the methodology used in the present study, but without clinical significance.

Rotary instruments with a diameter #25 and a 0.08 taper was used in the present study, consisting of a twisted fabrication and another of machining fabrication, and it was observed that both can be used for the apical preparation without creating a greater deviation, in accordance with other studies.[7] In addition, the present study demonstrating that the rotary instruments evaluated generally presented low deviation of the apical portion of the canal.

Another problem was related to the excessive decrease of dentin in the "danger zone" of the root canal, in other words, the distal walls of the cervical

and middle portions of curved mesial root canals of mandibular molars. Most rotary systems, especially stainless steel systems can significantly alter this part of the curvature by the remotion of dentin on the internal side of curvature,[14] a condition that can increase the risk of perforation and promote weakness in the root wall.

After the evaluation of the intragroup deviation, when compared at the different levels, it was found that the fifth level (cervical) presented the highest value for all groups evaluated. This fact was confirmed in the analysis of the quantity of remaining dentin, where in the fourth and fifth levels, the thicknesses were significantly reduced on the furcal side, corroborating with previous study.[29]

When evaluating the quantity of dentin removed from the furcal wall, there were no perforations found, which indicate that all systems evaluated were secure, although it was observed that in the 4 direction (Fig 1), minimum values below 0.5 mm in the fourth and fifth levels for the ProTaper system (level 4 – 0.4 mm and level 5 – 0.32 mm). However, the minimum values were not constant, it can be explained by the convex triangular section of the ProTaper system, which promotes a high metallic volume of the instrument in the portion. The lack of a compensatory wear at the cervical level may cause the instrument to have to support the cervical and apical curvature causing increased wear in the middle third. When considering the coronary and middle thirds of mandibular molars, there is a greater tendency of deviation toward the direction of furcation, attributed to the ProTaper instruments, probably due to the large increase in taper. The increased wear at this level could also be related to a greater volume of dentin on the mesial wall, which tends to force the instrument in this region to distal.[21]

With regard to the total and apical volumes of the canals analyzed, no significant differences were found between groups, complementing the results found in the evaluation of the amount of remaining dentin. These results were also observed by other authors[17] using instruments of the same caliber and tapers. When the three-dimensional shape of the root canal was studied by microCT,[16] NiTi rotary instruments did not consistently prepare between 20 and 40% of the inside surfaces of curved channels of maxillary molars, even in palatine canals, which commonly appear to be easier to model.[15]

As observed in the present study, all rotary instruments showed significant limitations regarding the amount of dentin removed along the canal. Due to the large amount of individual variation, there is no guarantee that rotary instruments with different designs and tapers result in an appropriate cut of the walls of the canal,[27] and the final form of the modeling can vary from tooth to tooth.

An important observation after the study of three-dimensional models is the presence of the isthmus, which may present the last 4 apical millimeters without evidence of its presence in the level of the mouth of root canals.[3] From a clinical point of view, there is no possibility to anticipate the presence of isthmus, based on the anatomy present in the cervical third[28] nor does its mechanical cleaning seem possible without the cervical dentin eliminated considerably, having to consider the complement of cleaning by physical means and chemical irrigation.

Conclusion

In conclusion, the rotary instrumentation in root canals of mesial roots of mandibular molars with the systems evaluated in diameters and tapers, and the manual instrumentation, did not promote significant changes in the apical third, and the wear caused was more pronounced in the middle and cervical levels.

References

1. Bergmans L, Van Cleynenbreugel J, Beullens M, Wevers M, Van Meerbeek B, Lambrechts P. Smooth flexible versus active tapered shaft design using NiTi rotary instruments. Int Endod J. 2002 Oct;35(10):820-8.
2. Davis SR, Brayton SM, Goldman M. The morphology of the prepared root canal: a study utilizing injectable silicone. Oral Surg Oral Med Oral Pathol. 1972 Oct;34(4):642-8.
3. Fan B, Min Y, Lu G, Yang J, Cheung GS, Gutmann JL. Negotiation of C-shaped canal systems in mandibular second molars. J Endod. 2009 July;35(7):1003-8.
4. Fornari VJ, Silva-Sousa YT, Vanni JR, Pécora JD, Versiani MA, Sousa-Neto MD. Histological evaluation of the effectiveness of increased apical enlargement for cleaning the apical third of curved canals. Int Endod J. 2010 Nov;43(11):988-94.
5. Gambarini G. Rationale for the use of low-torque endodontic motors in root canal instrumentation. Endod Dent Traumatol. 2000 Jun;16(3):95-100.
6. Gao Y, Fan B, Cheung GS, Gutmann JL, Fan M. C-shaped canal system in mandibular second molars part IV: 3-D morphological analysis and transverse measurement. J Endod. 2006 Nov;32(11):1062-5.
7. 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 May;36(5):904-7.
8. Glosson CR, Haller RH, Dove SB, del Rio CE. A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-Flex endodontic instruments. J Endod. 1995;35(3):146-51.
9. Min Y, Fan B, Cheung GS, Gutmann JL, Fan M. C-shaped canal system in mandibular second molars Part III: The morphology of the pulp chamber floor. J Endod. 2006 Dec;32(12):1155-9.
10. Nielsen RB, Alyassin AM, Peters DD, Carnes DL, Lancaster J. Microcomputed tomography: an advanced system for detailed endodontic research. J Endod. 1995 Nov;21(11):561-8.
11. Ordinola-Zapata R, Bramante CM, Duarte MAH, Cavenago BC, Jamarillo D, Versiani MA. Shaping ability of Reciproc and TF Adaptive systems in severely curved canals of rapid microCT-based prototyping molar replicas. J Appl Oral Sci. 2014;22:509-15.
12. Ozer SY. Comparison of root canal transportation induced by three rotary systems with noncutting tips using computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011 Feb;111(2):244-50.
13. Paqué F, Ganahl D, Peters OA. Effects of root canal preparation on apical geometry assessed by micro-computed tomography. J Endod. 2009 July;35(7):1056-9
14. Peters OA, Boessler C, Paqué F. Root canal preparation with a novel nickel-titanium instrument evaluated with micro-computed tomography: canal surface preparation over time. J Endod. 2010 Jun;36(6):1068-72.
15. Peters OA, Paqué F. Root canal preparation of maxillary molars with the self-adjusting file: a micro-computed tomography study. J Endod. 2011 Jan;37(1):53-7.
16. 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 Feb;36(2):86-92.
17. Peters OA, Schönenberger K, Laib A. Effects of four Ni-Ti preparation techniques on root canal geometry assessed by micro computed tomography. Int Endod J. 2001 Apr;34(3):221-30.
18. Pruett JP, Clement DJ, Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod. 1997 Feb;23(2):77-85.
19. Rhodes JS, Ford TR, Lynch JA, Liepins PJ, Curtis RV. A comparison of two nickel-titanium instrumentation techniques in teeth using microcomputed tomography. Int Endod J. 2000 May;33(3):279-85.
20. Ruddle CJ. The ProTaper technique. Endod Top. 2005;10:187-90.
21. Sant'Anna Júnior A, Cavenago BC, Ordinola-Zapata R, De-Deus G, Bramante CM, Duarte MA. The effect of larger apical preparations in the danger zone of lower molars prepared using the Mtwo and Reciproc systems. J Endod. 2014 Nov;40(11):1855-9.
22. Schäfer E, Lohmann D. Efficiency of rotary nickel-titanium FlexMaster instruments compared with stainless steel hand K-Flexofile--Part 2. Cleaning effectiveness and instrumentation results in severely curved root canals of extracted teeth. Int Endod J. 2002 Jun;35(6):514-21.
23. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am. 1974 Apr;18(2):269-96.
24. Schmitz MS, Santos R, Capelli A, Jacobovitz M, Spanó JC, Pécora JD. Influence of cervical preflaring on determination of apical file size in mandibular molars: SEM analysis. Braz Dent J. 2008;19(3):245-51.
25. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol. 1971 Aug;32(2):271-5.
26. Walia HM, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod. 1988 July;14(7):346-51.
27. Weiger R, ElAyouti A, Löst C. Efficiency of hand and rotary instruments in shaping oval root canals. J Endod. 2002 Aug;28(8):580-3.
28. Yin X, Cheung GS, Zhang C, Masuda YM, Kimura Y, Matsumoto K. Micro-computed tomographic comparison of nickel-titanium rotary versus traditional instruments in C-shaped root canal system. J Endod. 2010 Apr;36(4):708-12.
29. 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 Feb;95(2):228-33.
30. Zuckerman O, Katz A, Pilo R, Tamse A, Fuss Z. Residual dentin thickness in mesial roots of mandibular molars prepared with Lightspeed rotary instruments and Gates-Glidden reamers. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2003 Sept;96(3):351-5.