Root Canal Preparation with a Novel Nickel-Titanium Instrument Evaluated with Micro-computed Tomography: Canal Surface Preparation over Time

Ove A. Peters, DMD, MS, PhD, Claudia Boessler, DDS,† and Frank Paqué, Dr med dent†*

Abstract

Introduction: The aim of this part of an ongoing study was to describe the dentin removal ability of a novel nickel-titanium instrument, the self-adjusting file (SAF), by using micro–computed tomography. **Methods:** Twenty maxillary incisors were scanned preoperatively at 20-μm resolution and postoperatively after up to 6 minutes of preparation with an SAF with 1.5-mm or 2-mm diameter. SAFs were operated with continuous irrigation in a handpiece that provided an oscillating, in-and-out movement. Changes in canal volume compared with preoperative values as well as unprepared canal surface area were determined. Data were normally distributed and compared by analysis of variance and regression analyses. **Results:** Preoperatively canal volumes were statistically similar in both groups (9.86 $\pm$ 3.97 mm^3 and 9.80 $\pm$ 2.67 mm^3). Volumes increased during preparation to 13.58 $\pm$ 3.85 mm^3 (after 6 minutes with SAF 1.5 mm) and 16.43 $\pm$ 3.64 mm^3 (after 5 minutes with SAF 2.0 mm), and overall canal shapes were adequate. Unprepared canal surface area decreased from 63.0% $\pm$ 15.1% (2 minutes with SAF 1.5 mm) to 8.6% $\pm$ 4.1% (5 minutes with SAF 2.0 mm). **Conclusions:** Preparation of straight root canals in maxillary anterior teeth left little canal surface uninstrumented after shaping with the SAF. The time-frame of clinical application will depend on the amount of desired dentin removal and done with an SAF selected on the basis of apical gauging. *(J Endod 2010;■:1–5)*

Key Words

Micro–computed tomography, nickel-titanium instruments, root canal preparation, self-adjusting file

From the *Department of Endodontics, Arthur A. Dugoni School of Dentistry, University of the Pacific, San Francisco, California; and †Division of Endodontology, University of Zurich Dental School, Zurich, Switzerland.

Address requests for reprints to Dr Ove Peters, University of the Pacific, Arthur A. Dugoni School of Dentistry, 2155 Webster St, San Francisco, CA 94115. E-mail address: opeters@pacific.edu.

0099-2399/$0 - see front matter

doi:10.1016/j.joen.2010.02.023

The purpose of root canal preparation in the context of endodontic therapy is to (i) shape the canals to an adequate geometry and (ii) clean the canal system by promoting access for disinfection solutions; this strategy has been termed chemomechanical canal preparation (1). Importantly, mechanical canal preparation supports disinfection via disturbing biofilms that adhere to canal surfaces (2, 3) and, second, by removing a layer of infected dentin (4, 5).

Root canal preparation should be done with little or no shaping errors such as zipping or perforation. Many current preparation techniques, including the use of engine-driven nickel-titanium (NiTi) instruments, promote adequate canal shapes (6). Although rotary systems do prepare many canals without major procedural errors, they do not address canal types with long-oval or flat cross sections. Typically radicular walls of such canals will be incompletely prepared and buccal and lingual extensions uncleaned (7).

Various approaches have been described in the literature pertaining to testing of root canal preparation instruments. During the last decade high-resolution micro–computed tomography (MCT) has emerged as a powerful approach to study canal preparation techniques (8–11). This analytical tool permits detailed and nondestructive evaluation of root canal geometry. In addition, the approach yields quantitative data detailing the performance of any given root canal shaping instrument. With MCT, it has been shown that the amount of mechanically prepared canal surface and perhaps equally disturbed biofilm in main root canal, depending on canal type, is frequently below 60% of the canal surface (10, 12).

A newly developed self-adjusting file (SAF) (ReDent-Nova, Ra'anana, Israel) was designed to address the shortcomings of traditional rotary files by adjusting itself to the canal cross section (13). This instrument consists of a compressible opened NiTi tube that, on placement into a root canal, will exert pressure against the canal wall (Fig. 1, insert). The SAF is used in an in-and-out motion powered by a handpiece and under constant irrigation. The canal shaping performance of this novel instrument has not been described at this point in time.

The aim of this study was to detail dentin removal when the SAF is applied to root canals in maxillary anterior teeth. By using MCT, we specifically assessed in anterior teeth the decrease of untreated surface area over time as well as changes in overall and apical dentin volume.

Materials and Methods

Selection of Teeth

From teeth that had been extracted for reasons unrelated to the current study, 50 human maxillary incisors were collected and stored in 0.1% thymol solution at 4°C until further use. Teeth were mounted on scanning electron microscopy stubs and scanned in a desktop MCT unit at an isotropic resolution of 20 μm (μCT 40; Scanco Medical, Brüttisellen, Switzerland) by using previously established methods (10, 12). A total of 20 teeth were then selected on the basis of similar canal volumes and overall canal geometries; they were then accessed by using high-speed diamond burs, and patency of the coronal canal was confirmed. Coronal flaring was accomplished with #2 Gates Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland) placed to 2–3 mm below the cementoenamel junction. Subsequently, canal lengths and patency were determined with size 10 K-files (Dentsply Maillefer) and radiographs;

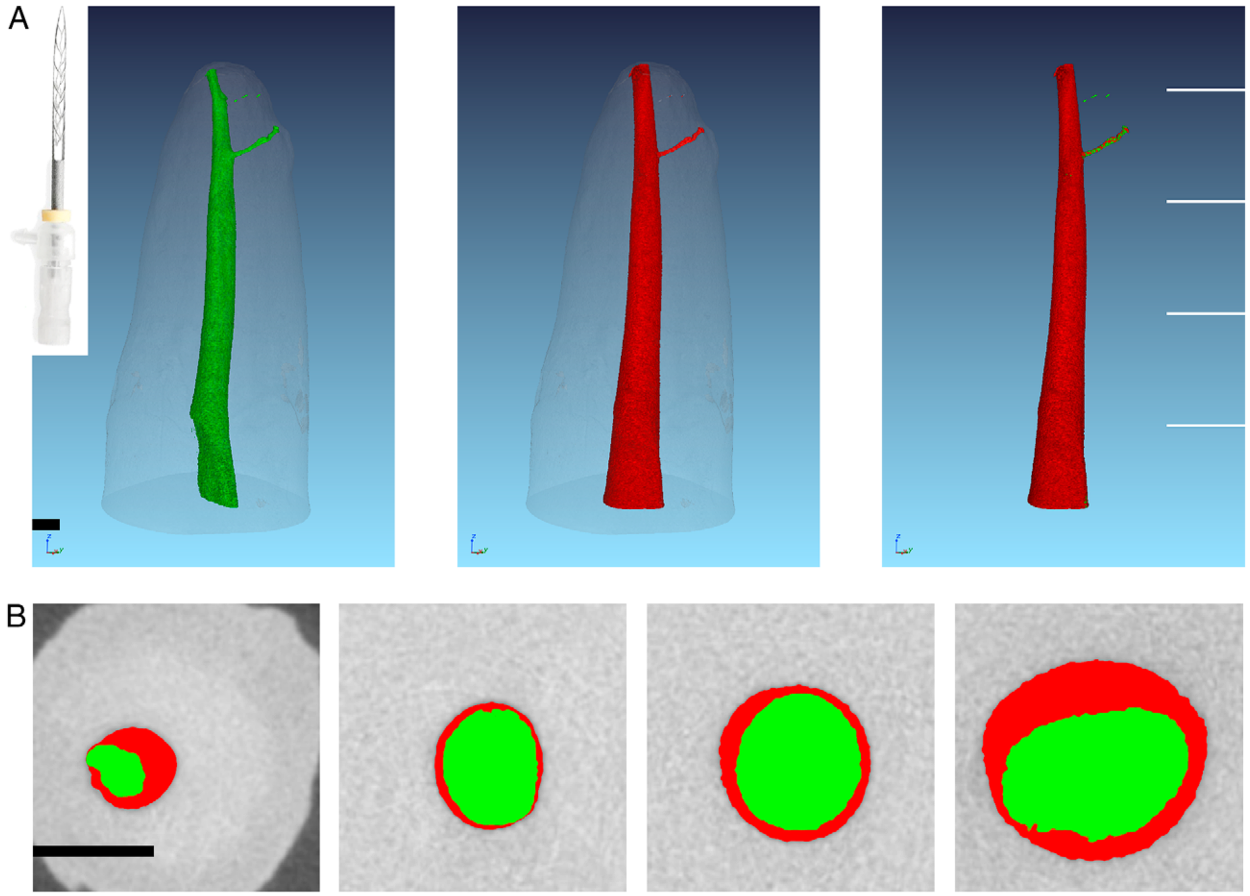

Figure 1. Representative example of MCT data of maxillary anterior root canals prepared with the SAF (inset, A). Preparation time was 5 minutes; note almost complete preparation of canal surface. Black length bars are 1 mm; green and red areas are preoperative and postoperative cross sections, respectively. (*A*) Preoperative, postoperative, and superimposed MCT reconstructions (from left to right) demonstrating a patent lateral canal in the apical 1/3 of the root (volume, 0.033 mm^3). (*B*) Cross sections at 1, 5, 9, and 13 mm coronal of the apex (white lines in *A*) detailing the amount of removed dentin along the canal perimeter.

working lengths were set 1 mm shorter than the radiographic apex. A glide path was confirmed at least to a size #20 K-file; however, apical gauging with increasing sizes of Nitiflex K-files (Dentsply Maillefer) revealed typical apical sizes to be #30 or #35 for the maxillary anteriors included in this study. Specimens were then randomly allocated to 2 groups with n = 10 each. That sample size was based on the following assumptions: an approximated prepared canal surface area for conventional preparation of about 65% ± 15% (14), α error = 0.05, 80% power, and at least 80% ± 5% prepared canal area for the SAF. Surface area preparation assumptions were supported by data from pilot experiments with maxillary anteriors prepared with NiTi rotaries as well as molars prepared with the SAF.

Root Canal Instrumentation with the SAF

The SAF was operated by using a trans-line (in-and-out) vibrating handpiece (GENTLEpower; KaVo, Bieberach a. d. Riß, Germany) combined with a RDT3 head (ReDent-Nova) (13) at a frequency of 83.3 Hz (5000 movements per minute) and an amplitude of 0.4 mm. This movement combined with intimate contact along the entire circumference and length of the canal and the slightly rough surface of the file removes a layer of dentin with a filing motion. The hollow design allows for continuous irrigation throughout the procedure. A special irrigation device (VATEA; ReDent-Nova) was connected to the irrigation hub on the file and provided flow of the irrigant (3% NaOCl) at a flow rate of 5 mL/min.

The SAF was inserted into the canal while vibrating and delicately advanced apically with an intermittent in-and-out hand movement of 5-mm amplitude until it reached the predetermined working length. It was operated with continuous irrigation (13). Canals in both groups were shaped by a single general practitioner, who had been specifically trained with the SAF instrument and participated during a pilot study.

In group 1, canals were prepared with the 1.5-mm diameter SAF; in group 2, canals were prepared with the 2.0-mm SAF. Preparation initially continued for 2 minutes, and teeth were then submitted to a postoperative MCT scan. Similarly, scans were done after 3, 4, 5, and 6 minutes of canal preparation; in group 2 no scans were done after 6 minutes. An individual SAF was assigned to each specimen; therefore, each SAF 1.5 and 2 mm instrument was used for a total of 6 and 5 minutes, respectively. Teeth were kept in containers with thymol solution during transport and scanning.

The clinicians were not allowed to see virtual models of the specimens before and during root canal preparation. This was done to avoid bias by an attempt to manually direct the preparation instrument into any potentially uninstrumented area.

Evaluation

Virtual root canal models were reconstructed on the basis of MCT scans and superimposed with a precision of better than 1 voxel. Precise repositioning of pre-preparation and various postpreparation images was ensured by a combination of a custom-made mounting device and a software-controlled iterative superimposition algorithm (9, 10, 15); the resulting color-coded root canal models (green indicates preoperative, red indicates postoperative canal surfaces) enabled quantitative comparison of the matched root canals before and after shaping.

From individual canal models, canal volumes up to the level of the cementoenamel junction as well as in the apical 4 mm were determined by using custom-made software (IPL; Scanco Medical) as described previously (10). Subsequently, the percentage of unprepared canal surface was assessed for the full canal length and the apical 4 mm. Analyses were done for each postoperative scan for a total of 90 MCT data sets.

With superimposed models and commercially available measurement software (VGStudioMax 2.0; VolumeGraphics, Heidelberg, Germany), canal areas with more than 100 μm dentin removal were determined. To this end, a threshold of 100 μm was preset for the distance measurement tool, and the surface fraction was determined at the end of the canal shaping period.

Statistical Analysis

Voxel volume in this data set was 8×10^{-6} mm^3, and such data are reported as means $\pm$ standard deviations, rounded to the nearest 1/100 mm^3. Data for prepared canal surface area are presented as percentages relative to preoperative canal surface areas. Because normality assumptions were verified, parametric methods were used for comparison; the level of statistical significance was set at $\alpha = 0.05$. Volumes and prepared areas, respectively, were compared with repeated-measures analysis of variance (ANOVA) within groups. The t tests were used for between-group comparisons. A regression analysis was done to correlate the amount of uninstrumented canal surface with the preparation time.

Results

Preoperatively, 7 root canals in maxillary anteriors demonstrated between 1 and 6 accessory canals, mainly in middle and apical root canal thirds, which were large enough to be detected by MCT with the selected resolution (Fig. 1*A*).

Overall, main canals were typically straight and relatively round in cross section (Fig 1*B*, green areas). Postoperative shapes were overall visibly error-free, and no instrument fragments remained in the root canals at the end of the preparation period (Fig. 1), except for one case with a small metal particle that was observed after 5 minutes of shaping. It was no longer present in the subsequent 6-minute MCT scan. Canal shapes were satisfactory, with similar amounts of dentin removed around the perimeter in most cross sections (Fig. 1*B*) and overall fully prepared canal surface areas.

Calculations based on postoperative MCT reconstructions showed a gradual increase in canal size, which was more pronounced after preparation with SAF 2.0 mm. Color-coded superimposed models of preoperative and postoperative MCT data demonstrated an increase in prepared canal surface, shown in red (Fig. 1), with canal preparation over time with both SAF 1.5 and 2.0 mm.

Quantitative assessment of canals assigned to the 2 groups yielded statistically similar canal volumes, with 9.86 $\pm$ 3.97 mm^3 and 9.80 $\pm$ 2.67 mm^3, respectively (Fig. 2, insert). Volume of accessory canals (n = 17) varied between 0.0002 and 0.038 mm^3 and averaged 0.01 $\pm$ 0.01 mm^3. Final canal volumes were 13.58 $\pm$ 3.85 mm^3 (after 6 minutes with SAF 1.5 mm) and 16.43 $\pm$ 3.64 mm^3 (after 5 minutes with SAF 2.0 mm).

Canal volume increased by 3.63 $\pm$ 1.80 mm^3 for SAF 2.0 mm and 1.65 $\pm$ 0.88 mm^3 for SAF 1.5 mm during the first 2 minutes of preparation. This amount was significantly greater (P < .01) than during the subsequent 2-minute period in both groups (Fig. 2*A*). Incremental smaller canal volume increases then occurred from minute 3 of activation onward in both groups.

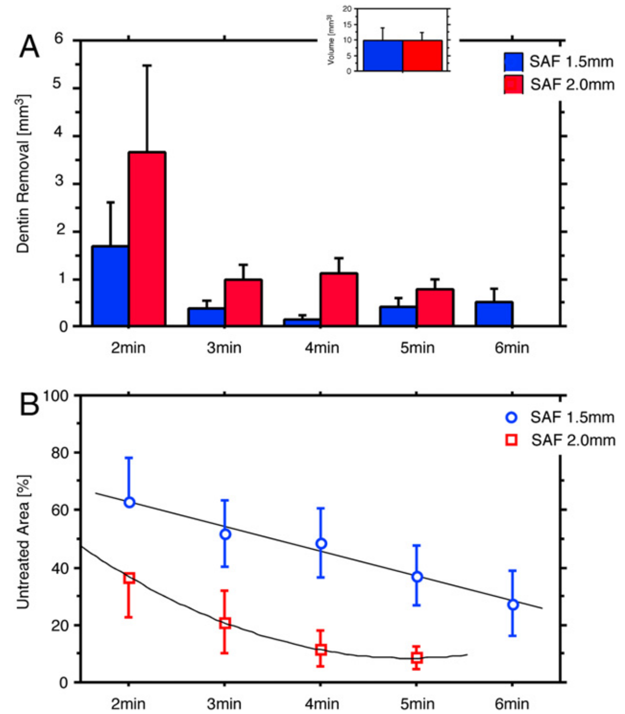

Figure 2. Effect of progressive preparation of root canals with SAF 1.5 mm and 2.0 mm. Initial canal volumes in both groups (n = 10 each) were statistically similar (insert). Preparation was done with 1.5 mm SAF (blue symbols) and 2.0 mm SAF (red symbols). (*A*) Canal volume increase with preparation over time. (*B*) Reduction in uninstrumented canal surface with progressive preparation. Data approximated by linear regression line (blue; untreated area = 80.02–8.59 $\times$ time) and second-order polynomial curve (red; untreated area = 89.31–32.91 $\times$ time + 3.35 $\times$ time^2).

A key variable for MCT assessment of canal preparation is untreated surface area. Overall untreated surface area decreased from 63.0% $\pm$ 15.1% (2 minutes with SAF 1.5 mm) to 8.6% $\pm$ 4.1% (5 minutes with SAF 2.0 mm) (Fig. 2*B*). Similarly, unprepared area in the apical 4 mm decreased from 88.0% $\pm$ 7.1% (2 minutes with SAF 1.5 mm) to 28.6% $\pm$ 12.6% (5 minutes with SAF 2.0 mm).

Regression analysis indicated a linear relationship of the reduction in overall unprepared area over time for SAF 1.5 mm (r^2 = 0.98, P < .0012). Linear regression was first also performed for the SAF 2 mm (r^2 = 0.909, P < .0468). However, a second-order polynomial yielded a better approximation, with an optimum in prepared surface area reached after 5 minutes of preparation (r^2 = 1, P < .0182; Fig. 2*B*).

There was a significant (P < .001) difference in the fraction of prepared surface with greater than 100-μm dentin removal, 23.2% $\pm$ 10.6% for SAF 1.5 mm after 6 minutes and 56.6% $\pm$ 10.3% after 5 minutes of preparation with the larger instrument.

Discussion

This study is a part of a comprehensive, MCT-based evaluation of the shaping potential of a novel root canal preparation instrument, the SAF. The design and mechanical parameters of this new system have been described in detail previously (13, 16). This report focuses on dentin removal over time in maxillary anterior canals and specifically the fraction of prepared surface area. The intention was to give clinicians guidelines as to how long a canal needs to be shaped with the SAF for a desired result. Moreover, information was gained for the selection of SAF 1.5 versus the larger diameter SAF 2.0 mm.

For this study, teeth with straight canals were selected. Such canal anatomy will likely not lead to preparation errors such as canal transportation; therefore, this parameter was not assessed here. However, subsequent studies on mandibular and maxillary molars will address that question, permitting in principle comparison of the SAF performance in curved canals with earlier MCT-based studies (10, 17). Canals in the present study also had larger initial canal volumes than buccal canals in maxillary molars (12), mirrored in gauged apical sizes of #30 or #35 in the majority of the present specimens. Data for canal surface preparation provided here suggest that the SAF 2.0 mm is adequate for such a canal size and might be also selected for palatal canals in maxillary molars that have similar sizes.

According to the presented data and earlier pilot trials (16), the SAF is most effective during the first 2 minutes of use, and hence under the present experimental conditions, the bulk of dentin removal was accomplished during the first 2 minutes of preparation. However, there is about 40% unprepared canal area even with the SAF 2.0 mm at that time. Regression analysis indicated that an optimum of prepared canal surface of more than 90% on average is reached after 5 minutes of activation.

Direct comparison of SAF performance with dentin removal over time by NiTi rotaries is difficult. However, one study with MCT of trenched bone slabs described similar result to what was seen in the present study, a leveling off in cutting ability after 300–400 cycles ($\sim$2 minutes of use in that experiment) (18).

This study is the first to focus on canal preparation with the SAF by using MCT. The latter technique was introduced to experimental endodontics about a decade ago (9); it has been used to assess, in a quantitative and 3-dimensional approach, the performance of current NiTi rotaries (10, 12). A direct comparison between MCT data on NiTi rotaries and the present study is possible; however, one has to keep in mind that resolutions differ from study to study, impacting the potential to detect canal surface preparation. In a pilot study maxillary anteriors were scanned at the same resolution as in the present study; preparation with ProTaper (Dentsply Maillefer) used to an apical size of #50 (F5) resulted in mean unprepared canal areas of about 57%. Moreover, compared with rotary NiTi preparation in oval canals in molars (11), it appears that the amount of prepared surface in such canals with the SAF is higher (data not shown).

A potential limitation of this study is the relatively small sample size of 20 canals in total. It is, however, in the same range as in earlier (12, 14, 17) and recent (19) MCT-based studies. The selected maxillary anterior teeth were also very similar in canal anatomy; hence a power analysis, which depends on the variance in the outcome variable, suggested that n = 10 samples per group were sufficient.

One strength of the selected nondestructive approach was to permit repeated evaluation after incremental preparation over time. This provided information for the clinically recommended usage time; 3 or 4 minutes of activation might be sufficient to address most of the canal surface.

Previous studies with an MCT system with 36-μm resolution documented on average untreated canal areas for rather large and straight palatal canals in maxillary molars of up to 49%, whereas smaller and relatively round distobuccal canals had up to 33% surface area unprepared (14). In the present study, the preparation even with the smaller SAF for 3 minutes accomplished about the same. Regarding removal of dentin, the observed values are similar to or slightly larger than those determined earlier for NiTi rotary instruments (12, 14).

By using canal cross sections in a 2-dimensional assessment, uninstrumented canal perimeters varied between 44% and 68% in long oval canals (20). In a recent study (21), the same group found less unprepared canal perimeter for canal shapes created with rotary instruments, ranging from 25%–35%. However, when material removal of at least 200 μm was required, 80% or more of the canal surface was counted as not prepared (21). In the present study after 5 minutes with SAF preparation, on average about 57% of the canal surface, at least 100 μm, was removed. This was circumferential, and no thinning of the radicular walls was noted.

Rotary NiTi root canal files have been linked to a 3%–5% incidence of intracanal breakage (22); although a retained instrument fragment per se does not significantly alter healing of periapical lesions, it is preferable to have no impediment to disinfection inside canals. In the present study only 1 of a total of 20 canals (90 preparation cycles) presented with a retained NiTi fragment, which was likely too small to pose any obstacle for disinfection. Moreover, pilot data and the present results suggest that probably as a result of the design of the SAF, any retained instrument fragments might be small and loose in the canal. Consequently, the one fragment observed in the present study was flushed out in the subsequent preparation cycle.

Eradication of microorganisms, a critical step for endodontic outcomes (23), is the result of a combination of mechanical preparation (24) and irrigation (25). Irrigation alone is not always effective (26), and mechanical action of instruments on canal walls, including removal of infected dentin, might be needed.

Mechanical disinfection can also be related to removal of a layer of infected dentin, at least of incompletely mineralized predentin (27). It has been shown, however, that bacteria might penetrate dentinal tubules to depths of 200 μm and more (5). The present study indicated that complete uniform enlargement of a root canal by 200 μm is not achieved with a novel instrument; this appears to be an unattainable goal for any contemporary mechanical canal preparation technique (10, 21).

Specifically, the preparation of the most apical canal section remains a challenge. With the SAF, unprepared area amounted up to 28.6% $\pm$ 12.6% after 5 minutes of shaping with SAF 2.0 mm, which still compares favorably to preparation with several popular NiTi rotaries (10). In this area, sufficient deposition of disinfecting irrigation solutions is particularly important. Antibacterial efficacy of canal surface preparation was not directly determined in the present study. However, another experiment involving the SAF suggested enhanced irrigation capacity promoted by continued application through the hollow center of the instrument (28).

Mechanical preparation might affect bacterial biofilms (29) rather than only microorganisms in their planktonic state. With further improvement in hardware and software, it might be possible in the future to directly determine the amount of biofilm removed from MCT-based experiments.

In conclusion, preparation of straight root canals in anterior teeth with the novel SAF left little canal surface uninstrumented after 5 minutes of activation; there were also no significant procedural errors. The timeframe of clinical application will depend on the amount of desired dentin removal and will be done with an SAF selected on the basis of apical gauging.

Acknowledgments

This study was financially supported by ReDent Nova. Helpful discussions with Dipl.-Ing. Christof Reinhart are also gratefully acknowledged.

References

1. Stewart GG. The importance of chemomechanical preparation of the root canal. Oral Surg Oral Med Oral Pathol 1955;8:993–7.
2. Distel JW, Hatton JF, Gillespie MJ. Biofilm formation in medicated root canals. J Endod 2002;510–3.
3. Svensäter G, Bergenholtz G. Biofilms in endodontic infections. Endod Topics 2004; 9:27–36.
4. Berkiten M, Okar I, Berkiten R. In vitro study of the penetration of Streptococcus sanguis and Prevotella intermedia strains into human dentinal tubules. J Endod 2000;26:236–9.
5. Love RM, Jenkinson HF. Invasion of dentinal tubules by oral bacteria. Crit Rev Oral Biol Med 2002;13:171–83.
6. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30:559–67.
7. Wu M-K, Wesselink PR. A primary observation on the preparation and obturation of oval canals. Int Endod J 2001;34:137–41.
8. Rhodes JS, Pitt Ford TR, Lynch JA, Liepins PJ, Curtis RV. Micro-computed tomography: a new tool for experimental endodontology. Int Endod J 1999;32:165–70.
9. Peters OA, Laib A, Rüegsegger P, Barbakow F. Three-dimensional analysis of root canal geometry using high-resolution computed tomography. J Dent Res 2000;79:1405–9.
10. Paqué F, Ganahl D, Peters OA. Effects of root canal preparation on apical geometry assessed by micro-computed tomography. J Endod 2009;35:1056–9.
11. Paqué F, Ballmer M, Attin T, Peters OA. Preparation of oval-shaped root canals in mandibular molars using nickel-titanium rotary instruments: a micro-computed tomography study. J Endod 2010;36:703–7.
12. 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;34: 221–30.
13. 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;36:679–90.
14. 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;36:86–92.
15. Paqué F, Laib A, Gautschi H, Zehnder M. Hard-tissue debris accumulation analysis by high-resolution computed tomography scans. J Endod 2009;35: 1044–7.
16. Hof R, Perevalov V, Zary R, Metzger Z. The Self-Adjusting File. Part 2: Mechanical Analysis. J Endod 2010;36:691–6.
17. Bergmans L, Van Cleynenbreugel J, Beullens M, Wevers M, Van Meerbeek B, Lambrechts P. Progressive versus constant tapered shaft design using NiTi rotary instruments. Int Endod J 2003;36:288–95.
18. Shen Y, Haapasalo M. Three-dimensional analysis of cutting behavior of nickel-titanium rotary instruments by microcomputed tomography. J Endod 2008;34: 606–10.
19. Moore J, Fitz-Walter P, Parashos P. A micro-computed tomographic evaluation of apical canal preparation using three instrumentation techniques. Int Endod J 2009;42:1057–64.
20. Weiger R, El Ayouti A, Löst C. Efficiency of hand and rotary instruments in shaping oval root canals. J Endod 2002;28:580–3.
21. El Ayouti A, Chu AL, Kimonis I, Klein C, Weiger R, Löst C. Efficacy of rotary instruments with greater taper in preparing oval root canals. Int Endod J 2008;41: 1088–92.
22. Spili P, Parashos P, Messer HH. The impact of instrument fracture on outcome of endodontic treatment. J Endod 2005;31:845–50.
23. Haapasalo M, Endal U, Zandi H, Coil JM. Eradication of endodontic infection by instrumentation and irrigation solutions. Endod Topics 2005;10: 77–102.
24. Byström A, Sundqvist G. Bacteriologic evaluation of the efficacy of mechanical root canal instrumentation in endodontic therapy. Scand J Dent Res 1981;89: 321–8.
25. Estrela C, Blitzkow G, Figuereido JAP, Estrela CRA. Antibacterial efficacy of intracanal medications on bacterial biofilms: a critical review. J Appl Oral Sci 2009;17:1–7.
26. Attin T, Buchalla W, Zirkel C, Lussi A. Clinical evaluation of the cleansing properties of the noninstrumental technique for cleaning root canals. Int Endod J 2002;35: 929–33.
27. Siqueira JF Jr, Araujo MC, Garcia PF, Fraga RC, Dantas CJ. Histological evaluation of the effectiveness of five instrumentation techniques for cleaning the apical third of root canals. J Endod 1997;23:499–502.
28. 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;36:697–702.
29. Burleson A, Nusstein J, Reader A, Beck M. The in vivo evaluation of hand/rotary/ultrasound instrumentation in necrotic, human mandibular molars. J Endod 2007;33:782–7.