

Geometric analysis of root canals prepared by single twisted file in three different operation modes

Xing-Chen Wu¹, Ya-Qin Zhu¹

Correspondence: Dr. Ya-Qin Zhu
Email: zyq1590@163.com

¹Department of General Dentistry, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, Shanghai Key Laboratory of Stomatology, Shanghai, China

ABSTRACT

Objective: The aim of this study was to evaluate and compare the effects of a single twisted file (TF) instrument in three different operation modes on the preparation of curved root canals in human molars and to explore a new possible method in canal shaping in the clinic setting. **Materials and Methods:** A total of 105 selected root canals with an angle of curvature ranging from 20° to 35° were divided into the following three groups with 35 samples each according to the different operation mode in canal preparation: “continuous rotation-500” (CR, 500 rpm), reciprocating movement-300 (RM-300 rpm) and CR-300 rpm. Root canals were prepared by single file (a size 25/0.06 TF). The pre- and post-instrumented images of the sections were scanned using a cone-beam computed tomography scanner to measure the root transportation and centering ratio. The data were evaluated at 1.5 mm, 3.0 mm and 6.0 mm positions from the apex. The significance level was set at $P < 0.05$. **Results:** The results showed a statistically significant difference in root transportation that was only found in cross-sections 3.0 mm from the anatomic apex between group “CR-500” and group “CR-300.” In addition, a significant difference in centering ratio was found between group “RM-300” and group “CR-300.” There was no significant difference in the two indices among the three groups at cross-sections 1.5 mm and 6 mm from the apex. **Conclusions:** Under the three conditions of this study, the continuous rotation mode has better shaping ability in root canal preparation than the RM mode when used with a TF single file (size 25/0.06).

Key words: Centering ratio, nickel-titanium instrument, root canal preparation, root canal transportation, twisted file

INTRODUCTION

Root canal preparation has been shown to be one of the critical phases in endodontic treatment, especially for curved canals. The introduction and application of nickel-titanium (NiTi) files, resulted in a major leap in the development of endodontic instruments, and a wide variety of sophisticated instruments have been developed and applied in the dental clinic. Several investigations have shown their better shaping and cleaning ability in root canal preparation.^[1-3]

Nickel-titanium instruments offer a few advantages over conventional stainless steel instruments in

dealing with the cleaning and shaping limitations imposed by the complex anatomy of root canal systems.^[4] However, the cost and unexpected fracture by cyclic fatigue after extended clinical life span have also been noted.^[5-7] Therefore, single use of rotary instruments has been recommended to reduce the instrument fatigue and save the working time.^[8]

In 2008, a new preparation technique using only one F2 Pro-Taper instrument under reciprocating movement (RM) was proposed.^[8] Under the reciprocating motion, only one instrument is needed to enlarge the canal to an adequate size

How to cite this article: Wu X, Zhu Y. Geometric analysis of root canals prepared by single twisted file in three different operation modes. *Eur J Dent* 2014;8:515-20.

Copyright © 2014 Dental Investigations Society.

DOI: 10.4103/1305-7456.143635

and taper, even in a narrow and curved root canal. In this operation mode, the instrument rotated in the counterclockwise (CCW) and clockwise (CW) directions with a 120° of difference between both movements.^[9] This new concept goes completely against the traditional teaching standard, which requires the gradual enlargement of the canal using different sizes of instruments until the desired shape is obtained.

Under RMs, this NiTi instrument related to the degree of CW and CCW rotations allowed for great advancement of the instruments during root canal preparation due to good results and decreased working time needed for root canal preparation. In addition, only very light apical pressure was applied to the instrument, which reduces the cyclic fatigue in comparison with continuous rotation (CR).^[6,10] and subsequent instrument fracture.^[8,11]

There are a lot of single file systems on the market-rotating and reciprocating, such as the “wave one” and “Reciproc” system. Their costs are much higher than a single rotary NiTi instrumentation. The twisted file (TF; Sybron Endo, Amersfoort, The Netherlands), with high flexibility and great cutting efficiency,^[12] has three unique design features, namely R-phase heat treatment, twisting of the metal, and special surface conditioning, which have significantly increased the instrument’s resistance to cyclic fatigue and provided greater flexibility,^[13-15] thus maintaining the original canal center and minimizing canal transportation even in severely curved root canals. These files have a triangular cross section with constant tapers of 0.04, 0.06, 0.08, 0.10, and 0.12. They are available in 5 tip sizes (25-50).

Studies demonstrated that “TF”^[16,17] and “RM”^[18] both performed well in root canal preparation separately. However, there was little information about the behavior of single instruments used in reciprocation motion. Furthermore, until date there have not been any studies regarding the shaping ability of these recently introduced instruments combined with this newly developed operation mode. It is possible that the advantages of the two can be enhanced. Thus the clinical operation could be easier and cheaper. Therefore, the purpose of this study was to compare the cured root canal preparation effect of a single TF file (size 25/0.06) operated at reciprocating motion or CR using cone-beam computed tomography (CBCT) scanning.

MATERIALS AND METHODS

Selection and specimen preparation

Ninety molars extracted from patients who had periodontal and prosthetic problems were selected in this study. The teeth had completed root formation, intact root apices, narrow canals and without visible apical resorption. The canal curvatures were assessed according to Schneider’s technique.^[19] Only canals with moderate (20-35°) and continuous curvature (without multiple curvatures) were included in this study.^[20,21] The teeth were stored in normal saline during the whole experimental period. The working length (WL) was established by measuring the length of the initial 10# K-file (Dentsply Maillefer, Switzerland) at the apical foramen subtracting 1 mm. All the teeth were embedded into several wax models. Specimens (including 105 roots) were coded and randomly divided into the following three equal experimental groups ($n = 35$) according to the operation mode used in canal preparation: CR-500 rpm, RM-300 rpm, CR-300 rpm.

Root canal instrumentation was performed by a single operator according to the manufacturers’ recommendations for each system. A size 25/0.06 TF was selected as the single file used in this experiment. The two CR groups were operated by ENDO-MATE DT (NSK Ltd., Japan), and the RM group was operated by VDW.SILVER® RECIPROC® motor (VDW, Germany). The rotational speed was set at 300 rpm or 500 rpm as needed. The torque was set at 3 Ncm as the manufacturer recommended. Before the preparation, the coronal third of the canal was instrumented by SX Pro-Taper (Dentsply Maillefer, Switzerland) to ensure that the canals could be freely negotiated by 15# K-file (Dentsply Maillefer, Switzerland). In each group, the canal was prepared to the WL in a crown-down sequence, and consequently, the final apical preparation was standardized to 0.06 taper, size 25. The TF instrument was used in the canal with “zero” light apical pressure until resistance was encountered (i.e. until more pressure was needed to advance the TF further into the canal). After the instrument was pulled out of the canal and cleaned, it was reinserted and employed in the same manner. This step was repeated until the TF had reached the full WL. During the operation period, ethylenediaminetetraacetic acid (EDTA) combined with 5.25% sodium hypochlorite solution was used (NaOCl). Patency was verified with a 15# K-file. To test the lifespan of the TF instrument, which will be discussed in further study, each instrument

was replaced when the uncoiling of the instrument or the instrument fracture occurred.

Image analysis

For the acquisition of pre- and post-operative CBCT scans, the samples were precisely repositioned on a unified specimen holder in which they were aligned vertically to the beam and scanned using the KODAK 9000C and KODAK 9000C 3D CBCT scanner (Carestream Health Inc, New York, USA) under the same conditions (a voltage of 65 kV and a current of 2.5 mA). The slices contained 2100 × 2092 pixels and the pixel size was 76 μm. Three cross-section planes corresponding to distances of 1.5, 3.0 and 6.0 mm from the anatomic apex were selected to view through the explorer mode.^[16] The reconstructed two-dimensional images were used to measure the data needed. After obtaining all CBCT images, the software Mimics 15.0 (MATERIALISE N.V. Company) was used to measure the data and the images were analyzed before and after root canal preparation [Figures 1 and 2].

Evaluation of canal transportation

The amount of canal transportation was calculated by the following formula: $|(a_1 - a_2) - (b_1 - b_2)|$, as described by Gambill *et al.*,^[22] where a_1 (b_1) is the shortest distance between the mesial (distal) edge of the root and the uninstrumented canal, and a_2 (b_2) is the shortest distance between the mesial (distal) edge of the root and the instrumented canal. Then, the presence or absence of deviations and the most affected region in canal anatomy were analyzed by comparing pre- and post-operative measurements. If the value was not zero, then transportation had occurred in the canal.^[23]

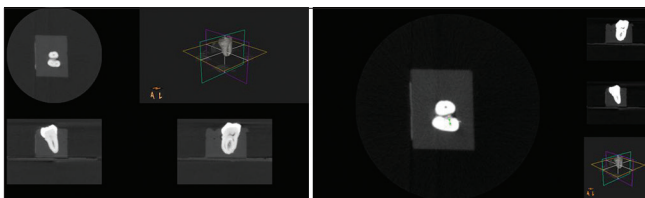


Figure 1: The image of cone-beam computed tomography

Evaluation of centering ability

The mean of the centering ratio was calculated for each cross-section using the following ratio: $(a_1 - a_2) / (b_1 - b_2)$ or $(b_1 - b_2) / (a_1 - a_2)$,^[22] which can indicate the ability of the instrument to stay centered within the canal. Once these numbers were not equal, the lower figure was considered as the numerator of the ratio. Accordingly, the value of 1, suggested perfect centering of the instrument in the root canal according to this formula.^[23]

Statistical analysis

Data were presented as means and standard deviations. One-way analysis of variance was conducted to compare the canal transportation and centering ratio in each group. The Tukey *post-hoc* test was used for pair-wise comparisons between the groups when the analysis of variance test was significant. The significance level was set at $P < 0.05$.

RESULTS

The average WL and curvature are calculated (The canals could be negotiated by 10[#] K-file initially in order to measure the WL). There was no statistically significant difference among the tested groups (As for the fracture of files during preparation and the damage of wax models, the final number of specimens of the tested group were “CR-500” -33, “RM-300” -34, “CR-300” -34).

The means and standard deviations for the canal transportation and the centering ratio at the studied levels for the experimental groups be shown in Table 1 after independent analysis of each cross-section.

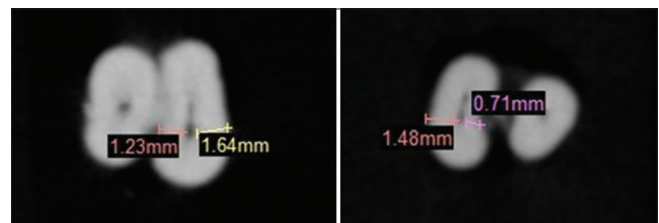


Figure 2: The measurement of distance

Table 1: Statistical analysis of mean values for the transportation (mm) and the centering ratio for tested groups

Level	Assessment	CR-500	RM-300	CR-300	P
1.5 mm apical	Transportation	0.026±0.024	0.031±0.022	0.034±0.025	0.4409
	Centering ratio	0.701±0.196	0.693±0.192	0.648±0.196	0.4842
3.0 mm middle	Transportation	0.025 ^a ±0.023	0.044 ^b ±0.025	0.037 ^{ab} ±0.030	<0.0001*
	Centering ratio	0.687 ^{ab} ±0.191	0.620 ^a ±0.156	0.739 ^b ±0.201	<0.0001*
6.0 mm cervical	Transportation	0.040±0.036	0.048±0.035	0.042±0.030	0.5907
	Centering ratio	0.710±0.206	0.650±0.186	0.627±0.240	0.2429

Means with different letters are statistically significantly different according to the Tukey test. CR: Continuous rotation, RM: Reciprocating movement, *The level of significance was set at $\alpha=0.05$

Canal transportation

At the 1.5 mm and the 6.0 mm levels, there was no statistically significant difference in canal transportation among the groups ($P > 0.05$). However, at the 3.0 mm level, group "RM-300" had the highest mean of transportation values among all groups (0.044 ± 0.025 mm), and this difference was statistically significant. Meanwhile, groups "CR-500" and "CR-300" yielded the significantly lowest mean of transportation values (0.025 ± 0.023 mm and 0.037 ± 0.030 mm, respectively), and no significance was found between the two groups.

Centering ratio

At the 1.5 mm and the 6.0 mm levels, there were no statistically significant differences in the canal-centering ratio among the groups ($P > 0.05$). However, at the 3.0 mm level, group "RM-300" showed the significantly lowest mean of centering ratio (0.620 ± 0.156), whereas group "CR-500" and group "CR-300" obtained the significantly highest mean of centering ratios (0.687 ± 0.191 and 0.739 ± 0.201 , respectively) with no significant differences between the two groups.

Image analysis

Using the software Mimics 15.0 (MATERIALISE N.V. Company), we compared the effect of the TF file (size 25/0.06) on root canal preparation more intuitively. The technology, such as two-dimensional measurement, three-dimensional reconstruction, and superposition of two preoperative and postoperative images from CBCT data were used. The results are showed in Figures 3 and 4.

DISCUSSION

The main objective of endodontic preparation is to disinfect and enlarge the root canal to a shape

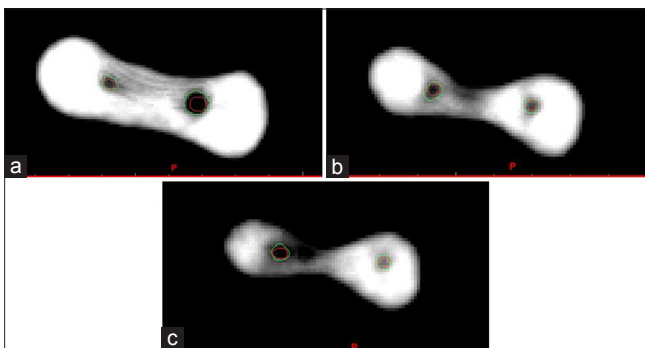


Figure 3: Cone-beam computed tomography data of sample canals prepared with single twisted file. Red and green areas are preoperative and postoperative cross sections, respectively. A to C images, represent the cross sections at 1.5, 3 and 6 mm coronal of the apex, respectively

that tapers from the apical to coronal part, while maintaining the original canal anatomy.^[24] An effective way to prepare curved canals using hand instruments in a CW and CCW movement has been already developed,^[25] as mentioned before. Results obtained in other studies have shown that symmetrical rotation makes progression along the canal more laborious.^[26]

Among the commonly used methods in investigating the efficiency of newly developed techniques and instruments before and after preparation, radiography can only provide a two-dimensional image and does not provide a view of the cross-section of the root canal. Other techniques, such as the serial sectioning technique, not only require a complicated setup and a physical sectioning of the specimens prior to preparation, but may also result in unexpected destruction of tissues and materials.^[22] Known as noninvasive methods, computed tomography imaging techniques have paid special attention to the analysis of root canal geometry and practical efficiency of shaping techniques.^[27-29] This technique allows a more accurate comparison of the anatomic structure of the root canal before and after instrumentation. This study shows that CBCT can provide images at a resolution of $76 \mu\text{m}$, which makes CBCT an acceptable method for evaluating the canal shaping ability.

The superiority of NiTi instruments has been generally acknowledged in previous reports; however, clinical practice is a more complex process. The cutting ability interrelates with multiple parameters such as the cross-sectional design, chip-removal capacity,

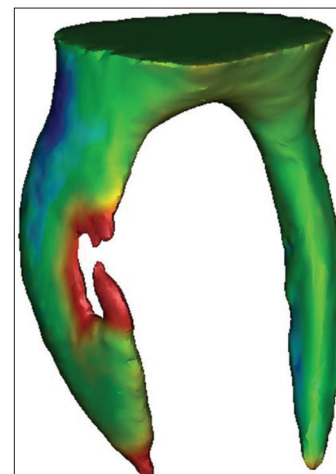


Figure 4: Three-dimensional reconstructed cone-beam computed tomography image of root canal. The color nephogram showed the difference between the preoperative and postoperative canal by superpositing the two images. The color from "blue" to "red" represents the degree of the difference; blue, over-cutting surface; green, affected surface; red, surface unchanged by the file

helical, rake angles, metallurgical properties, surface treatment of the instrument and so on.^[30,31] TF as a recently introduced file system is significantly different in its geometric design and manufacturing method.

In the present study, an extracted teeth model was employed because testing file systems under realistic circumstances in natural dentin canals is thought to be more beneficial than in standardized artificial canals.^[32] The TF (size 25/0.06) was selected because its size was suited to a large proportion of curved root canals in clinically treated molars. The CBCT scanning technique was used because it can provide a noninvasive, reproducible, three-dimensional evaluation of changes in root canals pre- and post-preparation with accurate images,^[22,33] as the same method introduced in the article of Hashem *et al.*^[16] Zhao *et al.*^[34] also concluded in their study that CBCT can be used as a new methodology for deviation analyses during root canal treatment. Three levels (1.5, 3.0 and 6.0 mm from the root apex) were selected, which were located at the apical and middle thirds of the root canal because these curvatures have highly susceptible to iatrogenic mischance and usually exist in reference to the WL of the molar canals inland (i.e. about 18 mm as our specimens represent). The coronal part of the canal was prepared by SX beforehand as SX has larger taper than TF and can help to remove the resistance from the coronal dentin. The effect of using NaOCl and EDTA as chelating agent because a combination of them can enhance the cleaning efficiency of the instruments evaluated in the present investigation.^[35]

As the results showed, TF single file did not show different results when operating under RM comparing to 360° CR at 1.5 and 6.0 mm levels. At 1.5 mm, the three groups showed no statistically significant differences in both canal transportation and the centering ratio. The possible reasons are the non-cutting tip design that TF possess, which functions only as a guide to allow easy penetration with minimal apical pressure,^[36] and the standardized size of master apical file.^[37] The current results are in accordance with the previous report by Hashem *et al.*^[16] No difference showed at 6.0 mm may because the use of SX already make the path to the canal easier, and the TF may feel less pressure from the root canal wall. Only cross-sections at 3.0 mm showed a statistically significant difference between the groups, with the “RM-300” group promoting higher levels of transportation than the other two groups, which eventually lead to a lower centering

ratio. These differences were probably observed because, at this point of the curvature, the crucial changes in the relationship of diameter and flexibility lead to a higher stress on the instrument.^[38] The fact that the outcome is not as well as expected when TF single file matched with the reciproc motor may relate to the following reasons: First, the rotational speed recommended for TF is 500 rpm, while the reciproc motor is set at 300 rpm and the difference may explain the performance of TF instruments to some extent; second, the helical and rake angles on the surface of TF instruments are designed for 360° CR and CW and CCW rotations in the RM may need a special helical design such as that of the RECIPROC® instruments (i.e. a possible explanation can be related to the different cross-sectional designs: Reciproc instruments have an S-shaped cross-section with two cutting blades, while the TF instrument has an equilateral triangular cross-section). Furthermore, TF should be applied with “zero” apical pressure as its advancement into the root canal would be almost automatic; however, very little but not “zero” apical pressure should be applied to the instrument under RM, which appears to be inconsistent and may influence the results. In summary, TF can indeed work well with the reciproc motor, there are no more fractures than in a continuous movement. Other factors such as the effect of the reciproc movement of the TF file on the internal anatomy, fracture resistance, etc., of root canals, and possibly on the outcome of endodontic treatment, remains to be determined.

The TF single file might be accepted if canal transportation occurred within 0.15 mm;^[27] however, there may be a negative impact on the apical seal and the prognosis of endodontic treatment if canal transportation exceeds 0.30 mm. This may be ignored by the dental professionals, and accordingly influence the prognosis of endodontic treatment.^[39] As we showed here, none of the specimens had transportation levels >0.20 mm, which could be regarded as a positive result.

CONCLUSION

This study demonstrated that the CR mode has better shaping ability in root canal preparation than the RM mode when used with a TF single file.

REFERENCES

1. Guelzow A, Stamm O, Martus P, Kielbassa AM. Comparative study of six rotary nickel-titanium systems and hand instrumentation for root canal preparation. *Int Endod J* 2005;38:743-52.
2. Schirmermeister JF, Strohl C, Altenburger MJ, Wrbas KT, Hellwig E.

- Shaping ability and safety of five different rotary nickel-titanium instruments compared with stainless steel hand instrumentation in simulated curved root canals. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006;101:807-13.
3. Sonntag D, Ott M, Kook K, Stachniss V. Root canal preparation with the NiTi systems K3, Mtwo and ProTaper. *Aust Endod J* 2007;33:73-81.
 4. Vaudt J, Bitter K, Neumann K, Kielbassa AM. *Ex vivo* study on root canal instrumentation of two rotary nickel-titanium systems in comparison to stainless steel hand instruments. *Int Endod J* 2009;42:22-33.
 5. Alapati SB, Brantley WA, Svec TA, Powers JM, Mitchell JC. Scanning electron microscope observations of new and used nickel-titanium rotary files. *J Endod* 2003;29:667-9.
 6. You SY, Bae KS, Baek SH, Kum KY, Shon WJ, Lee W. Lifespan of one nickel-titanium rotary file with reciprocating motion in curved root canals. *J Endod* 2010;36:1991-4.
 7. Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Fatigue testing of controlled memory wire nickel-titanium rotary instruments. *J Endod* 2011;37:997-1001.
 8. Yared G. Canal preparation using only one Ni-Ti rotary instrument: Preliminary observations. *Int Endod J* 2008;41:339-44.
 9. Yared G. Canal preparation with only one reciprocating instrument without prior hand filing: A new concept. *Aust Dent Pract* 2011;22:178.
 10. De-Deus G, Moreira EJ, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. *Int Endod J* 2010;43:1063-8.
 11. Varela-Patiño P, Ibañez-Párraga A, Rivas-Mundiña B, Cantatore G, Otero XL, Martín-Biedma B. Alternating versus continuous rotation: A comparative study of the effect on instrument life. *J Endod* 2010;36:157-9.
 12. Hülsmann M, Peters OA, Dummer PM. Mechanical preparation of root canals: Shaping goals, techniques and means. *Endod Topics* 2005;10:30-76.
 13. Gambarini G, Grande NM, Plotino G, Somma F, Garala M, De Luca M, *et al.* Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. *J Endod* 2008;34:1003-5.
 14. Larsen CM, Watanabe I, Glickman GN, He J. Cyclic fatigue analysis of a new generation of nickel titanium rotary instruments. *J Endod* 2009;35:401-3.
 15. Gambarini G, Gerosa R, De Luca M, Garala M, Testarelli L. Mechanical properties of a new and improved nickel-titanium alloy for endodontic use: An evaluation of file flexibility. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008;105:798-800.
 16. Hashem AA, Ghoneim AG, Lutfy RA, Foda MY, Omar GA. Geometric analysis of root canals prepared by four rotary NiTi shaping systems. *J Endod* 2012;38:996-1000.
 17. Bhagabati N, Yadav S, Talwar S. An *in vitro* cyclic fatigue analysis of different endodontic nickel-titanium rotary instruments. *J Endod* 2012;38:515-8.
 18. Pedullà E, Grande NM, Plotino G, Gambarini G, Rapisarda E. Influence of continuous or reciprocating motion on cyclic fatigue resistance of 4 different nickel-titanium rotary instruments. *J Endod* 2013;39:258-61.
 19. Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol* 1971;32:271-5.
 20. Nagy CD, Szabó J, Szabó J. A mathematically based classification of root canal curvatures on natural human teeth. *J Endod* 1995;21:557-60.
 21. Zhu YQ. Clinical key-points about fine and curved root canal preparation. *Chin J Pract Stomatol* 2011;4:518-21.
 22. Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *J Endod* 1996;22:369-75.
 23. Gergi R, Rjeily JA, Sader J, Naaman A. Comparison of canal transportation and centering ability of twisted files, Pathfile-ProTaper system, and stainless steel hand K-files by using computed tomography. *J Endod* 2010;36:904-7.
 24. Thompson SA, Dummer PM. Shaping ability of Hero 642 rotary nickel-titanium instruments in simulated root canals: Part 2. *Int Endod J* 2000;33:255-61.
 25. Roane JB, Sabala CL, Duncanson MG Jr. The "balanced force" concept for instrumentation of curved canals. *J Endod* 1985;11:203-11.
 26. Franco V, Fabiani C, Taschieri S, Malentacca A, Bortolin M, Del Fabbro M. Investigation on the shaping ability of nickel-titanium files when used with a reciprocating motion. *J Endod* 2011;37:1398-401.
 27. Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P. A methodology for quantitative evaluation of root canal instrumentation using microcomputed tomography. *Int Endod J* 2001;34:390-8.
 28. Garip Y, Günday M. The use of computed tomography when comparing nickel-titanium and stainless steel files during preparation of simulated curved canals. *Int Endod J* 2001;34:452-7.
 29. Peters OA. Current challenges and concepts in the preparation of root canal systems: A review. *J Endod* 2004;30:559-67.
 30. Peters OA, Laib A, Göhring TN, Barbakow F. Changes in root canal geometry after preparation assessed by high-resolution computed tomography. *J Endod* 2001;27:1-6.
 31. Schäfer E, Oitzinger M. Cutting efficiency of five different types of rotary nickel-titanium instruments. *J Endod* 2008;34:198-200.
 32. Setzer FC, Kwon TK, Karabucak B. Comparison of apical transportation between two rotary file systems and two hybrid rotary instrumentation sequences. *J Endod* 2010;36:1226-9.
 33. Gluskin AH, Brown DC, Buchanan LS. A reconstructed computerized tomographic comparison of Ni-Ti rotary GT files versus traditional instruments in canals shaped by novice operators. *Int Endod J* 2001;34:476-84.
 34. Zhao N, Chu JP, Yan B, Liu XJ. Cone-beam computed tomography analysis of the canal transportation after mechanical preparation with two different rotary nickel-titanium systems. *Chin J Conserv Dent* 2011;21:683-6.
 35. Bürklein S, Hinschitzka K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. *Int Endod J* 2012;45:449-61.
 36. Kum KY, Spångberg L, Cha BY, Il-Young J, Msd, Seung-Jong L, *et al.* Shaping ability of three profile rotary instrumentation techniques in simulated resin root canals. *J Endod* 2000;26:719-23.
 37. Fayyad DM, Elhakim Elgendy AA. Cutting efficiency of twisted versus machined nickel-titanium endodontic files. *J Endod* 2011;37:1143-6.
 38. Freire LG, Gavini G, Branco-Barletta F, Sanches-Cunha R, dos Santos M. Microscopic computerized tomographic evaluation of root canal transportation prepared with twisted or ground nickel-titanium rotary instruments. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011;112:e143-8.
 39. 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;26:210-6.

Access this article online

Quick Response Code:



Website:
www.eurjdent.com

Source of Support: The National Natural Science Foundation of China (No:81271134); Science and Technology committee of Shanghai (No: 08JC1414500).

Conflict of Interest: None declared