Evaluation of Canal Transportation after Instrumentation with Three Different Nickel-Titanium Systems Using Computed Tomography

Ragab M.D., H.A. Alhadainy, N.A. Shaheen

Endodontic department, Faculty of Dentistry, Tanta University, Egypt
maidessoky@yahoo.com

Abstract: Introduction: The purpose of this study was to evaluate canal transportation (degree and direction) after instrumentation with ProTaper, WaveOne and hand NiTiFlex files using computed tomography (CT). **Methods**: Sixty extracted human mandibular first molars with severely curved mesiobuccal (MB) canals were selected and randomly divided into three groups (n=20) according to the used instrumentation technique as ProTaper, WaveOne, and hand NiTiFlex. Specimens were scanned before and after instrumentation with 640-multi slice CT at three levels: coronal, middle and apical and all tomograms were analyzed using VITREA 2 V3.8 Imaging Software. **Results**: Less transportation occurred with reciprocating WaveOne Primary instrument followed by rotary ProTaper and Hand NiTiFlex respectively (P≤0.005). Apical level showed the least canal transportation value with mesial tendency than other two levels. **Conclusions:** Single file reciprocating system prepared curved root canal with less canal transportation compared to full rotary and hand NiTi systems. Canal transportation occurred at the apical level less than middle and coronal levels.

[M.D. Ragab, H.A. Alhadainy, N.A. Shaheen. **Evaluation of Canal Transportation after Instrumentation with Three Different Nickel-Titanium Systems Using Computed Tomography.** *Nat Sci* 2018;16(2):71-78]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 12. doi:10.7537/marsnsj160218.12.

Keywords: Canal transportation, computed tomography, NiTiFlex, ProTaper, reciprocating motion, WaveOne

1. Introduction:

Root canal instrumentation is considered as one of the most important procedures during root canal treatment. This step determines the results of subsequent procedures which include canal irrigation and obturation [1].

A tooth with straight root and canal is considered as an exception rather than normal [2] and preparation of curved root canals is usually associated with unwanted alterations such as canal transportation, ledges and sometimes perforations [3]. Therefore, nickel-titanium (NiTi) instruments were introduced to overcome these mishaps as they possess two phenomena; super elasticity and shape memory which are not found in stainless steel instruments (St-St) [4].

ProTaper (Dentsply, Maillefer, Ballaigues, Switzerland) is a rotary NiTi system with multiple progressive taper and a convex triangular cross-section that enhances the cutting action with minimal transportation and improves safety [5, 6].

The use of reciprocating motion was suggested as an alternative to the conventional continuous rotation [7]. WaveOne (Dentsply, Maillefer, Ballaigues, Switzerland) is a single-use single-file NiTi system used in reciprocating mode that helps WaveOne file to successively progress along the canal path, whilst respecting the original root canal anatomy [8].

To assess the action of endodontic instruments, several methods have been proposed such as; radiographic imaging, cross sectioning, and longitudinal cleavage of the root [1]. Recently, the use of computed tomography (CT) has been suggested for this purpose as it allows measuring the amount and direction of removed dentin after preparation in an accurate and non-destructive way [9].

Many attempts in the manufacturing of root canal preparation systems have been introduced for better maintaining of the original canal path without deviation. Therefore, the purpose of this study was to evaluate and comparetransportation in curved root canals after instrumentation with rotary ProTaper, reciprocating WaveOne NiTi systems and hand NiTiFlex K-files using computed tomography.

2. Materials and Methods:

Selection of Specimens

Sixty extracted human mandibular first molars with separate mesiobuccal canals were collected. All canal should accommodate file # 15 as an initial file with curvature angle ranging from 25^{O}-45^{O} according to Schnieder's method (10). The study protocol was approved by the local ethics committee of Tanta University.

Access opening cavities were prepared using round bur size # 3 (Dentsply, Maillefer) followed by Endo-Z (Dentsply, Maillefer). Teeth were numbered and randomly divided into three equal groups (n=20): Group I: ProTaper Universal up to F2, Group II: WaveOne Primary file, and Group III: hand NiTiFlex k- files up to master apical file size 25. A custom-made mold with Zetaplus heavy body impression

material (Zhermack, Italy) was made to support and fix samples while CT images were taken.

Multi-Slice Computed Tomography Analysis

The mounted specimens were placed in ONE Aquilion-640 multi-slice CT scanner (Toshiba, Japan) to be scanned for determination of MB canals' shape before instrumentation using the brain protocol supplied by the CT scanner. A complete volume of all specimens was viewed to select the desired specimen for analysis using VITREA 2 V3.8 Software (VITREA 2, Imaging Inc).

Three tomograms were selected for each assessed specimen [9]; the first corresponding to the area located 3 mm from the radiographic root apex (apical third), the second corresponding to 3 mm from the canal orifice (coronal third) and the third was at the middle third. CT scan images were then labeled and saved as JPG format.

Root Canal Biomechanical Preparation

Root canals were instrumented by the same operator and working length was visually determined by passing hand St-St K-file size 10 (MANI Inc, Japan) until it was visible at the apical foramen then subtracting 1 mm from that length [11]. A secured-glide path was ensured for NiTi rotary instrumentation using 0.02 tapered sizes 10 and 15 [9]. The preparation sequence was obtained using X-Smart Plus endodontic electro-motor (Dentsply, Maillefer) with a 16:1 gear reduction contra-angled handpiece following the manufacturer's preset mode and instructions for each system as follows:

Group I: MB root canals were prepared with ProTaper rotary system in crown down technique in the sequence of SX, S1, S2, F1 up to F2 (#25/0.08) respectively. All ProTaper instruments were discarded after preparing five canals [12].

Copious irrigation was used after each instrument with 2 ml of freshly prepared 5.25% NaOCL solution using a plastic disposable syringe with 27 gauge side-ended needle tip. The prepared canals were then flushed with 17% ethylene diamine tetracetic acid (EDTA) for 1 min and finally rinsed with normal saline solution. This irrigation protocol was applied for all groups' specimens.

Group II: Reciprocating WaveOne Primary file was used for MB root canal preparation in crown down technique. WaveOne primary files were replaced after instrumentation three canals corresponding to single use concept [13].

Group III: A classical crown down technique following Morgan and Montgomery [14] instructions using ISO 0.02 tapered hand NiTiFlex K-files. Coronal third enlargement was achieved with Gates Glidden drills size 3, 2 and 1 successively. Then root canal preparation was completed using reaming motion of NiTiFlex files in crown down manner up to master apical file #/ 0.02. Gates Glidden instruments were discarded after preparing five canals [15] and each hand NiTiFlex K-file was used for preparation of only four root canals [16].

Each specimen was returned back to its respective place in the custom-made impression mold and repositioned in the same orientation for obtaining post-instrumentation CT images under the same scanning parameters of pre-instrumented CT.

Evaluation of Canal Transportation

Canal transportation was calculated for each specimen at three selected levels of the MB canal using both pre- and post-instrumentation CT images. Calculation of canal transportation was performed using special equation developed by Gambill et al. (17): (a1 – a2) – (b1 – b2) where; **a1** is the shortest distance from the mesial edge of the root to the mesial edge of the uninstrumented canal, **b1** is the shortest distance from the distal edge of the root to the distal edge of the uninstrumented canal, **a2** is the shortest distance from the mesial edge of the root to the mesial edge of the instrumented canal, and **b2** is the shortest distance from the distal edge of the root to the distal edge of the instrumented canal (Fig.1).

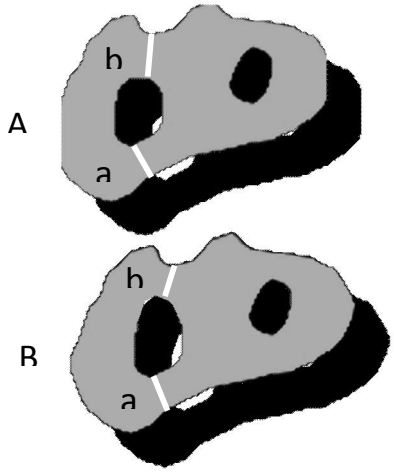

Fig.1: Diagrammatic representation of pre- (A) and post- (B) instrumentation CT scans for coronal level of P1 specimen showing a1, b1, a2 and b2 distances.

Evaluation of Canal Transportation Direction

According to this formula, a result of zero indicates no canal transportation, while results other than zero value representing direction of canal transportation. Positive values represent canal transportation toward the furcation region (distal), while negative values represent transportation away from furcal region (mesial) [17, 18].

Statistical Analysis

Descriptive statistics was obtained in the form of mean and standard deviation (SD) and statistical

analysis was performed using One-Way Analysis of Variance with SPSS software version 17 (SPSS inc, Chicago) at significance level of P-value ≤ 0.05. Multiple Pair wise comparisons were performed using Post-hoc Tukey test to determine which group or root canal level is significantly different from one another.

3. Results:

Mesiobuccal canal transportation results are presented in Table 1. Comparison between the three groups showed a significant difference at the three tested levels (P<0.05) with a significant difference between the tested levels only with Group II (WaveOne) (P<0.05).

Regarding root levels, apical level showed the least mean value of canal transportation followed by middle and coronal levels respectively with a significant difference in between (P<0.05). The least mean degree of canal transportation was statistically recorded with WaveOne (P<0.05), followed by NiTiFlex and the highest value with ProTaper regardless the tested level.

In all groups, cervical and middle thirds were transported distally toward the danger zone. However, the apical thirds were transported to the outer face of the root curvature without significant difference (P>0.05). Pre- and post-instrumentation CT scans at the apical level are represented in Fig. 2 for the three groups.

Table 1. Mean and standard deviations of canal transportation of the tested groups at the three levels.

Level	Group I (ProTaper)	Group II (WaveOne)	Group III (NiTiFlex)	P values
Coronal	0.52 ± 0.31	0.32 ± 0.18	0.38 ± 0.24	0.035*
Middle	0.47 ± 0.34	0.24 ±0.23	0.30 ± 0.31	0.043*
Apical	0.40 ± 0.12	0.14 ± 0.12	0.18 ± 0.18	<0.001*
P value	0.391	0.013*	0.052	

*Significant statistical result at p ≤ 0.05.

4. Discussion:

Preparation of curved root canal shows some difficulties and there is a tendency for all instrumentation techniques to divert the prepared canal away from its original axis [1].

NiTi rotary instruments have been shown a high efficiency in achieving optimal root canal shaping with less straightening and better centered preparations of curved root canals [19]. Several root canal preparation techniques together with NiTi systems and different kinematics have been developed to maintain the original canal shape [9].

In the present study, canal transportation was evaluated under realistic circumstances using extracted human permanent lower molars to detect the instrumentation effect on the root canal shape. Although the simulated canals in resin blocks have the advantage of standardized shape, size, taper and curvature; the hardness encountered in these acrylic block is completely different from that of normal dentin in addition to heat generation which may soften the resin materials [19-21].

Mesiobuccal root canals (MB) of mandibular molars with severe curves were selected because they contain canals that are often narrow and curved in two planes increasing the level of instrumentation difficulty [22]. Standardization of the initial canal width was performed by selecting only MB canals accommodating size #15 K-file as an initial apical file [8,9,23] and exhibiting (25°-45°) curvature according to Schneider's method [10]; this canal anatomy would likely lead to preparation errors such as canal transportation [11].

Furthermore, crowns were maintained to simulate as closely as possible the clinical endodontic practice in which the interference of cervical dentin projections creates tension on files during root canal instrumentation [24]. In addition, sectioning of the distal roots was performed to facilitate insertion and removal of specimens into the custom-made mold and enhance further evaluation of multi-slice CT scan images before and after instrumentation [25].

Final master apical file preparation diameter was restricted to size # 25 for all canals to achieve similar final apical preparation diameters [26] and keep standardization between the tested NiTi groups [27]. Crown down technique was used in preparation of all MB canals as this approach is recommended for curved root canal preparation; as it promotes straight-line access which reduces frictional intra-canal stresses, provides a conical configuration without excessively increasing the width of the apical third, allows easier instrumentation with better control of instruments, minimizes apical extrusion of debris and subsequently reduces canal aberrations such as root canal transportation [28].

Multi-slice CT imaging technique was used in this study to evaluate root canal transportation as it is considered as a noninvasive reproducible three dimensional method used for evaluation of external and internal morphology of the tooth and assessment of the degrees and directions of transportation before and after instrumentation, in addition to the advantages of eliminating both the limitation of the serial sectioning technique with its excessive tissue removal [29,30] and the drawback of the two-dimensional images of the traditional longitudinal radiographic method [31].

With various degrees of root canal curvatures, transportation of the canal during instrumentation occurs most frequently in three different levels [9]; the apical third where the apical portion of the instrument

enlarges the external wall of the canal, the middle third where the instrument tends to cut the internal wall of the canal and at the opening facing the external wall of the root canal [32]. Thus; canal transportation was evaluated in this study at these levels to investigate all possible canal transportations.

Using a specific formula developed by Gambill et al. (1996) [17], CT scan images was used to evaluate canal transportation by measuring the remaining dentin thickness around the original canal before instrumentation and comparing it to that around the post-instrumented canal to achieve accurate determination of the tendency, degree and course of canal deviation in two different directions [33].

The current study compared the ability of two NiTi systems; ProTaper continuous rotating system used up to F2 finishing file and WaveOne Primary reciprocating single-file system in preserving original canal path in comparison to the traditional hand NiTiFlex K-files. NiTi systems of the present study have four different concepts; file design, metallurgy, movement kinematics and the number of used files to complete root canal preparation.

In this study, Group I prepared with ProTaper rotary system showed the highest canal transportation which may be attributed to the sharp cutting edges of the convex triangle cross sectional design with its progressive taper sequence along the shaft [34]. In addition, ProTaper files have a greater number of spiraling flutes (i.e. smaller pitch) than WaveOne file which increases stiffness along the shaft of ProTaper [35].

Group II prepared with WaveOne reciprocating system showed the least value of canal transportation. A statistical significant difference was recorded with Group I (ProTaper) when compared with Group II (WaveOne) at the three tested levels and this may be explained by the special characteristics of reciprocating WaveOne system which are M-Wire technology, file design, reciprocating action and single use for each file [23].

Manufacturing process of WaveOne M-Wire technology promotes greater flexibility when compared with the conventional NiTi alloy of ProTaper system [36], along with its modified cross sectional design which results in lower cutting efficiency and less chip space, thus less canal transportation [8,9,37]. In addition, the reciprocating motion promotes a higher flexibility and concentricity that contributing to a balanced action motion by repeated clockwise and counterclockwise rotation. This motion allows continuous release of the file when engaged to the inner surface of the root canal during the cutting and shaping procedure [37-39] leading to reduction in torsional stress by preventing binding of the file, thereby canal transportation is reduced [40]. Moreover, this motion produces beneficial shaping results by reducing the screwing effect, yet this effect can be a reason for canal transportation because it occurs with active files that rotates in continuous motion and results in over-instrumentation beyond the apical foramen during canal preparation [37]. Furthermore, this motion is able to maintain the curvature without distorting the shape of the root canal and consequently results in lower possibility of canal transportation when compared to continuous rotary motion [37,41,42]. Finally, regarding canal transportation of single file preparation technique, this single file could produce a preserved preparation of curved root canals whenever used in reciprocating motion [8].

A significant difference was observed with ProTaper when compared with hand NiTiFlex K-files at the apical level. This may be due to the higher flexibility of the 0.02 tapered hand NiTi files in addition to their less taper allowing them to enlarge the apical portion without touching the previously flared coronal portion of the canal. Therefore, the lateral force produced in the apical preparation is diminished and consequently minimizes the incidence of apical transportation [43] in contrast to the more tapered files of ProTaper system.

Findings of this study are in agreement with Kim et al. [35] study who reported that reciprocating WaveOne single file system did not create excessive transportation compared with rotary ProTaper system. In addition, Berutti et al. [23] agreed with our results as they found that reciprocating WaveOne Primary single file maintained the original canal anatomy better with less modification of the canal curvature when compared to rotary ProTaper system up to F2 file. A study by Maitin et al. [44] also agreed with these results when compared the shaping abilities of four different rotary endodontic instruments (ProTaper, K3, Race and MTWO) using spiral CT and concluded that canal prepared with ProTaper system had more canal transportation at all the three levels of root canal.

Furthermore, the results obtained from this study confirmed the findings obtained by Tambe et al. [45] who compared canal transportation and centering ability of three rotary NiTi systems (ProTaper, OneShape and WaveOne) using cone beam CT. Dhingra et al. [46] reported similar results when the canal curvature modification was evaluated after canal instrumentation with WaveOne Primary reciprocating file was compared to other systems.

In contrary, our results are in disagreement with other studies [47-49] which did not demonstrate any drastic differences when compared reciprocating motion with continuous rotation. The contradictions may be due to the continuous change in direction of

the rotation under engine-driven reciprocating motion which might cause uncontrolled movement; resulting in greater canal transportation [37]. However, these studies recommended reciprocating motion as a good alternative method to prevent procedural errors.

Apical level showed the least value of canal transportation with a significant statistical difference when compared with the other two levels (coronal and middle). This was in accordance with study by Marzouk et al. [50] in which apical third significantly recorded the least canal transportation value. The least canal transportation at the apical level for Group I and II can be explained by the noncutting tip design of both ProTaper and WaveOne systems which enhances instrumentation with minimal apical pressure and functions as a guide for easier penetration without canal deviation [51,52], besides the standardized MAF diameter size # 25 for all tested groups [25]. Furthermore, the modified convex triangular cross sectional design with radial land [8] of the apical portion of WaveOne reciprocating files [53] could support the edge of the cutting angle and reduce canal transportation by distributing the pressure on the blades more uniformly around the circumference of a curved canal [54].

While, the least value of canal transportation at the apical level for Group III may be attributed to the using of crown down instrumentation technique which produces less constraint to the used files, better control of the file tip and subsequently less apical zipping and transportation [19, 55].

On the contrary, the highest mean value of canal transportation at the coronal level may be related to the highly-tapered coronal cross section (i.e. 0.08) in combination with the increased core diameter of both rotary ProTaper F2 and reciprocating WaveOne Primary files and the brushing motion during rotary preparation with S1 and S2 files toward the mesial aspect [22], while for NiTiFlex group; Gates Glidden drills were used for coronal third enlargement which might be responsible for the highest transportation at this level.

In ProTaper group, there was no statistical significant difference in canal transportation between the three tested levels, yet the coronal level showed the highest transportation value. As long as cross-sectional design has an effect on canal transportation [56], this result may be due to the thick core of the convex triangle cross section of ProTaper file which makes it less flexible and more resistant to bending leading to deviation in the coronal region.

This finding was in accordance with Miglani et al. [57] who found no statistical significant difference between 7.5 and 5 mm slices while, there was statistical significant less transportation in 3.5 mm than both 5 and 7.5 mm slices. In addition to Schäfer et al. study [58] in which 0.08 tapered files were recommended to safely prepare apical region of root canals without creating severe aberrations unless using less tapered files before 0.08 tapered ones.

However, this disagrees with You et al. [37] who found no statistical significant difference between 3 and 5 mm slices but the apical sections showed the highest mean of canal transportation. The results of the current study can't be compared directly with those of the previous one [37] as the difference in using simulated canals and the microscopic superimposed images as an evaluation method for their study.

Coronal level of WaveOne group also showed the highest canal transportation followed by middle level, while the apical level showed the least value with a statistical significant difference between the coronal and apical levels. This may be due to the difference of WaveOne cross sectional design as a modified convex triangular cross section with radial lands at the tip end and a convex triangular cross section at the coronal end [59]. The radial lands at the tip, the cutting angle projected and the reciprocating working motion are claimed to keep WaveOne instrument centered, whilst advancing apically into the root canal [60].

This result was augmented by a recent study conducted by Amaral et al. [61]. While, the present study findings regarding transportation of the coronal third after instrumentation with WaveOne system differ from those found in another study by Bürklein et al. [62] as their study was transformed on simulated resin blocks which may explain these conflicting results.

In addition, NiTiFlex group showed the highest canal transportation at the coronal level followed by middle level, while the apical level showed the least value of canal transportation; this reflects the difference in flexibility between Gates Glidden drills used in coronal section flaring and flexible 0.02 tapered NiTi files used for apical part instrumentation. However, this finding is in disagreement with studies by Lam et al. [63] and Oliveira et al. [64]; they stated that the greatest transportation occurs at the apex and 2 mm from the apex. It should be noted that simulated root canals were used which explaining the changes in obtained results.

Comparison of different levels regardless the used instrumentation technique revealed that the least canal transportation value was associated with the apical level, while the highest value was associated with the coronal one. This may be attributed to the difference in cross sectional geometry of MB canal of lower first molar among its three tested levels; starting with an oval cross section at the cervical and middle two thirds while ending with a rounded cross sectional configuration at its apical third [65]. Consequently, the

mechanical action of files is unlikely to affect the entire circumference of the oval cross section while, preparing the round cross sectional part of the canal with more uniform dentin removal [3].

The direction of canal transportation after instrumentation was also evaluated; results showed greater tendency toward the mesial aspect (outer) curvature of the root canal for all groups at apical third. While, the coronal and middle levels in all instrumentation groups; a greater tendency toward the distal aspect (inner) curvature of the root canal was observed. This may be attributed to the straightening of root canal instrument inside the curved canal with uneven removal of dentin from the inner aspect of coronal portion and outer aspect of apical portion, in addition to the used crown down approach which has a tendency to straighten curved canals and causes transportation toward the furcation at the middle and coronal levels predisposing the strip perforation as a susceptible consequence to canal transportation mainly found in this 'danger zone' of mesial roots of mandibular molars [66].

Several studies have reported similar results [64, 67], while these results were opposed by Lam et al. [63] study in which deviation toward the inner curvature aspect was observed and this conflict may be attributed to using S-shaped Endo-training blocks instead of natural teeth, however Peters et al. [68] demonstrated that there is no constant pattern regarding the direction of apical transportation. In addition, You et al. [37] conceived that ProTaper files have a tendency to straighten curved canals and causes transportation toward the furcation at middle and coronal levels, while transportation at the apical 1-3 mm level occurs toward the outer aspect of curvature.

5. Recommendations:

ProTaper is not encouraged as a rotary NiTi technique for apical preparation in severely curved canals. WaveOne reciprocating system is recommended in preparing canals with moderate and severe curvatures.

Further modifications in NiTi metallurgy, file design and system kinematics of current NiTi systems are recommended for better preservation of original canal curvature.

References:

1. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004; 30: 559–67.
2. Cohen S, Burns RC. Pathways of the pulp. 8th ed. St Louis: Mosby, 2002; 94, 243–74, 325–31, 644–5.
3. Zvi M, Michael S, Anda K. The role of mechanical instrumentation in the cleaning of root canals. Endo Topics 2013; 29: 87–109.
4. Schäfer E, Lohmann D. Efficiency of rotary nickel-titanium FlexMaster instruments compared with stainless steel hand K-Flexofile. Shaping ability in simulated curved canals. Int Endod J 2002; 35: 505–13.
5. Berutti E, Chiandussi G, Gaviglio I, Ibba A. Comparative analysis of torsional and bending stresses in two mathematical models of nickel-titanium rotary instruments: ProTaper versus ProFile. J Endod 2003; 29: 15–9.
6. Calberson FL, Deroose CA, Hommez GM, De Moor RJ. Shaping ability of ProTaper nickel-titanium files in simulated resin root canals. Int Endod 2004; 37: 613–23.
7. De-Deus G, Brandão MC, Barino B, Di Giorgi K, Fidel RA, Luna AS. Assessment of apically extruded debris produced by single-file ProTaper F2 technique under reciprocating movement. Oral Surg OralMed Oral Pathol Oral Radiol Endod. 2010; 110: 390–4.
8. 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 Wave One versus Mtwo and ProTaper. Int Endod J 2012; 45: 449–61.
9. Gergi R, Arbab-Chirani R, Osta N, Naaman A. Micro-computed tomographic evaluation of canal transportation instrumented by different kinematics rotary nickel-titanium Instruments. J Endod 2014; 40: 1223–7.
10. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971; 32: 271–5.
11. 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; 36: 1068–72.
12. 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.
13. Zhao D, Shen Y, Peng B, Haapasalo M. Root canal preparation of mandibular molars with 3 nickel-titanium rotary instruments: A micro–computed tomographic study. J Endod 2014; 40: 1860–4.
14. Morgan LF, Montgomery S. An evaluation of the crown-down pressureless technique. J Endod 1984; 10: 491–8.
15. Akhlaghi NM, Naghdi A, Bajgiran LM, Behrooz E. Computed tomography evaluation of residual root thickness after pre-flaring using gates Glidden drills: The sequence effect. J Conserv Dent 2014; 17: 142–5.
16. Ghoneim WM, Farag AM, Labib AH, Derrag AM. Cleaning efficacy of different root canal preparation systems and irrigation regimens. Tanta Dent J 2014; 11: 36–41.
17. 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.

18. Yamamura B, Cox TC, Heddaya B, Flake NM, Johnson JD, Paranjpe A. Comparing canal transportation and centering ability of EndoSequence and Vortex rotary files by using micro-computed tomography. J Endod 2012; 38: 1121–5.
19. Hülsmann M, Peters O, Dummer P. Mechanical preparation of root canals: shaping goals, techniques and means. Endo Topics 2005; 10: 30–76.
20. Kaptan F, Sert S, Kayahan B, Haznedaroğlu F, Tanalp J, Bayirli G. Comparative evaluation of the preparation efficacies of HERO Shaper and NiTiFlex root canal instruments in curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005; 100: 636–42.
21. Bertrand MF, Lupi-Pégurier L, Médioni E, Muller M, Bolla M. Curved molar root canal preparations using Hero 642 rotary nickel-titanium instruments. Int Endod J 2001; 34: 631–6.
22. Paqué F, Zehnder M, De-Deus G. Microtomography-based comparison of reciprocating single-file F2 ProTaper technique versus rotary full sequence. J Endod 2011; 37:1394–7.
23. Berutti E, Chiandussi G, Paolino DS, Scotti N, Cantatore G, Castellucci A, et al. Canal shaping with WaveOne Primary reciprocating files and ProTaper system: a comparative study. J Endod 2012; 38: 505–9.
24. Hartmann MS, Barletta FB, Camargo Fontanella VR, Vanni JR. Canal transportation after root canal instrumentation: a comparative study with computed tomography. J Endod 2007; 33: 962–5.
25. Marzouk AM, Ghoneim AG. Computed tomographic evaluation of canal shape instrumented by different kinematics rotary nickel-titanium systems. J Endod 2013; 39: 906–9.
26. 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.
27. Celik D, Tasdemir T, Er K. Comparative study of 6 rotary nickel- titanium systems and hand instrumentation for root canal preparation in severely curved root canals of extracted teeth. J Endod 2013; 39: 278–82.
28. Garip Y, Gençoğlu N. Comparison of curved canals preparations using ProFile, GT and Hero 642 rotary files. J Oral Rehabil 2006; 33: 131–6.
29. 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.
30. 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.
31. Peters OA, Laib A, Rüegsegger P, Barbakow F. Three-dimensional analysis of root canal geometry by high-resolution computed tomography. J Dent Res 2000; 79, 1405–9.
32. Freire LG, Gavini G, Cunha RS, Santos Md. Assessing apical transportation in curved canals: comparison between cross-sections and micro-computed tomography. Braz Oral Res 2012; 26: 222–7.
33. El Batouty KM, Elmallah WE. Comparison of canal transportation and changes in canal curvature of two nickel-titanium rotary instruments. J Endod 2011; 37, 1290–2.
34. 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.
35. Kim HC, Kwak SW, Cheung GS, Ko DH, Chung SM, Lee W. Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in reciprocation motion: Reciproc versus WaveOne. J Endod 2012; 38: 541–4.
36. Pereira ES, Peixoto IF, Viana AC, Oliveira II, Gonzalez BM, Buono VT, et al. Physical and mechanical properties of a thermomechanically treated NiTi wire used in the manufacture of rotary endodontic instruments. Int Endod J 2012; 45: 469–74.
37. 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: 1296–300.
38. 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.
39. Varela-Patiño P, Ibañez-Párraga A, Rivas-Mundiña B, Cantatore G, Otero XL, Martin-Biedma B. Alternating versus continuous rotation: a comparative study of the effect on instrument life. J Endod 2010; 36: 157–9.
40. 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.
41. 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.
42. Zhang L, Luo HX, Zhou XD, Tan H, Huang DM. The shaping effect of the combination of two rotary nickel-titanium instruments in simulated S-shaped canals. J Endod 2008; 34: 456–8.
43. Ribeiro MB, Albergaria SJ, Malvar MG, Crusoé-Rebello IM, Gomes BP, de Carvalho FB. Canal transportation and centering ability of curved root canals prepared using rotary and reciprocating systems. Braz J Oral Sci 2015; 14: 214–8.
44. Maitin N, Arunagiri D, Brave D, Maitin SN, Kaushik S, Roy S. An ex vivo comparative analysis on shaping ability of four NiTi Rotary endodontic instrument using spiral computed tomography. J Conserv Dent 2013; 16: 219–23.
45. Tambe VH, Nagmode PS, Abraham S, Patait M, Lahoti PV, Jaju N. Comparison of canal transportation and centering ability of rotary ProTaper, OneShape system and WaveOne system using cone beam computed tomography: An in vitro study. J Conserv Dent 2014; 17: 561–5.
46. Dhingra A, Gupta R, Singh A. Comparison of Centric Ability of ProTaper Next, WaveOne & ProTaper using

Cone Beam Computed Tomography. Endodontology 2014; 26: 244–51.
47. Iqbal MK, Firic S, Tulcan J, Karabucak B, Kim S. Comparison of apical transportation between ProFile and ProTaper NiTi rotary instruments. Int Endod J 2004; 37: 359–64.
48. Zhao D, Shen Y, Peng B, Haapasalo M. Root canal preparation of mandibular molars with 3 nickel-titanium rotary instruments: a micro–computed tomographic study. J Endod 2014; 40: 1860–4.
49. Gekelman D, Ramamurthy R, Mirfarsi S, Paqué F, Peters OA. Rotary nickel-titanium GT and ProTaper files for root canal shaping by novice operators: a radiographic and micro-computed tomography evaluation. J Endod 2009; 35:1584–8.
50. Marzouk AM, Ghoneim AG. Computed tomographic evaluation of canal shape instrumented by different kinematics rotary nickel-titanium systems. J Endod 2013; 39: 906–9.
51. Dhingra A, Kochar R, Banerjee S, Srivastava P. Comparative evaluation of canal curvature modifications after instrumentation with OneShape rotary and WaveOne reciprocating files. J Conserv Dent 2014; 17: 138–41.
52. Karabucak B, Gatan AJ, Hsiao C, Iqbal MK. A comparison of apical transportation and length control between EndoSequence and Guidance rotary instruments. J Endod 2010; 36: 123–5.
53. Bürklein S, Tsotsis P, Schäfer E. Incidence of dentinal defects after root canal preparation: reciprocating versus rotary instrumentation. J Endod 2013; 39: 501–4.
54. Lim YJ, Park SJ, Kim HC, Min KS. Comparison of the centering ability of WaveOne and Reciproc nickel-titanium instruments in simulated curved canals. Restorative Dentistry and Endodontics 2013; 38: 21–5.
55. Goerig AC, Michelich RJ, Schultz HH. Instrumentation of root canals in molar using the step-down technique. J Endod 1982; 8: 550–4.
56. Zhao D, Shen Y, Peng B, Haapasalo M. Micro-computed tomography evaluation of the preparation of mesiobuccal root canals in maxillary first molars with Hyflex CM, Twisted Files, and K3 instruments. J Endod 2013; 39: 385–8.
57. Miglani R, Narayanan LL, Rao CV. CT analysis of transportation and centering ratio using three rotary NiTi files in curved root canals-An in vitro study. Endodontology 2008:18–24.
58. Schäfer E, Vlassis M. Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus Race. Part 1. Shaping ability in simulated curved canals. Int Endod J 2004; 37: 229–38.
59. Versiani MA, Leoni GB, Steier L, De-Deus G, Tassani S, Pécora JD, et al. Micro-computed tomography study of oval shaped canals prepared with the Self-adjusting file, Reciproc, WaveOne, and ProTaper Universal Systems. J Endod 2013; 39: 1060–6.
60. Webber J, Machtou P, Pertot W, et al. The WaveOne single-file reciprocating system. Roots 2011; 1: 28–33.
61. Jatahy Ferreira do Amaral RO, Leonardi DP, Gabardo MC, Coelho BS, Oliveira KV, Baratto Filho F. Influence of Cervical and Apical Enlargement Associated with the WaveOne System on the Transportation and Centralization of Endodontic Preparations. J Endod 2016; 42:626-31.
62. Bürklein S, Poschmann T, Schäfer E. Shaping ability of different nickel-titanium systems in simulated S-shaped canals with and without glide path. J Endod 2014; 40: 1231–4.
63. Lam TV, Lewis DJ, Atkins DR, Macfarlane RH, Clarkson RM, Whitehead MG, et al. Changes in root canal morphology in simulated curved root canals over-instrumented with a variety of stainless steel and nickel-titanium files. Aust Dent J 1999; 44: 12-9.
64. Oliveira CA, Meurer MI, Pascoalato C, Silva SR. Cone-beam computed tomography analysis of the apical third of curved roots after mechanical preparation with different automated systems. Braz Dent J 2009; 20, 376-81.
65. Cohen S, Burns RC. Pathways of the pulp. 8th ed. St Louis: Mosby, 2002; 94, 243–74, 325–31, 644 –5.
66. Young GR, Parashos P, Messer HH. The principles of techniques for cleaning root canals. Aust Dent J 2007; 52: 52–63.
67. Pasternak-Júnior B, Sousa-Neto MD, Silva RG. Canal transportation and centring ability of RaCe rotary instruments. Int Endod J 2009; 42: 499–506.
68. Oliveira CA, Meurer MI, Pascoalato C, Silva SR. Cone-beam computed tomography analysis of the apical third of curved roots after mechanical preparation with different automated systems. Braz Dent J 2009; 20, 376-81.
69. 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.

1/10/2018