Clin Oral Invest (2016) 20:2227–2233
DOI 10.1007/s00784-016-1732-4

ORIGINAL ARTICLE

Shaping ability of two nickel–titanium instruments activated by continuous rotation or adaptive motion: a micro-computed tomography study

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Received: 26 October 2015 / Accepted: 19 January 2016 / Published online: 15 February 2016

Abstract
Objectives The objective of the study was to evaluate the shaping ability of curved root canals using Twisted File Adaptive (TFA) files (SybronEndo, Orange, CA) and Mtwo (Sweden & Martina, Padova, Italy) activated by continuous rotation or adaptive motion.
Materials and methods Thirty-two mandibular molars with two separate mesial canals and severe angles of curvature were selected. Each canal was randomly assigned to one of the four experimental groups ($n = 16$): TFA and Mtwo files used in continuous rotation (groups 1 and 3) or in adaptive motion (groups 2 and 4). Root canals before and after preparation were assessed by micro-computed tomography. Volume, surface area, canal transportation, and centering ability were recorded and analyzed using two-way analyses of variance.
Results Volume and surface area increased less with TFA files in continuous rotation than in other groups ($P < 0.001$ and $P < 0.01$, respectively, for each comparison) that were not different ($P > 0.05$). TFA files had significantly less transportation and higher centering ability than Mtwo both in continuous and adaptive motion ($P < 0.0001$). Centering ratio, but not canal transportation, was improved by adaptive motion compared with continuous rotation for both instruments ($P < 0.01$). However, no differences were found in canal transportation and centering ability in the apical third for both instruments and motions ($P > 0.05$).
Conclusions No difference between the devices and kinematics was found in the apical third; TFA performed significantly better in the middle and coronal parts of the root canal.
Clinical relevance The use of NiTi files made by heat-treated alloy and/or adaptive motion could improve the qualities of root canal shaping rather than the use of conventional NiTi instruments and/or continuous rotation in the coronal and middle thirds of the root canals, but not in the apical one. Moreover, these findings encourage the use of adaptive motion with conventional NiTi files to improve centering ability without affecting other preparation qualities of root canals.

Keywords Shaping ability · Micro-computed tomography · Nickel–titanium instruments · Adaptive motion · Continuous rotation

Electronic supplementary material The online version of this article (doi:10.1007/s00784-016-1732-4) contains supplementary material, which is available to authorized users.

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Introduction

The use of nickel–titanium (NiTi) rotary instruments enhanced the quality of canal shaping [1, 2].

However, particularly in curved canals, iatrogenic procedural errors, such as ledges, zips, perforations, or root canal transportation, can occur [3] because instrumentation techniques can divert the canal away from its original axis [4].

Numerous root canal shaping techniques using different NiTi systems (as M-wire, R-phase, conventional NiTi) and different kinematics (continuous rotation, reciprocating motion, and adaptive motion) have been suggested to maintain the original canal shape centered [5, 6].

S-shaped cross-section Mtwo rotary files (Sweden & Martina, Padova, Italy), made by traditional NiTi, and Twisted Files (SybronEndo, Orange, CA), made by R-Phase treated NiTi with an equilateral triangular cross-section, are two NiTi rotary systems [7] designed to be used with clockwise (CW) continuous rotation (CR) [8].

Recently, the Twisted File Adaptive system has been introduced. This system includes a specific sequence of Twisted File instruments called "Twisted Files Adaptive" (TFA) activated by adaptive motion (AM) which combines a continuous rotation in a CW direction, when the instrument is exposed to a minimal load, and a reciprocating motion (370° CW and 50° counterclockwise (CCW), when the file engages dentin and load is applied [6, 9].

The values of CW and CCW rotating angles of the AM reciprocation are different. A large rotating angle in the cutting direction (CW) allows the instrument to advance in the canal and cuts dentine, whereas a smaller angle in the opposite direction (CCW) minimizes the risk of instrument fracture caused by torsional stress [10].

For these reasons, this movement could be used efficiently and safely by endodontic instruments designed to cut in CW rotation as Mtwo and Twisted File Adaptive.

However, little is known about the differences in canal shaping ability of Mtwo and TFA instruments and CR or AM movements. Moreover, no study has investigated the shaping ability of TFA files or Mtwo activated by either CR or AM.

Therefore, the purpose of this study was to compare the effects of different nickel–titanium files activated by CR or AM on canal volume, surface area, transportation, and centering ability using micro-computed tomography (μCT).

The null hypothesis was that no difference could be detected in the analyzed parameters between the two different instruments and kinematics tested.

Materials and methods

Specimen selection and preparation

Thirty-two extracted mandibular molars with completely formed apices and curved mesial root canals were selected and stored in a glass bottle containing 0.9 % saline solution. Inclusion criteria were as follows: two separate mesial canals confirmed by periapical radiographs in a mesio-distal and bucco-lingual projection with two separate apical foramina; similar root shape with angles of curvature between 25° and 35° measured by Schneider's method [11] (Schneider 1971) and a radius below 10 mm [12] using digitized buccolingual radiographs and AxioVision 4.5 software (Carl Zeiss Vision, Hallbergmoos, Germany) [13].

After resection of the distal root, teeth were decoronated [13] and their length was standardized at 13 mm [14, 15]. The patency of the root canals was confirmed when a #10 K-flexofile (Dentsply Maillefer) was visible at the apical foramen. The working length was then set at 0.5 mm shorter. Six small round holes, acting as reference points, were made on the external surface of the root using a #801-010 round diamond bur (Komet Italia S.r.l, Milan, Italy) and filled with composite (Z250, 3 M, St Paul, MN, USA) at levels 2.0, 4.0, 6.0, 8.0, 10.0, and 12.0 mm from the apex of the tooth [16]. Then, the specimens were disinfected in 0.5 % chloramine T and stored in 0.1 % thymol solution at 4 °C [13].

The root canals ($n = 64$) were randomly assigned to four different instrumentation groups. Randomization was stratified to ensure that mesiobuccal and mesiolingual canals were distributed equally to each group [17].

Micro-CT (μCT) scanning and measurements

Specimens were scanned before and after root canal preparation by a GE Locus SP micro-CT scanner (GE Pre-clinical Imaging, London, ON, Canada) at 80 kV and 80 μA with an isotropic resolution of 20 μm [16].

A 0.02-mm aluminum filter was used to reduce beam-hardening artifacts and scattering.

All the scans were reoriented with respect to the x-, y- and z-axes, using the imaging software MicroView (GE Pre-clinical Imaging).

3D models, morphological parameters of the mesial canals (volume and surface area) and 2D measurements calculating canal transportation and centering ratio were obtained importing the TIFF converted cross-sectional images from MicroView software into a 3-D visualization and analyses software Amira 4.1 (Mercury Computer System Chelmsford, MA, USA).

The apical, middle, and coronal-third regions of the canals were determined by the number of cross-sectional slices from the apex of the tooth to the full 12.00 mm reference point and then divided by three.

Preparation of canals

The same expert operator carried out the preparation of the canals using the Elements Motor (SybronEndo, Orange, CA) and 8:1 reduction ratio contra-angle handpiece.

The canals were divided into four experimental groups ($n = 16$): prepared with TFA and Mtwo files up to size 25, 0.06 taper used in CR (groups 1 and 3) or in AM (groups 2 and 4). A new series of files was used for each canal.

Continuous rotation was performed at 300 rpm and maximum torque value, while adaptive motion was performed with the specific "TF-ADAPTIVE" pre-set program.

Canals assigned to Mtwo groups (1 and 3) were prepared using each of four instruments (size 10, 0.04 taper, size 15, 0.05 taper, size 20, 0.06 taper and size 25, 0.06 taper) to the full working length.

Those assigned to TFA files groups (2 and 4) were prepared as recommended by the manufacturer using SM1 (size 20, 0.04 taper) and SM2 (size 25, 0.06 taper) in sequence until each file reached the working length.

In all groups, the root canals were irrigated with 3 mL of 5.25 % sodium hypochlorite solution before each instrument was inserted into the root canal by using a disposable syringe on which Endo Irrigation Needle single side vent (Transcodent, Kesselort, Germany) irrigator tip was mounted.

When root canal instrumentation was completed, 1 mL of 17 % EDTA (Ogna, Milan, Italy) was applied for 1 min and the canals were flushed with 3 mL of bi-distilled water.

Measurement of canal volume and surface area

Volume of the canals before and after instrumentation was assessed separately to match precisely the areas of interest using the software AMIRA 4.1 and its segmentation editor tool to create a three-dimensional region of interest of canal whose volume and surface area were measured (Supplemental Video). Moreover, the histogram tool was employed to calculate an automatic threshold, which was then used to produce an iso-surface (3-D μCT image) of the canal (Fig. 1).

Mean and standard deviation of the volume and surface area increase (Δ) were determined in mm^3 and mm^2, respectively, for each root canal by subtracting the non-instrumented value from the instrumented one. Moreover, mean increase percentage (%Δ) and standard deviations of these 3D parameters were calculated.

Measurement of canal transportation and centering ratio

The pre- and post-instrumentation scans were superimposed in AMIRA 4.1 by multiplanar-viewer function to investigate canal transportation and centering ratio applying the technique developed by Gambill et al. [18]. Therefore, the measures were determined by the shortest distance from the edge of the uninstrumented canal to the edge of the tooth in both mesial and distal directions and then compared with the values measured from the prepared canals. Transportation and centering ratio were evaluated by two blinded operators at twelve different equidistant levels predetermined with the line measuring tool of AMIRA 4.1: four equidistant levels for each root canal third. The examiners were trained and calibrated prior to execute the measurements.

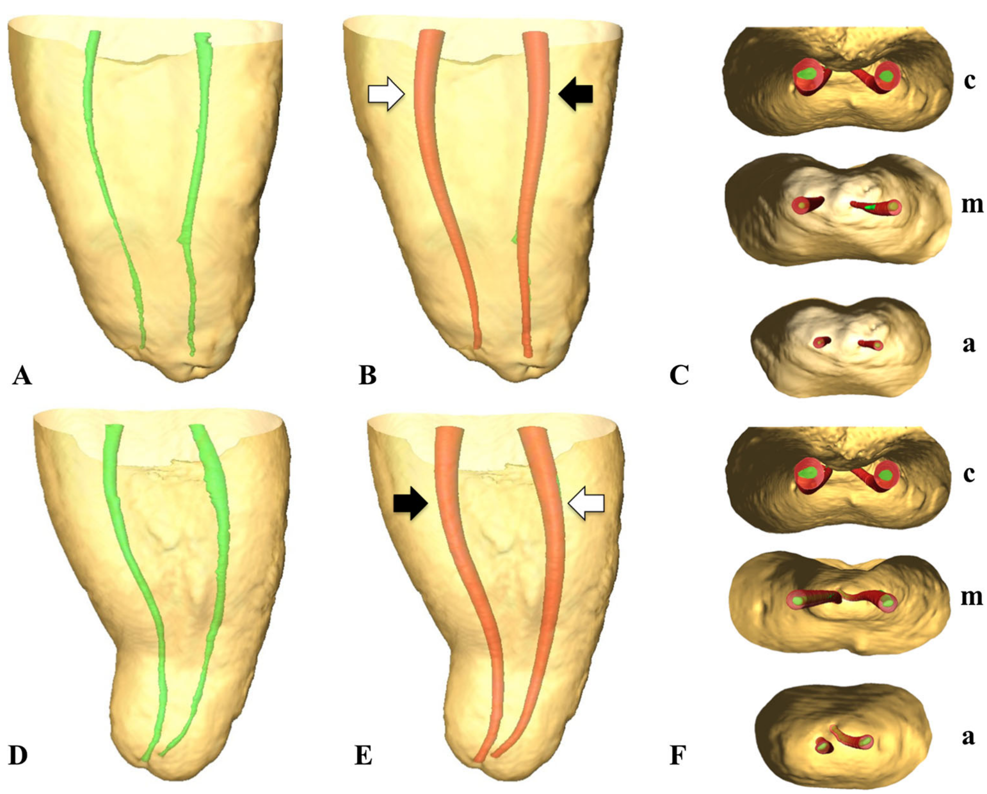

Fig. 1 Representative 3D reconstructions of the root canals of mesial root of mandibular molars before (in *green*) and after (in *red*) canal preparation. (A–C = Twisted File Adaptive instruments; D–F = Mtwo files). **a**, **b** Lateral view of root canals and **c** axial view of superimposed root canals before (*green*) and after (*red*) preparation at coronal (*c*), middle (*m*), and apical (*a*) thirds by TFA instruments in continuous rotation (*black arrow*) or in adaptive motion (*white arrow*). **d**, **e** Lateral view of root canals and **f** axial view of superimposed root canals before (*green*) and after (*red*) preparation at coronal (*c*), middle (*m*), and apical (*a*) thirds by Mtwo instruments in continuous rotation (*black arrow*) or in adaptive motion (*white arrow*)

Data presentation and statistical analysis

The mean differences and standard deviations in volume and surface area of the entire canal as well as canal transportation and centering ratio of the apical, middle, and coronal-third of the canals were calculated.

Data were first verified with the D'Agostino & Pearson test for the normality of the distribution and the Levene test for the homogeneity of variances. Data were normally distributed and homogenous; therefore, they were statistically analyzed by using two-way analysis of variance and Bonferroni post hoc test for multiple comparisons at a level of significance set at $P < 0.05$ (Prism 5.0; GraphPad Software, Inc, La Jolla, CA). Volume, surface area, canal transportation, and centering ratio were dependent variables, whereas file and kinematics types were independent measures.

Results

No significant difference was found between groups concerning angle and radius of curvature before root canal shaping ($P > 0.05$) (Table 1).

Volume and surface area (3D parameters)

Instrumentation of the canals resulted predictably in increased canal volume and surface area. Table 2 shows the three-dimensional analysis of volume and surface area increase for the entire canal.

TFA files in AM and Mtwo instruments activated by both movements tested produced higher volume and surface area increase than TFA files in continuous rotation ($P < 0.01$ and $P < 0.05$, respectively, for each comparison), but no difference was found between them ($P > 0.05$).

Table 1 Angle of curvature (degree) and radius of curvature (mm) in each instrumentation group (mean ± SD)

Group ($n = 16$)	Curvature angle	Curvature radius
Mtwo–CR	29.05 ± 3.81	6.76 ± 1.61
Mtwo–AM	28.86 ± 3.17	6.51 ± 1.40
TFA–CR	29.52 ± 3.63	6.81 ± 1.05
TFA–AM	29.14 ± 2.88	6.20 ± 1.37
P value	0.8329[a]	0.5267[a]

SD standard deviation

[a] Not significantly different (ANalysis Of VAriance, ANOVA test)

Canal transportation and centering ability

The results of canal transportation and centering ratio are summarized in Table 3.

In the cervical and middle section of the root canal, less canal transportation and higher centering ratio were achieved by TFA files than by Mtwo in CR and AM ($P < 0.0001$), while centering ability, but not canal transportation, was improved by the adaptive motion and not by continuous rotation for both instruments ($P < 0.001$).

However, in the apical third, there were no difference between both instruments and movements tested in canal transportation and centering ability ($P > 0.05$).

Discussion

Few studies have investigated the shaping ability of NiTi instruments activated by different movements [6, 13, 15–17, 19–21]. However, none of them used different kinematics to activate each instrument tested. This study compared the effects on canal volume, surface area, transportation, and centering ability of Mtwo and Twisted Files Adaptive instruments activated by both CR and AM using micro-CT.

Micro-computed tomography was preferred to other methodologies such as the reassembly technique [22–24], radiographic comparisons [25–28], and silicone impressions of canals in order to obtain a non-invasive and reproducible three-dimensional evaluation of root canal systems [12, 13].

The same motor (Elements Motor) was used to perform two movements tested. The adaptive motion is achieved by a preset and unchangeable program that changes CW continuous rotation into reciprocating motion with advancement in CW direction of the file on the basis of the applied load [19].

Mtwo and TFA files were used because these are made by different alloy (conventional NiTi and R-phase respectively) with different flexibility that influences canal transportation even in severely curved root canals as previously stated in literature [6, 29, 30].

Moreover, both these instruments have a right-handed angulation of the blades, which means that they cut in the CW direction [10]. For this reason, they could shape root canals both in CW continuous rotation and in reciprocating motion with rotating angle larger in CW than in CCW direction as in adaptive motion kinematic.

In the present study, mesial roots of mandibular molars with severe angles of curvature were selected because these roots contain canals that are often narrow and curved increasing the difficulty of instrumentation [19].

The curvatures of all root canals ranged between 25° and 35° and the absence of a significant difference between the angles of curvature and radius of the different groups before

Table 2 3D morphometric data (mean ± standard deviation) before and after preparation using Mtwo or TFA in continuous rotation (-CR) or "adaptive" motion (-AM)

	Experimental groups			
	Mtwo–CR	Mtwo–AM	TFA–CR	TFA–AM
Volume (mm^3) (initial)	2.27 ± 0.85	2.61 ± 0.95	2.31 ± 0.92	2.42 ± 0.80
After preparation	4.74 ± 1.27	5.01 ± 1.21	3.43 ± 1.02	4.34 ± 0.98
Δ	2.47 ± 0.64^a	2.40 ± 0.83^a	1.12 ± 0.86^b	1.92 ± 0.76^a
Δ%	109.62 ± 44.52	99.80 ± 62.03	60.55 ± 55.58	91.20 ± 69.91
Surface area (mm^2) (initial)	19.31 ± 4.90	20.60 ± 5.47	17.03 ± 4.63	18.82 ± 0.75
After preparation	27.38 ± 5.24	28.16 ± 6.07	22.04 ± 4.28	26.93 ± 4.59
Δ	8.06 ± 2.75^a	7.56 ± 2.90^a	5.01 ± 2.95^b	8.11 ± 2.86^a
Δ%	40.73 ± 15.34	39.62 ± 27.31	27.40 ± 15.85	45.95 ± 31.02

Δ, mean increase (±standard deviation) of the analyzed parameter

Different superscript letters in the same line indicate statistical significant difference between groups (two-way ANOVA and post hoc Bonferroni test, $P < 0.05$)

Within groups, values of volume and surface area after preparation are significant increased than the initial ones in all groups (two-way ANOVA test, $P < 0.05$)

instrumentation provided an adequate standardization of the test groups [31].

Canal volume and surface area are variables used to assess quality of preparation by different instrumentation techniques [15].

However, no data is available on volume and surface area changes by TFA files or Mtwo used in CR or AM. Thus, these present findings cannot be directly compared with previous reports [32].

In this study, Mtwo showed a higher increase of volume and surface area than TFA files in continuous rotation, but not in adaptive motion. On the other hand, adaptive motion showed a significantly higher increment of volume and surface area than continuous rotation obtained by TFA files, but not by Mtwo.

These differences are probably due to the different flexibility, cross-sectional design, metallurgical properties of the files, and the adaptive motion (which combines continuous rotation and reciprocating motion) that could influence the cutting ability, the amount of root canal walls touched as well as the amount of dentine removed by the instruments [6].

Moreover, the lower increase of volume and surface area by TFA than Mtwo could be due to the possible undersized dimensions of the last TFA instrument (SM2) used to prepare the specimens. In fact, SM2 TFA is exactly the same as a Twisted File instrument with a tip diameter of 25 and 0.06 taper and it was reported that the Twisted File size 25, 0.06 taper is smaller than the declared dimensions [33].

The higher increase of volume and surface area obtained using Mtwo could be a sign of their higher cutting efficiency due to their positive axial angle of the two cutting edges [34]. However, the higher amount of dentin removed by Mtwo could reduce the resistance to vertical root fracture of the instrumented teeth [35].

In the coronal and middle thirds, TFA files showed less canal transportation and higher centering ability than Mtwo

Table 3 Canal transportation mean ± standard deviation (SD) in mm and centering ratio after preparation with Mtwo or TFA in continuous rotation (-CR) or "adaptive" motion (-AM)

		Canal transportation				Centering ratio			
File–motion	Number	All thirds Mean ± SD	Coronal third Mean ± SD	Middle third Mean ± SD	Apical third Mean ± SD	All thirds Mean ± SD	Coronal third Mean ± SD	Middle third Mean ± SD	Apical third Mean ± SD
Mtwo–CR	16	0.15 ± 0.04^a	0.28 ± 0.04^a	0.23 ± 0.10^a	−0.04 ± 0.07^a	0.37 ± 0.14^a	0.23 ± 0.06^a	0.32 ± 0.24^a	0.54 ± 0.17^a
Mtwo–AM	16	0.13 ± 0.08^a	0.35 ± 0.04^a	0.22 ± 0.18^a	−0.03 ± 0.05^a	0.54 ± 0.13^b	0.33 ± 0.14^b	0.46 ± 0.25^b	0.68 ± 0.09^a
TFA–CR	16	0.04 ± 0.03^b	0.09 ± 0.28^b	0.07 ± 0.04^b	−0.02 ± 0.04^a	0.52 ± 0.15^b	0.32 ± 0.04^b	0.51 ± 0.15^b	0.59 ± 0.14^a
TFA–AM	16	0.01 ± 0.03^b	0.06 ± 0.06^b	0.03 ± 0.04^b	−0.03 ± 0.01^a	0.67 ± 0.07^c	0.68 ± 0.15^c	0.72 ± 0.13^c	0.60 ± 0.13^a

Values of canal transportation in the all thirds; according to Gambil et al. method, coronal and middle thirds are positive indicating transportation towards the furcal (distal) aspect of the root; while in the apical third, they are negative indicating a minimum transportation towards the mesial aspect of the root

Centering ratio: the closer the result is to zero, the worse the ability is of the instrument to remain centered

Different superscript letters in the same column indicate significant differences among groups (two-way ANOVA post hoc Bonferroni test, $P < 0.05$)

instruments with both CR and AM. However, AM produced higher centering ratio, but not a better canal transportation, than CR using TFA files and Mtwo.

These findings are in agreement with previous papers in which twisted file adaptive system reported lower value of canal transportation and higher value of centering ratio in comparison with reciprocating systems [17, 19]. Same results were obtained by twisted files when compared with continuous rotating instruments (including Mtwo) [13, 36]. Conversely, another study reported no difference in canal transportation and centering ratio of Twisted files and Mtwo assessed by using a modified double digital radiographic technique. The differences in these results are probably due to the different methodology of these studies [37].

The lesser canal transportation of the TFA files than Mtwo could be due to the improved flexibility of the Twisted File [38], as a result of the thermal pre-treatment of the alloy during manufacturing which makes it more ductile, reducing the magnitude of the restoring forces [38].

However, in the apical third, no difference was found in canal transportation and centering ability of the different instruments (TFA files or Mtwo) or kinematics tested (CR or AM). These results are in agreement with a previous study that reported no influence due to the type of mechanical movements or instruments on apical canal transportation and centralization [39].

The absence of a statistically significant difference at the apical third between the groups could be attributed to the non-cutting modified safety tip of the Mtwo and TFA instruments, the standardization of the apical diameter size [40], and the small file dimensions that cause only a little increment of TFA files flexibility compared to Mtwo in the first millimeters from the tip of the files. In fact, the bigger is the instrument dimensions (coronal and medium parts of the files are bigger than the apical one due to the instruments taper) the greater will be the benefits of the improved flexibility due to heat-treated alloy of TFA files.

The use of the AM with conventional NiTi instruments made for CW continuous rotation, such as Mtwo, could represent a clinical possibility to improve their centering ratio without worsening other preparation qualities as volume, surface area, and canal transportation.

Conclusion

Within the limits of this study, the null hypothesis that there is no difference between Twisted File Adaptive and Mtwo in continuous rotation or in adaptive motion in the preparation of mesial root canals of mandibular molars was partially rejected.

Adaptive motion produces higher volume and larger surface area than continuous rotation with TFA; however, no difference was found with Mtwo instruments.

In the coronal and middle parts of the root canal, TFA files showed lesser canal transportation and higher centering ratio than Mtwo with both movements tested (continuous rotation and adaptive motion), while adaptive motion improved the centering ability, but not the canal transportation, for both TFA and Mtwo.

However, in the apical third, there was no difference between the instruments and movements tested.

Compliance with ethical standards This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest The authors declare that they have no competing interests.

Informed consent For this type of study, formal consent is not required.

Funding The work was supported by the Department of General Surgery and Surgical-Medical Specialties of Catania University in Catania, Italy.

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