

Hand file and manual rotary file behavior in curved canals: an ex vivo micro-CT study

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ABSTRACT

Several instrumentations systems are available in the market and it is necessary to assess their behavior in curved root canals. **Aim:** To analyze the ability of two manual instrumentation techniques to center mesial root canals of mandibular molars, studied by computed microtomography (micro-CT). **Materials and Method:** Twenty mesial root canals of mandibular molars were matched based on similar morphological dimensions using micro-CT evaluation and divided in 2 groups (n=10): (1) Crown-down technique with Gates-Glidden drills and K-Flexofiles and (2) M manual NiTi rotary system. Changes in volume, surface area and canal transportation were compared using an unpaired t-test with a 5% significance level. **Results:** No significant differences were observed between groups regarding volume surface area after root canal preparation (p>0.05). Variation in the centroid differed between groups in the total canal length, and in the cervical and middle thirds, with better centralization for the M files (p<0.05). **Conclusions:** Both manual instrumentation techniques had similar volume and surface area variation. Both techniques left unprepared canal areas with similar values. M manual NiTi files caused minor canal transportation.

Keywords: molar teeth - root canal preparation - dental instruments - X ray microtomography

To cite:

Amoroso-Silva PA, Jussiani EI, Prescinotti R, Cassanova Andrelo A, Moreira Teodosio L, Garcia Guerreiro Abrão A, Abreu Laffayett H, Chavier Guimaraes C, Limoeiro AG, Guimarães TS, Machado de Carvalho Coutinho T, Marceliano-Alves MF. Hand file and manual rotary file behavior in curved canals: an ex vivo micro-CT study. Acta Odontol Latinoam. 2025 Aug 25;38(2):146-153. <https://doi.org/10.54589/aol.38/2/146>

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Received: March 2025

Accepted: August 2025



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Comportamento de limas manuais e rotatórias acionadas à mão em canais curvos: um estudo ex vivo em micro-TC

RESUMO

Vários sistemas de instrumentação estão disponíveis no mercado, e é necessário avaliar seu desempenho em canais radiculares curvos. **Objetivo:** Analisar, por microtomografia computadorizada (micro-CT), a capacidade de centralização dos canais radiculares mesiais de molares inferiores preparados com duas técnicas de instrumentação manual. **Materiais e Método:** Vinte canais radiculares mesiais de molares inferiores foram pareados com base em dimensões morfológicas semelhantes, utilizando avaliação por micro-CT e divididos em dois grupos (n=10): Técnica Crown-down com brocas Gates-Glidden e K-Flexofiles e sistema rotatório manual NiTi M. Alterações no volume, área de superfície e transporte do canal foram comparadas usando o teste t não pareado com um nível de significância de 5%. **Resultados:** Não foram observadas diferenças significativas entre os grupos em relação à área de superfície do volume após a preparação do canal radicular (p>0,05). A variação no centro de gravidade mostrou diferenças entre os grupos em todo o comprimento do canal e nos terços cervical e médio, com melhor centralização para os sistemas testados M (p<0,05). **Conclusões:** Ambas as técnicas de instrumentação manual apresentaram variação semelhante de volume e área de superfície. Ambas as técnicas deixaram áreas do canal não preparadas com valores semelhantes. Os sistemas manuais de NiTi M apresentaram menor transporte do canal.

Palavras-chave: dentes molares - preparo do canal radicular - instrumentos odontológicos - microtomografia de raios X

INTRODUCTION

The mechanical objectives of root canal instrumentation are to prepare and shape the root canals without causing deviation or modifying their original path¹, thereby improving the efficacy of irrigation and final obturation.

In recent years, advancements in NiTi metallurgical designs and heat treatments have significantly improved endodontic mechanized rotary instrumentation. For example, heat-treated NiTi files are more flexible and more resistant to cyclic fatigue. This technical evolution in modern endodontic instrumentation has led to several micro-CT studies comparing different methods of mechanized instrumentation^{2,3}.

Some schools of dentistry still teach manual techniques using stainless-steel hand files for preparing root canals. Hand file instrumentation with K-files usually requires a longer learning curve and acquisition of clinical competence in technical procedures⁴. Moreover, manual techniques are usually time consuming and involve several steps and files to prepare the root canal⁵. Although K-files can be bent to negotiate canal curvatures, they do not achieve the desired instrumentation quality, especially in posterior teeth, since the rigidity of the instrument metal results in canal transportation⁴.

Mesial roots of mandibular molars usually have narrow canals, especially in the cervical third, in which their mesiodistal diameter is smaller than the buccolingual diameter⁶, and Gates-Glidden (GG) drills are frequently used to enlarge the cervical and middle third of the canals when manual techniques are used. Even though a previous study reported that GG drills were safe regarding dentin thickness removal⁷, their use often leads to procedural errors such canal deviation, strip perforations or excessive and irregular dentin removal⁵.

Although it has been well established that mechanized instrumentation with NiTi files has significant advantages over manual K-file techniques^{8,9}, engine-driven instruments require costly investment in electric endodontic motors and NiTi files. Not all universities can afford this kind of equipment¹⁰, and students in some countries cannot afford them due to different socioeconomic profiles¹¹. To overcome these limitations, some manufacturers created manual NiTi rotary files, which according to some studies, provide better results than K-file manual instrumentation techniques^{12,13}. The M file (Easy

Bassi, Belo Horizonte, Brazil) is a manual NiTi rotary file system with controlled memory (CM) heat treatment, that consists of few instruments to prepare the canals in a crown-down technique. The system includes orifice shapers (15.10 and 15.08), instruments from 15.05 to 40.05 for most of the cases, and complementary finishing files 50.05, 60.05, and 70.05. NiTi heat-treated alloys such as CM have greater flexibility and higher resistance to cyclic fatigue compared to conventional NiTi instruments. Another advantage of this treatment is the controlled shape memory, which is the ability of an instrument to stay deformed after insertion into the curved canal, returning to their original shape only after heat is applied, thereby maintaining the canal centered curvatures, and decreasing the risk of ledging, transportation or perforation¹⁴.

X-ray computed microtomography (micro-CT) imaging has been widely used for quantitative and qualitative morphologic 2D and 3D analyses on the shaping ability of endodontic instruments and possible alterations in the original root canal path^{2,6}. The aim of this study was therefore to use micro-CT technology to assess the differences between systems by comparing the shaping ability of manual instrumentation using a crown-down technique with Gates Glidden and K-files versus manual rotary instrumentation with M files in the mesial canals of mandibular molars. The null hypothesis was that there is no difference in shaping and centering ability between these two instrumentation techniques.

MATERIALS AND METHOD

Sample selection and initial scanning

This research was approved by the Londrina State University ethics committee (No, 93558018.8.0000.5231). The teeth used in this study were extracted for orthodontic or periodontal reasons and selected based on specific criteria, including similar morphological dimensions and moderate mesial root curvature (10° to 20° according to Schneider's classification)¹⁵. Twenty mandibular extracted first molars with Vertucci type IV canals (two independent canals in the mesial root) were selected from a pool of 422 stored micro-CT scanned teeth collection using the CTan software v1.14.4 (Bruker-microCT, Kontich, Belgium). The CTan software was also used to measure the total root length from tip of the root to the cemento-enamel

junction of each root, giving a median root length of 10.5 mm.

The endodontic access cavity was prepared with diamond burs, and prior to the initial micro-CT scan, the buccal side of each molar was marked at the cemento-enamel junction (CEJ) with a round diamond bur to facilitate differentiation of the MV and ML canals in the 3D micro-CT image processing. All teeth were scanned in a custom attachment using a Skyscan 1173 (Bruker-microCT, Kontich, Belgium) device. The scanning parameters were 80 kV, 90 mA, pixel size 12.1 μm , 360° around the vertical axis, and rotation step 1.0, frame average (3) using a 0.5-mm-thick aluminum filter. Images of the mesial roots were reconstructed using the NRecon v.1.6.9 software (Bruker-microCT) with ring artifact correction 5, beam hardening correction 51%, and smoothing 5, to create axial and transverse slices of the internal structure. Initial analysis of volume and surface area were recorded using the CTAn v.1.14.4, (Bruker-microCT), and data homogeneity was confirmed ($p > 0.05$).

Root canal instrumentation and final micro-CT scan

Both mesial root canals were explored under magnification using a size 10 K-file (Dentsply-Maillefer Baillagues, Switzerland) until the instrument tip was visible at the apical foramen. Then, the working length (WL) was set 1.0 mm shorter than the apical foramen. To control variables related to anatomy of the mesial root system, both instruments were used in the same root although alternating the mesial canals from root to root⁶. Thus, 20 root canals were included per group. Each set of instruments was used to prepare 2 root canals.

Gates Glidden and K-Flexofile instrumentation group

Instrumentation with K-Flexofiles was performed using a crown-down technique¹⁶. Initially, canals were explored with #10 and #15 K-files (Dentsply-Maillefer). Then, the cervical third was pre-enlarged using #40 and #35 K-flexofiles (Dentsply-Maillefer). Subsequently, #2 and #1 Gates-Glidden drills (Dentsply-Maillefer) were used to flare the straight part of the canal. The movement performed with the GG drill was slight apical pressure and ups and downs with only one penetration with each drill. Manual files were used with the balanced

force technique¹⁷ until the full WL was achieved. After instrumentation, each file was removed from the canal and cleaned with moist gauze to remove the debris. Apical enlargement was completed at 35.02 apical diameter, and a step-back technique was performed with flexofiles #40.02 K (1 mm short of WL), #45.02 (2 mm short of WL), and #50.02 (3 mm short of WL), confirming canal patency with the master apical file. All canals were irrigated with 1 mL of 2.5% NaOCl (CloroRio, São José do Rio Preto, Brazil) using a disposable syringe and 27-G NaviTip needles (Ultradent Products, Inc., South Jordan, UT, USA) after each file or GG bur insertion. The total irrigation volume was 15 mL per canal.

M instrumentation group

For instrumentation with M (Easy Bassi), an initial canal exploration was performed with #10 and #15 K-flexofiles, and the cervical portion of the root canal was enlarged with #15.05 and 15.08 M files. The instrument was inserted with clockwise (CW) and counterclockwise (CCW) movement using light apical pressure until no resistance was encountered. Then, rotation movements were performed to cut dentin. The file was removed from the canal and cleaned with moist gauze to remove the debris. A 25.05 file was used in the same manner until 2/3 of the canal length was reached. The apical portion of the canal was instrumented with a 15.05 M file and subsequently finished until the 35.05 files using the same movements described above. After instrumentation of each third, the canal was irrigated with 5 mL of 2.5% NaOCl using a disposable syringe and 27-G NaviTip needles with 15 mL of irrigation volume per canal.

Once instrumentation was complete in both groups, final irrigation with 5 mL of 2.5% NaOCl and 17% ethylenediaminetetraacetic acid (EDTA) (Biodinamica, Ibiporã, Brazil) was applied to remove the smear layer. The EDTA was removed with saline solution and the canals were dried with paper points (Dentsply-Maillefer).

Volume, surface area and unprepared area analysis

Reconstructed images acquired after instrumentation were geometrically co-registered with the preoperative data sets using the 3D Slicer 4.4.0 software (<http://www.slicer.org>) with a custom combination of a rigid registration module based on

image intensity similarities with accuracy greater than 1 voxel. All micro-CT analyses were performed by authors blinded to the instrumentation system groups. The analysis included the binarization of the root canals and measurement of the total canal volume (mm^3) and surface area (mm^2) using the CTAn v.1.14.4 software (Bruker). The unprepared surface of the root canal length was analyzed using the ImageJ 1.50 d software (National Institutes of Health, Bethesda, MD) by calculating the number of static voxels. All values were calculated by subtracting the scores for the treated canals from those recorded for their untreated counterparts and then converted into percentages.

The CTVol v.2.3.1 software (Bruker micro-CT) was used to define a color-coded standard for root canal models (green for preoperative canal, red for Manual K-flexofile instrumentation, and blue for M files postoperative canal surfaces), enabling a qualitative comparison of the superimposed root canal models before and after preparation.

Canal transportation

Canal transportation was assessed as specified in a previous study⁸. The centers of gravity were calculated for each slice and connected along the z-axis with a fitted line in a total of 14.040 Manual K-flexofiles and 15.866 M Files cross sections using XLSTAT-3DPlot for Windows (Addinsoft,

New York, NY). Mean transportation (in mm) was calculated by comparing the centers of gravity before and after preparation for the coronal, middle and apical canal segments. Representative measurements were also graphically presented in diagrams (Figs. 1 and 2).

Statistical analysis

Data distribution was checked for normality using the Shapiro–Wilk test. An unpaired T-test was used for group comparison of volume, surface area, unprepared surface areas and canal transportation before and after preparation. For intergroup comparison, a paired t-test was used. All values were analyzed using Prism 7.0 (GraphPad Software, Inc., La Jolla, CA, USA) and expressed as mean and standard deviation, and the median, minimum and maximum values were presented. The significance level was set at 5%.

RESULTS

Volume, surface area and unprepared areas

Volume, surface area and unprepared canal surface areas data before and after preparation are shown in Table 1. No statistical differences were found between groups in the initial and final canal volume and surface area changes ($p>0.05$). Nonetheless, these values significantly increased after preparation with both systems in the intragroup comparison

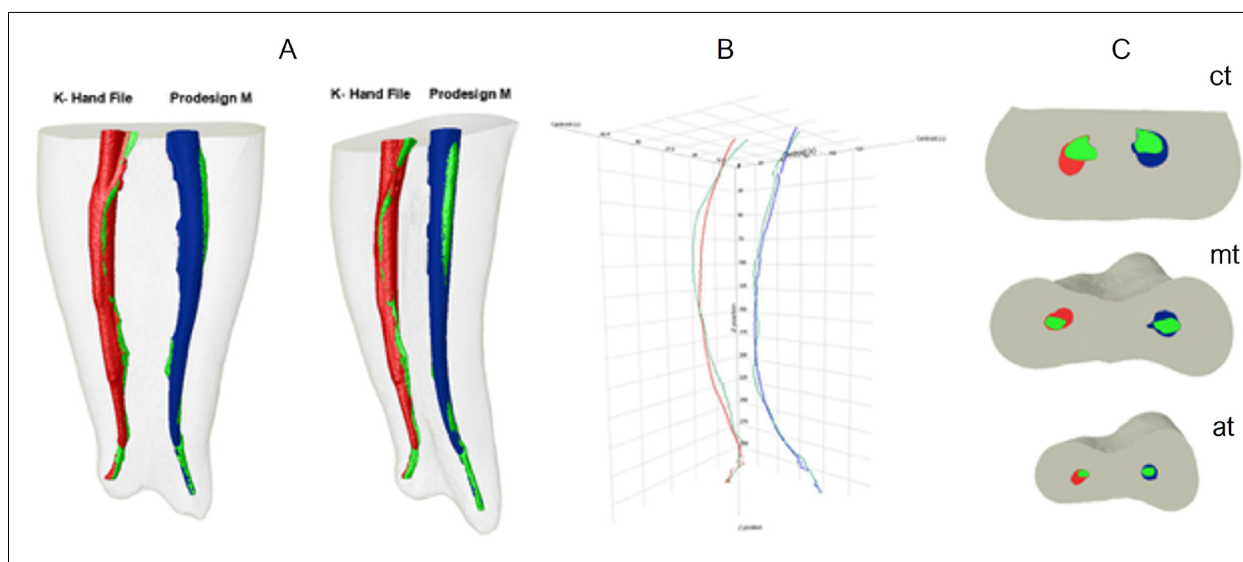


Fig. 1: A) Representative three-dimensional images of micro-CT scan taken before (green) and after preparation using either K-Flexofiles (red) or M files (blue) instruments. Superimposed views show unprepared areas in green. (B) Graph shows the centroid variation before (green) and after: K-Flexofiles (red) and M files (blue) canal preparation. (C) Cross-sectional views of the canal changes before and after coronal (ct), middle (mt), and apical (at) canal thirds.

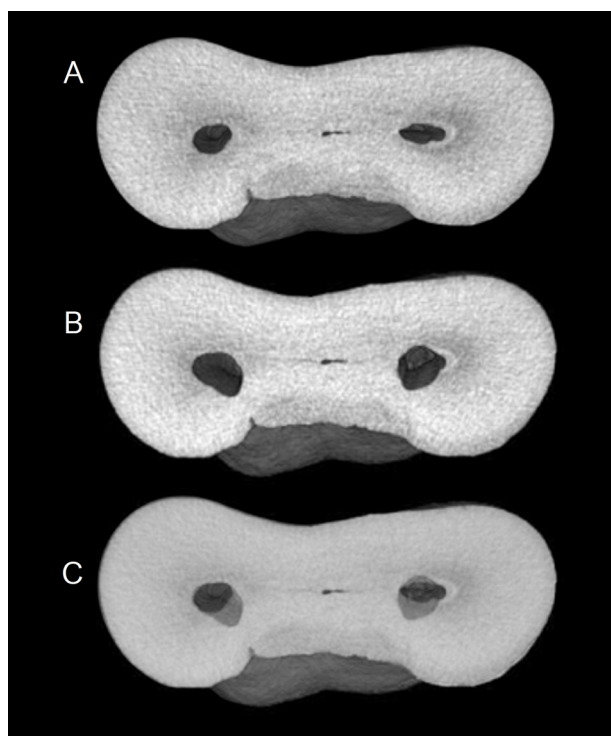


Fig. 2: Representative images of the dentin removal with each instrument towards the furcation area, located at 3 mm from the canal orifice. Left canal images were instrumented with GG/K-flexofiles and right canal images were instrumented with M files rotary Niti files. A) preoperative images, B) postoperative images, and C) superimposed images of A and B.

($p < 0.05$) (Table 1). Regarding the unprepared surface area of the canals, K-flexofile instrumentation yields around 22 % while M files yield 18 % of unprepared areas, without significant differences between systems ($p > 0.05$).

Canal Transportation

Canal transportation data is shown in Table 2. Variation in the centroid differed significantly between groups in the total canal length, and in the comparison of the cervical and middle thirds ($p < 0.05$). At the apical level, the centroid shift was higher for K-file (0.69 mm) than M file (0.51 mm) instrumentation, though without statistical differences ($p > 0.05$). The mean scores for total canal length were 0.88 mm for K-flexofiles and 0.58 mm for M files. The comparison of the cervical, middle and apical thirds within the same groups showed significant differences between the apical level vs. both cervical and middle thirds in the K-flexofile group ($p < 0.05$), but no significant difference in the M-file group ($p < 0.05$).

DISCUSSION

Mesial roots of mandibular molars were used to compare two manual techniques. To reduce biases, only one person with experience in both manual techniques prepared all the root canals. Regarding the root canal anatomical variations, canals with similar curvatures, pre-operative volumes and surface areas were selected. The instrumentation of the mesiobuccal and mesiolingual canals were alternated from specimen to specimen, enabling comparison of the two techniques under similar anatomical conditions¹⁸.

According to the micro-CT morphological analyses of volume and surface area, there was no statistical difference between groups ($p > 0.05$). In the intragroup comparison, canal volumes and surface

Table 1. Volume and surface area of mandibular molar mesial root canals before and after instrumentation with both systems.

Instrument system	Volume (mm ³)	Mean $\pm$ SD	Median (range)	Surface Area (mm ²)	Mean $\pm$ SD	Median (range)	Unprepared surface area (%)	Median (range)
K-Flexofile	Initial	1.80 $\pm$ 0.69	1.77 (0.77 - 3.65)	Initial	20.05 $\pm$ 4.42	20.75 (10.87 - 26.71)		
	Final	4.08 $\pm$ 0.59	4.12 (3.02 $\pm$ 5.06)	Final	27.28 $\pm$ 3.88	27.71 (20.81 - 36.22)	22.32 $\pm$ 11.3	17.93 (8.57 - 44.3)
	% increase	55.92 $\pm$ 14.90	58.81 (25.81 - 81.02)	% increase	25.95 $\pm$ 15.90	26.16 (4.61 - 55.25)		
M files	Initial	1.90 $\pm$ 0.81	1.40 (0.7 - 4.21)	Initial	19.83 $\pm$ 4.92	20.98 (11.99 - 28.02)		
	Final	3.69 $\pm$ 1.04	4.18 (2.49 - 5.77)	Final	25.58 $\pm$ 4.01	25.43 (19.39 - 32.19)	18.58 $\pm$ 10.15	15.81 (6.92 - 8.43)
	% increase	48.42 $\pm$ 15.00	44.70 (26.66 - 75.91)	% increase	22.75 $\pm$ 13.53	18.26 (7.50 - 50.14)		

Table 2. Centroid shift (mm) in root canals after preparation with two manual instrument systems.

Instrument system	Level	Mean $\pm$ SD	Median	Range	25 -75 percentile
K-flexofiles	Cervical	1.17 $\pm$ 0.42 ^{aA}	1.13	0.46 - 1.84	0.77 - 1.48
	Middle	1.09 $\pm$ 0.58 ^{aA}	1.12	0.10 - 1.91	0.65 - 1.58
	Apical	0.69 $\pm$ 0.43 ^{aB}	0.74	0.04 - 1.58	0.34 - 1.01
	Total canal length	0.88 $\pm$ 0.51 ^a	0.94	0.01 - 1.96	0.49 - 1.10
M files	Cervical	0.51 $\pm$ 0.31 ^{bA}	0.52	0.01 - 1.10	0.21 - 0.73
	Middle	0.68 $\pm$ 0.56 ^{bA}	0.62	0.02 - 2.06	0.19 - 0.92
	Apical	0.51 $\pm$ 0.33 ^{aA}	0.46	0.09 - 1.47	0.26 - 0.64
	Total canal length	0.58 $\pm$ 0.34 ^b	0.51	0.00 - 1-10	0.34 - 0.91

Different lowercase letters in the mean column indicate significant differences between the Manual K-flex and M instruments. Different uppercase letters indicate significant differences between different thirds in the same group.

area increased significantly ($p > 0.05$). Nevertheless, 22 % (K-flexofile) and 18 % (M) of unprepared canal surface areas were observed after root canal instrumentation. Although canal surface area or volume increase could improve irrigation, from the mechanical standpoint, it does not mean that all canal walls will be completely cleaned¹⁹. Tissue remnants, debris and unaltered bacteria biofilms can remain harbored in canal irregularities and attached to the unprepared canal walls²⁰. Thus, chemical irrigation solutions alone cannot be expected to clean these areas, so supplementary instrumentation techniques²¹ and final irrigation protocols such as passive ultrasonic irrigation (e.g., Xpendo Finisher, among others), are recommended²².

When canal curvatures are present, there is a tendency for all preparation techniques to divert the prepared canal away from the original axis²³. However, in this study, only the apical 2 mm were measured in linear mesiodistal direction using CBCT images. In our study, canal transportation in the apical portion of the canals did not differ significantly between groups. Our method using a more accurate imaging device (Micro-Ct)² was based on calculation of the centers of gravity for each slice connected along the z-axis with a fitted line. Thus, more cross-sections were analyzed, which might provide more accurate measurements. Another possible explanation for the minimal apical transportation in our study could be that, by first enlarging the coronal and middle portion of the root, both files (pre-curved K and NiTi rotary hand files) instrumented the apical portion of the canal with low deviation values. The final apical enlargement up to a size 35 was chosen based on a previous study which showed significantly higher

root canal disinfection after large apical diameters²⁴. In mesial roots of mandibular molars, the pericervical dentine must be removed carefully, avoiding excess removal and deviation towards the danger zone²⁵, which can weaken the root. A previous study reported that the risk of root fracture increases when the canal width is larger than 40% of the root width^{16,17,25}. Although analysis the remaining dentin thickness towards the inner portion was not part of the aim of this study, the crown-down technique with GG drills and K-files significantly deviated the original canal centroid, rejecting our null hypothesis (Table 3).

Our results showed that deviation in the coronal portion with GG drills was more than 0.50 mm compared to the M-files, especially towards the furcation area (Figs. 1 and 2, Table 2). Gates-Glidden drills were used to instrument the cervical third as orifice openers in the K-file group. However, when M-files were used, a 15.08 orifice shaper, which is more conservative, was used for pre-flaring the cervical third. In our study, GG drills caused more deviation than M-files. These differences might be explained by instrument design, rigidity, rpm needed (20,000) to increase cutting ability, which might produce a fulcrum effect at the orifice level which would move the Gates Glidden blade of the bur towards the furcal aspect of the canal wall²⁵.

CONCLUSIONS

In this *ex vivo* study, both manual instrumentation techniques produced similar enlargement of the root canal in relation to volume and surface area. Neither technique achieved 100% of unprepared canal areas, presenting similar values. The M manual

Table 3. Centroid shift (mm) in the root canals after preparation with two manual instrument systems.

Instrument system	Level	Mean $\pm$ SD	Median	Range	25 -75 percentile
K-flexofiles	Cervical	1.17 $\pm$ 0.42 ^{aA}	1.13	0.46 - 1.84	0.77 - 1.48
	Middle	1.09 $\pm$ 0.58 ^{aA}	1.12	0.10 - 1.91	0.65 - 1.58
	Apical	0.69 $\pm$ 0.43 ^{aB}	0.74	0.04 - 1.58	0.34 - 1.01
	Total canal length	0.88 $\pm$ 0.51 ^a	0.94	0.01 - 1.96	0.49 - 1.10
M files	Cervical	0.51 $\pm$ 0.31 ^{bA}	0.52	0.01 - 1.10	0.21 - 0.73
	Middle	0.68 $\pm$ 0.56 ^{bA}	0.62	0.02 - 2.06	0.19 - 0.92
	Apical	0.51 $\pm$ 0.33 ^{aA}	0.46	0.09 - 1.47	0.26 - 0.64
	Total canal length	0.58 $\pm$ 0.34 ^b	0.51	0.00 - 1.10	0.34 - 0.91

Different lowercase letters in the mean column represent significant differences between the Manual K-flex and M files instruments. Different uppercase letters represent significant differences between different thirds in the same group.

NiTi system maintained the original canal path with significantly less canal transportation than did the

K-Flexofiles crown-down technique.

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