Canal transportation and centering ability of rotary and reciprocal files in mandibular molar root canals using micro computed tomography: an ex-vivo study

Yazdan Shantiaee
Shahid Beheshti University of Medical Sciences
Babak Zandi
Shahid Beheshti University of Medical Sciences
Fatemeh Soltaninejad
Shahid Beheshti University of Medical Sciences
Kourosh Shantiaee
Shahid Beheshti University of Medical Sciences
Ali Rahbar Taramsari (ali.rahbar.taramsari@gmail.com)
Dentist

Research Article

Keywords: apical transportation, canal-centering ability, microcomputed tomography, root canal preparation

Posted Date: December 20th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3733232/v1

Additional Declarations: No competing interests reported.

Abstract

Background

It is important to use proper endodontic rotary files during treatment. Because of the canal curvature and the desire of the endodontic files to return to their original form during root canal preparation, errors such as canal transportation and deviation from the root canal center might occur. This study aimed to assess the canal transportation and centering ability of 2Shape, Neoniti, and EdgeFile X1 in extracted human mandibular molar root canals with 20-40-degree curvature by using micro computed tomography (micro-CT).

Methods

Out of two hundred and fifty extracted human mandibular molars, thirty with mesiobuccal canals with 20-40-degree curvature were selected. They were then randomly assigned to three groups (n = 10). The crowns of the teeth and the distal roots were cut off, and the mesial roots were standardized to have 12 ± 1 mm length. The roots were mounted in acrylic blocks, and the primary micro-CT images were obtained. Root canal instrumentation was then performed, and secondary micro-CT images were taken. RadiAnt software was used to compare before- and after-instrumentation images at 1, 3, 5, and 7 mm from the apex and make the measurements.

Results

Root canal instrumentation with all three systems caused apical transportation and deviation from the original central path of the canal. No significant difference was found in apical transportation ($P > 0.05$) or centering ability ($P > 0.05$) among the three file systems at the aforementioned four levels from the apex.

Conclusions

All three file systems showed some degrees of apical transportation and deviation from the original central canal path with no statistically significant difference among them in this respect.

Background

The main goal of chemomechanical preparation of the root canal system is to eliminate the microorganisms, pulpal tissue, and debris from the root canal system, and shape the root canal to create a suitable space for the application of root filling material.(1) Optimal preparation of straight root canals is easy to achieve; however, root canal instrumentation is challenging in curved canals, especially in the narrow and curved canals of maxillary and mandibular molars.(2) Greater root canal curvature increases the magnitude of stress applied to the rotary file and subsequently to the root canal walls, which can lead to canal transportation, straightening of the canal path, and deviation from the original path.(3–5) According to Wu et al(6) teeth with apical transportation < 0.3 mm had significantly lower apical leakage than those with > 0.3 mm transportation.(6)

Centering ability of an endodontic file is defined as position of the file axis at the center of the canal path to prevent ledging, zipping, and perforation of the root canal in endodontic treatment.(7)

Rotary nickel-titanium (NiTi) instruments with improved properties are produced by different manufacturers. NiTi rotary files have numerous advantages such as high flexibility and expedition of the process of root canal instrumentation.(8)

2Shape (Micro-Mega, Besancon, France) instruments are known for their sequential rotational movement and specific heat treatment (T-Wire). They are claimed to have higher flexibility and cyclic fatigue resistance, and preserve the elasticity of the nickel-titanium (NiTi) alloy.(9)

EdgeFile X1 (EdgeEndo; Albuquerque, New Mexico, USA) is a reciprocating system made of annealed heat-treated NiTi alloy with the commercial name of Fire Wire. The manufacturer claims that it has a high torque strength along with optimal flexibility and high cyclic fatigue resistance.(10)

Neoniti (Neolix, Charters, la-Foret, France) is a single-file system with full-rotational movement, which benefits from the electric discharge machining technology. According to the manufacturer, it has high flexibility and fracture resistance, and optimal shaping ability due to its unique properties, rectangular cross-sectional design, efficient cutting blades, and built-in abrasive surface.(11)

Micro-computed tomography (micro-CT) is a recommended technique for assessment of radicular dentin and its alterations without damaging the tooth structure.(12) Also, micro-CT has a higher quality than cone-beam computed tomography (CBCT), and is therefore commonly used for assessment of new endodontic file systems.(13)

This study aimed to compare apical transportation and centering ability of 2Shape, EdgeFile X1, and Neoniti in human extracted mandibular molars with 20-40-degre root curvature using micro-CT.

Methods

A total of 250 human mandibular first and second molars were collected from multiple dental clinics inside the city of Tehran. All the extractions were performed with the patient’s informed consent. These 250 teeth were evaluated and their roots were inspected under a stereomicroscope at x12 magnification, and those with immature apex and external dentinal defects were excluded. Next, high-resolution CBCT images were obtained from the teeth using NewTom VGI CBCT scanner (QR, SRL Co, Verona, Italy) with the exposure settings of 110 kV, 9.5 mA, 0.1 mm voxel size, and 6 x 6 cm field of view. OnDemand 3D software (CyberMed Inc., Irvine, CA, USA) was used for assessment of different sections.

The root canal curvature was measured by the Schneider's method.(14) In this method, the canal curvature is calculated by measuring the angle formed between the longitudinal axis of the canal and a line drawn from the initiation of curvature to the apical foramen. Molar roots with 20-40-degree curvature in the sagittal or coronal plane or both, no calcification, no internal/external root resorption, and no history of previous endodontic treatment were included in the study. The mesiobuccal canals of the mesial roots of eligible teeth were selected for this study,(15) and 30 teeth were included as such. All teeth were stored in 0.1% thymol solution during the experiment. The tooth crown and distal root were cut by a low-speed saw (Isomet 4000; Buehler Ltd, Lake Bluff, IL, USA) under water coolant, and the root length was standardized at 12 ± 1 mm from the apex.

To simulate the periodontal ligament, the root surface was covered with one layer of aluminum foil, and the roots were mounted in plastic tubes with 55 mm diameter and 20 mm height filled with acrylic resin (Kulzer GmbH, Leipziger, Hanau, Germany). After setting of the acrylic resin, the aluminum foil was removed from the root surface and replaced with silicone impression material (GC Co., Tokyo, Japan). The specimens were then mounted back in the acrylic resin.(16)

Subsequently, the specimens were randomly assigned to three groups (n = 10) of 2Shape, EdgeFile X1, and Neoniti. All teeth were scanned by a micro-CT scanner (LOTUS-inVivo, Behin Negareh Co., Tehran, Iran) prior to instrumentation,(17) and 400–500 transverse cross-sectional images with 24 μm slice thickness were obtained from each root. The exposure parameters included 31 μm isotropic resolution, 99 kV voltage, 88 μA amperage, 2 s frame exposure time, aluminum filter with 0.5 mm thickness, 360-degree rotation, and 0.3-degree rotation step.

The canal length was measured by introducing a #10 K-file (Mani Inc., Tochigi, Japan) into the canal until its tip was visible at the apex; 1 mm was subtracted from this length to determine the working length. A #15 K-file (Mani Inc., Tochigi, Japan) was used to create a glide path.

Instrumentation in all groups was performed by one operator. Each file was used for only two canals with a VDW motor (VDW Silver motor; VDW GmbH, Munich, Germany) and the speed and torque recommended by the manufacturer.

In the 2Shape group, TS1 (25, 04) and TS2 (25, 06) files with 1.5 N/cm torque and 300 rpm speed were progressively used with three up-and-down and upward circumferential filing movements. In case of presence of resistance against the file movement, circumferential brushing movement was used to eliminate resistance. Filing was continued after irrigation until the file reached the working length.

In the EdgeFile X1 group, EdgeFile-X1 instrument (25/.06) was used with reciprocating motion by using the WaveOne setting with gentle apical pressure and inward pecking movement (2–3 mm inward movement, and 1–2 mm outward movement) until the working length was reached.

In the Neoniti group, Neoniti A1 instrument (25, 06) was used with 1.5 N/cm torque and 300 rpm speed with pecking and circumferential brushing movements until the working length was reached.

In all systems, after three pecking movements, the file was removed from the canal and its flutes were cleaned with a gauze. The root canals were then rinsed with 2 mL of 5.25% sodium hypochlorite (Chloraxid 5,25%, Cerkamed Medical Company, Stalowa Wola, Poland) with a 5 mL syringe (SinaMax, Tehran, Iran) and 30-gauge irrigation needle (Endo irrigation needles ENDO-TOP; Cerkamed Medical Company, Stalowa Wola, Poland). Recapitulation was performed with a #10 K-file. After preparation of specimens, they underwent micro-CT again with the parameters similar to those of the primary scanning.

The reconstructed micro-CT images were transferred to a Dataviewer (RadiAnt DICOM Viewer 2020.2). Cross-sectional micro-CT images of specimens before and after root canal instrumentation were superimposed, and the mesiodistal and buccolingual root canal dimensions were measured at 1, 3, 5, and 7 mm from the apex (Fig. 1). Two observers blinded to the group allocation of specimens evaluated all sections twice and made the measurements. In case of disagreement between the two observers, the images were evaluated again until a consensus was reached.

Mesiodistal transportation was calculated using the following formula: (M1-M2) - (D1-D2)

Buccolingual transportation was calculated using the following formula: (B1-B2) - (L1-L2)

The abovementioned formulae were adopted from studies by Gambill et al,(18) and Hasheminia et al.(19) A positive quotient would indicate the occurrence of transportation in the mesial or buccal direction while a negative quotient would indicate the occurrence of transportation in the distal or lingual direction.

Centering ability was evaluated using the formula:

(M1-M2)/(D1-D2) or (D1-D2)/(M1-M2)

The larger value was placed as the numerator so that the quotient would range from 0 to 1. The same was done for buccolingual direction. In this formula, a quotient of 1 would indicate the highest (best) centering ability while 0 would indicate the lowest (worst) centering ability. Four sections of each specimen were evaluated as such, and the abovementioned formulae were separately used for each of the 4 levels from the apex.

Data were collected through observation of before- and after-instrumentation micro-CT cross-sectional images.

ANOVA was applied with one within-factor (canal cross-section) and one between-factor (file type). The Shapiro-Wilk test was used to analyze the normality of data distribution. SPSS version 26 (2020) was used for statistical analysis of the data. The mean and standard deviation of the values were reported.

Results

This study was conducted on the mesiobuccal canals of mandibular molars instrumented with three different rotary systems to assess their canal transportation and centering ability:

Group 1: 2Shape rotary file

Group 2: Neoniti rotary file

Group 3: EdgeFile X1 reciprocal file

Table 1

presents the mean and standard deviation of mesiodistal and buccolingual canal transportation and centering ability of the files at 1, 3, 5, and 7 mm from the apex. The results showed no significant difference among the three groups regarding canal transportation and centering ability at any level from the apex ($P > 0.05$). The results showed that in all three groups, apical transportation and centering ability in mesiodistal direction increased as the distance from the apex increased; however, this increase was not significant ($P > 0.05$). In the 2Shape group, the majority of canal transportations occurred in mesiodistal direction (60%); however, the difference was not significant ($P > 0.05$).

File system	Distance from apex	Mean and standard deviation of mesiodistal transportation	Mean and standard deviation of buccolingual transportation	Mean and standard deviation of centering ability in mesiodistal direction	Mean and standard deviation of centering ability in buccolingual direction
2Shape	1 mm	0.08 (0.07)	0.08 (0.07)	0.36 (0.33)	0.44 (0.41)
	3 mm	0.10 (0.10)	0.14 (0.15)	0.37 (0.32)	0.39 (0.35)
	5 mm	0.12 (0.08)	0.05 (0.05)	0.34 (0.26)	0.53 (0.32)
	7 mm	0.17 (0.23)	0.08 (0.12)	0.71 (0.16)	0.34 (0.33)
NeoNiTi	1 mm	0.07 (0.08)	0.07 (0.08)	0.37 (0.32)	0.48 (0.37)
	3 mm	0.07 (0.02)	0.08 (0.06)	0.38 (0.23)	0.31 (0.27)
	5 mm	0.09 (0.07)	0.14 (0.13)	0.6 (0.24)	0.42 ()0.39
	7 mm	0.14 (0.14)	0.2 (0.23)	0.61 (0.24)	0.31 (0.29)
EdgeFile X1	1 mm	0.04 (0.02)	0.10 (0.12)	0.33 (0.3)	0.28 (0.37)
	3 mm	0.09 (0.09)	0.06 (0.05)	0.4 (0.29)	0.39 (0.33)
	5 mm	0.10 (0.08)	0.13 (0.09)	0.47 (0.34)	0.22 (0.27)
	7 mm	0.11 (0.08)	0.08 (0.07)	0.54 (0.32)	0.49 (0.33)

Table 1. Mean and standard deviation of mesiodistal and buccolingual canal transportation and centering ability of the files at 1, 3, 5, and 7 mm from the apex.

Discussion

This study evaluated the mesiobuccal canals of mandibular molars with 20-40-degree curvature and showed similar level of apical transportation and centering ability of all three file systems. The goal behind preparation of a narrow and curved canal is to create a conical shape with proper taper for correct obturation. Excessive dentin removal from one direction causes a deviation from the main canal path and prevents proper cleaning and shaping of the canal.(20) Thus, assessment of the changes following root canal cleaning and shaping is performed to evaluate the mechanical properties and tendency of endodontic instruments to preserve the original anatomy of the canal.(21) Micro-CT was used in the present study to assess canal transportation since this modality has the highest accuracy and resolution among the available radiographic techniques.(22, 23) Moreover, files with the same taper were used in all teeth to standardize the apical preparation of specimens and eliminate its confounding effect on the results. In the present study, natural extracted teeth were used to better simulate the clinical setting, which is more reliable than evaluation of post-instrumentation changes by using resin blocks. Nonetheless, use of resin blocks also has advantages such as standardization of root diameter, canal length, and canal curvature, which is ideal for in vitro studies. However, differences in mechanical structure of resin and dentin such as microhardness and particle size can interfere with the file movement.(24) The mesial roots of mandibular molars were selected for the present study because they usually have an apical curvature and are therefore prone to instrumentation errors.(25) Moreover, the teeth were decoronated to eliminate the confounding effect of access cavity on root canal instrumentation. Furthermore, the root length was standardized at 12 ± 1 mm to ensure correct working length determination. Also, CBCT scans were obtained from the teeth at baseline to evaluate their length, anatomy, and degree of curvature. All root canal preparations and evaluation of micro-CT scans were performed by one operator. A second observer confirmed the accuracy of the measurements. Assessments were made in a double-blind manner.

The 2Shape file system has novel heat-treatment properties which need to be investigated. Also, the available studies comparing the 2Shape and EdgeFile systems with other files are scarce.

In the present study, all the tested files caused canal transportation with no significant difference with each other. The magnitude of mesiodistal canal transportation at 1, 3, 5, and 7 mm from the apex was greater in the 2Shape than EdgeFile and Neoniti; however, this difference did not reach statistical significance.

Faisal et al,(26) in a similar study evaluated the magnitude of dentin removal, apical transportation, and centering ability. They compared the 2Shape and Neoniti systems and found no significant difference between them. They evaluated the mesial roots of mandibular molars with 25 to 35-degree curvature. Their results were in agreement with the present findings. Nehme et al(24) evaluated canal transportation, centering ability, and canal volume changes in mesial roots of mandibular molars following instrumentation with ProTaper Gold and 2Shape. They found no significant difference between the two systems and reported that both systems caused some degrees of canal transportation.(27) The present results were in line with their findings. Drukteinis et al(28) evaluated the shaping ability, canal transportation and centering ability of HyFlex CM, HyFlex EDM, and EdgeFile in mesial roots of mandibular molars and found no significant difference among the three systems. However, they noticed that EdgeFile had higher cyclic fatigue resistance than the other two systems, which may be attributed to the use of NiTi alloy namely Fire Wire in this system. In their study, the magnitude of canal transportation in all systems was lower than the acceptable canal transportation threshold of 0.3 mm,(6) which indicates the acceptable performance of all files. The present results regarding canal transportation and centering ability of the files were in accordance with their findings.

Yilmaz et al(29) evaluated canal transportation and dentin removal from the mesiobuccal root of maxillary molars after using ProTaper Next, OneShape, and EdgeFile X3. They found no significant difference in performance of the three systems. All these systems have rotational movement, which may be one reason for lack of a significant difference in their performance. All systems caused canal transportation < 0.3 mm, which is not clinically significant.(6) Nonetheless, EdgeFile X1 with reciprocal movement was used for instrumentation of mandibular molar canals in the present study and yielded results similar to those reported by Yilmaz et al.(29) Nehme et al(24) used micro-CT and found no significant difference in canal transportation between 2Shape and ProTaper Gold. Singh et al(30) used the same file systems and reported that the 2Shape had lower transportation and higher centering ability than ProTaper Gold. However, they used CBCT to measure the magnitude of transportation, which has a lower accuracy than micro-CT, and may be one reason for the difference between their results and the present findings.

Hasheminia et al(19) used CBCT and reported lower canal transportation and higher centering ability of the EdgeFile system compared with the Reciproc and WaveOne. Use of CBCT instead of micro-CT in their study may explain the difference between their results and the present findings.

A systematic review by Ahn et al(31) found that reciprocal systems caused lower canal transportation than rotary systems in studies conducted on resin blocks. However, studies conducted on extracted human teeth showed no significant difference between rotary and reciprocal systems in this regard. This difference may be due to the presence of anatomical variations in extracted human teeth. Nonetheless, the magnitude of canal transportation in both methods was lower than the acceptable threshold of 0.3 mm, and was therefore not clinically significant. Another systematic review by Nagendrababu et al(32) confirmed the results of the above-mentioned systematic review(31) and demonstrated that in ex vivo studies (conducted on extracted teeth), the difference in canal transportation was not significant between files with rotary and reciprocal movements. In the present study, two rotary and one reciprocal file systems were used, and the results were in agreement with the findings of the above-mentioned systematic reviews.

Conclusions

Statistical analysis in the present study revealed no significant difference among 2Shape, EdgeFile, and Neoniti file systems regarding apical transportation or centering ability. Thus, it appears that all of them have optimal efficacy for root canal instrumentation in the clinical setting.

Abbreviations

micro-CT: micro computed tomography

CBCT: cone-beam computed tomography

Declarations

Ethics approval and consent to participate:

The study was conducted in accordance with the Declaration of Helsinki, and the protocols were approved by the ethics committee of Shahid Beheshti Medical University (code: IR.SBMU.DRC.REC.1398.195).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors' contributions

Ali Rahbar came up with the concept of the research. Yazdan Shantiaee alongside Babak Zandi validated the concept and the idea. Fatemeh Soltaninejad with the help of Ali Rahbar Taramsari prepared the methodology of the research. They also collected all the data. Each process was supervised by Yazdan Shantiaee and Babak Zandi. Ali Rahbar wrote the main manuscript text. Fatemeh Soltaninejad reviewed and edited the main script. Kourosh Shantiaee was our english editor. Finally all authors read and approved the final manuscript.

Acknowledgments

We would like to thank Dr. Mahshid Namdari for the statistical consult.

References

1. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am. 1974;18(2):269-96.
2. Johnson WT. Instrumentation of the fine curved canals found in the mesial roots of maxillary and mandibular molars. Quintessence Int. 1986;17(5):309-12.

3. Gao Y, Cheung GS, Shen Y, Zhou X. Mechanical behavior of ProTaper universal F2 finishing file under various curvature conditions: a finite element analysis study. J Endod. 2011;37(10):1446-50.
4. Kim HC, Sung SY, Ha JH, Solomonov M, Lee JM, Lee CJ, Kim BM. Stress generation during self-adjusting file movement: minimally invasive instrumentation. J Endod. 2013;39(12):1572-5.
5. Versluis A, Messer HH, Pintado MR. Changes in compaction stress distributions in roots resulting from canal preparation. Int Endod J. 2006;39(12):931-9.
6. 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(4):210-6.
7. Vallaeys K, Chevalier V, Arbab-Chirani R. Comparative analysis of canal transportation and centring ability of three Ni-Ti rotary endodontic systems: Protaper®, MTwo® and Revo-S™, assessed by micro-computed tomography. Odontology. 2016;104(1):83-8.
8. Walia HM, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod. 1988;14(7):346-51.
9. Micro-Mega. The 2Shape Brochure. Available at: https://micro-mega.com/wp-content/uploads/2018/03/60301807-C_Brochure-2Shape_EN_WEB.pdf. Accessed November 19, 2020.
10. EdgeEndo. EdgeFile X1 directions for use. Available at: https://edgeendo.com/wp-content/uploads/2015/08/DFU-EdgeFile-x1.pdf. Accessed November 19, 2020.
11. Neolix. NeoNiti Instruction manual. Available at: https://www.neolix.eu/themes/neo/assets/img/pdf/flyer/FLYER-NEONITI-ENGLISH.pdf. Accessed November 19.
12. Zaslansky P, Fratzl P, Rack A, Wu MK, Wesselink PR, Shemesh H. Identification of root filling interfaces by microscopy and tomography methods. Int Endod J. 2011;44(5):395-401.
13. Bernardes RA, Rocha EA, Duarte MA, Vivan RR, de Moraes IG, Bramante AS, de Azevedo JR. Root canal area increase promoted by the EndoSequence and ProTaper systems: comparison by computed tomography. J Endod. 2010;36(7):1179-82.
14. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral surgery, Oral medicine, Oral pathology. 1971;32(2):271-5.
15. Kırıcı D, Demirbuga S, Karataş E. Micro–computed Tomographic Assessment of the Residual Filling Volume, Apical Transportation, and Crack Formation after Retreatment with Reciproc and Reciproc Blue Systems in Curved Root Canals. Journal of Endodontics. 2020;46(2):238-43.
16. Miguéns-Vila R, Martín-Biedma B, De-Deus G, Belladonna F, Peña-López A, Castelo-Baz P. Micro-computed tomography evaluation of dentinal micro-cracks after preparation of curved root canals with ProTaper Gold, WaveOne Gold and ProTaper NEXT instruments. Journal of Endodontics. 2020.
17. Fouladi M-R, Gholami K, Ghadiri H. LOTUS-inVivo Micro Computed Tomography System for Imaging of Small Animals and Ex-Vivo Biological Samples. Frontiers in Biomedical Technologies. 2020;7(2):134-7.

18. Gambill JM, Alder M, del Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. J Endod. 1996;22(7):369-75.
19. Hasheminia SM, Farhad A, Sheikhi M, Soltani P, Hendi SS, Ahmadi M. Cone-beam Computed Tomographic Analysis of Canal Transportation and Centering Ability of Single-file Systems. J Endod. 2018;44(12):1788-91.
20. 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(8):962-5.
21. Merrett SJ, Bryant ST, Dummer PM. Comparison of the shaping ability of RaCe and FlexMaster rotary nickel-titanium systems in simulated canals. J Endod. 2006;32(10):960-2.
22. Cotton TP, Geisler TM, Holden DT, Schwartz SA, Schindler WG. Endodontic applications of cone-beam volumetric tomography. J Endod. 2007;33(9):1121-32.
23. Nielsen RB, Alyassin AM, Peters DD, Carnes DL, Lancaster J. Microcomputed tomography: an advanced system for detailed endodontic research. J Endod. 1995;21(11):561-8.
24. Nehme W, Araji S, Michetti J, Zogheib C, Naaman A, Khalil I, et al. Assessment of root canal transportation of 2Shape and ProTaper gold in mandibular molar mesial canals: A micro-computed tomographic study. Microsc Res Tech. 2021;84(4):746-52.
25. Imura N, Pinheiro ET, Gomes BP, Zaia AA, Ferraz CC, Souza-Filho FJ. The outcome of endodontic treatment: a retrospective study of 2000 cases performed by a specialist. J Endod. 2007;33(11):1278-82.
26. Faisal I, Saif R, Alsulaiman M, Natto ZS. Shaping ability of 2Shape and NeoNiTi rotary instruments in preparation of curved canals using micro-computed tomography. BMC Oral Health. 2021;21(1):595.
27. Marzouk AM, Ghoneim AG. Computed tomographic evaluation of canal shape instrumented by different kinematics rotary nickel-titanium systems. J Endod. 2013;39(7):906-9.
28. Drukteinis S, Peciuliene V, Bendinskaite R, Brukiene V, Maneliene R, Rutkunas V. Shaping and Centering Ability, Cyclic Fatigue Resistance and Fractographic Analysis of Three Thermally Treated NiTi Endodontic Instrument Systems. Materials (Basel). 2020;13(24).
29. Yılmaz F, Eren İ, Eren H, Badi MA, Ocak M, Çelik HH. Evaluation of the Amount of Root Canal Dentin Removed and Apical Transportation Occurrence after Instrumentation with ProTaper Next, OneShape, and EdgeFile Rotary Systems. J Endod. 2020;46(5):662-7.
30. Singh S, Gupta T, Pandey V, Singhania H, Pandey P, Gangavane S. Shaping Ability of Two-shape and ProTaper Gold Files by using Cone-beam Computed Tomography. J Contemp Dent Pract. 2019;20(3):330-4.
31. Ahn SY, Kim HC, Kim E. Kinematic Effects of Nickel-Titanium Instruments with Reciprocating or Continuous Rotation Motion: A Systematic Review of In Vitro Studies. J Endod. 2016;42(7):1009-17.
32. Nagendrababu V, Ahmed HMA. Shaping properties and outcomes of nickel-titanium rotary and reciprocation systems using micro-computed tomography: a systematic review. Quintessence Int. 2019;50(3):186-95.

Figures

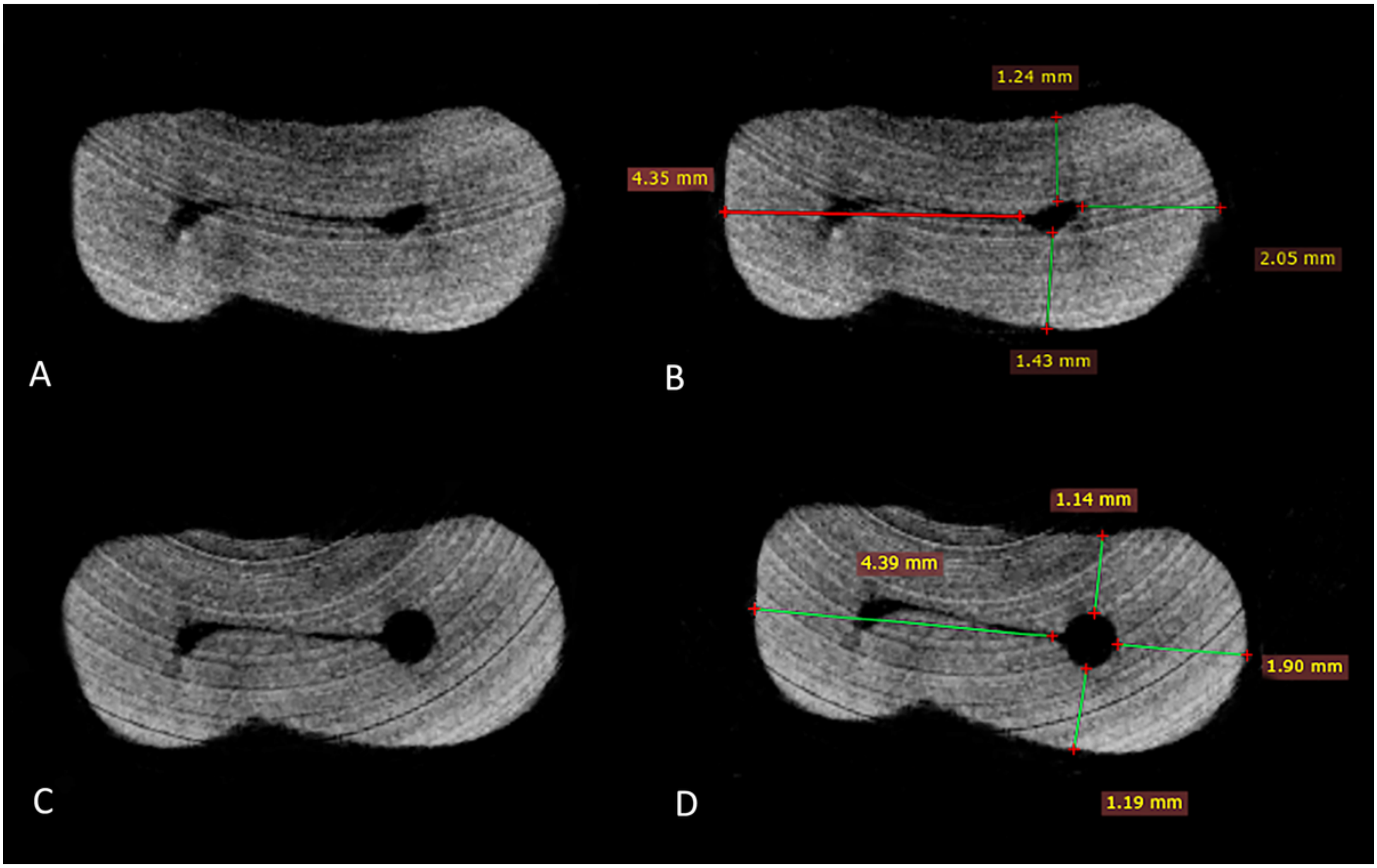

Figure 1

A) A specimen cross-section at 7 mm from the apex prior to instrumentation, without measurements B) The same specimen cross-section at 7 mm from the apex prior to instrumentation, with measurements C) The same specimen cross-section at 7 mm from the apex after instrumentation, without measurements D) The same specimen cross-section at 7 mm from the apex after instrumentation, with measurements (RadiAnt Dicom Viewer software)