ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
March 2025 • Vol. 37

# Cone Beam Computed Tomographic Evaluation of Remaining Dentine Thickness in the Danger Zone after Using Different Rotary File Systems

***Sabah M. Sobhy[1], Eman M. Hassan[2], Hanaa S. Mansy[3]***

**Aim:** The research was pointed to assess the remaining dentine in the danger zone in mandibular molars following the preparation of root canal with ProTaper Next, Videya N and Twisted File Adaptive systems using cone beam computed tomography.

**Materials and methods**: Forty-eight mandibular molars were selected for the study. After access cavity preparation and pre-instrumentation CBCT scanning, the teeth were randomly assigned to three groups (16 teeth each) based on the file system used: ProTaper Next, Videya N, and TF Adaptive. Following instrumentation, CBCT scanning was performed using standardized exposure parameters. Measurements of the danger zone dentin thickness were taken before and after using the file systems at 4 mm, 5 mm, and 6 mm below the orifice. The amount of dentin removed was calculated by subtracting the post-instrumentation measurements from the pre-instrumentation measurements. Statistical analysis of the collected data was performed using one-way ANOVA test ($p > 0.05$).

**Results**: A statistical significance was found between the examined grouping in the residual dentin thickness and removed dentin at any level under the canal orifice.

**Conclusion**: The mesibuccal root canals of mandibular molar were effectively and safely prepared in the danger zone by the used file systems.

**Keywords:** CBCT, Danger Zone, Dentin Thickness, Videya N, Twisted File Adaptive system.

1. Endodontic Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt.
2. Oral medicine, Periodontology, Diagnosis and Radiology Department, Faculty of Dental Medicine for Girls, Al-Azhar University, Cairo, Egypt.
3. Oral and Maxillofacial Radiology Department, Faculty of Dentistry, Cairo University, Cairo, Egypt.
   Corresponding author: Hanaa Sayed Mansy, email: hana.manssy@dentistry.cu.edu.eg

## Introduction

Successful endodontic treatment relies on the efficient and potent biomechanical preparation of the root canal. Maintaining the primary canal morphology and dentine width enhances treatment outcomes. [1] Danger zone (DZ) is a critical zone in the mesial root of the lower molars with the least dentin thickness, which is located at the side facing the distal root [2] apical to canal orifice by 4 and 6 mm [3] and beneath the furcal area by 1 and 2 mm. The average dentine thickness in this area is from 0.78 to 1.27 mm. [4–6]

Additionally, the associations of the danger zone thickness with several factors namely age, gender of the individual and the length of MB the root were assessed in the literature by some studies. One of these studies reported by Sauaia et al. [4], found that the width of the danger zone was significantly correlated with the length of the mesiobuccal root. As, the length of the root increases the width of the DZ dentine decreases. Consequently, they concluded that the possibility of the occurrence of strip root perforation increases with the increase of the MB root length. Also, Zhou et al [7] found that the danger zone thickness was associated with the gender and age of the participant. They found that men owned thicker danger zone than women, and both had thicker danger zone with age. Thus, the possibility of root strip root perforation and faulty of the treatment increases in females with young age. [7,8]

The market has seen the innovation of several nickel titanium (NiTi) instrument systems aimed at improving canal preparation dependent on morphology of the tooth canals. [9] A distinctive configuration that offers increased flexibility and precision throughout the process was boasted by the ProTaper Next system. The ProTaper Next files have a variable taper design that enables gradual widening of the canal during use. This design mitigates the chance of file fracture and permits enhanced mastery during utilization of the instrument. Furthermore, the files feature a non-cutting tip, which serves to minimize the potential for harm to the canal structure and are manufactured of M wire with an off-centered rectangular cross section design. [10]

Market tries to mimic the file configuration of the ProTaper Next system by introducing file Videya N rotary system. This system is characterized by an off-centered rectangular cross-section, which significantly improves debris removal efficiency. Additionally, it features a non-cutting tip that allows the file to navigate the canal safely, minimizing the risk of perforation. It is made of CM wire rather than M wire and has a different heat treatment which increases the fatigue resistance. [11]

M Wire alloy has physical and mechanical properties that can render endodontic instruments more flexible and more resistant to fatigue than those made from a conventional NiTi wire. It contains austenite, martensite, and R-phase. The relative proportions depended on the processing conditions[12] while CM wire is specially processed to increase the flexibility, reduce the shape memory and enhance memory control of the material.[13]

Twisted File Adaptive file system is another innovative file system that is employed in adaptive motion, where file rotates in steady rotation while little force is done on and reciprocation with specially designed CW and CCW angles when it catches dentin and the stress increases. Furthermore, these angles are not constant and change based on anatomical complexity and intracanal stress. The Adaptive motor automatically selects the appropriate movement for each clinical circumstance, reducing the chance of intracanal failure without impairing performance. [14,15]

Cone beam computed tomography (CBCT) is an effective nondestructive tool for diagnosis due to its three-dimensional (3D) view, accuracy, and reliability. In terms of thickness measurement of dentin in root canal walls, CBCT is essential for evaluating remaining dentin thickness, especially in teeth with complex root canal architecture. [16,17] The remaining dentin following mechanical preparation in the danger zone was measured using CBCT by several studies. [7,8,18] CBCT imaging can accurately estimate dentin thickness following simulated instrument removal, as compared to micro-computed tomography (μCT). [19]

The thickness of residual dentin is critical for preventing tooth fractures and maintaining restoration longevity. [20] Studies have shown that the survival of a tooth after endodontic treatment is significantly influenced by the amount of residual dentin. [21,22] Therefore, the current research was designed to check the remaining width of dentin in the thin risky area of the mandibular molars subsequent to root canal adjustment with ProTaper Next, Videya N and Twisted File Adaptive systems using CBCT.

The null hypothesis states that the residual thickness of dentin in the danger zone is the same for all tested rotary Ni-Ti systems.

## Materials and methods

Instruments, irrigating solutions and devices used in the present study were listed in Table (1).

**Table 1: Instruments, irrigating solutions and devices used in this study**

| Product | Manufacturer |
|---|---|
| ProTaper Next | Dentsply, Maillfer, Switzerland |
| Videya N rotary file system. | Huizhou Videya Technology, China |
| Twisted File Adaptive | Sybron Endo, Orange, CA, USA |
| Sodium hypochlorite (NaOCl) | Alex. Detergents and Chemical Co., Egypt. |
| Ethylene diamine-tetraacetic acid (EDTA). | Colgate Oral Care Company, Waverly, Australia. |
| Saline. | MottAHedoonpharma, Egypt. |
| Twisted File Adaptive motor | Sybron Endo, Orange, CA , USA |
| EndoEst Motor Mini | Geosoft Dent., Russia |

### Study design

The present experimental study was performed in the endodontic department of faculty of dental medicine for Girls, Al-Azhar University and ethically approved by the Research Ethics Committee (REC) of the institute (REC-PD-24-17).

### Sample selection

Human anonymous permanent completely formed mandibular molars extracted from patients aged from 20 - 50 years due to periodontal disease or severe damage of coronal tooth structures, with mesial roots having 13 ±1 mm root length and two separate canals in the mesial root were chosen in this study. Additionally, the mesiobuccal canals curvature range between 20° –40° according to Schneider's technique [23] and the mesiobuccal canal was assigned for instrumentation in each molar. Tooth with root caries, cracks, calcification or resorption was excluded.

### Sample size calculation

Sample size calculation was performed using G*Power version 3.1.9.7 based on the results of a previous study (Turker et al., 2023) [8]. A power analysis was designed to have adequate power to apply a two-sided statistical test to reject the null hypothesis that there is no difference between groups. By adopting an alpha level of (0.05) and a beta of (0.05), i.e. power = 95% and an effect size (d) of (0.6) calculated based on the results of a previous study. The predicted sample size (n) was (48), i.e., 16 samples each group. To detect differences in the remaining thickness of dentin in the danger zone between groups.

### Sample preparation

The chosen teeth were thoroughly cleaned under running tap water with a soft toothbrush. They were then disinfected by soaking in a 5.25% sodium hypochlorite (NaOCl) solution for one hour and subsequently stored in saline until instrumentation. A total of forty-eight completely formed human permanent mandibular molars with no evidence of cracks or root caries were selected in this study.

An access cavity was created using a #3 round bur (Dentsply Maillefer), followed by an Endo-Z bur (Dentsply Maillefer). The presence of two separate canals in the mesial root was confirmed by inserting two size 10 K-files simultaneously. Apical patency of the mesiobuccal root canals was assessed with a #10 K-file until it was just visible at the apex, then 1 mm was subtracted from this length to determine the working length. The occlusal surfaces were flattened to standardize the sample length to 18 mm.

**Pre instrumentation CBCT imaging**

The samples were numbered and positioned in plastic dental arches, which served as holders to ensure stability during scanning. A CBCT scan was performed using the i-CAT imaging system, with a voxel size of 0.2 mm, an exposure cycle of 26.8 seconds, 37.1 mAs, and 120 KVP. The DICOM data files were then transferred to In VivoDental software.

**Sample grouping**

The forty-eight teeth were randomly divided into 3 groups (16 teeth each) based on the file system used:

**Group I (Control group):** 16 mesiobuccal root canals were prepared utilizing ProTaper Next nickel-titanium rotary system (Dentsply, Maillfer, Switzerland) driven by EndoEst motor mini (Geosoft Dent., Russia) endomotor till size x2 (#25/0.06) file in continuous rotation at 300 rpm and 2 Ncm.

**Group II:** 16 mesiobuccal root canals were prepared utilizing Videya N rotary file system (Huizhou Videya Technology, China) driven by EndoEst motor mini (Geosoft Dent., Russia) endomotor till size x2 (#25/0.06) file in continuous rotation at 300 rpm and 2 Ncm .**Group III:** 16 mesiobuccal root canals were prepared utilizing TF Adaptive file system till size (SM2) (# 25, 0.06) instruments driven by TF Adaptive program Elements motor in adaptive motion.

All preparation procedures were performed by a single operator, who irrigated with 2 ml of 2.6% sodium hypochlorite (NaOCl) solution (Alex Detergents and Chemical Co., Egypt) for 1 minute after each instrument, using a 31-gauge Navi-Tip flexible irrigating needle (Navi-Tip, Ultradent, South Jordan, UT). This was followed by 5 ml of saline. The smear layer was removed with 5 ml of 17% EDTA for 1 minute, followed by a final rinse with 5 ml of saline solution.

**Post-Instrumentation CBCT imaging**

Each sample was rescanned with the same scanning parameters as the initial CBCT, but following root canals instrumentation.

The dentin thickness in the danger zone was determined by measuring the distance from the root canal edge to the external surface of the distal root concavity (Fig. 1).

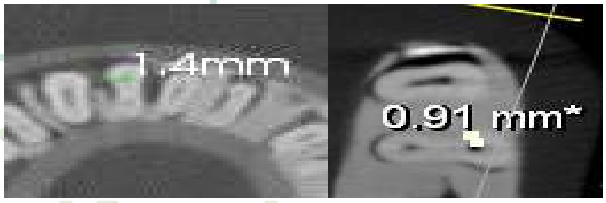


**Figure 1: Measurement of dentin thickness at 4 mm below the canal orifice in the mesiobuccal canals of mandibular molar on CBCT image. a) Pre-instrumentation. b) Post-instrumentation.**

This measurement was taken three times, and the average thickness was recorded. Measurements were taken at 4, 5, and 6 mm below the canal orifice. The amount of dentin removed was calculated by subtracting the post-instrumentation measurements from the initial values. [8]

**Statistical analysis**

Statistical analysis was conducted using SPSS software (version 20, Statistical Package for Scientific Studies, SPSS, Inc., Chicago, IL, USA).

The amount of dentin removed was determined by subtracting the post-instrumentation measurements from pre-instrumentation measurements (D1-D2)

Numerical data were summarized with the mean and standard deviation, confidence intervals and range. Data normality was assessed for by examining data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Since the data followed a normal distribution, group comparisons were made using a One-Way ANOVA test, with Bonferroni's post hoc test for pairwise comparisons. A two-way ANOVA test was conducted to analyze the effects of study variables and their interactions. All p-values are two-sided, with values ≤0.05 considered statistically significant.

**Results**

**Comparison of the remaining and amount of removed dentin among the tested groups at 4,5,6 mm from the canal orifice: (Table 2)**

**At 4 mm from the canal orifice:**

The highest mean value of remaining dentin thickness was recorded in Group III TF adaptive (0.97±0.04) and group I ProTaper Next (0.93±0.04); whereas group II Videya N recorded a significantly lower value (0.63±0.12), (p=0.000).

A significantly higher value of amount of removed dentin was recorded in Group II Videya N (0.43±0.16), in comparison to Group I ProTaper Next (0.22±0.1) and Group III TF adaptive (0.14±0.08), (p=0.000).

**At 5mm from the canal orifice:**

The highest mean value of remaining dentin thickness was recorded in Group III TF adaptive (0.86±0.05) and group I Pro Taper Next (0.83±0.03); whereas group II Videya N recorded a significantly lower value (0.51±0.11), (p=0.000).

A significantly higher value of amount of removed dentin was recorded in Group II Videya N (0.36±0.15), in comparison to Group I ProTaper Next (0.18±0.08) and Group III TF adaptive (0.14±0.08), (p=0.000)

**At 6mm from the canal orifice:**

The highest mean value of remaining dentin thickness was recorded in Group III TF adaptive and group I Pro Taper Next (0.72±0.03); whereas group II Videya N recorded a significantly lower value (0.41±0.08), (p=0.000).

A significantly higher value of amount of removed dentin was recorded in Group II Videya N (0.3±0.11), in comparison to Group III TF adaptive (0.13±0.04) and Group I ProTaper Next (0.11±0.04), (p=0.000).

**Comparison of the remaining and amount of removed dentin within each group at 4,5,6 mm from the canal orifice: (Table 2)**

Within each group, the remaining dentin thickness had a significantly higher value in 4 mm in comparison to 5 mm, whereas a significantly lower value was recorded in 6 mm from the canal orifice.

**Amount of removed dentine within each group:**

Group I (ProTaper Next): A significantly higher value was recorded in 4 mm (0.22±0.1) and 5 mm (0.18±0.08), in comparison to a significantly lower value in 6 mm (0.11±0.04), (p=0.000).

Group II (Videya N): A significantly higher value was recorded in 4 mm (0.43±0.16), followed by 5 mm (0.36±0.15), whereas a significantly lower value was recorded in 6 mm (0.3±0.11), (p=0.000). The value at 5 mm was not significantly different from each of 4 mm and 6mm.

In Group III (TF adaptive): The same value was recorded at 4 mm and 5 mm (0.14±0.08), with a slightly lower value at 6 mm (0.13±0.04), (p=0.000). The difference between 4, 5 and 6mm was not significantly different (p=0.865).

**Table 2: Descriptive statistics (Mean and standard deviation) and comparison between groups and within the same group regarding the remaining dentin thickness and amount of removed dentin at 4, 5 and 6 mm from the canal orifice (ANOVA test)**

| | | 4mm | | 5mm | | 6 mm | | F | P value (within group) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Dev | Mean | Std. Dev | Mean | Std. Dev | | |
| Remaining dentin thickness | Group I: ProTaper Next | $.93^{mA}$ | .04 | $.83^{mB}$ | .03 | $.72^{mC}$ | .03 | 19.99 | .000* |
| | Group II: Videya N | $.63^{nA}$ | .12 | $.51^{nB}$ | .11 | $.41^{nC}$ | .08 | 17.87 | .000* |
| | Group III: TF adaptive | $.97^{mA}$ | .04 | $.86^{mB}$ | .05 | $.72^{mC}$ | .03 | 3.39 | .042* |
| | F value | 89.21 | | 116.2 | | 180. 7 | | | |
| | P value (between groups) | .000* | | .000* | | .000* | | | |
| Amount of removed dentin | Group I: ProTaper Next | $.22^{Az}$ | .10 | $.18^{Az}$ | .08 | $.11^{Bz}$ | .04 | 40.46 | .000* |
| | Group II: Videya N | $.43^{Ay}$ | .16 | $.36^{ABy}$ | .15 | $.30^{By}$ | .11 | 143.90 | .000* |
| | Group III: TF adaptive | $.14^{Az}$ | .08 | $.14^{Az}$ | .08 | $.13^{Az}$ | .04 | .15 | .865 ns |
| | F value | 24.51 | | 18.67 | | 34.91 | | | |
| | P value (between groups) | .000* | | .000* | | .000* | | | |

## Discussion

One of the challenges during the endodontic treatment of the mandibular molars is the complicated anatomy of the root canal. The mesial roots exhibit a concavity with minimal dentine thickness at the furcation area [24,25], and have been described as the dangerous zone, subjecting this zone to risk of perforation during root canal instrumentation. [2] During chemo-mechanical preparation of root canal systems, appropriate coronal flaring must be performed without jeopardizing the dentine wall integrity. The best endodontic treatment outcomes are obtained by adopting less invasive procedures that preserve the fundamental structure of the root canal. [26] Thus, an important aim is to maintain the tooth structure during the preparation of this location that requires very careful selection of the preparation instrument.

The ability of the tooth to bear the stress following endodontic treatment depends on the residual dentinal thickness. [22] Therefore, the present research was designed to check the remaining width of dentin in the thin risky area in the mandibular molars following root canal adjustment with ProTaper Next, Videya N and Twisted File Adaptive systems using CBCT.

Regarding the selection of the root length, the roots with 13 ± 1 mm lengths were recruited since the root length has a correlation with the danger zone thickness. [6,27] It has been noted that 4-6 mm apical to the root canal orifice is the area liable to be perforated in the mesiobuccal root of the mandibular molar. [2,28,29] As a result, the levels of 4,5 and 6 mm under the canal orifice were selected for analysis of residual dentin thickness.

In the current research, the remaining dentin thickness was measured using CBCT. CBCT imaging is effective for examining the anatomic structure of root canals [30], particularly in the area of the danger zone, which are commonly affected during preparation. [31] Throughout mechanical preparation of the root canal, CBCT offers highly reproducible, detailed precise data about the root canal configuration and tooth structure measurements. [32-34] Several studies have utilized CBCT to measure the residual dentin in the danger zone after mechanical preparation of the root canals. [7,8,18]

Plastic dental model was used to hold and stabilize the teeth throughout scanning and standardize measurements. [35]

The results showed a significantly higher value of amount of removed dentin by Videya N files in comparison to ProTaper next and TF adaptive files. Videya N file has rectangular cross section and it is manufactured from CM wire. In addition to heat treatment process significantly improves the fatigue resistance. This design provides more cutting edges, wider flutes for debris removal, and a larger contact area which enhance cutting efficiency. [11]

TF adaptive files achieved the highest mean value of remaining dentin thickness. This is caused by the triangular cross section of the instruments, twisted design, metallurgical properties and adaptive motion used which results in a more conservative approach to dentin removal and preservation of tooth structure. Pedulla et al (2016) [36] showed results with higher canal volume following the adaptive movement preparation with TF Adaptive instruments.

The comparable results between Protaper next and TF adaptive files could be attributed to their innovative design features. The off-centered cross section of the PTN files offers a snake-like swaggering movement as it advances into the root canal. This, combined with progressive taper which contribute to efficient cutting. This design emphasizes a balance between cutting efficiency and safety making ProTaper next instruments ideal for preparing curved root canals. [37] The recommendation is noted to minimize the risk of overpreparation in the danger zone by using PTN in a continuous rotation motion and brushing movement which helps in anticurvature filing. [38] These results agreed with those of Pattanaik et al. (2023) [39] who suggested that ProTaper Next files had optimal canal shaping ability.

The current in vitro results obtained significantly higher amount of dentin removal by Videya N files suggesting they might be more suitable for cases requiring extensive cleaning, while ProTaper Next and TF adaptive files could be better for more conservative approaches. However, this study was conducted under controlled laboratory conditions, which may not fully replicate the complexities of clinical scenarios. It focused on three file systems; incorporating additional systems could provide a broader comparison and deeper insights. Although CBCT delivers precise 3D imaging, its resolution may not capture very thin dentin layers. Utilizing higher-resolution imaging techniques could enhance measurement accuracy.

## Conclusion

The present study concluded that ProTaper Next, Videya N and TFAdaptive file systems all effectively and safely prepared the MB root canals of mandibular molars in the danger zone. Among these, Videya N files demonstrated higher amount of removed dentin suggesting their potential as a promising tool for cases requiring extensive cleaning.

Further research is recommended to assess the dentin width in the danger zone of mandibular molars subsequent to using these files, utilizing micro-CT analysis.

## Declarations

### Ethical approval

The present experimental study was done in the Endodontic Department, Faculty of Dental Medicine for Girls, Al-Azhar University and ethically accepted by the Research Ethics Committee (REC) of the institute (REC-PD-24-17) and it complies with the Declaration of Helsinki (2013). The extracted teeth were collected from the Oral Surgery Department, Faculty of Dentistry, Cairo University.

### Patient declaration of consent

Patient declaration of consent was obtained in a Helsinki declaration consent form in their native language (Arabic). Provided is the English version of said form and a signed Arabic one by one of the study contributors.

### Availability of data and materials statement

The data that support the findings of this study are available from the corresponding author, [HSM], upon reasonable request

## Competing of interest

We affirm that none of the work described in this article could have been influenced by any known conflicting financial interests or personal relationships.

## Funding

Funding organizations from the governmental, private, or nonprofit sectors did not specifically award money for this study.

## References

1. Chaudhary N, Singh D, Somani R, Jaidka S. Comparative evaluation of efficiency of different file systems in terms of remaining dentin thickness using cone-beam computed tomography: An in vitro study. Contemp Clin Dent. 2018 Jul 1;9(3):367–71.
2. Abou-Rass M, Frank AL, Glick DH. The anticurvature filing method to prepare the curved root canal. . J Am Dent Assoc . 1980;101:792–4.
3. Kessler JR, Peters DD, Lorton L. Comparison of the Relative Risk of Molar Root Perforations Using Various Endodontic Instrumentation Techniques. Vol. 9. 1983.
4. SauaiaTS, Gomes BPFA, Pinheiro ET, Zaia AA, FerrazCCR, Souza-Filho FJ, et al. Thickness of dentine in mesial roots of mandibular molars with different lengths. Int Endod J.2010;43: 555-9.
5. Tabrizizadeh M, Reuben J, Khalesi M, Mousavinasab M, Ezabadi MG. Evaluation of radicular dentin thickness of danger zone in mandibular first molars. J Dent (Tehran). 2010 ;7(4):196-9.
6. Dwivedi S, Dwivedi CD, Mittal N. Correlation of root dentin thickness and length of roots in mesial roots of mandibular molars. J Endod. 2014;40(9):1435–8.
7. Zhou G, Leng D, Li M, Zhou Y, Zhang C, Sun C, et al. Root dentine thickness of danger zone in mesial roots of mandibular first molars. BMC Oral Health. 2020 Feb 6;20(1):43.
8. Turker SA GGGC. Effect of Different Single File Systems on The Dentin Thickness In The Danger Zone Of Mandibular First Molars. J Int Dent Sci. 2023;9:113–8.
9. Pérez-Higueras JJ, Arias A, De La Macorra JC. Cyclic fatigue resistance of K3, K3XF, and twisted file nickel-titanium files under continuous rotation or reciprocating motion. J Endod. 2013;39(12):1585–8.
10. Koçak S, Şahin FF, Özdemir O, Koçak MM, Sağlam BC. A comparative investigation between protaper next, hyflex cm, 2shape, and tf-adaptive file systems concerning cyclic fatigue resistance. J Dent Res, Dent Clin, Dent Prospects. 2021;15(3):172–7.
11. Vidaya Technology Co., Ltd. [Internet]. [cited 2023 Mar 22]. Available from: https://www.videya-gd.com/products.html.
12. Alapati SB, Brantley WA, Iijima M, Clark WAT, ovarik,L, Buie C, et al. Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. J Endod 2009; 35:1589-93.
13. Santos L de A, Bahia MG de A, de Las Casas EB, Buono VTL. Comparison of the mechanical behavior between controlled memory and superelastic nickel titanium files via finite element analysis. J Endod 2013; 39:1444-7.
14. Gambarini G, Testarelli L, De Luca M, Milana V, Plotino G, Grande NM et al. The influence of three different instrumentation techniques on the incidence of postoperative pain after endodontic treatment. Ann Stomatol (Roma) . 2013;4:152–5.
15. Alsofi L, Al Harbi M., Stauber M., Balto K. Analysis of the Morpho-Geometrical Changes of the Root Canal System Produced by TF Adaptive vs. BioRace: A Micro-Computed Tomography Study. . Materials . 2021;14:531.
16. Durack C, Patel S. Cone beam computed tomography in endodontics. Braz dent J. 2012;23:179–91.
17. Elsherief SM, Zayet MK, Hamouda IM. Cone-beam computed tomography analysis of curved root canals after mechanical preparation with three nickel-titanium rotary instruments. J Biomed Res. 2013;27(4):326–35.
18. Yanık D, Nalbantoğlu AM. Dentin Thickness at Danger Zone and Canal Morphology of Maxillary Molars. Acta Stomatol Croat. 2022 Mar 1;56(1):50–60.
19. Xu J, He J, Yang Q, Huang D, Zhou X POGY. Accuracy of Cone-beam Computed Tomography in Measuring Dentin Thickness and Its Potential of Predicting the Remaining Dentin Thickness after Removing Fractured Instruments. J Endod. 2017;43(9):1522–7.
20. Shaheen N. Influence of heat-treated single file rotary systems on remaining dentin thickness in the danger zone of the mandibular first molar. An in-vitro CBCT study. Egypt Dent J. 2024 Jan 1;70(1):853–9.
21. Nassar S, Shetty HK, Nair PMS, Gowri S, Jayaprakash K. comparative Evaluation of Fracture Resistance of Endodontically Treated Bicuspids Instrumented With Hand Files, TruNatomy, ProTaper Next, ProTaper Gold, and WaveOne - An In vitro Study. . J Pharm Bioallied Sci . 2022;14(Suppl 1):S600-4. .

22. Jaggi P, Mulay S, Tandale A, Jadhao R, Joshi P, Aras S, et al. Comparative Evaluation of Debris Extrusion, Remaining Dentin Thickness and Fracture Resistance of Endodontically Treated Teeth Using Rotary and Reciprocating Endodontic File Systems: An In Vitro Study. Cureus. 2023 Jul 22;15:e42290.
23. Schneider SW. Acomparison of canal preparation in straight and curved root canals. . Oral Surg Oral Med Oral Path . 1971;32:271–5.
24. Barker BCW, Parsons KC, Mills PR, Williams GL. Anatomy of root canals. III. Permanent mandibular molars. Aust Dent J. 1974;19:408–13.
25. Berutti E, Fedon G. Thickness of cementum/dentin in mesial roots of mandibular first molars. J Endod . 1992;18:545–8.
26. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. . J Endod . 2004;30:559–67.
27. Saua'ia TS, BPFA G, Pinheiro ET et al. Thickness of dentine in mesial roots of mandibular molars with different lengths. Int Endod J. 2010;43:555–9.
28. McCann JT, Keller DL, LaBounty GL. A modification of the muffle model system to study root canal morphology. J Endod . 1990;16:114–5.
29. De-Deus G, Rodrigues EA, Belladonna FG, Simões-Carvalho M, Cavalcante DM, Oliveira DS, et al. Anatomical danger zone reconsidered: a micro-CT study on dentine thickness in mandibular molars. Int Endod J. 2019 Oct 1;52(10):1501–7.
30. Zanette F, Grazziotin-Soares R, Flores ME, Camargo Fontanella VR, Gavini G, Barletta FB. Apical root canal transportation and remaining dentin thickness associated with protaper universal with and without pathfile. J Endod. 2014;40(5):688–93.
31. Gluskin AH, Brown DC, Buchanan LS. A reconstructed computerized tomographic comparison of Ni-Ti rotary GT$^{TM}$ files versus traditional instruments in canals shaped by novice operators. Int Endod J. 2001 Sep;34(6):476–84.
32. Madani ZS, Goudarzipor D, Haddadi A, Saeidi A, Bijani A. A CBCT assessment of apical transportation in root canals prepared with hand K-Flexofile and K3 rotary instruments. IEJ . 2015;10:44–8.
33. Ibrahim M A, El Gendy A A H , El Sewfy T M , Comparative evaluation of shaping abilities of two different rotary files ( an in vitro study ). ASDJ 2021 ;22 (2) : 28- 38.
34. Ahmed J M M O , EL Gendy A A H , Mustafa T Shaping Ability of Three Different Rotary Nickel Titanium Systems An In Vitro Study. ASDJ 2024 ; 33 ( 1) : 156 – 63.
35. Roshdy NN, Hassan RE. Comparison of the effect of different orifice openers on the cervical dentine thickness of mesiobuccal root canals of mandibular molars: a cone beam computed tomography (CBCT) study. ENDO (Lond Engl). 2017;11(4):257–63.
36. Pedulla E, Plotino G, Grande NM, et al. Shaping ability of two nickel–titanium instruments activated by continuous rotation or adaptive motion: a microcomputed tomography study. Clin Oral Investig 2016;20:2227–33.
37. Bürklein S, Mathey D, Schäfer E. Shaping ability of ProTaper NEXT and BT-RaCe nickel-titanium instruments in severely curved root canals. Int Endod J 2015;48:774-81.
38. Sousa, V.C., Alencar, A.H.G., Bueno, M.R., Decurcio, D.A., Estrela, C.R.A., Estrela, C., 2022. Evaluation in the danger zone of mandibular molars after root canal preparation using novel CBCT software. Braz. Oral Res. 36, e038.
39. Pattanaik P, Balasubramanian A, Veeralakshmi P, Singh G, Sadananda V, Ahmed H, et al. Comparative Evaluation of the Shaping Ability of the Recent, Fifth-generation ProTaper Next and Revo-S NiTi Rotary Endodontic Files Using Three-dimensional Imaging: An Imaging-based Study. J Microsc Ultrastruct. 2023 Dec 12;10:4103.