RESEARCH PAPER

Evaluation of Remaining Dentin Thickness Following Root Canal Instrumentation Using Micro Ct Analysis: An In Vitro Study

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***Received:** 24th April, 2026; Revised: 20th May 2026; Accepted: 30th June, 2026; Available Online: 10th July, 2026*

ABSTRACT

Background: Successful root canal instrumentation requires an optimal balance between effective canal debridement and preservation of radicular dentin. Variations in apical diameter size and taper may influence shaping outcomes, particularly in curved canals. With advancements in nickel–titanium rotary systems, it is essential to evaluate their effect on remaining dentin thickness (RDT), canal centering ability, and canal transportation.

Aim: To evaluate influence of variations in apical diameter size and taper on RDT, canal centering ability, and canal transportation following instrumentation with micro CT.

Materials and Methodology: Fifteen extracted moderately curved human mandibular first molars (10°–20° based on Schneider's classification) were selected. The specimens were decoronated and standardized to a root length of 10 mm. Pre- operative micro- CT scans were performed. Random allocation of specimens resulted in three groups, each consisting of 10 canals: Group I – VDW Rotate 25/.06, Group II – VDW Rotate 30/.04, and Group III – HyFlex EDM OGSF 30/.04. Following instrumentation under standardized conditions, post-operative micro- CT scans were obtained. RDT, canal centering ability, and canal transportation were measured 1 – 10 mm levels from the apex.

Statistical Analysis: Data analysis was carried out using one- way ANOVA in SPSS (version 26.0), with significance determined at $p < 0.05$.

Results: No statistically significant differences were observed among three groups for RDT, canal centering ability, and canal transportation at any evaluated levels (1 – 10mm) from apical foramen. However, HyFlex EDM OGSF demonstrated a tendency toward improved centering ability and minimal canal transportation in coronal region (7 –10 mm), although not statistically significant.

Conclusion: With the obtained results, it can be stated that variations in apical diameter size and taper did not significantly influence shaping outcomes. Both VDW Rotate and HyFlex EDM OGSF systems exhibited comparable performance and can be considered clinically acceptable for root canal instrumentation

How to cite this article: Kuzhanchinathan M, Rajasekaran S, Kalaiselvam RG, Kuzhanchinathan M, Rajakumaran A, Ramesh SR, Rajendran MR, Evaluation of Remaining Dentin Thickness Following Root Canal Instrumentation Using Micro Ct Analysis: An In Vitro Study. Int J Drug Deliv Technol. 2026;16(7): 246-253. DOI: 10.25258/ijddt.16.7.27
Source of support: Nil.
Conflict of interest: None

INTRODUCTION

The primary objective of endodontic therapy is to prevent or elimination of apical periodontitis[1] through thorough debridement of root canal system, aimed at removing microorganisms, their byproducts, and necrotic pulp tissue This objective is accomplished by the shaping and cleaning of the root canal system. Mechanical instrumentation serves two roles: creates a space that facilitates the deeper penetration of chemical irrigants and it physically disrupts the biofilm on the canal walls [2].

Endodontic rotary instrumentation has evolved significantly through successive generations of Nickel–Titanium (NiTi) rotary systems[3]. First generation NiTi files were relatively rigid and lacked flexibility, often leading to procedural errors such as ledge formation, canal transportation, and apical deviation, particularly in curved canals[4]. They also showed limited ability to maintain the original canal anatomy, resulting in uneven dentin removal. These limitations led to the development of NiTi rotary systems, which improved shaping efficiency and enabled better preservation of canal anatomy[5].

The modification of the atomic structure of NiTi alloys has enabled the transition from shape memory to controlled memory characteristics and enhanced superelasticity, thereby improving the ability of instruments to preserve the original canal anatomy[6]. In addition, advancements such as heat treatment and surface modifications have been introduced to further enhance flexibility, fatigue

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resistance, and shaping performance. Recent NiTi instruments such as HyFlex EDM OGSF (Orifice opener, Glide path file Shaping and Finishing) files are manufactured using an innovative electrical discharge machining (EDM) process and are composed of controlled memory nickel–titanium alloy, contributing to improved flexibility and canal adaptation during preparation. Similarly, VDW Rotate, which incorporates advanced heat-treated NiTi technology, represents these advancements in instrument design and metallurgy.

The effectiveness of NiTi roatary instrumentation and the overall treatment outcome are determined by three critical parameters:

- Remaining Dentin Thickness,
- Canal Centering Ability
- Canal Transportation.

Remaining dentin thickness (RDT) refers to the thickness of dentin between the prepared canal and the external root surface[7]. Canal centering ability and canal transportation are directly related parameters and are critical to evaluate shaping performance. Centering ability refers to the instrument's capacity to remain equidistant from the canal walls during preparation. A loss of centering leads to uneven dentin removal, which will be resulting in canal transportation. It is defined as deviation from the original canal path. Therefore, better centering ability is associated with reduced transportation and improved preservation of canal anatomy.

Recently published systematic review and meta analysis by Sabeti et al.[8], suggests that favorable endodontic outcomes are associated with an apical preparation size of approximately #30; however, this may vary depending on the tooth type and instrument taper. In multirooted teeth with moderate root curvature (10°–20° as per Schneider's technique), particularly in the mesial roots of mandibular first molar, achieving an optimal apical preparation size of #30 may not always be achievable due to anatomical constraints.

In such cases, optimization of shaping and disinfection with smaller apical sizes may be attempted by modifying the taper of the preparation, often up to 0.06. However, there is currently no clear consensus regarding the ideal combination of apical preparation size and taper, and the available literature remains limited. Therefore, evaluating the influence of apical preparation size and taper on parameters such as remaining dentin thickness, canal centering ability, and canal transportation is essential to optimize shaping procedures while preserving the structural integrity of the tooth.

In recent years, **micro-computed tomography (micro-CT)** has emerged as a highly reliable, non-destructive imaging modality for evaluating root canal morphology and instrumentation outcomes. It provides high-resolution, three-dimensional analysis, allowing precise assessment of parameters such as remaining dentin thickness, canal transportation, and centering ability following instrumentation.

The present study aimed to evaluate and compare the remaining dentin thickness, canal centering ability, and canal transportation of two NiTi rotary systems (HyFlex EDM OGSF and VDW Rotate) using micro-CT analysis in the mesial roots of mandibular first molars.

MATERIALS AND METHODS

Armamentarium:

Rotary Instruments:

- VDW Rotate (LOT NO: 469175)
- HyFlex CM OGSF (30/.04) (LOT NO: N82930)

Hand Instruments:

- Stainless steel K- files (#10) (LOT NO: R24B03200) Irrigants:
- 3% Sodium Hypochlorite (LOT NO: SMH 2409005)
- 17% EDTA liquid (LOT NO:DSS/068)
- Distilled water

Equipment

- Endodontic motor (Extreme,Orikam healthcare Pvt.Ltd.,India)
- 30-gauge side- vented needle (Dispovan, Hindustan Syringes & Medical Devices Ltd., Faridabad, India)
- Ultrasonic scaler (UDS- P LED; Guilin Woodpecker Medical Instrument Co., Ltd., Guangxi, China)
- Carborundum disc and mandrel (DFS-Diamon, Germany)

Imaging Equipment

- SkyScan 2214 Micro- CT scanner (Bruker microCT, Kontich, Belgium)
- NRecon, DataViewer, CTAn, CTVox software (Bruker microCT. NRecon reconstruction software. Kontich, Belgium: Bruker microCT; 2020.)

METHODOLOGY

Ethical approval:

- The approval for the present research was obtained from the committee for the student's proposal, a constituent of the Institutional Ethical Committee of Sri Ramachandra Institute of Higher Education and Research (DU), Porur, Chennai. (CSP/ 26/MAR/ 177/95).

Sample Size Estimation:

- Using G*Power 3 software (version3.1.9.2) with a power of 80% and an alpha error of 5%, a sample size of n = 10 canals per group was determined. Therefore a total sample size of n =30 was fixed for the present study.

Teeth selection:

- Fifteen freshly extracted human mandibular first molar teeth with mature apices extracted for periodontal purposes procured from the Department of Oral and Maxillofacial Surgery, Sri Ramachandra Dental College & Hospital, Porur and stored in 0.1% Thymol solution.

Inclusion criteria for teeth selection:

- Anatomical Specifications: Mandibular first molars with fully formed apices.
- Canal Configuration: Only teeth with a Vertucci Type IV canal configuration in the mesial root (two separate canals - orifice to apex) were confirmed with radiograph.
- Curvature: Mesial roots with a moderate curvature ranging between 10° and 20° based on Schneider's classification.

Exclusion Criteria

- Teeth exhibiting visible cracks or fractures
- Evidence of internal or external root resorption.
- Calcified canals
- Teeth that had undergone previous endodontic intervention.

Sample Preparation

Storage and Disinfection

Immediately following extraction, the teeth were cleaned of any remaining soft tissue debris, calculus, and bone fragments using ultrasonic scalers. The specimens were decoronated using a diamond disc apical the cemento- enamel junction and the root length was standardized to 10 mm and then immersed in 0.1% Thymol solution until preparation.

Pre- operative Micro- CT Scanning Scanning Parameters

The specimens were mounted on a custom jig and scanned using a micro computed tomography system (SkyScan 2214, Bruker, Belgium) with the following parameters: X- ray source set at 80 kV and 110 µA, a 1 mm filter, and a pixel size 10 µm. Scanning was performed with a 360° rotation.

Apical Patency and working length determination:

In all decoronated samples, working length determination was carried out using a size #10, stainless steel K-file (Mani, Japan) to ensure apical patency and to verify the working length. The file was gently advanced until its tip extended beyond the apical foramen. Patency was maintained throughout the procedure using the same file.

Group Allocation

Random allocation of specimens was performed to form three experimental groups (n = 10 per group). A computer - generated chart was used to perform random allocation.

Group 1 – Root canal enlargement till 25.06 (VDW Rotate) Group 2 – Root canal enlargement till 30.04 (VDW Rotate) Group 3 – Root canal enlargement till 30.04 (Hyflex EDM OGSF)

Instrumentation Protocol

Canals were instrumented using an endodontic motor following manufacturer setting.

Irrigation was done using 20 m L of 3% sodium hypochlorite. A 30-gauge side- vented needle was used for irrigation after each instrumentation step. Following completion of instrumentation, irrigation of the canals was carried out with 17% EDTA for 1 minute and again with 3% sodium hypochlorite. A final rinse was performed using distilled water.

INSTRUMENTATION SEQUENCE: GROUP 1

- VDW Rotate 15/.04, 20/.05.25/.06

GROUP 2:

- VDW Rotate 15/.04, 20/.05, 25/.04, 30/.04

GROUP 3:

- Orifice opener 18/.11
- Glide path file 15/.03
- Shaping file 18/.045
- Finishing file 30/.04

Post-operative Micro-CT Scanning and Image Reconstruction

- The same scanning parameters used for the pre -operative scans were applied for the post-operative scans to ensure standardization.

The acquired projection images were reconstructed using NRecon (Bruker microCT, Kontich, Belgium; version 2.1.0.2). The reconstruction was performed with a pixel size of approximately 10 µm over a 360° angular range with a rotation step of 0.45°. Image processing parameters included smoothing set at 1 with a Gaussian kernel of 2, ring artifact correction of 11, and beam hardening correction of 20%.

Evaluation of RDT, Centering Ability and Canal Transportation: These parameters were evaluated 1 - 10 mm from the apical foramen using crosssectional images obtained through micro-computed tomography. Scanning was performed using the SkyScan 2214 (Bruker microCT, Kontich, Belgium) under standardized conditions, including a tube voltage of 80 kV, current of 110 μA, rotation step of 0.45° over 360°.

For RDT evaluation, thickness of dentin is measured as shortest distance from canal wall to external root surface.

Evaluation of canal centering ability involved measuring shortest distance from canal wall to external root surface in both mesial and distal directions before and after instrumentation.

Centering Ratio was calculated using formula=

(A1 − A2) / (B1 − B2) or **(B1 − B2) / (A1 − A2)**

wherein:

A1 and A2: shortest distance from mesial root surface to canal before and after instrumentation, respectively.

B1 and B2: shortest distance from distal root surface to canal before and after instrumentation, respectively.

Smaller ratio was selected for evaluation. A value of 1 denotes perfect centering, while values approaching 0 reflect poorer centering.

Transportation = (A1 − A2) − (B1 − B2)

A 0 value signifies no transportation, wherein positive and negative data reflect deviation in the mesial and distal direction, respectively.

Canal centering ability and canal transportation were assessed by method described by Gambill et al. [9]

3D Analysis and Visualization:
Three- dimensional visualization and qualitative assessment were performed using CTVol (Bruker microCT, Kontich, Belgium; version 3.3.0) software. Quantitative morphometric analysis, including validation of measurements and region - of- interest (ROI) standardization, was carried out using CTAn micro- CT analysis software.

Statistical Analysis

Statistical evaluation was done using SPSS software (IBM SPSS Statistics for Windows, Version 26.0, Armonk, NY: IBM Corp., 2019). One- way ANOVA was applied for evaluation of RDT, canal transportation, and canal centering ratio across three groups. Significance cutoff of $p < 0.05$ was set.

RESULTS

Table 1 presents the intergroup comparison of RDT, canal transportation and canal centering ability ratio among the three groups at different levels using one-way ANOVA.

For RDT, the mean values across Groups 1, 2, and 3 were comparable at all levels from 1 mm to 10 mm, as shown in **Table 1 and Graph 1.** The differences were not statistically significant at any level ($p > 0.05$), with p- values ranging from 0.216 to 0.961.

Similarly, for canal transportation, no statistically significant difference was observed among the three groups at any level, as shown in **Table 1 and Graph 2** ($p > 0.05$). Although comparatively higher variation was noted at 10 mm ($F = 3.01$, $p = 0.066$) and 8 mm

($F = 2.67$, $p = 0.087$), these differences did not reach statistical significance.

For canal centering ability ratio, the mean values were also comparable across all groups at each level, as shown in **Table 1 and Graph 3** . No statistically significant differences were observed ($p > 0.05$), with p- values ranging from 0.091 to 0.835.

Overall, intergroup comparison revealed that there was no statistically significant difference among Groups 1, 2, and 3 with respect to RDT, canal transportation, and canal centering ability at any of the evaluated levels.

DISCUSSION

The efficiency of root canal instrumentation with Ni Ti rotary system is largely determined by their ability to maintain RDT, canal centering ability, and canal transportation. Advancements in Ni Ti instruments have markedly improved shaping outcomes by enhancing flexibility and reducing undesirable forces during canal preparation [3]. Earlier NiTi instruments, although advantageous, exhibited greater stiffness and limited adaptability in curved canals[4]. Subsequent developments, including heat- treated and controlled memory Ni Ti systems, have improved flexibility and reduced shape memory, allowing more conservative dentin removal and better maintenance of canal centricity[5]. In addition, surface modification techniques such as electrical discharge machining have further optimized cutting action with enhanced cyclic fatigue while preserving the integrity of instrument.

The present study evaluated the influence of variations in taper and apical diameter size on RDT, canal centering ability, and canal transportation. By comparing preparations with differing taper –apical diameter size combinations, the study aimed to determine their relative impact on shaping outcomes and dentin preservation.

The choice of taper in the present study was based on its influence on both shaping efficiency and dentin preservation. Preparations of 25/.06 and 30/.04 were chosen as they represent clinically relevant strategies that balance apical enlargement and taper[9]. A 30/.04 preparation provides a larger apical diameter with a relatively conservative taper, thereby favouring preservation of radicular dentin, particularly in anatomically vulnerable regions. In contrast, a 25/.06 preparation incorporates a greater taper with a smaller apical size, which may enhance coronal enlargement and

facilitate irrigant penetration, but may also increase the risk of dentin removal.

Mesial roots of mandibular first molars were considered viewing the intricate root canal morphology, characterized by narrow canals in mesiodistal direction, thin dentinal walls, and moderate curvature. These features make them prone for canal transportation and excessive dentin removal, making them a suitable model for evaluating shaping ability. [10,11] Moderate curvature (10°–20° as per Schneider' s classification) [12] represents a commonly encountered clinical situation and provides a balanced level of difficulty for standardized in vitro assessment.

Micro- CT imaging was carried out in this study for analysis was due to its high accuracy in evaluating root canal morphology and instrumentation outcomes. Studies reported in the literature by Swain et al. (2009) [13] and Metscher et al. (2009) [14] demonstrated its ability to provide detailed three- dimensional analysis without specimen sectioning, thereby preventing material loss. Owing to these advantages, micro-CT is considered reliable without compromising the structural integrity of the specimen.

The present study findings presented no statistically significant differences within three groups pertaining to RDT, canal centering ability, and canal transportation at all evaluation levels. This suggests that both the tested rotary Ni Ti systems exhibited comparable shaping performance. However, Group 3 (Hyflex EDM OSGF) showed improved canal centricity with less deviation, particularly in the coronal region (7–10 mm), in comparison to Group

1 and Group 2. This may be attributed to the controlled memory characteristics of the Ni Ti alloy[6]. Controlled memory files exhibit reduced shape memory, allowing them to closely adapt to the canal curvature during instrumentation. This enhanced adaptability reduces lateral forces exerted on the canal walls and promotes more uniform and conservative dentin removal. Such behaviour is particularly advantageous in the coronal and pericervical regions, where preservation of dentin is critical for maintaining structural integrity [7].

Consequently, the ability of these instruments to maintain a more centered preparation in this region may contribute to better preservation of tooth strength while still achieving effective canal shaping. This region corresponds to the pericervical dentin, [15] a critical zone which is important in distributing occlusal stresses and improving the overall fracture resistance of the tooth.

Preservation of dentin in this region is essential, as it contributes significantly to the structural stiffness of the tooth and its ability to withstand functional loading. Any excessive removal of dentin in this area may lead to stress concentration and increased susceptibility to vertical root fracture.

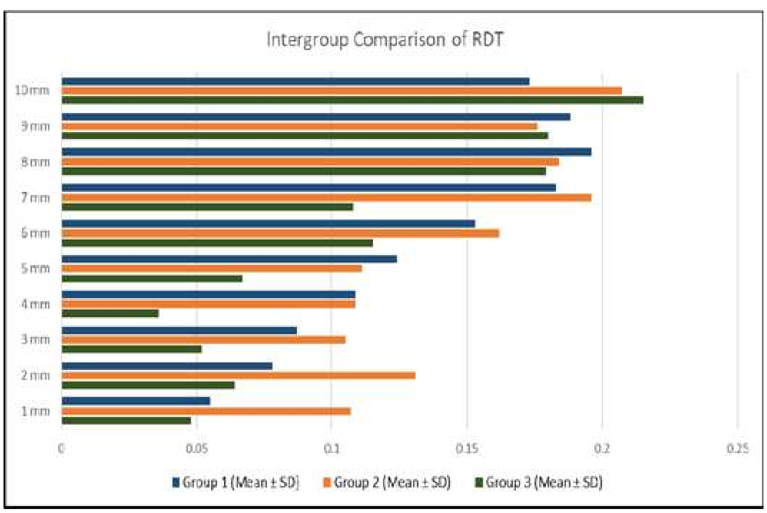
In contrast, the VDW Rotate groups (Group 1: 25/.06 and Group 2: 30/.04) also demonstrated consistent shaping performance across all evaluated parameters. The comparable results observed in these groups may be attributed to the heat -treated Ni Ti alloy, which provides an optimal balance between flexibility and cutting efficiency. This allows effective canal preparation while maintaining acceptable dentin preservation and canal centricity. Similar findings have been reported by Falakaloğlu et al. (2022) [16] , who demonstrated comparable shaping efficiency of VDW Rotate with other contemporary NiTi systems.

The findings may be considered clinically relevant as mesial roots of mandibular first molars were used and reliable high-resolution imaging technique were employed to evaluate two widely used Ni Ti rotary systems. The results demonstrated comparable performance of both systems. Based on these observations, it can be inferred that both systems exhibit acceptable shaping characteristics and may be considered suitable for clinical use in root canal instrumentation.

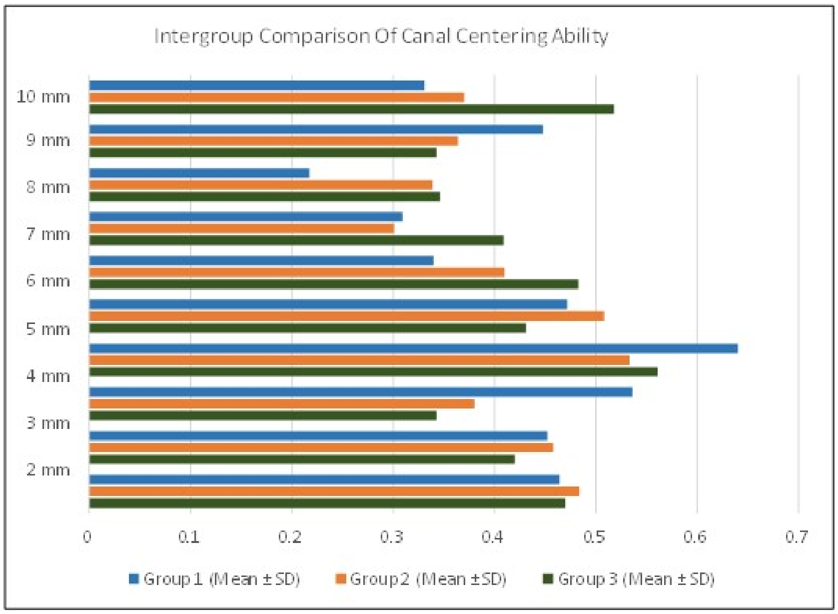
The present study is limited by its in vitro design and the use of extracted teeth, which may not fully replicate clinical conditions. As the study was conducted under controlled experimental settings, the findings may not directly reflect in vivo outcomes. Further studies employing similar designs under clinical conditions, including investigations on human subjects, are necessary to validate these results.

Table1: Comparison of mean and standard deviation of RDT, canal transportation, and canal centering ability among the three groups at levels 1 to 10 mm from the apical foramen.

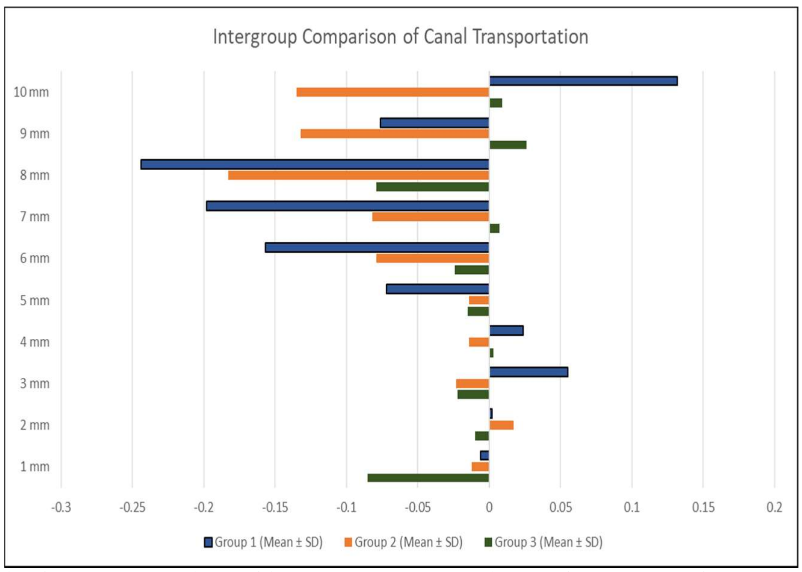
Level	Parameter	Group 1 (Mean ± SD)	Group 2 (Mean ± SD)	Group 3 (Mean ± SD)	p-value
10 mm	RDT	0.173 ± 0.101	0.207 ± 0.151	0.215 ± 0.124	0.736
	CNL–TRN	0.132 ± 0.157	-0.135 ± 0.206	0.009 ± 0.159	0.066
	CCA	0.331 ± 0.204	0.370 ± 0.235	0.518 ± 0.202	0.091
9 mm	RDT	0.188 ± 0.102	0.176 ± 0.120	0.180 ± 0.134	0.961
	CNL–TRN	-0.076 ± 0.180	-0.132 ± 0.210	0.026 ± 0.178	0.232
	CCA	0.448 ± 0.267	0.364 ± 0.249	0.343 ± 0.244	0.424
8 mm	RDT	0.196 ± 0.090	0.184 ± 0.095	0.179 ± 0.156	0.942
	CNL–TRN	-0.244 ± 0.146	-0.183 ± 0.170	-0.079 ± 0.245	0.087
	CCA	0.217 ± 0.160	0.339 ± 0.213	0.346 ± 0.178	0.283
7 mm	RDT	0.183 ± 0.083	0.196 ± 0.139	0.108 ± 0.121	0.216
	CNL–TRN	-0.198 ± 0.133	-0.082 ± 0.223	0.007 ± 0.129	0.34
	CCA	0.309 ± 0.246	0.301 ± 0.252	0.409 ± 0.240	0.52
6 mm	RDT	0.153 ± 0.088	0.162 ± 0.101	0.115 ± 0.118	0.545
	CNL–TRN	-0.157 ± 0.131	-0.079 ± 0.142	-0.024 ± 0.160	0.422
	CCA	0.340 ± 0.214	0.410 ± 0.267	0.483 ± 0.281	0.561
5 mm	RDT	0.124 ± 0.067	0.111 ± 0.087	0.067 ± 0.138	0.426
	CNL–TRN	-0.072 ± 0.086	-0.014 ± 0.104	-0.015 ± 0.142	0.478
	CCA	0.472 ± 0.287	0.508 ± 0.301	0.431 ± 0.297	0.495
4 mm	RDT	0.109 ± 0.045	0.109 ± 0.094	0.036 ± 0.145	0.284



Graph 1: Graphical representation of intergroup comparison of mean RDT at various levels 1 to 10 mm from the apical foramen.



GRAPH 2: Graphical representation of intergroup comparison of mean canal centering ability at various levels from 1 mm to 10 mm from the apical foramen.



GRAPH 3: Graphical representation of intergroup comparison of mean canal transportation at various levels from 1 mm to 10 mm from the apical foramen.

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