Original Article

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Dentistry Section

Evaluation of Root Dentin Removal and Apical Debris Extrusion during Root Canal Preparation Related to the Different Endodontic Access Cavities: An In-vitro Study

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ABSTRACT

Introduction: The restricted access cavity and the remaining roof of the pulp chamber may change the angle at which the instrument enters the root canal, which could have an impact on the effectiveness of chemo-mechanical canal preparation, potentially leading to endodontic mishaps.

Aim: To evaluate the effect of the Traditional Endodontic Cavity (TEC) and Conservative Endodontic Cavity (CEC) on the amount of Root Dentin Removal (RDR) and the related Apical Debris Extrusion (ADE) in the curved root canals prepared with ProTaper Next (PTN) and TruNatomy (TN).

Materials and Methods: The in-vitro study included a total of 120 extracted human mandibular molars, separated into four groups (n=30) based on the type of endodontic cavity and file used: TEC-TN, CEC-TN, TEC-PTN, and CEC-PTN. Before biomechanical preparation, Cone Beam Computed Tomography (CBCT) scans were taken. During the preparation, apically extruded debris was collected in Eppendorf tubes. After canal preparation, a post-CBCT scan was performed, and the RDR was evaluated by comparing the pre- and post-CBCT scans. To determine the amount of ADE, the weight of the clear tubes was subtracted from the weight of the tubes containing the debris. The data were analysed using one-way analysis of variance and post-hoc Tukey test. The significance level was set at $p<0.05$.

Results: Analysis and comparison of four groups each with n=-30 extracted mandibular molars was done in the present study. The CEC-PTN group showed the highest total RDR of 0.32. Additionally, the CEC-PTN group produced the highest ADE with statistically significant differences between the TEC-TN, CEC-TN, and TEC-PTN groups ($p<0.05$).

Conclusion: The CEC causes engagement of the rotary instrument with the dentinal wall, leading to RDR, debris production, and ultimately more ADE compared to TEC. The TN file caused less RDR and ADE in both endodontic access cavities compared to the PTN file.

Keywords: Pedodontic instrumentation, ProTaper next, Rotary instrumentation, TruNatomy

INTRODUCTION

During root canal preparation, dentinal filings, necrotic pulp tissue, bacteria, and their byproducts can protrude from the apical foramen, causing periapical irritation and inflammation [1,2]. The methods of instrumentation, kinematics, number and design of instruments, canal curvature, working length, and design of the endodontic access cavity all have an impact on the amount of Apical Debris Extrusion (ADE) [3,4].

In the Traditional Endodontic Cavity (TEC), the roof of the pulp chamber is fully removed to facilitate identification of the root canals and create a straight path for instrumentation [5,6]. However, these techniques remove a significant amount of tooth structure, which can increase stress on the crown and root, reducing the tooth's fracture resistance [7,8]. As an alternative to the TEC design, the Conservative Endodontic Cavity (CEC) was developed [9,10]. The CEC aims to preserve more tooth tissue, such as the Pericervical Dentin (PCD) and the soffit of the pulp chamber, by producing less destructive access cavities [11,12]. However, the CEC may alter the instrument's entry angle into the root canal, potentially impacting the efficiency of chemo-mechanical canal preparation and leading to endodontic mishaps due to possible binding of the instrument with the dentinal wall [12,13]. Although several studies have investigated the preservation of PCD with different endodontic access cavities [7,8], none have examined the effects of different endodontic cavities on root dentin thickness at various root levels using different file systems.

All current preparation methods and tools are associated with debris extrusion. To address these issues, various new design concepts have been implemented in Nickel-titanium (NiTi) rotary instruments, which help maintain canal shape with minimal iatrogenic errors [2]. TruNatomy (TN; Dentsply Sirona, Charlotte, NC, USA), a unique heat-treated NiTi instrument, features a slip shape with an off-centered parallelogram cross-section, regressive narrow taper, limited shape memory, and specific heat treatment, allowing better adaptability to the natural tooth anatomy and enhanced coronal debris removal, especially in highly curved canals [14,15]. Another NiTi file, called ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland), is made of M-Wire NiTi alloy and has a rectangular off-centered cross-section with progressive and regressive tapers, which minimises the screw-in effect by reducing the contact between the file and the dentin [16,17].

Several studies have demonstrated significant root dentin loss during root canal preparation with these file systems [18-20], while others have shown that TEC results in PCD reduction [21]. To the best of our knowledge, no investigations have examined the effect of the conservative access cavity on Root Dentin Removal (RDR) at different root levels or the relationship between RDR and the amount of ADE using different single-file systems. Thus, the objectives of this study were to compare the effects of CEC and TEC on RDR and its correlation with ADE using different single rotary file systems during root canal preparation, analysed with a microbalance and CBCT.

MATERIALS AND METHODS

The in-vitro study was conducted between June 2022 and January 2023 in the Department of Conservative Dentistry and Endodontics at Karnavati School of Dentistry, Gandhinagar, Gujarat, India.

Inclusion criteria: The study included 120 fully developed, healthy, and undamaged human mandibular first molars that were extracted due to periodontal disease and had no cavities. The curvature of the root canal was calculated using Schneider's approach [22] to ensure that only mesial roots with a curvature angle between 20°-30° were chosen. Teeth with a single canal in the distal root and two canals in the mesial root were selected for the investigation.

Exclusion criteria: Each tooth's mesial and distal roots were examined under a stereomicroscope (Labomed, LA, CA, USA) with 20X magnification to identify any cracks, fractures, or fusion. Teeth with cracks, previous root canal therapy, internal or external root resorption, or pulpal calcification were excluded from the study.

Sample size calculation: A previous study [22] investigating the effects of the endodontic access cavity on ADE during root canal preparation using various single-file systems found that a sample size of 20 teeth per group was sufficient to detect a significant difference between two groups. Therefore, the present study used a sample size of 30 teeth per group to ensure 80% power and a significance level of 5% using statistical power analysis [22].

Study Procedure

Physiological saline solution was used to store each tooth until needed. To ensure a uniform working length and reliable reference points for all included teeth, occlusal reduction was performed. The crown-to-apical length of the teeth was measured using a digital Vernier caliper, and teeth of the same length (20±1 mm) were selected to ensure uniformity.

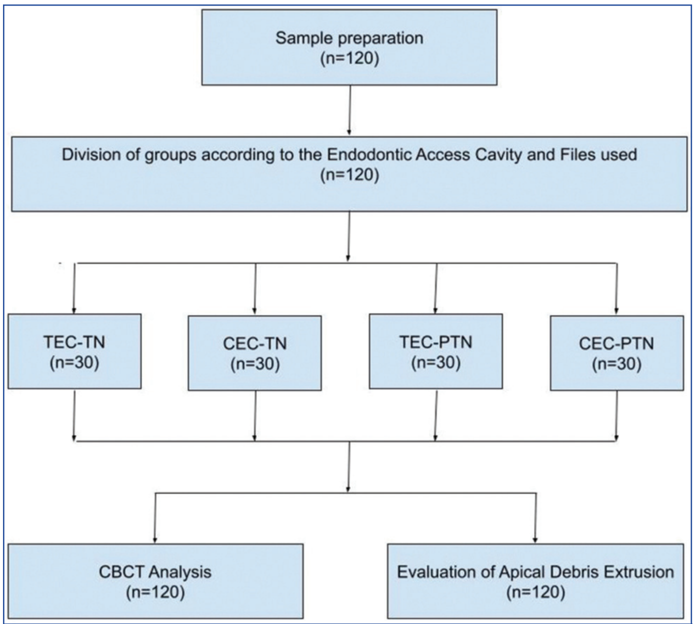
Group division: All endodontic procedures were performed by the same endodontist across all groups. The following four groups were created by randomly assigning numbers to the teeth [Table/Fig-1]:

Group-1: Traditional Endodontic Cavity-TruNatomy (TEC-TN) (n=30)

Group-2: Conservative Endodontic Cavity-TruNatomy (CEC-TN) (n=30)

Group-3: Traditional Endodontic Cavity-ProTaper Next (TEC-PTN) (n=30)

Group-4: Conservative Endodontic Cavity-ProTaper Next (CEC-PTN) (n=30)



[Table/Fig-1]: Division of groups according to endodontic access cavity and file systems used.
TN: TruNatomy; PTN: ProTaper next

Cavity preparation: The TEC was prepared using an Endo Access Bur (no #1, Dentsply Maillefer, Ballaigues, Switzerland) with water cooling at a high rate. In the TEC group, the access cavities were created according to the instructions from previous studies [6]. The CEC preparation was performed using a Dental Operating Microscope (DOM) (Labomed, LA, CA, USA) at 16X magnification and CK burs (Clark/Khademi burs, SS White burs Inc, Lakewood, NJ, USA) no. 2, while preserving the soffit and PCD. The access cavities were opened at the mesial fourth of the central fossa by partially preserving and extending the roof of the pulp chamber in the apical and distal directions. The pulp chamber roof was preserved, and only a minimal amount of dentin was removed from all directions [23]. The location of the root canal orifices could be visualised, and the enamel was beveled in each cavity.

An initial apical file size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was used to check the apical patency of the Mesiobuccal (MB) root canal after the access cavity was opened. Teeth with MB root canals larger than the initial apical K-file size 10 were excluded. The working length was determined to be 1 mm shorter than the measurement when the size 10 K-file was visible at the major apical foramen.

Sample preparation: All groups were evaluated for ADE using the technique outlined by Bürklein S et al., 2014 [24]. Eppendorf tubes were used to collect the debris extruded from the root canal apex during shaping. The teeth were inserted into a rubber stopper and secured with cement made of addition silicone (Aquasil, Dentsply DeTrey GmbH, Konstanz, Germany). Glass bottles were filled with Eppendorf tubes, which held the teeth at the cement-enamel junction point. A microbalance (Sartorius, Otto-Brenner-Str, Göttingen, Germany) with a sensitivity of 10-5 g was used to measure the weight of each tube three times before placing it inside the glass bottle. The average of these measurements was then calculated. To equalise the pressure inside and outside the bottle, a 26-gauge syringe was inserted through the rubber stopper. The Eppendorf tubes were covered with aluminum foil during preparation to prevent the operator from seeing the debris extrusion.

Root canal preparation: The MB canal preparation in the TEC-TN and CEC-TN groups was performed according to the manufacturer's instructions, using an endodontic motor (Endomate TC2, NSK, Japan) and a TN file (size 26/0.04) in a continuous rotation motion at 500 rpm and 1.5 N cm of torque.

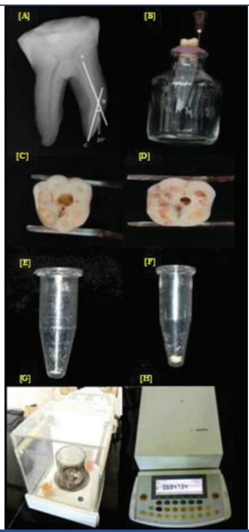
In the TEC-PTN and CEC-PTN groups, the MB canals were prepared using a PTN-X2 (size 25/0.06) file with a continuous rotating motion at 300 rpm and a torque of 2.4 N cm, as recommended by the manufacturer.

All files were used in an in-and-out pecking motion with slow, light movements during root canal preparation. The files were removed from the canal and checked every three pecking motions. The file grooves were cleaned, and the preparation steps were repeated until the working length was achieved. A 27-gauge side-vented needle and 20 mL of distilled water were used to irrigate the root canal of the teeth in each group. Separate files were used for each tooth during MB root canal preparation.

Evaluation of ADE: After the root canal preparation was completed, the Eppendorf tubes were removed from the glass bottle. Before removing the teeth from the tubes, the roots were cleaned in the Eppendorf tube using 1 mL of distilled water to remove any debris that had accumulated on the outer surface of the root apex. The tubes were kept at 70°C for five days to evaporate the distilled water inside before weighing the extruded debris [25].

Each tube was weighed three times consecutively using a microbalance, and the average results were recorded. By subtracting the empty weight of the tube from the measurement taken after root canal preparation, the amount of extruded debris was determined. The ADE was measured by a second independent operator, and the results of the two sets of measurements were compared [Table/Fig-2].

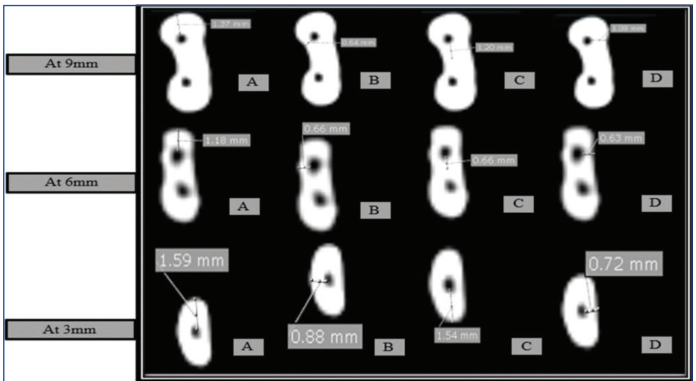
Afterwards, the teeth were analysed using CBCT for RDR assessment. Dentin loss was evaluated on the mesial, distal, buccal, and lingual surfaces of the root canal at three different levels: coronal, middle, and apical third.



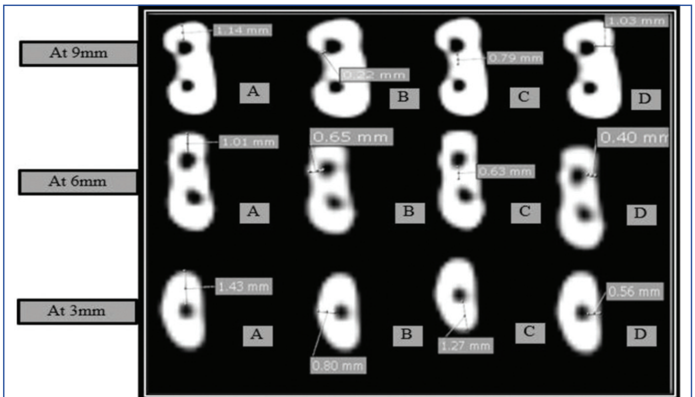
[Table/Fig-2]: a) Schematic illustration of Schneider's approach; b) An illustration of the sample model; c) Image of the mandibular first molar showing the Traditional Endodontic Cavity (TEC); d) Photo of the mandibular first molar that display the Conservative Endodontic Cavity (CEC); e) Image of the debris extrusion by TEC; f) Photo of the extruded debris in CEC; g,h) an illustration of the microbalance.

CBCT analysis: The teeth were placed on a modeling wax (Rolex, Mumbai, Maharashtra, India) and shaped like a horseshoe to fit into the scanning tray of the CBCT machine (Carestream Dental, CS 900, New Delhi, India), which had a similarly shaped Field Of View (FOV). Images of the specimens were captured using exposure parameters of 90 kV, 8 mA, and 7.7 seconds, with the FOV set to 8 cm X 8 cm and resolution set to 75 µm.

CBCT scans taken before [Table/Fig-3] and after instrumentation [Table/Fig-4] were evaluated. The dimensions were established by measuring the shortest path from the canal outline to the nearest adjacent root surface in the mesial, distal, buccal, and lingual directions. The RDR for each stage was calculated using the formula [Table/Fig-3,4] [18].



[Table/Fig-3]: Preoperative CBCT image at 9 mm, 6 mm and 3 mm from apex for various groups. a,c) for bucco-lingual dentin thickness; b,d) for mesio-distal dentin thickness.



[Table/Fig-4]: Postoperative CBCT image at 9 mm, 6 mm and 3 mm from apex for various groups. a,c) for bucco-lingual dentin thickness; b,d) for mesio-distal dentin thickness.

Preinstrumentation RDR in the Mesio (M)-distal (D) direction (MD1):

$MD1=M1+D1/2$

M1: pre-instrumentation RDR in the mesial direction

D1: pre-instrumentation RDR in the distal direction

Pre-instrumentation RDR in the Bucco (B)-lingual (L) direction (BL1):

$BL1=B1+L1/2$

B1: pre-instrumentation RDR in the buccal direction

L1: pre-instrumentation RDR in the lingual direction

Post-instrumentation RDR in the Mesiodistal Direction (MD2):

$MD2=M2+D2/2$

M2: post-instrumentation RDR in the mesial direction

D2: post-instrumentation RDR in the distal direction

Post-instrumentation RDR in the Buccolingual direction (BL2):

$BL2=B2+L2/2$

B2: post-instrumentation dentin removal in the buccal direction

L2: post-instrumentation dentin removal in the lingual direction

RDR in the Mesiodistal Direction (MD):

$MD=MD1-MD2$

RDR in the Buccolingual direction (BL):

$BL=BL1-BL2$

Total RDR: The RDR in both MD and BL directions for each group was added to determine the total RDR.

Total RDR=MD+BL

The ratio was used to determine which group in this study had more total RDR and less ADE.

Ratio=Total RDR/ADE

STATISTICAL ANALYSIS

For statistical analysis, the amount of extruded debris and dentin removal data were compiled in an Excel spreadsheet, and SPSS (version 20.0; SPSS Inc., Chicago, IL, USA) was used. Descriptive statistics were used to determine the means and standard deviations. One-way analysis of variance (one-way ANOVA) was performed for numerical data to evaluate the means of three or more groups of samples, using the F distribution. A post-hoc Tukey test was conducted to determine which group was responsible for the significant difference. An independent t-test was used for additional data analysis. Statistical significance was considered at $p<0.05$.

RESULTS

In [Table/Fig-5], CEC showed higher RDR with both file systems compared to TEC. Among the different groups, the CEC-PTN group had the highest RDR in both MD and BL directions at all three root levels, with significant removal at the root curvature (0.08±0.02). The TEC-TN group had higher RDR at 9 mm in the BL direction compared to the TEC-PTN group, with a statistically significant difference (p-value=0.006). The CEC-PTN group had higher RDR at 3 mm, 6 mm in the mesiodistal direction, and 3 mm in the buccolingual direction compared to the CEC-TN group, with statistically significant differences of <0.001, <0.001, and 0.005, respectively [Table/Fig-6].

CEC-PTN showed the highest ADE with a mean value of 0.043228 g [Table/Fig-7]. Comparing the ADE values of different groups, CEC-PTN caused the highest ADE with statistically significant differences compared to TEC-TN, CEC-TN, and TEC-PTN groups, with values of 0.003, 0.001, and 0.005, respectively [Table/Fig-8].

[Table/Fig-9] presented the ratio between total RDR and ADE. Except for the CEC-TN group, all other groups showed no significant correlation between the Total RDR and ADE values

Access cavity	RDR at 3 levels	TEC (n=30) Mean±SD	CEC (n=30) Mean±SD	p-value
TN	In mesiodistal direction			
	3 mm	0.02±0.01	0.03±0.01	**<0.001***
	6 mm	0.05±0.01	0.06±0.02	0.554
	9 mm	0.05±0.01	0.05±0.01	0.259
	In buccolingual direction			
	3 mm	0.02±0.01	0.03±0.01	**0.022***
	6 mm	0.04±0.01	0.05±0.01	**0.001***
	9 mm	0.04±0.01	0.04±0.01	0.697
	Total RDR	0.22	0.26	
PTN	In mesiodistal direction			
	3 mm	0.03±0.01	0.05±0.02	**<0.001***
	6 mm	0.06±0.01	0.08±0.02	**<0.001***
	9 mm	0.05±0.01	0.06±0.02	**0.025***
	In buccolingual direction			
	3 mm	0.02±0.01	0.04±0.01	**<0.001***
	6 mm	0.04±0.01	0.05±0.01	0.158
	9 mm	0.03±0.01	0.04±0.01	0.202
	Total RDR	0.23	0.32	

[Table/Fig-5]: Independent t-test to compare groups for RDR at three different levels.
*The mean difference is significant at the 0.05 level
P: Probability value

Access cavity	RDR at 3 levels	TN (n=30) Mean±SD	PTN (n=30) Mean±SD	p-value
TEC	In mesiodistal direction			
	3 mm	0.02±0.01	0.03±0.01	0.131
	6 mm	0.05±0.01	0.06±0.01	0.11
	9 mm	0.05±0.01	0.05±0.01	0.906
	In buccolingual direction			
	3 mm	0.02±0.01	0.02±0.01	0.601
	6 mm	0.04±0.01	0.04±0.01	0.273
	9 mm	0.04±0.01	0.03±0.01	**0.006***
	Total	0.22	0.23	
CEC	In mesiodistal direction			
	3 mm	0.03±0.01	0.05±0.02	**<0.001***
	6 mm	0.06±0.02	0.08±0.02	**<0.001***
	9 mm	0.05±0.01	0.06±0.02	0.111
	In buccolingual direction			
	3 mm	0.03±0.01	0.04±0.01	**0.005***
	6 mm	0.05±0.01	0.05±0.01	0.639
	9 mm	0.04±0.01	0.04±0.01	0.167
	Total	0.26	0.32	

[Table/Fig-6]: Comparing groups using an independent t-test for RDR at three distinct levels.

	Groups	N	Mean	Standard deviation	Statistics/ mean squares	df2 (welch)/F (Anova)	p-value
ADE	TEC-TN	30	0.026681	0.016006	4.274	63.715	**0.008**
	CEC-TN	30	0.024562	0.015339			
	TEC-PTN	30	0.027289	0.014851			
	CEC-PTN	30	0.043228	0.024795			
	Total	120	0.03044	0.019477			
			6 mm		0.05±0.01	0.05±0.01	0.639
			9 mm		0.04±0.01	0.04±0.01	0.167
			Total		0.26	0.32	

[Table/Fig-7]: The one-way ANOVA test for ADE.
P: Probability value; df: Degrees of freedom
F value=variance of group means/mean of within-group variance

Dependent variable	Comparison groups	Compared with	Mean difference	Standard error	p-value
ADE	**TEC-TN**	CEC-TN	0.002119	0.004703	0.969
		TEC-PTN	0.0006083	0.004703	0.999
		CEC-PTN	0.0165473	0.004703	**0.003***
	CEC-TN	TEC-PTN	0.0027273	0.004703	0.938
		CEC-PTN	0.0186663	0.004703	**0.001***
	TEC-PTN	CEC-PTN	0.0159390	0.004703	**0.005***

[Table/Fig-8]: A post-hoc Tukey test for inter-group comparison for the weight of ADE in grams.
*The mean difference is significant at the 0.05 level
P: Probability value

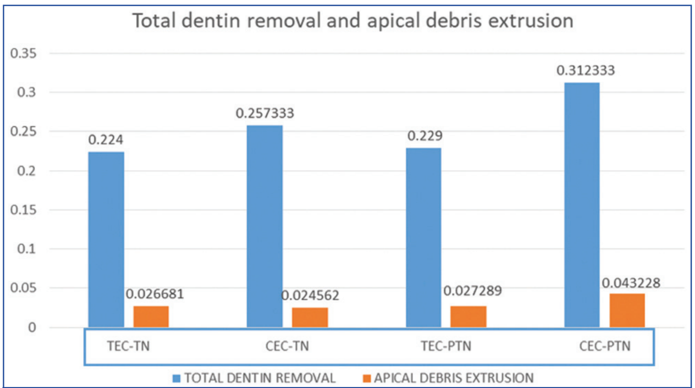
[Table/Fig-10]. In the CEC-TN group, the ADE value did not increase along with the increase in Total RDR. In CEC, the TN file showed higher total RDR and lower ADE. The TN file showed similar ADE in both endodontic access cavities, with no statistically significant difference (p-value=0.969). Therefore, it can be concluded that for the TN file, ADE is not affected by the type of endodontic cavity and RDR [Table/Fig-11].

Files used	The ratio between total RDR and ADE	
	TEC	CEC
TN	0.22/0.03=7.3	0.26/0.02=13
PTN	0.23/0.03=7.6	0.32/0.04=8

[Table/Fig-9]: The ratio between total RDR and ADE.

No.	Groups	N	Correlation (r)	p-value
1	**TEC-TN**	30	0.262	0.163
2	**CEC-TN**	30	0.396	**0.03***
3	**TEC-PTN**	30	0.075	0.695
4	**CEC-PTN**	30	0.008	0.966

[Table/Fig-10]: Following table shows the r and p-values for correlation.



[Table/Fig-11]: Total RDR and its correlated ADE of various groups.

DISCUSSION

In this study, mandibular molars with curved MB canals were used to simulate clinical scenarios and illustrate the challenges faced by clinicians during instrumentation. Furthermore, endodontically treated molars have a considerably higher incidence of flare-ups [26].

The amount of ADE has been measured using various methods, including scoring systems and microbalance weighing. However, the amount of extruded material is extremely small, typically in milligram-sized fragments. Additional factors that could affect the weight measurement need to be considered, such as the impact of damp fingers touching the assembly or contamination from the storage environment of the specimens [27]. In the current study, precautions were taken to avoid any direct contact that could affect the results. One limitation of this method was that it did not replicate the normal periapical resistance in a tooth under clinical conditions. Agar gel and floral foam are some materials that can be used to simulate this environment. However, there are challenges in determining the specific thickness of the agar gel at the apex to simulate the extent of the periapical lesion and the penetration of the foam [28].

Distilled water was used as the irrigation solution because sodium hypochlorite can increase the amount of extruded debris through crystallisation [29]. A total of 20 mL of distilled water was used during the preparation of the entire canals. To prevent excessive apical pressure, which could increase the risk of apical ejection of debris, the irrigation needle was passively inserted 2 mm shorter than the working length [26].

The majority of dentin loss and RDR occur during root canal instrumentation, with the mesial and distal directions being the most affected [18]. It is important for an endodontically treated tooth to maintain an adequate thickness of residual dentin throughout instrumentation to ensure its strength and durability. Research has suggested that a minimum of 0.3 mm of dentin should remain after root canal preparation for optimal resistance to lateral stresses [30]. However, a study by Raiden G et al., in 2001 found that radiographs often overestimate dentin thickness. In the current study, CBCT was used to provide 3D observations of the root canal space and to measure the amount of dentin removed before and after instrumentation [31]. Three sections of the root canal system (3 mm, 6 mm, and 9 mm) were examined as they correspond to the apical, middle, and coronal thirds of the root canal, which are at high risk of iatrogenic accidents [16].

In the CEC group, TN files showed lower RDR compared to PTN files, which was associated with lower debris extrusion. The TN file system is made from 0.8 mm NiTi wire, unlike the majority of generic files that are made from 1.2 mm NiTi wire [32]. The TN file is engineered with advanced technology, providing advantages such as improved performance and efficiency, minimal tooth preparation, preservation of structural dentin, and maintenance of tooth strength by respecting the natural tooth architecture. The 0.8 mm maximum flute diameter, off-centered parallelogram cross-section, and regressive narrow taper of the TN file reduce binding contact with dentin and allow for more coronal debris extrusion compared to the 1.2 mm flute diameter of PTN files. Additionally, the taper of the TN file system is smaller than that of the PTN file system. These factors help support the findings of the study [22,29,30].

Properly opening the access cavity has several benefits, including facilitating adequate irrigation of the root canal system and optimising instrumentation, which can improve the outcomes of root canal therapy [5]. In this study, the TEC group performed better than the CEC group in terms of less ADE. The TEC preparation technique allows for the access cavity to be opened in a way that creates a straight path to the root canals and enables visualisation of the canal orifices from the occlusal view [22]. According to Marchesan MA et al., the CEC group required more pecking actions for the files to reach the apical foramen [33]. This may have resulted in the files engaging more dentin, leading to increased dentin loss and ADE in the CEC group.

In the TEC group, there were no statistically significant differences in ADE between the two file systems. The employed file systems have a design that facilitates the extrusion of debris in a coronal direction. The PTN and TN files rotate continuously, acting like a screw conveyor to remove debris in the coronal direction [17]. The offset center of mass and/or rotation axis in PTN and TN files produces a swaying motion along the active part of the file. This swaying effect reduces the interaction between the file and dentin. Additionally, the offset design provides more cross-sectional space for enhanced cutting, loading, and removal of material from the canal. This offset file design significantly reduces the likelihood of lateral compaction of debris and obstruction of the root canal anatomy. Numerous studies have shown that PTN and TN files extrude less debris compared to other file systems due to reduced contact with dentin [34].

Limitation(s)

Some limitations of this study include the inability of the in-vitro study to replicate clinical settings, such as the periapical condition of the tooth. Additionally, the study used different file systems, file designs, and kinematics, which may introduce variability. Another limitation is the potential differences in root architecture among the specimens.

CONCLUSION(S)

Within the limitations of this study, it can be concluded that the CEC group exhibited higher total RDR and ADE compared to the TEC group. Furthermore, the TN file caused less RDR and ADE compared to the PTN file in both endodontic access cavities. However, the clinical significance of extrusion needs to be further investigated in terms of postoperative flare-ups and postoperative pain.

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