ORIGINAL ARTICLE

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Influence of instrument taper on the fracture strength of endodontically treated maxillary premolars

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Purpose: An increase in instrument taper decreases the amount of residual radicular dentin thickness (RRDT), thus increasing the fracture strength of teeth. The aim of this study was to determine the residual dentin thickness and evaluate the fracture strength and mode of fracture of endodontically treated bifurcated maxillary premolars with different tapered file systems.

Methods: Fifty bifurcated maxillary first premolars were randomly divided into five groups. Group 1, consisting of 10 intact teeth, served as control. The 40 remaining teeth were divided into four groups consisting of 10 specimens per group. Group 2: 30.02% K file, group 3: 30.04% K3 system, group 4: 30.06% Mtwo system, and group 5: 30.09% ProTaper Universal System. Chemomechanical preparation was done up to apical preparation ISO 30. Assessment of RRDT was performed using the pre- and post-instrumentation cone -beam computed tomography scans. The obturated specimens were then subjected to static loading in a universal testing machine until fracture, and fracture strength & and mode of fracture were evaluated using scanning electron microscopy analysis. Data were analyzed using ANOVA, Tukeys HSD for multiple comparisons, with a significance level set at $p< 0.05$.

Results: The mean of difference in RRDT at 3 mm and 6 mm and the mean of maximum fracture loads were greatest for group 5: 30–9% ProTaper Universal System, while Group 2: 30-2% K file exhibited the least values among the experimental groups. There was a statistically significant difference in vertical and oblique loading between the experimental groups ($p< 0.05$). The most common mode of fracture was the crown-initiated vertical fractures in the root.

Conclusion: The findings showed that an increase in taper decreased the amount of residual dentin thickness, consequently increasing the fracture strength of maxillary premolars.

Keywords: Cone beam computed tomography, fracture susceptibility, instrument taper, residual radicular dentin thickness, vertical root fractures.

Introduction

Vertical root fractures (VRFs), the necropolis of endodontic dreams, are catastrophic events eventually leading to the extraction of teeth. They can be “histologic VRF,” clinically asymptomatic, or “clinical VRF,” with clinical signs and symptoms (1). The incidence of VRFs in endodontically treated teeth ranges from 11% to 20%, and lamentably 27.2% of the cases are maxillary premolars (2).

A VRF can originate at any level in the root. The fractures originate in the root canal wall and extend to the

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root surface over time and may involve either one side—buccal or lingual (incomplete)—or both sides (complete fracture).

The advent of NiTi rotary instruments has revolutionized the instrument geometry with varied taper designs to improve flexibility, strength, and fracture resistance. An increase in taper decreases the amount of residual radicular dentin thickness (RRDT), thus increasing the fracture strength of teeth; therefore, it is imperative that the iatrogenic precursor be identified and addressed (3).

Some recent studies have evaluated remaining dentin thickness during re-treatment and post-placement procedures (4–6). However, an assessment of RRDT focusing on the chemomechanical preparation of premolars is yet to be performed. The aim of this in vitro study was to determine the residual dentin thickness and evaluate the fracture strength and mode of fracture of endodontically treated bifurcated maxillary premolars with different tapered file systems.

This will serve as a clinical reference to customize the instrument geometry regarding taper and design, according to the morphology and dimensions of root canals, consequently decreasing the iatrogenic precursors for VRFs.

The two questions endeavored to be answered in this study are:

1. Do greater taper files increase the fracture susceptibility of endodontically treated maxillary premolars?
2. If yes, which is the safest/conservative taper design?

Materials and Methods

The study protocol was approved by the Ethics Committee of Amrita Institute of Medical Sciences and Research Sciences, Cochin, India (IEC-AIMS-2018-DENT-153). Fifty bifurcated maxillary premolars, from mixed populations (extracted, cleaned, and stored in Chloramine-T (Explicit Chemicals Pvt Ltd) with coronal and radicular integrity, were selected.

Inclusion Criteria: Extracted, intact, bifurcated maxillary first premolars with normal anatomy, no wear, no incipient occlusal or proximal caries, minimal or no restorations, no root resorption, no root canal calcifications or sclerosis, and normal root curvatures (assessed by Schneider's technique) (7), with root lengths of >8 mm and canal diameter of <0.3 mm at 3 mm and 6 mm levels when measured in pre-instrumentation cone beam computed tomography (CBCT) to minimize size and shape variations on results.

Exclusion Criteria: Specimens that were severely dehydrated or fractured or had accessory canals, significant caries or restorations, and dilacerated roots.

Specimen Preparation

Ultrasonic scalers (Dentsply, Germany; Piezon Systems, EMS, Switzerland) were used to remove soft tissues, calculus, and debris from the teeth before examination under a dental operating microscope (G3, Global Surgical Corporation) for detection of any cracks or fractures.

Cleaned specimens were numbered and arranged in floral form by inserting each tooth up to the cervical line, and a pre-instrumentation CBCT scan was taken (8). Teeth were randomly divided into five groups of 10 teeth each by using a manual block randomization protocol. Group 1, consisting of 10 intact teeth, served as control. The 40 remaining teeth were divided into 4 experimental groups consisting of 10 specimens per group. Group 2 is 30.02% K file, group 3 is 30.04% K3 system, group 4 is 30.06% Mtwo system, and group 5 is 30.09% ProTaper Universal System (Fig. 1 and Table 1).

Endodontic access was prepared with a # 4 round diamond rotary instrument, and root canal permeability and scouting were performed with a # 10 K file. Working

Table 1. Instrument taper of different file systems used as experimental groups at D0, D3, D6, and D16 (in mm)

File system	Taper	D0	D3	D6	D16
K file 2%	Constant taper	0.30	0.36	0.42	0.62
K3 system 4%	Constant taper	0.30	0.42	0.54	0.94
Mtwo system 6%	Constant taper	0.30	0.48	0.66	1.26
ProTaper Universal 9%	Progressive taper	0.30	0.57	0.76	1.26

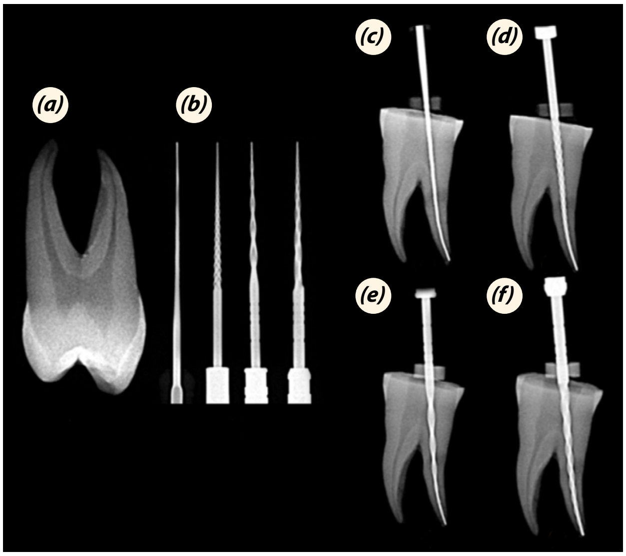

Fig. 1. **(a)** RVG image of a representative sample. **(b)** RVG image of four experimental groups (from left): 30.02% K file, 30.04% K3 system, 30.06% Mtwo system, and 30.09% ProTaper Universal System. **(c)** RVG image of 30.02% K file in a representative sample. **(d)** RVG image of 30.04% K3 file in a representative sample. **(e)** RVG image of 30.06% Mtwo file in a representative sample. **(f)** RVG image of 30.09% ProTaper Universal file in a representative sample.

length was determined and chemomechanical preparation was performed up to apical preparation ISO 30 size according to the experimental groups.

A post-instrumentation CBCT scan was taken using similar parameters as pre-instrumentation CBCT.

Root canals were dried and obturated with resin-based sealer (AH Plus, Dentsply, Germany) and corresponding gutta-percha points using the single-cone technique.

Assessment of Residual Radicular Dentin Thickness (RRDT)

Each tooth in the pre-instrumentation CBCT scan was aligned in a cross-sectional view. The root diameter buccopalatally and mesiodistally and the canal diameter for each root was measured at 3 mm and 6 mm from the root tip (Fig. 2).

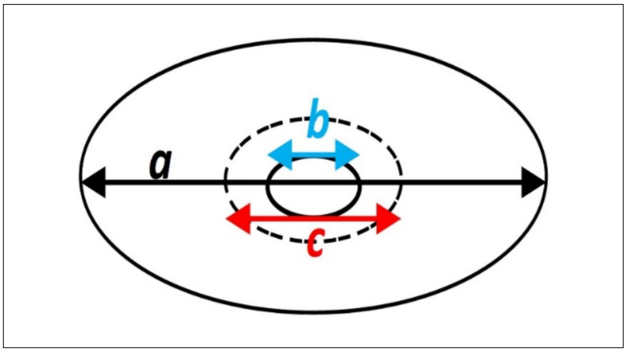

Fig. 2. Diagrammatic representation of measurement from a cross-sectional view. (a) Buccopalatal diameter of root at the desired level, (b) root canal diameter pre-instrumentation at the desired level, and (c) root canal diameter post-instrumentation at the desired level.

The same procedure was repeated for the post-instrumentation CBCT scan (Fig. 3).

The RRDT was calculated using the following formulas:

$RRDT_{pre\text{-}ins.}$ = (B-P or M-D diameter of root$_{pre\text{-}ins.}$) – (root canal diameter$_{pre\text{-}ins.}$),

$RRDT_{post\text{-}ins.}$ = (B-P or M-D diameter of root$_{post\text{-}ins.)}$ – (root canal diameter$_{post\text{-}ins.}$).

The difference $RRDT_{pre\text{-}ins.} - RRDT_{post\text{-}ins.}$ was calculated in millimeters. The data were tabulated and analyzed statistically.

Evaluation of Fracture Strength and Mode of Fracture

The 10 samples in each group were further subdivided into 2 groups, consisting of 5 specimens per group to be subjected to vertical loading at 90° to the long axis and obliquely at 135° to the long axis of teeth.

A custom-made jig with grippers for vertical loading and oblique loading and a load application tip with a tip diameter of 1.5 mm were manufactured (Fig. 4). The grippers of the jig secured the specimen while fracture loading without simulation of supporting periodontium. The specimens were subjected to static loading along the inclines of the palatal cusp in a universal testing machine with a 5000 N load cell unit until fracture was detected by the system (Fig. 4). This is graphically recorded in Fig. 5.

The maximum fracture load until fracture was recorded, and the data were subjected to statistical analysis. The

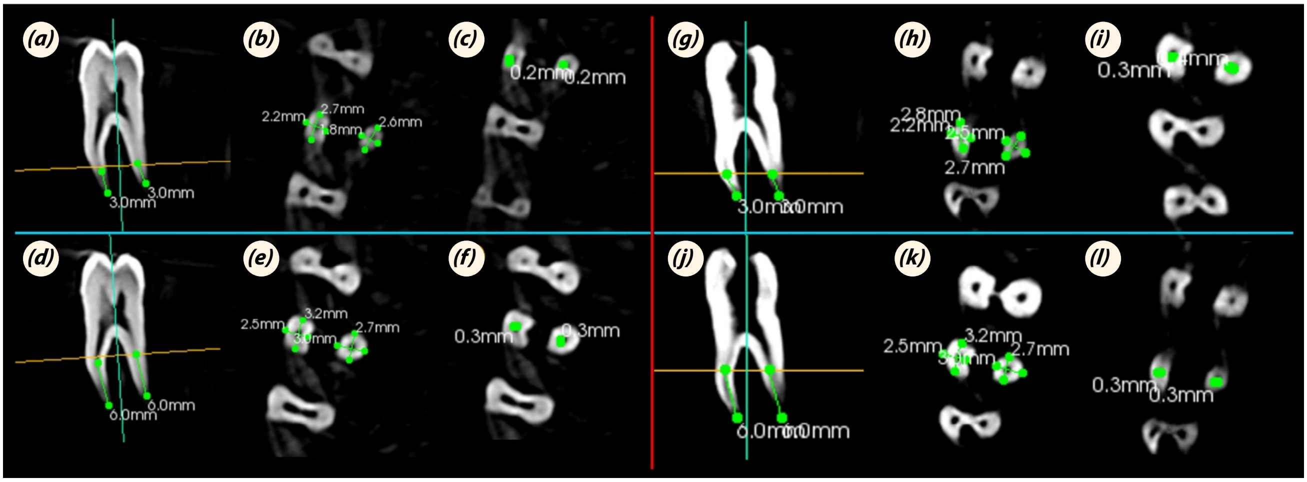

Fig. 3. **(a)** Assessment of residual radicular dentin thickness (RRDT) from pre-instrumentation CBCT image 3 mm from the root apex. **(b)** Dentin thickness B-L and M-D measurements for buccal and palatal roots at 3 mm. **(c)** Canal diameter measurements for buccal and palatal roots at 3 mm. **(d)** Six millimeters from the root apex. **(e)** Dentin thickness B-L and M-D measurements for buccal and palatal roots at 6 mm. **(f)** Canal diameter measurements for buccal and palatal roots at 6 mm. **(g)** Assessment of RRDT from post-instrumentation CBCT image 3 mm from the root apex. **(h)** Dentin thickness B-L and M-D measurements for buccal and palatal roots at 3 mm. **(i)** Canal diameter measurements for buccal and palatal roots at 3 mm. **(j)** Six millimeters from the root apex. **(k)** Dentin thickness B-L and M-D measurements for buccal and palatal roots at 6 mm. **(l)** Canal diameter measurements for buccal and palatal roots at 6 mm.

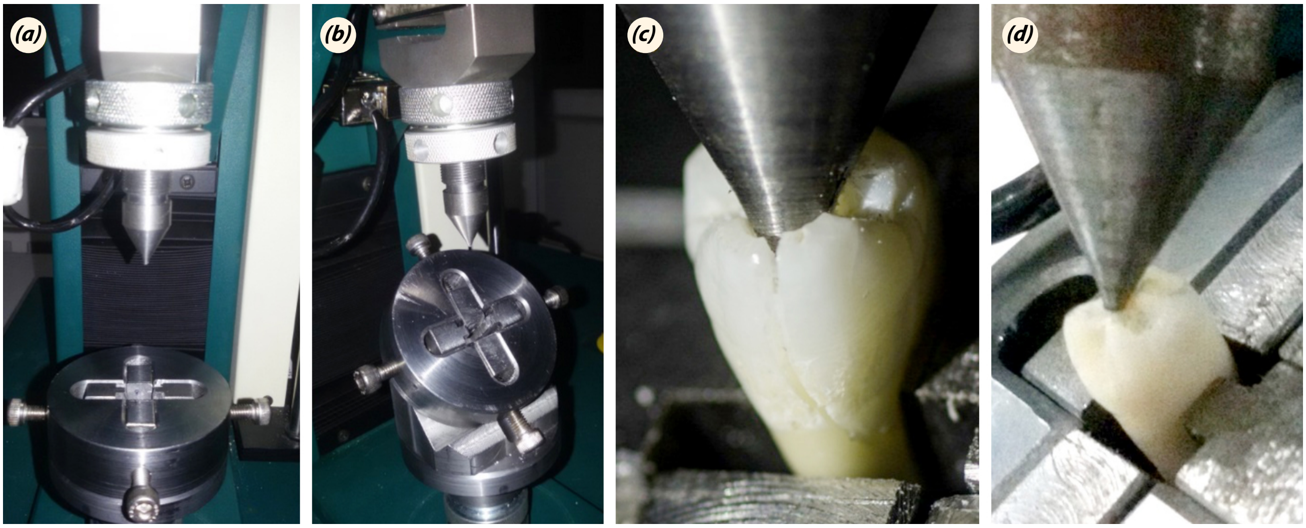

Fig. 4. **(a)** Custom-made jig with grippers for vertical loading. **(b)** Custom-made jig with grippers for oblique loading. **(c)** Static vertical loading of the sample until fracture. **(d)** Static oblique loading of the sample until fracture.

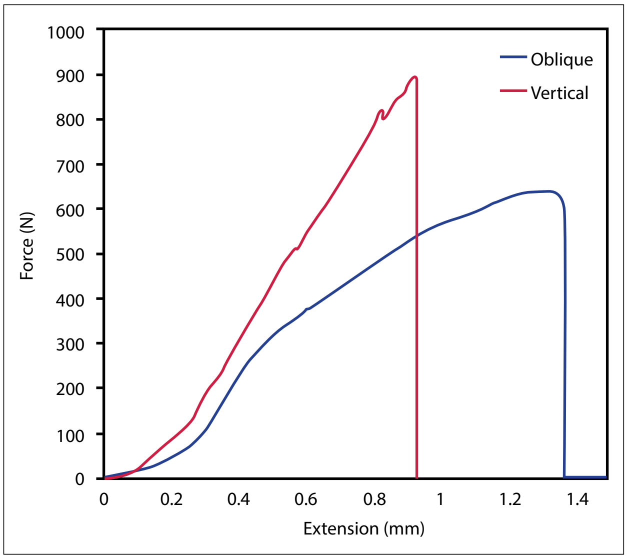

Fig. 5. Graph indicating fracture loads.

most common mode of fracture was assessed through a visual examination, and a representative specimen was subjected to SEM analysis. The data regarding the mode of fracture was analyzed descriptively.

Dependent variables were fracture resistance and taper of the instrument used for mechanical preparation.

Statistical Analysis

The sample size was calculated after the pilot test using software nMaster 2.0. The data were analyzed using statistical software (SPSS 20.0; SPSS, Inc., Chicago, IL, USA). The data were subjected to ANOVA to analyze the differences among group means and Tukey's HSD for multiple comparisons. A preset significance level ($p< 0.05$) was used for all statistical analyses.

Results

The mean of difference in RRDT for each group at 3 mm and 6 mm is presented in Table 2. Root canals instrumented with 30.02% K file exhibited the least difference in RRDT, while on the contrary, 30.09% ProTaper Universal System showed the greatest difference in RRDT (almost 2 times and 4 times that of 30.02% K file at 3 mm and 6 mm levels, respectively) among the experimental groups at both 3 mm and 6 mm levels from the apex.

On tabulation of the mean of maximum fracture loads in vertical and oblique loading for the 5 groups, intact maxillary premolar showed the maximum resistance to fracture on vertical and oblique loading substantiating that instrumentation techniques have an impact on the fracture resistance of teeth. Among the experimental groups, canals instrumented with 30.02% K file demonstrated the maximum fracture strength, whereas 30.09% ProTaper Universal System showed the least in both vertical and oblique loading of specimens (Table 3).

On statistical analysis, there was a statistically significant difference ($p< 0.05$) in:

Table 2. Mean of difference in residual radicular dentin thickness for each group at 3 mm and 6 mm levels (in mm)

Group	Category	At 3 mm level	At 6 mm level
1	Intact maxillary premolar	0	0
2	K file 30.02%	0.16	0.12
3	K3 30.04%	0.22	0.24
4	Mtwo 30.06%	0.28	0.36
5	ProTaper Universal 30.09%	0.37	0.46

Table 3. Mean of maximum fracture loads for each group (in N)

Group	Category	Vertical loading	Oblique loading
1	Intact maxillary premolar	2097.6	1218.8
2	K file 30.02%	1873.8	815.6
3	K3 30.04%	1706.2	670.6
4	Mtwo 30.06%	1619.8	646.4
5	ProTaper Universal 30.09%	1151.2	534.8

1. Vertical loading at 3 mm level and 6 mm level between 2% and 9%, 4% and 9%, and 6% and 9%,
2. Oblique loading at 3 mm level and 6 mm level between 2% and 9%, and 4% and 9%.

SEM analysis of the most common mode of fracture evaluated was buccolingually oriented, crown-initiated vertical fractures in the root (Fig. 6).

Discussion

VRF is a leading failure mode in teeth, which has been studied diligently. VRF may be caused by wedging forces or pressure transmitted to the root canal surface during root canal obturation or from cyclic occlusal forces.

Incidences of VRFs in endodontically treated premolars are higher. The susceptibility of maxillary premolars can be attributed to several predisposing as well as contributing factors. The predisposing factors can be their position in the arch and the typical anatomical and biochemical characteristics.

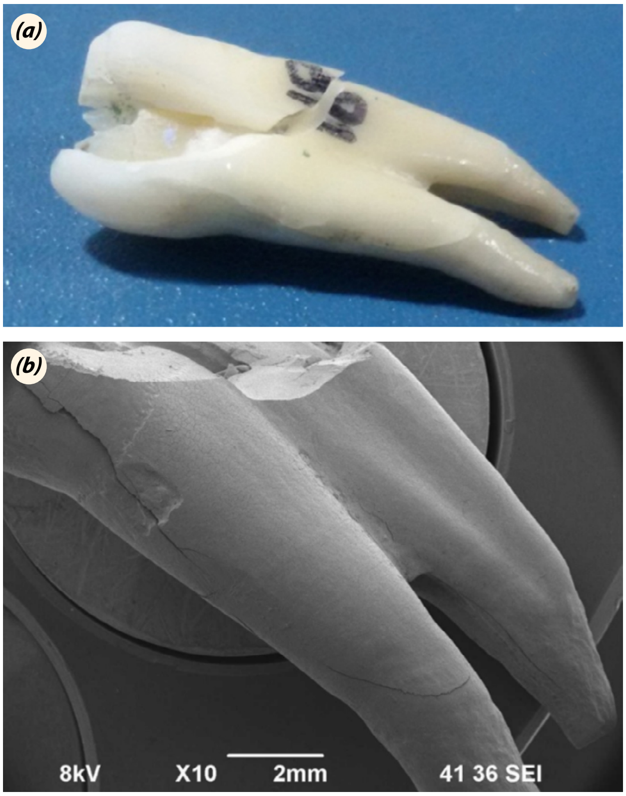

Fig. 6. **(a)** Representative sample showing most common modes of fracture for SEM imaging. **(b)** SEM image showing buccolingually oriented crown-initiated vertical fractures in the root.

The premolars occupy a transitional juncture between the canines and the molars and are highly susceptible to succumb to cyclic functional loads. Another predisposing factor is the peculiar morphology: (a) decreased diameter mesiodistally giving a kidney-shaped appearance in cross-section and (b) developmental root depression on the buccal root of bifurcated maxillary premolars is also an anatomical entity that can predispose the likelihood for fractures. The amount of remaining sound tooth structure and the biochemical changes after caries or endodontic therapy are also significant factors.

The contributing factors could be excessive removal of the pericervical root dentin during chemomechanical preparation or post space preparation and the pressure of inadvertent lateral condensation.

According to Shillingburg and Sather, a root can be compared to a ring, the strength of which is directly proportional to the difference between the fourth powers of its internal and external radii (9).

Lertchirakarn et al. (10) and Sathorn et al. (11) presented tensile stress contour plots for circular and elliptical canal sections subjected to wedging forces or uniform pressure on the canal surface. The results showed that the tensile stress responsible for crack initiation was maximized at the inner canal surface where the radius of curvature is the smallest, which is consistent with clinical observations.

A dominant feature in micrographs of root sectioning experimental studies done in extracted teeth with VRF is that cracks tend to initiate on the canal surface where the radius of curvature is the smallest irrespective of the outer root surface curvature (12).

Basic fracture mechanics considerations suggest that the driving force responsible for VRF is the tensile hoop stress in the dentin wall (i.e., the stresses that tend to open up cracks propagating from the inner to outer dentin wall). It implies that fracture strength increases with increasing RRDT and fracture conclusively initiates at the root canal surface where the radius of curvature is the smallest (13).

Instrument design was based on root canal morphology and dimensions, factors influencing being root length, radius of curvature, apical diameter, level of furcation, and resiliency of dentin (14).

CBCT was used to measure RRDT as it has acceptable diagnostic accuracy for measurement of canal wall thickness as confirmed and reported in previous studies (8,15,16).

The mean diameters at 3 mm and 6 mm in pre-instrumentation CBCT was 0.2 mm and 0.3 mm, respectively. Therefore, the canals were instrumented up to apical preparation size of ISO 30. The instrumented samples were obturated using a resin-based sealer and corresponding gutta-percha points using the single-cone technique for standardization as it provides three-dimensional apical sealing with minimum condensation forces (17,18).

To simulate clinical functional masticatory loading, both vertical loading at 90° to the long axis and obliquely at 135° to the long axis of teeth were experimented with (19). Custom-made assembly of the jig with grippers for vertical loading and oblique loading and load application tip with impact tip with a contact area of 2 x 2 mm^2 were fabricated for standardization of load application on the inclines of the palatal cusp (20).

The grippers of the jig were customized to secure the specimen while fracture loading without PDL simulation. Though laboratory simulation of clinical situations is an influential factor in fatigue testing, recent literature posits no significant difference in results with or without PDL simulation in static loading. When the indenter gradually applies a load until failure, it compresses the resilient elastomer layer representing the PDL, and at some point, with the continuously increasing load, the elastomer material could be compressed beyond its elastic limit and it might lose its cushioning effect (21). Consequently, the load applied by the indenter only influences the specimen until it fails, which results in no significant differences between the groups with and without PDL simulation (22). Undeniably, the cushioning effect through artificial PDL simulation might be an influential parameter during fatigue testing because of the relatively low load compared with the load applied during fracture test (23).

According to this study at the 3 mm level from the apex, all instrumentation techniques except 30–9% ProTaper Universal System removed almost equal amounts of radicular dentin. Root canals instrumented with 30–9% ProTaper Universal System showed the least RRDT among the experimental groups at both 3 mm and 6 mm levels from the apex. The least resistance to fracture was also seen by the same in both vertical and oblique loading.

The SEM analysis of the most common mode of fracture evaluated was the crown-initiated vertical fractures in the root.

This implies that the diameter of the canal and RRDT dictates the mechanical limit of instrumentation so as not to weaken the dentinal walls.

Also, on evaluation of the taper of various orifice openers [(i) ProTaper Universal SX Tip 0.19 mm; D16 1.2 mm taper D1–3.5, D6–11%, D9–19%, D14–2%, D16–0%; (ii) K3 Orifice openers Tip 0.25 mm tapers 12%, 10%, 8%, used in crown down technique; (iii) ProFile Orifice Openers Tip 0.3 mm 6% taper, 0.4 mm 6% taper, 0.50 mm 7% taper], they can remove substantial amount of pericervical dentin, permitting the advancement of instruments toward apex, thus reducing RRDT.

As a limitation of this study, it adopted a fracture test design that failed to replicate the exact chewing simulation compared with fatigue tests that have high-translational meaning (24,25). Moreover, in the present study, CBCT was used for measuring RRDT, which provides measurements precise up to two decimal points even though micro-computed tomography is currently considered the gold standard. Micro-computed tomography provides high-quality and detailed images of the root canal anatomy and measurements accurate to three decimals (26,27).

Conclusion

Within the limitations of the present study, 30–9% ProTaper Universal System showed the least residual dentin thickness measured at 3 mm and 6 mm levels in post-instrumentation CBCT scan and the maximum fracture strength on fracture loading (1151.2 N on vertical and 534.8 N on oblique loading) compared with other experimented groups.

The most common fracture pattern was buccolingually oriented crown-initiated VRFs, which is consistent with clinical observations.

An increase in taper decreases the amount of residual dentin thickness, thus increasing the fracture strength of maxillary premolars.

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Conflict of Interest: None declared.

Ethical Approval: The study protocol was approved by the Ethics Committee of Amrita Institute of Medical Sciences and Research Sciences, Cochin, India (IEC-AIMS-2018-DENT-153).

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