ORIGINAL RESEARCH PAPER

Endodontics

IN VITRO COMPARATIVE STUDY OF THE INFLUENCE OF INSTRUMENT TAPER ON THE FRACTURE RESISTANCE OF ENDODONTICALLY TREATED TEETH

KEY WORDS: Fracture resistance, vertical root fracture, rotary instrument and instrument taper.

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ABSTRACT

Context: Preparation of the root canal system is recognized as being one of the most important stages in root canal treatment which removes organic debris and microorganisms from the root canal system by means of chemico-mechanical preparation and irrigation of the canals. The use of nickel-titanium instruments has drastically reduced the time and the difficulties that were encountered with traditional hand instruments made up of stainless steel. Utilizing properties of super-elasticity, shape memory and different tapers of these instruments reduces not only the possibility of canal transportation but also affects both the geometry and volume of root canals. This subjects the root dentin to stress and consequently dentinal defects which increases the risk of root fracture during or after root canal treatment. Clinicians now have the opportunity to choose from differently tapered instruments having unique characteristics in their geometry and metallurgy. These are progressively tapered instruments, fixed tapered instruments, and variable tapered instruments, which come with the benefit of conforming to the root canal anatomy as well as removing dentin as little as possible while cleaning and shaping. **Aim:** The aim of this study was to examine the influence of instrument taper on the fracture resistance of endodontically treated roots under in vitro experimental conditions. Conclusion: Under the limitations of this study in in-vitro conditions there were no significant differences between the fracture loads between the different file systems used, however samples prepared with Hyflex EDM recorded the highest fracture resistance, followed by ProTaper NEXT, ProTaper Gold and NeoEndo Flex respectively.

INTRODUCTION:

Preparation of the root canal system is regarded as one of the most important stages in root canal treatment, the goal of which is to facilitate irrigation of the canals and to make the canals free of micro-organisms, in order to receive the obturating material. Mechanical preparation affects both the geometry and volume of root canals, leading to stresses on the root dentin that results in dentinal defects which increases the risk of root fracture during or after root canal treatment [1].

Nickel-Titanium [NiTi] is called an exotic metal because it does not conform to the normal rules of metallurgy. The NiTi alloys used in root canal treatment contain approximately 56% [weight] nickel and 44% [weight] titanium. The resultant combination is a 1:1 atomic ratio [equiatomic] of the major components. Like other metallic systems, this alloy can exist in various crystallographic forms. NiTi instruments are highly flexible and elastic and they have nearly eliminated the iatrogenic instrumentation complications that are often related to stainless-steel endodontic instruments. Over time the instrument design of these NiTi instruments has undergone a revolution to produce instruments that cut effectively while exhibiting resistance to fracture even in the most challenging anatomical confines [1].

Technological innovations in rotary nickel-titanium files have led to new concepts of root canal instrumentation including an increased taper of preparation. A higher taper of mechanical preparation offers sufficient enlargement of the root canal entailing better removal of debris and smear layer [1], improvement of irrigant flow [2], and better distribution of stresses during both lateral and vertical gutta-percha compaction [3, 4]. However, the possible excessive removal of dentin raised concerns regarding the susceptibility of roots to fractures [5]. Vertical root fracture [VRF] is a complication in both endodontically and non-endodontically treated teeth, usually leading to extraction [6]. Predisposing factors for root fractures have been discussed thoroughly in the literature, and various classifications have been proposed [7, 8]. Mechanical preparation affects both the geometry and volume of root canals, as a result of the removal of peri-cervical and radicular dentin, leading to stresses of the root dentin and, consequently, dentinal defects [5,9] resulting in VRF. The prevalence of VRFs in endodontically treated teeth is 11% [14]. Previous studies have attempted to compare the susceptibility to fractures of endodontically treated teeth instrumented with hand and rotary instruments of different tapers [10-13]. Methodologic limitations concerning both the standardization and randomization of the sample combined with the instrumentation and experimental techniques used have produced a variety of results.

The prognosis of a root-filled tooth with VRF is very poor because of its potential to weaken the tooth structure [15]. The initiation of the crack was related to canal preparation while filling techniques were associated with the propagation of this. Advances in rotary instruments Nickel - Titanium have led to the introduction of canal instrumentation systems with different file designs, metallurgical alloys, and rotational motions [16]. Clinicians can now choose from differently tapered instruments having unique characteristics in their metallurgy and geometry, namely progressively tapered instruments, fixed tapered instruments, and variable tapered instruments. These instruments come with the benefit of conforming to the root canal anatomy as well as removing dentin as little as possible while cleaning and shaping. Research and clinical experience have demonstrated many advantages of tapered root canal preparations over the commonly taught 'apical stop preparation.' These advantages include improved cleansing ability [Ram 1977], dramatically enhanced apical control of instruments [Schilder 1974], less dependence on exact length determination, more dependable apical resistance form, greater confidence of cone fit [Buchanan 1991], and that these tapered preparation shapes are optimal for virtually all filling techniques [George et al . 1987]. However, these instruments/files are associated with high-stress generation within the root canals that progresses into cracks that gradually succumbs to VRFs. Hence, this study aimed to compare the differences in fracture resistance of the roots prepared with instruments having varying tapers – ProTaper Gold [Dentsply-Maillefer; Ballaigues, Switzerland] – Progressively tapered instrument, ProTaper NEXT and Hyflex EDM [Coltene Whaledent, Switzerland] – Variable tapered instrument, and NeoEndo Flex [Orikam Healthcare Pvt Ltd, India] – Fixed tapered instrument [16-20].

MATERIALS AND METHODS:

Sample Selection:

80 freshly extracted mandibular premolar teeth for periodontal and/or Orthodontic reasons were collected which were free of caries, free of cracks, free of restorations, having completely formed root apices, with single root and devoid of anatomic variation. Teeth were discarded if they had calcified canals, more than one root and one root canal, with any anatomic variation and teeth with any resorption.

Of these 80 samples, 75 human mandibular premolars were selected for the study that complied with the following inclusion criteria: single-rooted teeth with fully formed apices without calcifications without previous endodontic treatment as confirmed radiographically and a similar diameter (buccolingual [BL], mesiodistal [MD]) as measured 7 mm from the anatomic apex using a digital calliper. The samples were stored in 0.1% thymol solution for 5 days after extraction and then in saline solution until the performance of the compressive test. All teeth were sectioned at 13 mm from the anatomic apex using a diamond-coated bur under water cooling. After sectioning, all roots were examined with a stereomicroscope under 10x magnification to detect pre-existing craze lines or cracks and weighed using a sensitive precision balance.

Preparation Of Specimens:

The roots were allocated to 5 groups as follows:

- **Group 1:** control group (n = 15); the root canals were not instrumented or filled.
- **Group 2:** instrumentation with ProTaper Gold files up to file F2 (25/.08, n = 15); the root canals were shaped with stainless steel hand K-files (Mani, Japan) up to file 20/.02 followed by ProTaper Gold rotary files up to #F2 (25/.08) following manufacturer's instructions (i.e. SX, S1, S2, F1 and F2).
- **Group 3:** instrumentation with Hyflex EDM (Coltene Whaledent, Switzerland) rotary files up to OneFile (25/~ , n = 15); the root canals were shaped with stainless steel hand K-files (Mani, Japan) up to file 20/.02 followed by HyFlex EDM rotary files following manufacturer's instructions (i.e. Orifice shaper – 0.25/0.12, Glide-path – 0.10/0.05% and Hyflex OneFile – 0.25/~).
- **Group 4:** instrumentation with NeoEndo Flex rotary files up to file 25/.06 (n = 15); the root canals were shaped with stainless steel hand K-files (Mani, Japan) up to file 20/.02 followed by NeoEndo Flex rotary files up to file 25/.06 following the manufacturer's protocol (ie, 30/.08, 17/.04, 20/.04, 25/.04, 20/.06 and 25/.06).
- **Group 5:** instrumentation with ProTaper NEXT files up to file X2 (25/~, n = 15); the root canals were shaped with stainless steel hand K-files (Mani, Japan) up to file 20/.02 followed by ProTaper Gold rotary files up to #X2 (25/.08~) following manufacturer's instructions (i.e. XA, X1 and X2).

During instrumentation, root canals were irrigated with approximately 6 mL 5.2% sodium hypochlorite (NaOCl) solution. After instrumentation, a final irrigation procedure was applied using 2 mL 17% EDTA, and the roots were obturated using single-cone obturation technique using Nishika BC sealer (Japan) as the root canal sealer.

A single operator instrumented all root canals in order to minimize operator variation. Each file (hand and rotary) was discarded after 3 uses. Acrylic resin blocks were prepared according to the method used in similar studies [24]. Each root was wrapped in a single layer of lead foil and invested in a silicone mould with acrylic resin (DPI, India) that served as an artificial socket, leaving approximately 1mm of the coronal portion of the root exposed (Figure 1) after which the lead foil was removed and vertical placement of each sample was radiographically confirmed (Figure 2). The roots were then covered with silicone impression material (President light body, Coltene, Switzerland) and placed in the acrylic sockets in order to create an artificial periodontal ligament (Figure 3) [24]. All specimens were kept in an environment of 100% humidity throughout the experiment (Thermolab Scientific Equipments, India). The roots were tested with a universal testing machine (Hounsfield, USA). A steel conical tip tapered at 60° was aligned with the centre of the canal orifice of each specimen (Figure 4). Force was applied with a 1mm/min crosshead speed until root fracture occurred. The load necessary to cause fracture was recorded in Newton.

Statistical Analysis:

Parametric tests were carried out for inferential statistics. One-way Analysis of variance (ANOVA) was employed to test the differences of teeth dimension and weight measurements between the five study groups. A confirmatory factor analysis (CFA) was carried out in Amos (Version 26.0). Chicago: IBM SPSS to compute a latent variable from the Buccolingual-mesiodistal tooth dimensions and the weight of the tooth to represent the tooth as a single entity. A hierarchical multiple linear regression analysis was carried out to find the determinants for fracture resistance. The *P* value of 0.05 was considered as the level of significance.

Having controlled for the background variables, it was assumed that all four study groups had a significantly lesser fracture resistance than the control group (ProTaper Gold-Model 1:0.002, Model 2:0.003; Hyflex EDM-Model 1:0.043, Model 2:0.045; NeoEndo Flex-Model 1:<0.001, Model 2:<0.001; ProTaper Next-Model 1:0.000, Model 2:0.012) (Graph 2).

Among the file groups studied, the highest fracture resistance was found in Hyflex EDM (305.29±80.5 N), followed by ProTaper Next (290.33±54.94 N), then by ProTaper Gold (275.52±102.05 N) and least by NeoEndo Flex (254.87±28.35 N) (Table 2).

DISCUSSION

The standardization of the sample is an important parameter in fracture resistance studies using natural teeth. It is generally accepted that the fracture resistance of an endodontically treated tooth is directly related to the amount of remaining sound tooth structure. Variations in root dimensions may affect the residual dentin thickness after instrumentation with different tapers. Also, the most susceptible roots to fracture are those with a narrow MD diameter compared with the BL dimension. For this reason, mandibular premolars were selected for samples, which were easy to collect. In the present study, approximately similar teeth were selected, and a step-by-step process was followed for unbiased standardized groups and analysis to be achieved [25].

Specifically, these steps were as follows:

1) All teeth were randomly distributed into 4 groups (using

random.org).

2) Having ensured the homogeneity of variances and the normality of the BL and MD diameters and weight, a 1-way analysis of variance showed that the mean values of the variables involved among the 4 groups were not statistically significant, thus supporting the standardization of data (Table 1).
3) Confirmatory Factor Analysis (CFA) was introduced for integrating all 3 characteristics of the roots (BL and MD diameters and weight) into 1 latent variable that simulates the tooth as a single entity. This latent variable was developed as a weighted average of the BL and MD diameters and weight with the factor loadings derived by CFA being used as the weighting coefficients, respectively (Table 1).
4) Having ensured the homogeneity of variances and the normality of the latent variable, 1-way ANOVA showed that the mean values of this variable among the 4 groups were not statistically significant, thus verifying the standardization between groups (Table 1, Graph 1).

The fracture resistance of samples instrumented with HyFlex EDM and ProTaper NEXT rotary instruments was found to be higher than the rest of the instrumented groups which can be attributed to the number of instruments used in sequence for biomechanical preparation. Hyflex EDM and ProTaper NEXT feature variable taper design. Hyflex EDM OneFile has a quadratic cross-section at the apical portion, it is trapezoidal in cross-section in the middle third and almost triangular at the coronal part. Kumar et al in their study found that ProTaper NEXT file system removed more dentin at 7 mm, showed a lower mean value of removed dentin and least cutting at the middle level, i.e. 5 mm from the apex in the mesiodistal direction [26]. The most probable reason for more dentin removal at the coronal level could be attributed to the fact that ProTaper NEXT has less taper in the apical than at the coronal level. ProTaper NEXT preserved more dentin due to its variable tapered design and off-centred mass cross-section which makes no more than two points at all times while shaping. The influence of cross-section on dentin removal can be attributed to ProTaper Gold files having progressive taper that enhances cutting action while decreasing rotational friction between the blade of the file and dentin [16] that results in canal transportation and canal centring ability which can be compared to ProTaper Universal.

The L6 cross-section was located 6 mm from the apex, which coincides with the greatest taper of the ProTaper Next files. Therefore, the significant difference in transportation observed at L6 could be related to the instrument taper. Similar findings were reported in a study comparing the shaping abilities of the ProTaper Next, ProTaper Universal, and WaveOne instruments in L-shaped simulated root canals. ProTaper Next maintained the canal curvature with minimal apical transportation and the highest coronal transportation above the curvature [17, 18, 19]. Gagliardi et al in their study concluded that ProTaper Next maintained greater canal-centric ability than ProTaper Gold [20]. Soujanya et al in their study, concluded that the least number of dentinal cracks were found in ProTaper Gold compared to NeoEndo Flex files. These results are similar to the study conducted by Nishad and Shivamurthy, and Chole et al. [21, 22], (who compared ProTaper Gold, ProTaper Next, and ProTaper Universal); where ProTaper Gold had shown least number of cracks. This could be due to greater flexibility, two-stage specific transformation behaviour, a reverse transformation of the alloy. ProTaper Gold has an intermediate R-phase aiding as an advantage at some point in the manufacturing process, and high transition temperature (A_f), explaining the A_f superelasticity of ProTaper Gold. The progressively decreasing taper and the convex triangular cross-section of ProTaper Gold ultimately aid in greater canal-centric ability than Neo Endo Flex files, decreasing the friction against dentin walls and thereby contributing to lesser crack formation [23]. Datta et al found that NeoEndo flex file system group removes the maximum amount of peri-cervical dentin when compared to the other three groups (ProTaper Gold, ProTaper Next and HyFlex CM) [23]. This may be due to the increased diameter of the orifice shaper file at the region of peri cervical dentin(D14). The taper and tip diameter of Neoendo flex file is 8% #30-fixed taper, as compared with Hyflex CM: 8%,#25-Fixed taper & Protaper Gold: 4% ,#19-variable taper. NeoEndo Flex files have a triangular cross-section design with active cutting edges which enhances the cutting efficiency of the file system. It is also stiffer compared to the other three file system groups. It also used more files in sequence to reach the standardized apical enlargement as compared to other groups [23].

A final strong argument for these tapered root canal shapes is that they are very similar to the morphology of root canals when they are first formed. Fixed tapered files have a constant angle of increasing diameter along the active portion of the file, while The ProTaper instruments present a convex triangular cross-sectional design, a progressive [decreasing] taper that aims to prevent taper lock. Variable-tapered files on the other hand have different tapers of increasing and decreasing angles along that portion of the file. Variable-tapered files have been shown straighten and transport the outer aspect of the apical curvature when compared with fixed-tapered files. However, on the mid-root curvature, the variable-tapered file was better at preserving tooth structure than fixed-tapered endodontic files [16-17].

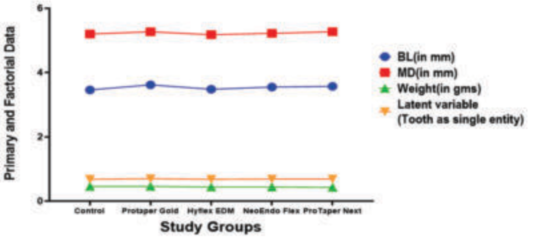
CONCLUSION

Within the limitations of this study, it can be said that there was no significant difference among the file systems used with respect to the fracture resistance under in-vitro conditions but samples instrumented with HyFlex EDM files appeared to have the most fracture resistance followed by samples instrumented with ProTaper NEXT, followed by samples instrumented with ProTaper Gold followed by samples instrumented with Neo Endo Flex Files.

Table 1: Descriptive statistics of the variables included in the study for the five study groups

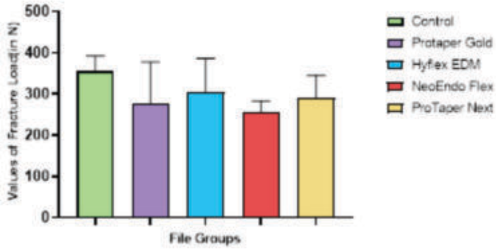
Variables	Study Groups					
	Control	Pro Taper Gold	Hyflex EDM	NeoEndo Flex	ProTaper Next	P value[a]
Primary Data						
Bucco-Lingual dimension(in mm)	3.46±0.15	3.62±0.32	3.48±0.19	3.55±0.26	3.57±0.24	0.07 ns
Mesio-Distal dimension(in mm)	5.2±0.09	5.27±0.12	5.18±0.09	5.22±0.1	5.27±0.15	0.12 ns
Mass (in gms)	0.46±0.06	0.46±0.05	0.44±0.05	0.44±0.05	0.43±0.03	0.32 ns
Factorial Data						
Latent Variable (Tooth as a single entity)	0.68±0.02	0.7±0.04	0.68±0.02	0.69±0.03	0.69±0.03	0.13 ns
Fracture Load (N)	355.38±37.27	275.52±102.05	305.29±80.57	254.87±28.35	290.33±54.94	-

- Total sample size(N)=75, sample size per group(n)=15
- a:analyzed by the one-way ANOVA test
- ns:Not significant(P>0.05)



Graph 1: Mean values of variables(BL,MD dimensions,

weight and latent variable) included in the study for the five study groups



Graph 2: Mean values of fracture load for the five study groups

Table 2: Linear regression model of determinants for the fracture load

Model	Predictors	Unstandardized Coefficients		Standardized Coefficients	P value	Adjusted R2
		B	Std. Error	Beta		
Model 1	(Constant)	355.38(321.13-389.63)	17.172		<0.001**	0.173
	Protaper Gold vs Control*	-79.86(-128.3--31.43)	24.285	-0.44	0.002**	
	Hyflex EDM vs Control*	-50.093(-98.53--1.66)	24.285	-0.276	0.043*	
	NeoEndo Flex vs Control*	-100.513(-148.95--52.08)	24.285	-0.553	<0.001**	
	Protaper Next vs Control*	-65.047(-113.48--16.61)	24.285	-0.358	0.009**	
Model 2	(Constant)	400.048(1.51-798.58)	199.773		0.049*	0.162
	Protaper Gold vs Control*	-78.429(-128.84--28.02)	25.27	-0.432	0.003**	
	Hyflex EDM vs Control*	-49.968(-98.76--1.18)	24.458	-0.275	0.045*	
	NeoEndo Flex vs Control*	-99.742(-149--50.48)	24.692	-0.549	<0.001**	
	Protaper Next vs Control*	-64.005(-113.66--14.36)	24.888	-0.352	0.012*	
	Latent(Tooth as a Single Entity)	-66.027(-652.91-520.86)	294.185	-0.025	0.823ns	

*Control taken as reference variable

NS: Not significant(*P*>0.05); *:Significant(*P*<0.05); **:Highly Significant(*P*<0.001)

Figure 1: Root Sample Wrapped In A Lead Foil Being Invested In A Silicone Mold Containing Acrylic

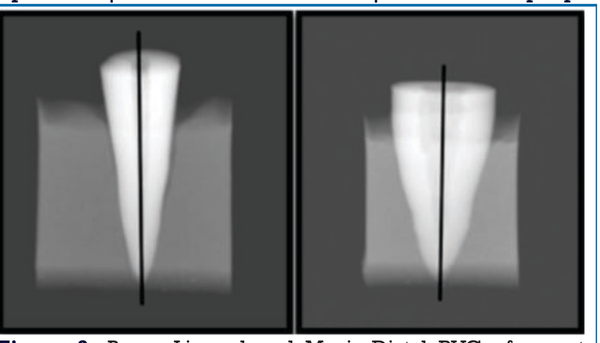


Figure 2: Bucco-Lingual and Mesio-Distal RVG of a root mounted in artificial acrylic socket showing vertical positioning

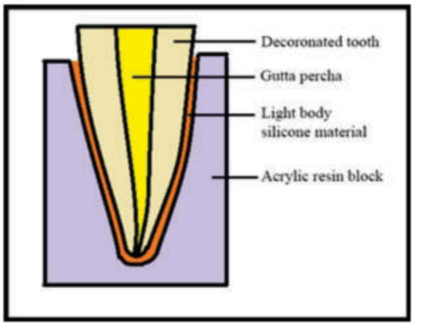


Figure 3: Schematic diagram showing mounting of a prepare specimen

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