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Comparative evaluation of dynamic torsional resistance of the nickel titanium instruments manufactured with different technologies

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Abstract

Aims: To compare and evaluate the dynamic torsional resistance of nickel titanium instruments manufactured with different technologies.

Methods: 60 new rotary NiTi instruments were selected and divided into 4 subgroups of 15 files each: Protaper (Dentsply Maillefer, Ballaignes, Switzerland) based on coventional SE wire technology, Twisted file (Sybron Endo, Orange, CA) based on R-phase technology, Hyflex CM (Coltene Whaledent, Cuyahoga Falls, Ohio) based on Controlled Memory and Protaper Next (Dentsply Maillefer, Ballaignes, Switzerland) based on M-wire technology. A customised stainless steel apparatus consisting of block with a cubical hole (5mm×5mm×5mm) and assembly for holding and adjusting the handpiece was fabricated. 5 mm of the tip of each file was embedded in this composite resin block, and a uniform torsional stress at a speed 300 rpm and 1.8 N.cm torque were applied repetitively by an endodontic motor (X-Smart; Dentsply Maillefer, Ballaigues, Switzerland) with auto-stop mode until the file subjected to torsional failure. The number of load applications leading to fracture were recorded. All fractured surfaces were examined under the SEM for determining the mode of fracture. Tabulated data was statistically analysed using mean and standard deviation. ANOVA and Unpaired 't' test were applied to find the significant difference between the different groups.

Results: Protaper files showed significantly higher dynamic torsional Resistance followed by Protaper Next (45.2), Hyflex CM (2.733) and lowest values were obtained for Twisted file but there was no statistical difference between Hyflex CM and Twisted file groups. SEM examination revealed a typical pattern of torsional fracture for all the groups characterized by circular abrasion marks and skewed dimples near the center of rotation

Conclusions: Protaper files showed comparatively and significantly higher dynamic torsional resistance than all other file systems followed by Protaper Next, Hyflex CM and Twisted files. Hyflex CM and Twisted files exhibited the same dynamic resistance to torsion.

Keywords: Controlled Memory, Conventional SE wire, dynamic, M-wire, R-phase, torsional resistance

Introduction

Nickel titanium alloys represent a major breakthrough in endodontics, particularly in regard to the preparation of curved root canals. These alloys present a lower modulus of elasticity when compared with stainless steel files, which combined with its unique mechanical properties and innovative file designs, can lead to a more effective and safer enlargement of curved canals without losing their original path [1].

Despite numerous other advantages, incidence of instrument fracture during root canal preparation is a major concern. Ni-Ti instruments show no visible signs of previous permanent deformation before fracture occurs [2]. Fracture of instruments used in rotary motion occurs in two different ways: fracture caused by torsion and fracture caused by flexural fatigue [2, 3]. Torsional fracture occurs when an instrument tip or another part of the instrument is locked in a canal while the shank continues to rotate. When the elastic limit of the metal is exceeded by the torque exerted by the handpiece, fracture of the tip becomes inevitable. Instruments fractured because of torsional loads often carry specific signs such as plastic deformation [3].

In comparison, Sattapan *et al* reported that torsional fracture occurred in 55.7% of all fractured files, whereas flexural fatigue occurred in 44.3%. The results of study indicated that torsional failure, which may be caused by using too much apical force during instrumentation or by other contributing factors such as the pre-existing size of the canal, occurred more frequently

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than flexural fatigue, which may result from use in curved canals [4].

Significant improvements in the raw material properties, instrument design and enhancements in the manufacturing process have taken place to devise instruments with better fracture resistance. Recently, series of proprietary thermomechanical processing procedures have been developed with the objective of producing SE Nickel titanium wire blanks that contain the substantially stable martensite phase under clinical conditions. Enhancements in these areas of material management have led to the development of the next-generation endodontic instruments based on Controlled Memory, M-Wire technology and R-Phase technology [5]. Manufacturers claim that the instruments made from these techniques have better torsional resistance and cyclic fatigue compared to traditional super elastic (SE) wire.

The NiTi shape Memory alloys can exist in 2 different temperature dependent crystal structures (phases) called martensite (low-temperature phase, with a monoclinic B190 structure) and austenite (high temperature or parent phase, with the B2 cubic crystal structure). When martensite NiTi is heated, it begins to change into austenite. The temperature at which this phenomenon begins is called the austenite transformation start temperature (As). The temperature at which this phenomenon is complete is called the austenite finish temperature (Af), which means that at and above this temperature the material will have completed its shape Memory transformation and will display its SE characteristics. When austenite NiTi is cooled, it begins to change into martensite. The temperature at which this phenomenon begins is called the martensite transformation start temperature (Ms). The temperature at which martensite is again completely reverted is called the martensite transformation finish temperature Mf. The Af temperature for most conventional SE NiTi files is at or below room temperature, whereas the Af of the new Controlled Memory files and M-wire is clearly above body temperature. As a result, the conventional NiTi files are in the austenite phase during clinical use, whereas CM files and M-wire alloys are mainly in the martensite phase [6].

M-wire is a modification of the SE 508 Nickel titanium alloy and is produced by applying a series of heat treatments to Nickel titanium wire blanks. It is based on a proprietary Nickel titanium thermal processing procedure that yields a complex microtwinned martensitic structure [5].

The R-Phase of nitinol is an intermediate martensitic phase that competes with the martensite phase. It transforms into a rhombohedral (R) phase by a heat treatment process. The transformation from austenite to R-phase takes place on cooling to the R phase transition temperature, Martensite begins to form on further cooling to and below the martensite - start temperature (Ms). The rhomobohedral structure can be stabilized by applying a suitable holding temperature. R-phase shows good superelasticity (1% strain) and shape Memory effects. Its modulus of elasticity is lower than austenitic phase [7].

Controlled Memory technology have been manufactured using a special thermomechanical process that controls the Memory of the material, making the files extremely flexible but without the shape Memory of other NiTi files, as opposed to what is found with conventional SE forms of NiTi. It is characterized by a austenitic finish temperature of approx. 55^0c, indicating that at body temperature, the instrument would contain a significant proportion of martensitic alloy. Instruments in the martensitic phase can be easily deformed and will recover their shape when heated beyond the transformation temperature [8, 9].

In the present study, the instruments based on these new technologies: Protaper Next (Dentsply Maillefer, Ballaignes, Switzerland) based on M wire technology, Hyflex CM (Coltene Whaledent, Cuyahoga Falls, Ohio) based on Controlled Memory, Twisted file (Sybron Endo, Orange, CA) based on R phase technology were selected to be compared with Protaper (Dentsply Maillefer, Ballaignes, Switzerland) based on conventional SE wire.

Materials and Methods

Sixty new rotary files with ISO tip size of 25, a taper of 6% except protaper and length 25mm were selected except for twisted files which were available in 23mm and 27mm lengths as 25mm is not commercially available and divided into 4 subgroups: Subgroup T_P (Protaper), Subgroup T_T (Twisted file), Subgroup T_N (Protaper Next) and Subgroup T_H (Hyflex CM) each consisting of 15 files each.

To test the Dynamic Torsional Resistance, a customised stainless steel model as suggested by Park S.Y *et al*. (2010) was fabricated [10]. A cubical hole (5mm×5mm×5mm) was made in the center of the stainless steel metal block. This metal block with the hole was held horizontally in the main assembly. Torque Controlled gear reduction endo handpiece (X-Smart; Dentsply Maillefer, Ballaigues, Switzerland) was then mounted rigidly in the main assembly in such a manner that its position could be adjusted in a vertical manner.

Thereafter, different rotary NiTi files were engaged in a handpiece and position of the handpiece was altered in such a manner that 5mm (from the tip) of each instrument could be engaged in the cubical hole of the metallic block with the help of resin composite (Filtek Z250 XT, 3M ESPE). The resin composite was incrementally added cured with the help of curing light CU-100A (Gnatus, Brazil) for 80 secs.

Though different manufacturers have advocated different speed and torque values for their instruments. So, an average value i.e. 300 rpm and 1.8N.cm was selected to simulate clinical used values for all the instruments used in the study. The endomotor was set at auto stop mechanism with torque values not exceeding 1.8 N.cm. Each file was driven clockwise at 300 rpm until the preset torque was reached and the engine stopped automatically.

This was counted as one start-stop loading cycle. The engine was allowed to start again and the process repeated. The number of such load application cycles before fracture were recorded for each instrument.

The data so obtained were tabulated and statistically analysed. Fractured surfaces of all the files were analyzed under the scanning electron microscope (Carl Zeiss Evo 40) and observed for signs of fracture mode.

Results

The mean,standard deviation and standard error of mean (*Table* 1) were calculated from tabulated data and One way ANOVA- F test (*Table* 2) and Unpaired ‘t’ test (*Table* 3) were applied to find the significant difference among and between the different groups at 5% level of significance. The results showed that Subgroup Protaper has significantly higher Dynamic torsional Resistance followed by Protaper Next & Hyflex CM. Lowest values were obtained for Twisted files but there was no statistical difference between Hyflex CM and Twisted file.

Since F calculated is greater than F tabulated (F 3, 56, .05) hence, a significant difference ($p<.05$) exists between the subgroups at .05 level of significance in Dynamic Torsional resistance

SEM analysis for Dynamic torsional resistance

The topographic appearance of the fractured surfaces demonstrated the typical pattern of torsional fracture characterized by circular abrasion marks at lower magnification i.e. 200X and 500X and at higher magnification i.e. 1000X skewed dimples were seen near the centre of rotation.

Table 1: Mean, Standard Deviation and Standard Error of Mean of number of cycles for dynamic torsional fatigue of different rotary NiTi instruments (300 rpm at 1.8 N.cm torque)

S. No.	Subgroup T_P (Rotary Protaper Files) (F2/25)	Subgroup T_N (Rotary Protaper Next files) (X2/25)	Subgroup T_H (Rotary Hyflex CM Files) (.06/25)	Subgroup T_T (Rotary Twisted Files) (.06/23/27)
1.	44	2	1	1
2.	45	1	1	1
3.	47	3	1	2
4.	46	5	1	1
5.	42	2	2	1
6.	49	2	1	1
7.	45	4	2	1
8.	50	6	1	1
9.	52	2	1	1
10.	38	5	1	1
11.	46	3	2	1
12.	43	2	1	1
13.	48	1	1	1
14.	44	1	1	1
15.	39	2	1	1
Mean	45.2	2.733	1.2	1.07
S.D.	45.2±3.8210	2.733±1.579	1.2±.4140	1.07±.2582
S.E.M.	0.9868	0.4080	0.1069	0.0667

Abbreviations: S.D. standard deviation, S.E.M. standard error of mean.

Table 2: One way anova f- table for comparing significant difference among different subgroups in the dynamic torsional resistance

Source of Variation	SS	df	MS	F (calculated)	p-value	F critical/tabulated
Between Groups	21154.85	3	7051.617	1310.477434	8.10344E-52	2.769430932
Within Groups	301.3333333	56	5.380952		P<.05 (SIG.)	
Total	21456.18333	59				

Abbreviations: SS: Sum of squares, df: Degree of freedom, MS: Squares of mean

Table 3: Unpaired “t” test for comparsion between different pairs of subgroups in dynamic torsional resistance

S.no.	Pairwise comparsion of subgroups	Probable values of unpaired “t” test	p-value / significance
1	Subgroup T_P & T_N	.0000*	P<.05 (significant)
2	Subgroup T_P & T_H	.0000*	P<.05 (significant)
3	Subgroup T_P & T_T	.0000*	P<.05 (significant)
4	Subgroup T_N & T_H	.0055*	P<.05 (significant)
5	Subgroup T_N & T_T	.0036*	P<.05 (significant)
6	Subgroup T_H & T_T	.3007**	P>.05 (not significant)

* shows a significant difference b/w different pairs at.05 level of significance.

** shows no significant difference b/w different pairs at.05 level of significance.

Discussion

Regarding Torsional Resistance testing, the American Dental Association Specification No. 28 describes the ultimate torsional strength of the instrument by applying a torsional load running in a clockwise direction at 2 rpm [10]. However, the main Limitation of this approach is that it does not evaluate the chance of fracture because of repeated ‘‘taper locking”. Park S.Y *et al* (2010) suggested a new method for torsional testing: Dynamic Torsional Resistance [10]. In this, uniform torsional stress is applied repetitively to simulate repeated locking of the rotary file during canal preparation. A higher number of load application cycles to failure would indicate a higher resistance to torsional failure of the instrument. It is thought that such a loading condition would better reflect the torsional resistance of Nickel titanium rotary instruments with clinical relevance. So, this test was selected for our experiment as it is more clinically relevant.

Though, the torsional behavior of a rotary Nickel titanium instruments can be attributed to various factors i.e. metallurgic composition, thermo mechanical treatment applied during manufacturing, cross section diameter, flute depth. torque applied etc. [10-13]. Type of predominant phase in the alloy plays a major role in the torsional properties of the material (Austenite v/s Martensitic) [13-16]. The higher values so obtained for Subgroup Tp in our study can be attributed to the presence of predominant austenite phase which is more torsion resistant whereas nickel titanium files with thermal processing would essentially be in the martensite condition at body temperature [10, 16]. In addition, the critical stress for martensite reorientation of CM wires and M-wire is in the range of 128–251 MPa at room temperature and 37^0C, which is much lower than the critical stress for stress-induced martensite transformation of the SE wires (490–582 MPa). The ultimate tensile strength for the CM Wires and M-wire (about 1094 MPa) is also lower than that of SE wires (about 1415 MPa) [5].

Though twisted files are based on R phase technology and are in austentite phase at room temperature still these files showed the least torsional strength because the files are manufactured by twisting rather than grinding. The torque during instrumentation was applied in the opposite direction as the initial twisting during manufacturing, and, therefore, the torsional stress is in the effect returning the file to the original configuration by unwinding. it [11]. Moreover, the equilateral triangular cross-section (Twisted files) is expected to show a lower torsional resistance than convex triangular cross section (Protaper files) because of the high stress concentration at the middle of each side, the distance between this point and the centroid of the cross-section being the shortest [10, 12].

As supported by Park SY *et al* (2010) [10], Camara AS *et al* (2009) [17], Ninan E and Berzins DW (2013) [13], the second main factor for fracture resistance is cross sectional dimension which also plays an important role in torsional resistance. It has been shown that if the central core of the file design is larger, file will be more resistant to torsional stress.

Protaper with convex triangular cross section and larger core diameter presented with higher values of torsional resistance whereas Twisted files with least cross section dimensions were least resistant to torsional stress [12]. As far as Protaper Next and Hyflex CM are concerned, both are based on M-wire technology but Protaper Next has got a larger rectangular cross section diameter than Hyflex CM which is having triangular slight convex cross section. This supports the larger values so obtained for Protaper Next as compared to Hyflex CM. There are number of studies relating cross section diameter to the torsional resistance Camara AS *et al* (2009) [17], Wycoff R C and Berzins D.W (2012) [11], Ninan E and Berzins D W (2013) [13]. They all concluded that bigger cross sectional diameter accounts for higher torsional resistance. We also found the same correlation in our study.

In a similar study done by Park S Y *et al* (2010) [10] and Yum J *et al* (2011) [16], it was observed that Twisted file showed least torsional resistance and were not able to withstand even a single torsional cycle as also observed in the present study.

On fractographic examination, torsional fracture (shear failure) would generally show plastic deformation, absence of fatigue striations, and presence of concentric abrasion marks and skewed dimples near the center of the fractured surface [10]. In the present study, the fractured surface of all the files exhibited circular abrasion pattern of torsional failure and at higher magnification (1000X) skewed dimples were observed near the centre of rotation thus confirming the nature of fracture

Thus, various Nickel titanium rotary system should be used according to the condition of the root canal in the clinical situation. Nickel titanium files with a high flexibility i.e. Twisted file, Hyflex CM and Protaper Next could be used for preparing curved canals, whereas those that are more resistant to torsional stress i.e. Protaper should be used to prepare highly constricted (but patent) and/or straight root canals. Further research *in vitro* and *in vivo* for newly launched instrument such as Protaper Next will help in clinical correlations for successful outcome of the root canal treatment.

Conclusion

Within the limitations of the study, Protaper files based on conventional SE wire based technology showed comparatively and significantly higher dynamic torsional resistance followed by Protaper Next, Hyflex CM and Twisted files.

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