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EFFECT OF TWO DIFFERENT HEAT-TREATED MINIMALLY INVASIVE NICKEL-TITANIUM ROTARY FILE SYSTEMS ON ROOT FRACTURE RESISTANCE (AN IN VITRO STUDY)

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ABSTRACT

BACKGROUND: Nickel-Titanium rotary files can induce dentinal cracks on the root canal walls and over time functional load can develop and cause vertical root fracture.

AIM: To evaluate the vertical root fracture (VRF) resistance of endodontically treated teeth prepared with two different heat-treated minimally invasive rotating file systems.

MATERIALS AND METHODS: 45 human mature mandibular first molars were selected & decoronated followed by sectioning of distal roots, obtaining mesial roots 14 mm long. The mesial roots were mounted in resin molds and randomly assigned to three equal groups; one negative control group (n=15) and two experimental groups (each n=15) according to the file system used. Group 1 –instrumented by HyFlex EDM, Group 2 –instrumented by Protaper Ultimate, Group 3 –negative control (no instrumentation). Single cone obturation was performed with resin sealer and gutta-percha. Subsequently, all specimens were subjected to vertical compressive load using the universal testing machine to record the force (N) needed until root fracture. Data were statistically analyzed.

RESULTS: The control group showed the greatest fracture resistance, followed by HyFlex EDM and Protaper Ultimate. No statistical difference was noted between the two tested groups (P =0.055) and between the control and HyFlex EDM (P =0.295). In contrast, a statistically substantial difference was observed between the control and the Protaper Ultimate (P =0.001).

CONCLUSIONS: Minimally invasive heat-treated files could preserve more pericervical dentin (PCD), enhancing fracture resistance. HyFlex EDM files maintain tooth strength better than Protaper Ultimate system, with no significant difference.

KEYWORDS: Fracture resistance, Dentinal cracks, Protaper Ultimate, HyFlex EDM, Minimally invasive files.

RUNNING TITLE: Fracture resistance assessment following minimally invasive canal preparation.

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INTRODUCTION

The key providing effective endodontic therapy is to precisely shape the root canal using chemo-mechanical preparation, followed by three dimensional obturation. Rotating nickel-titanium (NiTi) files are frequently utilized during root canal therapy. However, these procedures over time run the risk of causing or exacerbating dentinal defects which could progress into vertical root fractures (VRF) under functional loads. Therefore, modern advancements in NiTi rotary files throughout the years, such as various cross-section designs and heat treatment techniques, have minimized structural damage during root canal procedures.

The most valuable tooth structure to conserve is the peri-cervical dentin (PCD), extending 4 mm above and beneath the crystal bone and is thought to be crucial in transferring occlusal forces to the root (1). Thus, the use of instruments with variable tapers might significantly weaken the PCD.

Researchers have recently placed a greater emphasis on conservative endodontics in an attempt to preserve tooth integrity; this can be achieved with minimally invasive endodontic (MIE) therapy (2). Both Protaper Ultimate and HyFlex EDM systems are two examples of these modern and advanced file systems with different heat treatments that emphasize the mechanical preparation of a canal with a deep apical shape and a conservative body, which is in line with the MIE philosophy of root shaping (3).

HyFlex EDM (Coltene, Whaledent, Allstetten, Switzerland) is a single file system used in a continuous rotation and one of the earliest endodontic instruments manufactured from controlled memory (CM) wire utilizing electrical discharge machining (EDM) technology which makes the HyFlex EDM files stronger and more

resistant to fracture (4). In an attempt to protect the PCD, the OneFile (25/ variable taper) file has a continuous taper of 8% at the apical 4mm and a taper of 4% toward the remaining coronal area (4). Protaper Ultimate (Dentsply Sirona, Baillagues, Switzerland) is a continuous rotation full sequence system. It is a further advancement of the Protaper family with significant added benefits including increased flexibility and maximal preservation of PCD (3). Based on the diameter of each file, three distinct heat-treated alloys with varying mechanical behaviors are used in their manufacturing: M-wire (slider), Gold-wire (SX, shaper, F1, F2, F3), and Blue heat-treated wire (FX, FXL) (5). The core Finishers (F1, F2, F3) have fixed tapers from D1 to D3, followed by reducing percentage tapers from D4 to D16 (3). This design component follows the idea and trend of minimally invasive endodontics (MIE) by keeping the characteristic apical one-third deep form feature while preserving the coronal two-thirds preparation (3).

The exact influence of the regressive tapered design and various heat-treated alloys of these two minimally invasive NiTi rotary file systems (HyFlex EDM and Protaper Ultimate) on the resistance to root fracture is still up for debate.

Thus, the research question was to identify whether the use of heat-treated minimally invasive rotary files during canal preparation could resist the functional load or not. The null hypothesis was that there would be no significant difference in resistance to root fracture among the two examined file systems.

MATERIALS AND METHODS

The study was conducted after receiving approval from the ethical committee at the Faculty of Dentistry, Alexandria University, Egypt (IRB No: 00010556-IORG: 0008839). The sample size was estimated to be 13 per group, which increased to 15 to make up for processing errors. Total sample = Number per group x Number of groups = 15 x 3 = 45 samples.

This study was conducted on 45 freshly extracted human permanent mature first mandibular molars that were obtained from Department of Oral Surgery, Faculty of Dentistry, Alexandria University, Egypt. They were extracted for periodontal and prosthetic reasons.

Preparation of specimens

The external surfaces were inspected under a stereomicroscope to exclude the possibility of any external defects or cracks (6,7). Periapical radiographic examination was performed in buccal and proximal views (8) to include teeth with intact roots, mesial canals with Type IV Vertucci's classification and moderate root curvature ranging from (20 to 40 degrees) according to Schneider's technique (9). For standardization, only teeth with 22 +/- 1 mm total length and 14 +/- 1 mm root length were included.

The coronal portions were sectioned, followed by resection of their distal roots at the furcation with a diamond disc bur under cooling system leaving 14 mm of the mesial root in length (6,10). Teeth were then disinfected and stored in distilled water until the time of use.

To check canal patency, a # 10 k file was inserted into the mesiobuccal and mesiolingual canals until just visible at the apical foramen, after which 1 mm was subtracted to determine the working length (2,8).

Each root was wrapped with a single layer of aluminum foil and embedded vertically in acrylic resin (Acrostone; Dent Product, Egypt), set in a uniform mold. The root was then removed from the mold, and the aluminum foil was peeled off. A light body silicone-based material (Oranwash; Zhermack SpA, Rovigo, Italy) was injected into the space created by the foil to mimic the periodontal ligament (PDL), and the root was embedded in the acrylic mold (2,11).

Grouping

The specimens were randomly allocated using permuted block randomization technique (12) to three equal groups; one negative control group (n=15) and two experimental groups (n=15) depending on the file system utilized, as follows: (Figure 1)

Group I: prepared using HyFlex EDM single file system.

Group II: prepared using Protaper Ultimate multiple file system.

Group III: unprepared canals (negative control).

Biomechanical preparation

For both groups, X-Smart plus motor (Dentsply Maillefer, Ballaigues, Switzerland) was used with the tested file systems at speed and torque assigned by the manufacturer for each system. Instrumentation was performed for each of the experimental groups.

Group I: specimens were instrumented with HyFlex EDM files. The root canals were subsequently prepared as follows: Orifice opener (25\12), manual glide path with # 10K file, followed by the Glidepath file (10\05), and finally the HyFlex OneFile (25\variable taper). For all used files, the recommended speed was 400 rpm in continuous rotation with a torque of 2.5 Ncm, except for the Glidepath files which were employed at 300 rpm and up to 1.8 Ncm. Each file was introduced in an in-and-out pecking motion with no pressure, and then withdrawn in a brushing motion for cervical pre-flaring (4).

Group II: specimens were instrumented with Protaper Ultimate files. Canals were subsequently prepared with the slider (16\02), the shaper (20\04) with selective brushing motion on the outstroke. F1 (20\07), and F2 (25\08) were utilized passively

without brushing to advance deeper into the canal. The recommended speed was 400 rpm in continuous rotation with torque 4.0 N cm (3).

Specimens in Group III acted as a negative control (no preparation).

For both tested groups, each rotary instrument was discarded and replaced after 4 canal uses. Specimens in all groups were flushed with 2ml of 2.5% NaOCl (Chlorox, Egyptian industry, ARE) as an irrigating solution after each file change during instrumentation, followed by a standardized volume of 5ml of 17% EDTA solution for 1 min, and finally 10 ml of normal saline solution (7).

After drying the canals, AdSeal™ resin sealer was mixed depending on the manufacturer's recommendations. Obturation was performed with gutta-percha cone size 25 with taper 0.04 using the single cone technique in group I and group II (7).

Fracture resistance testing

A gradually increasing compressive force was applied on the root samples until fracture with a 4 mm diameter spherical steel ball centralized between the two orifices and 1 mm/min downward parallel speed, using a Universal testing machine. The force required to fracture each root specimen was recorded in Newton (N) (7,10). **(Figure 2 and 3)**

Statistical analysis of data

Normality of the fracture resistance values was checked using the Shapiro-Wilk test and Q-Q plots. Values were normally distributed thus, mean, standard deviation (SD), and 95% confidence interval (CI) were used mainly for data presentation in addition to median, minimum, and maximum. Analysis was performed using One Way ANOVA followed by Tukey's post hoc test to analyze variations in fracture resistance between the study groups. All tests were two-tailed and the significance level was set at p value≤0.05. Data was analyzed using IBM SPSS version 23, Armonk, NY, USA.

Figure (1): (a) HyFlex EDM files (b) Protaper Ultimate files.

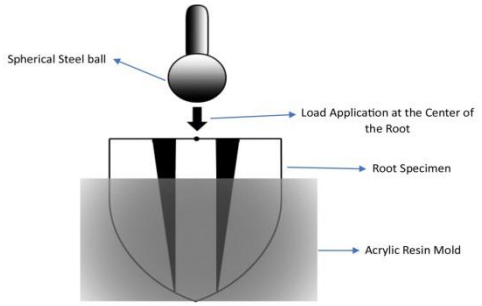

Figure (2): Diagrammatic representation for the fracture resistance test.

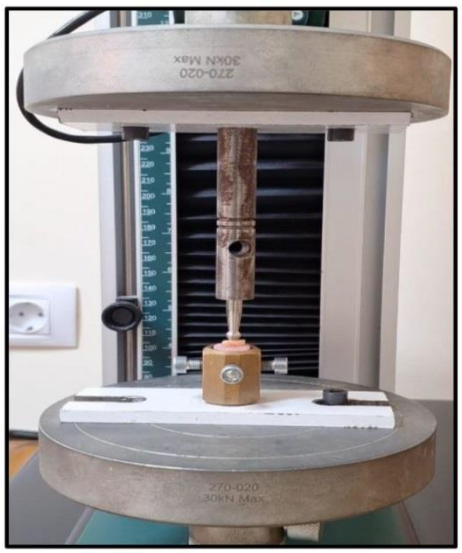

Figure (3): Load applied at the center of the roots using the universal testing machine.

RESULTS

The mean fracture resistance values were (781.08 ±175.26) and (620.27 ±196.45) for the HyFlex EDM and the Protaper Ultimate groups, respectively with no statistically significant difference among the two tested groups (P=0.055). While the mean fracture resistance was (883.15 ±181.48) for the control group. (Table 1) (Figure 4) Moreover, a statistically substantial difference was noted on comparing the mean fracture resistance values of the control group and the Protaper Ultimate group (P=0.001*). However, there was no statistically significant difference in comparing the control group and HyFlex EDM group (P=0.295). (Table 2)

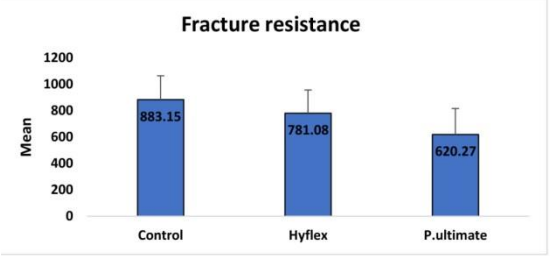

Figure (4): The mean fracture resistance values in the two study groups. (P value <0.05).

Table (1): Fracture resistance values between the examined groups.

	Control (n=15)	**Hyflex (n=15)**	**P.ultimate (n=15)**
Mean ±SD	883.15 ±181.48	781.08 ±175.26	620.27 ±196.45
95% CI	782.65, 983.65	684.02, 878.13	511.48, 729.06
Median	894.81	830.63	636.34
Min - Max	557.67 – 1189.95	420.12 – 1056.52	308.41 – 1116.11
F test (P value)	7.730 (0.001*)		

*Statistically substantial difference at p value≤0.05

Table (2): Pairwise comparison between the study groups regarding fracture resistance.

Groups	Compared to	Mean difference	P value
Control	Hyflex	102.07	0.295
	P.ultimate	262.88	0.001*
Hyflex	P.ultimate	160.81	0.055

*Statistically substantial difference at p value≤0.05

DISCUSSION

Vertical root fracture in endodontically treated teeth may lead to poor treatment prognosis and decrease tooth survival rate over the long term (13). Therefore, the amount of dentin removed and dentinal defects formation during mechanical instrumentation are considered one of the iatrogenic factors leading to VRF (14).

The impact of minimally invasive endodontic preparation with different kinds of NiTi rotary files on the VRF resistance of root canal-treated teeth remains a controversial topic. It is important to strike a balance between preserving the remaining tooth structure and removing enough diseased tissue. A minimally invasive approach may reduce stress concentration sites and dentinal micro-cracks development, but sufficient cleaning and shaping may be questionable (1,15,16). On the other hand, larger taper instrumentation offers more diseased tissue removal as well as an appropriate irrigant penetrating level, but may impair the tooth structure and increase the chance of micro-cracks development (15).

The current study examined and compared the impact of two minimally invasive Ni-Ti rotary systems, HyFlex EDM and Protaper Ultimate, on the VRF resistance of the mesial roots of extracted human permanent first mandibular molars using a universal testing machine. These systems differ in terms of sequences (single or full sequence file systems), type of heat treatment, and cross section designs, but they all have the same characteristic feature of having a fixed taper at the apical one third and a regressive tapered design across the coronal two thirds.

The mesial roots of the first mandibular molars were selected to be utilized in the present investigation, rather than premolars. Since they have narrow canal diameters and are very vulnerable to VRF and strip perforation (1,17,18). The use of premolars in previous studies (7,8) showed some limitations as the unfilled areas in the prepared oval root canal may negatively affect the VRF resistance of teeth and serves as a stress dissipation mechanism (14).

In the present study, the mesial root length of 14 mm was decoronated for standardization and ruling out the impact of the coronal anatomy and the access cavity preparation on fracture behavior of the tested samples (4,19,20). Conversely, other research methodologies (16,21) preserved the crown in order to serve as an irrigant reservoir and replicate clinical intraoral situation.

Root samples in this study were surrounded with a light body silicone-based material to mimic the PDL and compensate some of the vertically applied forces produced by the test machines. This was in accordance with Krikeli et al., (2018) (19) and Lin et al., (2022) (7). Conversely, previous investigation (22) found no difference in fracture force with or without PDL modeling.

During instrumentation procedure in the present investigation, it was preferred to use a lower concentration of 2.5% NaOCl to preserve mechanical properties of the dentin (19,23). In addition, single cone obturation approach was preferred to be used in compliance with previous studies (6,8). As the wedging stresses of spreaders in cold lateral condensation or improper temperature control during warm vertical condensation could lead to dentinal defects and matrix collapse, which may affect the final results of VRF values (24). To assess root fracture resistance, a universal testing machine was employed in this study. Since it is the most widely used and easiest approach to examine tooth strength (7,10).

According to the current findings, the control group had the greatest VRF resistance levels among all tested groups. This outcome demonstrates the detrimental effects of tooth structural loss and dentinal defect development during root canal therapy (6,7,16). Both experimental groups showed a minimal decrease in the VRF resistance values with no significant difference in between. This could be due to that both systems share some common features including taper design and surface heat treatment. The variable (regressive) taper present in both

tested systems, preserves more dental hard tissue in the PCD, thus enhancing their fracture resistance and preventing cuspal flexure under functional loads. This complied with Yuan et al., (2016) (25), Malakpour et al., (2019) (26) and Smoljan et al., (2021) (1). In contrast, Shyma et al., (2023) (27) observed that VRF and tooth preservation were not affected by using various file taper designs of Protaper Gold, HyFlex EDM, and Trunatomy during root canal preparation. Moreover Shah et al., (2023) (28) noticed higher dentinal damages were generated by HyFlex EDM files in the coronal and apical thirds. These conflictions were supported by Usta et al., (2023) (29) in their systematic review, where they could not find sufficient evidence about the impact of smaller apical taper or size on enhancing fracture resistance of endodontically treated teeth due to the low methodological quality along with wide variation in fracture resistance values. Another reason for the non-significant results between the two tested groups could be due to the special heat treatment of their alloys with enhanced flexibility, which may cause less internal stresses and micro-cracks during instrumentation procedure (4). This was following Pedullà et al., (2017) (30) and Devi et al., (2021) (4), who attributed the lower incidence of cracks with Hyflex EDM or Protaper Gold to their special heat treatment used in the manufacturing process. To the best of our knowledge, the fracture resistance or dentinal micro-cracks formation exhibited by teeth instrumented using Protaper Ultimate files has not been reported in the literature. However, we could relate the decrease of dentinal defects with the Shapers and Finishers (F1, F2, F3) of Protaper Ultimate system to their enhanced flexibility, as they are made of Gold heat-treated wire, similar to Protaper Gold system (3). In contrast, Salem et al., (2022) (31) found that VRF was not affected when using heat-treated alloys (Protaper Next and Protaper Gold). Consequently, according to the above mentioned results in this study the null hypothesis was accepted.

The performance of HyFlex EDM was better than Protaper Ultimate although with no significance, the minimal difference in VRF values between the two tested groups could be attributed to several reasons. The first explanation was that the single file system may cause a minimal number of dentinal flaws when assessed against multiple file systems (32,33). This was in accordance with Devi et al., (2021) (4) and Ozlek et al., (2021) (34). The difference in the cross-sectional design and shape between the two tested rotary file systems might be the second reason. The Protaper Ultimate files possess the same cross-sectional design as a constantly changing parallelogram with changing acute angles over their entire working part (5). This kind of design with its increased number of blades and helical angles might induce more screw in forces and increase the chances for dentinal root cracking and VRF, as suggested by Rinastiti et al., (2023) (20). On the contrary, HyFlex OneFile has three different horizontal cross sections with a higher variable pitch length which increases gradually all through its entire working part: from rectangular at the apical end, to trapezoidal in the middle and finally triangular near the handle (4, 35). These differences could influence in reducing the possibility of internal stresses and defects especially at the critical PCD region by modifying their spiral shape and adapting to the internal anatomy of the root canal, leading to less root cracking (4), and consequently lowering the chances of VRF. This was following Cheema et al., (2018) (33) and Devi et al., (2021) (4) who related the cause of minimizing dentinal micro-cracks formation in HyFlex EDM tested group to its variable cross-sectional design. The greater torque used with Protaper Ultimate of 4 Ncm as recommended by the manufacturer, compared to 2.5 Ncm used with HyFlex EDM, might be a third reason for the higher chances of VRF, as it increases torsional and flexural stresses leading to more dentinal defects during instrumentation (36). The last possible contributing factor might be attributed to the use of Slider in Protaper Ultimate as a rotary glide path only without cervical pre-flaring (3), on the other hand the pre-use of orifice openers was recommended to be used in case of HyFlex EDM (4). This was supported by Kwak et al. (2022) (37) and Oh et al., (2022) (35) who noticed that performing coronal flaring before glide path procedure could decrease screw-in stresses and torque, and eventually this could explain the higher performance of HyFlex EDM in this study.

Limitations

Some limitations might have negative impacts in the current investigation. The tested specimens were not identical and might have various dentin thicknesses. In addition, the oral environment exposes teeth to a variety of physical, chemical, and thermal factors.

The force delivered from the universal testing machine in the current investigation was constant in speed with static direction. This was in contrast to the dynamic stresses produced in the clinical condition under functional loads, which vary in magnitude, intensity, and direction (7). Moreover, fracture resistance studies can provide inconsistent results because there might be variations in the total number of specimens, tooth types, eligibility standards, and methodologies for experimentations. For this reason, we are unable to compare our results with the literature.

Despite all these restrictions, the objective of the current in vitro research was to compare various groups under controlled conditions. The instrumentation quality and the long-dated prognosis of teeth treated with minimally

invasive endodontic therapy should all be the subject of research in the future.

CONCLUSION

Within the limited conditions of the present in-vitro investigation, it could be deduced that minimally invasive files with their special heat treatment and cross-sectional designs could preserve more peri-cervical dentin, enhancing fracture resistance. HyFlex EDM files maintain tooth strength better than Protaper Ultimate system, without significant difference.

CONFLICT OF INTEREST

The authors stated no conflicts of interest related to this investigation.

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