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FRACTURE RESISTANCE OF LOWER MOLARS AFTER MESIAL CANALS PREPARATION WITH THREE DIFFERENT ROTARY FILES (A COMPARATIVE IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: Rotary canal preparation might lead to tooth micro-cracking due to stresses on root canal walls. It is not known if modifications in rotary file manufacturing and the way they work inside the canals impact the resistance of teeth to fracture under loading.

AIM OF THE STUDY: To compare the fracture resistance of lower molars after the preparation of mesial canals with three different rotary files: Protaper Ultimate (PTU), Protaper Gold (PTG), and Wave One Gold (WOG).

MATERIALS AND METHODS: Forty-four permanent lower molars were assigned in this study and were allocated into four groups (n=11 each). Access cavity was done for all teeth. Group I: Protaper Ultimate (PTU) files were used in both mesial canals up to size F2 (25/08). Group II: Protaper Gold (PTG) files were used in both mesial canals up to size F2 (25/08). Group III: Wave One Gold (WOG) reciprocating files were used in both mesial canals up to the primary file (25/07). Group IV: Control Group; teeth where access cavities were done with no further preparation to the root canal. All samples were inserted in acrylic resin blocks and fracture loading was applied by a universal testing machine. One-way ANOVA was used to assess differences between groups, and the significance level was set at p value<0.05.

RESULTS: The control group significantly demonstrated higher fracture resistance than the testing groups (PTU, PTG, and WOG). There was no significant difference among the fracture resistance of the three testing groups (PTU, PTG, and WOG).

CONCLUSION: Both rotary file systems (PTU, PTG) showed higher fracture resistance values, with minimal differences between them, when compared to the reciprocating file system (WOG), although the difference was statistically non-significant.

KEYWORDS: Endodontically treated teeth, Fracture resistance, Protaper Ultimate, Protaper Gold, Wave One Gold.

RUNNING TITLE: Fracture resistance following rotary preparations of mandibular molars.

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INTRODUCTION

In endodontic treatment, the root canal system is shaped to remove bacteria and remaining pulp tissue and to create space for irrigation and obturation (1).
During root canal preparation procedures, micro-cracks or craze lines might develop and propagate due to the repetition of stress applied by the occlusal forces, which can lead to fractures in root canal-treated teeth. Therefore, maintaining more tooth structure enhances the teeth' resistance to fracture and preserves their structural integrity (2).

In the past years, clinicians and manufacturers attempted to develop new techniques that improve nickel-titanium (NiTi) endodontic instrument design as well as root canal shaping and maintaining the tooth structural integrity (3).

These developments showed three different ways: altering the instrument design, heat treatments of the alloy, and the use of different kinds of motions (4).

Protaper Ultimate (PTU) is the recent rotary file system of the Protaper group, where heat treatment creates instruments with various mechanical characteristics using three alloys with different heat treatments: M-wire (Slider), Gold-wire (Shaper and three finishers) and Blue heat-treated wire (auxiliary files) to balance between strength and flexibility (5-7).
Protaper Gold (PTG) is a rotary system in which the file has similar geometries as the Protaper Universal system. However, once the alloy is ground, it undergoes a thermo-mechanical treatment (Gold Wire) that improves its mechanical behavior (5, 8).

Wave-One Gold (WOG), is a single reciprocating file with heat-treated NiTi alloy and parallelogram cross-section cutting in an anti-clockwise motion. This file system has a progressively decreasing taper designed to preserve coronal dentin (9, 10).

The goal of this study was to examine the resistance of permanent lower molars to fracture after mesial canals were prepared by PTU, PTG and WOG.

The null hypothesis of this study was that no significant difference would be found regarding the fracture resistance of permanent mandibular molars prepared by the three studied file systems (PTU, PTG, and WOG) would be found.

MATERIALS AND METHODS

The study was accepted by the ethical committee at the Faculty of Dentistry, Alexandria University, Egypt (IRB No. 001056 – IORG 0008839). The sample size calculation was based on a previous study that evaluated the fracture resistance of Protaper Universal, Protaper Next, and Protaper Gold (11). The sample size was estimated to be nine teeth per group but increased to 11 teeth to compensate for the processing errors. Total sample = Number per group x Number of groups = 11 x 4 = 44 teeth.

The study was conducted on 44 extracted human permanent lower molars with two separate (non-fused) roots .Teeth were extracted due to periodontal disease or orthodontic reasons. Teeth were collected from the outpatient clinic of the Oral and Maxillofacial Surgery Department, Faculty of Dentistry, Alexandria University.

Teeth were then inspected using a stereomicroscope (Olympus, Japan) under x10 magnification to eliminate the probability of any defects or pre-existing cracks (11). Periapical radiograph was performed in buccal and proximal views to include teeth with intact roots, mesial canals with Type IV Vertucci's classification and canal curvature that ranges between (10° to 20°) according to Schneider's technique (12).

Standardization is ensured by selecting teeth with 22 to 23 mm total tooth length in the study. The cusps of the teeth was then flattened with a diamond stone to achieve a final tooth length of 17 mm. Teeth were then preserved in saline until the time of use.

Conventional access cavity was performed in all teeth using a high-speed round bur and an endo-Z bur under copious water cooling.

A manual glide path was prepared by size 10, and 15 k-files in all specimens in both MB and ML canals of the three experimental groups.

The specimens were numbered and allocated into a control and three testing groups (n=11). Group I: eleven teeth where both mesial canals; mesiobuccal (MB) and mesio-lingual (ML) canals were shaped by using PTU files till F2 (25/08). Group II: eleven teeth where mesial canals (MB and ML) were shaped by using PTG files till F2 (25/08). Group III: eleven teeth where mesial canals (MB and ML) were shaped by using WOG files till Primary file (25/07). Group IV: Control group; eleven teeth with access cavities only and no further root canal preparation.

For group I, the PTU rotary system (Dentsply-Maillefer, Switzerland) was used to prepare both mesial canals (MB and ML). PTU SX (20/03) was used in the canal's coronal part. The PTU Slider (16/02) and the PTU Shaper (20/04) were then used to the canal's full working length. Then, the PTU finishers were used: F1 (20/07) followed by F2 (25/08) as the final file in the canal preparation. The speed and torque for all PTU files were adjusted at 400 rpm and 4 Ncm as recommended by the manufacturer.

For group II, the PTG rotary system (Dentsply-Maillefer, Switzerland) was used to prepare both mesial canals (MB and ML). Protaper Gold SX (19/04) was used in the canal's coronal part. PTG Shapers S1 (18/02) and S2 (20/04) were implemented in the canal to its full working length. The PTG Finishers F1 (20/07) and F2 (25/08) were used as the final files in the canal preparation. The speed for all the PTG files was adjusted at 300 rpm while the torque was adjusted for each file as follows: SX and S1 file with torque 5 Ncm, while S2 and F1 file with torque 1.5 Ncm, and F2 file with torque 3 Ncm as recommended by the manufacturer.

For group III, the WOG reciprocating system (Dentsply-Maillefer, Switzerland) was used to prepare both mesial canals (MB and ML). WOG Proglider (15/02) was used to the full working length of the canal. The WOG primary file (25/07) was then used as the final file in the canal preparation. WOG files were used with the X-Smart Plus motor (Dentsply Maillefer, Ballaigues, Switzerland) as recommended by the manufacturer.

For the control group (group IV), a conventional access cavity was done in each specimen with no further root canal preparation.

For all groups, X-Smart plus motor (Dentsply-Maillefer, Switzerland) was utilized in the instrumentation procedure. EDTA gel (MD chelcream-Meta) served as a chelating agent during the instrumentation in addition to 2ml of 2.5% (NaOCL) (Chlorox, Egyptian industry, ARE) as an irrigating solution using a 30-gauge side vented needle after each file change during the instrumentation procedure. For the smear layer removal, 5 ml of 17% EDTA for one minute, then 5 ml of 2.5% sodium hypochlorite was used as a final flush in the irrigation procedure (10, 13). All the specimens were kept moist throughout the instrumentation process and were then preserved in saline after completing the instrumentation procedure.

The canals were not obturated prior to fracture resistance testing to exclude the forces applied by the spreaders during lateral condensation and the increased removal of dentine needed to ease the insertion of pluggers during vertical condensation (14, 15).

Fracture Resistance Testing

Teeth were inserted into a mold made of acrylic resin (Acrostone; Dent Product, Egypt) up to the cement-enamel junction (CEJ). Teeth were exposed to vertical compressive force by a round-end ball of 2 mm diameter placed at the centre between the orifices of the mesial canals using a universal testing machine (5ST, Tinuis Olsen, England) at a crosshead speed of 1 mm/ min until tooth fracture occurred. The load at fracture was then recorded in Newton's (N) (11, 13). Figure (1, 2)

Statistical analysis

Data were analysed by IBM SPSS version 23, Armonk, NY, USA. The normality of fracture resistance was evaluated by the Shapiro-Wilk test and Q-Q plots. Normal distribution was confirmed; thus, data was presented using mean, standard deviation, median, minimum and maximum values. One-way ANOVA assessed the differences between groups, followed by Tukey's post hoc test with Bonferroni correction. The percentage change in fracture resistance compared to the control group was analysed by Kruskal-Wallis test, followed by Dunn's post hoc test with Bonferroni correction. All tests were two-tailed, and the significance level was set at p value<0.05.

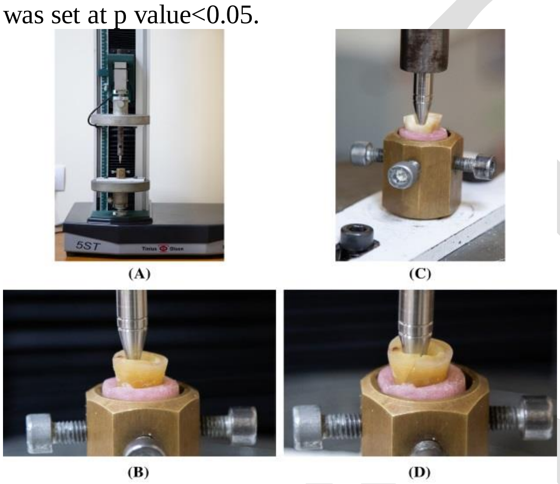

Figure (1): (A) Universal testing machine, **(B)** Vertical compressive force applied at the center of the mesial canals orifices **(C, D)** Representative specimens showing fracture lines generated in the teeth.

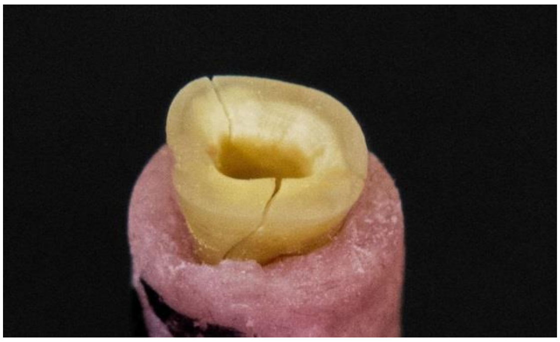

Figure (2): Representative specimens showing fracture lines generated in the tooth after compressive loading.

RESULTS

The results of the study showed a significant difference between the control (Group IV) and all testing groups. Group IV exhibited significantly higher fracture resistance in comparison with Group I (Protaper Ultimate) with a mean difference of -336.27 (95% CI: -455.84, -216.70; $p < 0.001$), Group II (Protaper Gold) with a mean difference of -345.0 (95% CI: -464.57, -225.42; $p < 0.001$), and Group III (Wave One Gold) with a mean difference of -419.45 (95% CI: -539.03, -299.88; $p < 0.001$). Figure (3)

The difference among the experimental groups was not statistically significant. Group I and Group II showed a negligible mean difference of 8.73 (95% CI: -110.85, 128.30; $p = 0.997$), while Group I and Group III had a mean difference of 83.18 (95% CI: -36.39, 202.76; $p = 0.259$), and Group II and Group III exhibited a mean difference of 74.45 (95% CI: -45.12, 194.03; $p = 0.353$). Table (1)

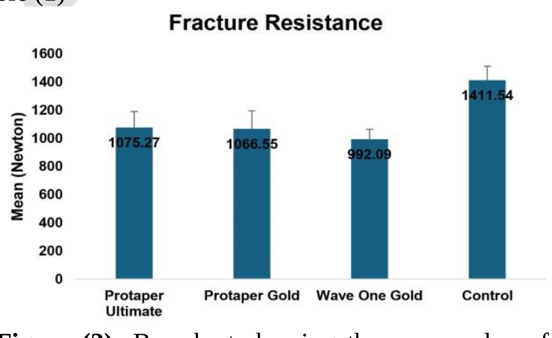

Figure (3): Bar chart showing the mean value of the fracture resistance of the study groups and the control group.

Table (1): Pairwise comparisons between groups regarding fracture resistance

Groups	Compared to	Mean Diff	95% CI	*p* value[ǂ]
Group I (Protaper Ultimate)	Group II (Protaper Gold)	8.73	-110.85, 128.30	0.997
	Group III (Wave One Gold)	83.18	-36.39, 202.76	0.259
	Group IV (Control)	-336.27	-455.84, -216.70	<0.001*
Group II (Protaper Gold)	Group III (Wave One Gold)	74.45	-45.12, 194.03	0.353
	Group IV (Control)	-345.0	-464.57, -225.42	<0.001*
Group III (Wave One Gold)	Group IV (Control)	-419.45	-539.03, -299.88	<0.001*

*Statistically significant difference at p value<0.05, CI: Confidence Interval, ǂ: Tukey's post hoc test

DISCUSSION

Vertical root fracture (VRF) is a complicated clinical outcome that arises during root canal shaping of endodontically treated teeth. The incidence of VRFs in root filled teeth is significantly greater than in teeth with vital pulps. This is attributed to the of loss of structural integrity, together with pre-existing fractures and the biochemical changes due to loss of vitality in terms of depletion of root dentin from its organic components as well as dehydration as a result of reduced free water content. (16)

During root canal instrumentation, the canal is prepared by the interaction between dentin walls and the instrument. These contacts produce transient stress concentrated in dentin. Increased stress may create dentinal defects that occur anywhere in the coronal or apical regoins. These cracks may develop into areas of elevated stress concentration and propagate gradually to the surfaces of the root canal. Micro-cracks may propagate during increased occlusal load during mastication or through parafunctional habits and can develop a VRF. (17, 18).

Various factors can contribute to crack formation during instrumentation procedure such as the taper , cross-section and metalurgic characteristics of the files, and the motion utilised to instrument the canals.(19)

Root canal shaping should be performed in a conservative manner so that the tooth structural integrity is preserved which is the main concern of the new concept of endodontics i.e. minimally invasive endodontics (MIE). Instruments with smaller taper may reduce the clinical errors that occur during shaping but it also might compromise the irrigation process of the canal space. However, larger tapers may lead to strip perforations and predispose to VRF (20).

The current study compared the impact of three different rotary systems; Protaper Ultimate files (PTU), ProTaper Gold files (PTG), and Wave One Gold (WOG) on the resistance of permanent lower molars to fracture after mesial canals preparation using Universal testing machine.

In this in-vitro study, mandibular molar teeth were the teeth of choice as they are the first to erupt and have the highest prevalence for endodontic treatment about (42%) as mentioned in a study by Jain and Anjaneyulu (2022) (21). Also, they are more prone to fracture as they withstand a lot of stresses during mastication, so they have the lowest survival rate among all dentition (22).

In addition, mesial root canals were chosen as the study groups and were instrumented as they have narrow diameters and are the most susceptible roots to VRF. Also, the thin distal wall of the mesial root which is caused by the mandibular molars' furcal concavity, especially in the coronal third area, referred to as the danger zone, makes instrumentation procedures more challenging and may lead to endodontic failures (23, 24).

Standardizing the specimens is important in testing the fracture resistance involving natural teeth, as the resistance of root canal-treated teeth to fracture is significantly linked to the remaining sound tooth structure (25). To provide standardized experimental conditions, the teeth cusps were flattened using a diamond stone to achieve a final length of 17 mm for each tooth. Several previous studies also utilized standardized preparation methods, including teeth storage in saline to prevent dehydration, flattening the cusps to achieve a consistent tooth length, and dividing specimens into groups based on different rotary file systems (26).

In the present study, during root canal instrumentation, 2 ml of 2.5% sodium hypochlorite (NaOCl) was used with a 30-gauge side-vented needle. The canals were irrigated with 5 ml of 17% EDTA for one minute and then 5 ml of 2.5% NaOCl as the final irrigation protocol. This irrigation method was in agreement with Cassimiro et al. (2018) (10).

Teeth were inserted in acrylic resin blocks without periodontal simulation in accordance with Capar et al. (2014) (27). Also Nawafleh et al. (2020) (28) claimed that the load of fracture between groups with and without PDL simulation did not significantly differ.

The universal testing machine has been utilised in the present study to examin the resistance of fracture of teeth prepared by different systems as it is the most simple and widely used technique to investigate tooth strength (10, 29).

In this study, the selected apical preparation size used in all file systems was size 25. De Gregorio et al. (2012) (30) stated that greater apical size preparation enhances the effect of disinfection and debris removal in the root canal. However, using large instruments in root canal shaping is associated with a higher risk of crack formation or pre-existing crack propagation as explained by Capar et al. (2014) (27). Another study by Akhlaghi et al. (2014) stated that apical preparation size 25 did not significantly decrease bacteria when compared to greater apical preparation sizes (31).

The results of this study revealed that the control group had the highest values of fracture resistance compared to all the experimental groups. While no significant difference was found between the values of fracture resistance of the three experimental groups (PTU, PTG, and WOG). This was in agreement with previous studies (29, 32) that suggested that the amount of remaining dentin wall was related directly to the vulnerability of teeth to fracture.

The Protaper Gold system has unique design and metallurgical properties which may contribute to the preservation of root dentin integrity and, consequently, higher values of fracture resistance than the WOG group even though the fracture resistance values between them are non-significant (33). PTG instruments are acknowledged for the 2-stage transformation behaviour (Austenite [A]-R phase-Martensite [M]) and the high Austenite Finish (Af) temperatures which enhance its mechanical properties as stated by Devi et al. (2021) (34).

The reason for the non-significant results between the PTU and PTG groups could be because both systems share some common features including the heat treatment of their alloy as the shaper and finishers of the PTU system is made of gold wire as the PTG system which enhance their flexibility and decrease internal stress that may lead to microcracks formation during instrumentation (5, 9). This was also in agreement with Devi et al. (2021) (34).

The fracture resistance values of PTU were slightly higher than PTG but not significant which can be related to the use of higher speed of rotation with PTU instruments, which was 400 rpm while for PTG instruments, the speed used was 300 rpm, this was in accordance with Peters et al. (2014) (35) who stated that higher speed of rotation was correlated with higher cutting efficiency and increased cutting efficiency could be related to decreased formation of crack as proposed by Capar et al. (2014) (27).

The lower values of fracture resistance observed in the WOG group than in the PTU and PTG group although non-significant also could be related to the design and kinematics of the Wave One Gold system. The WOG files are characterized by a single-file, reciprocating motion, which may result in more aggressive dentin removal and increased stress on the root structure during instrumentation (36). This was in agreement with Godiny et al. 2021 (37) who supported that the use of a multi-file rotary system had higher fracture resistance levels with less micro-cracks compared to a single-file rotary system.

Another reason is that in the WOG system, the WOG Proglider was used in the mesial canals without coronal pre-flaring which may increase the screw in stress and induce dentinal micro-crack formation. This was supported by Kwak et al. (2022) (38) and Oh et al. (2022) (39)

One limitation of this study, the fracture resistance test was performed just after the root canals were shaped. In clinical conditions, tooth fracture is a process that occurs gradually due to the crack propagation over time (40). It is recommended to perform an aging process after preparing the teeth to accurately simulate the clinical conditions before the fracture resistance testing mechanical aging could not be done in this study.

Another limitation is that the force applied from the universal testing machine in this study was with constant speed and in a static direction. This was in contrast to the clinical condition where dynamic stresses were produced under functional loads, which vary in magnitude, intensity, and direction (29). Additionally, the pattern and location of the VRF were not considered in this study.

Within the limitations of the study, it is recommended that future studies need to be conducted with obturated teeth and without crown removal to simulate the oral clinical conditions. Further studies may be conducted using dynamic loading instead of static loading to evaluate the fracture resistance of ETT. Specimens used in future research may be aged before testing as this can give a better idea about the survival of ETT. More studies are needed to compare the fracture resistance of teeth after instrumentation with different heat-treated rotary files.

Based on our findings, the null hypothesis of this study has been accepted.

CONCLUSION

Both rotary file systems (PTU, PTG) showed higher fracture resistance values, with minimal differences between them, when compared to the reciprocating file system (WOG), although the difference was statistically non-significant.

CONFLICT OF INTEREST
The authors declare that they have no conflicts of interest.
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The authors received no specific funding for this work.

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