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# EVALUATION OF THE DEFECTS IN RECIPROCATING AND ROTATING NICKEL-TITANIUM FILES USED AS A SINGLE FILE TO PREPARE MOLAR TEETH

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## ABSTRACT

**Aim:** To evaluate the defects in five nickel-titanium instruments activated by reciprocating and rotating motions and used as a single file in molar teeth.

**Materials and methods:** Twenty files size 25 from five brands [WaveOne (WO); Reciproc (RC); OneShape (OS); ProTaper Next (PTN); and ProTaper Universal (PTU)] were tested as a single file to prepare mandibular molars teeth. Thereafter, the five brands were redistributed into two tested groups, rotating and reciprocating groups. The time required for instrumentation was recorded. New and used instruments were examined under a scanning electron microscope for defects, deformations and fractures. One-way ANOVA and Kruskal Wallis were used for data analysis.

**Results:** The RC and PTN were significantly faster than WO and OS ($P<0.05$), while PTU required significantly the longest time ($P<0.05$). The fracture incidence was zero % in the PTN and OS, and 5% in the WO and RC, while it was (10 %) in the PTU. The fractographic analysis revealed cyclic failure of PTU and WO and torsional failure in RC. OS had (15%) percentage of deformation, WO (5%), while it was zero% in the PTN, RC and PTU. Reciprocating motion was significantly faster than rotating motion ($P<0.05$) without significant difference in deformation incidence ($P>0.05$).

**Conclusions:** The ProTaper Next, Reciproc and WaveOne files, were less vulnerable to fracture and deformation than ProTaper Universal and OneShape files when used as a single file to prepare molar teeth. The ProTaper Next was faster and more resistant to failure than other groups. In addition, files used with the reciprocating motion were faster to finish molar teeth than rotating motion without a significant effect on the defect incidence.

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## INTRODUCTION

The preparation of curved root canals is a challenging process where unexpected instrument fracture may occur due to stresses. In narrow curved canals, the rotary instruments are subjected to cyclic stresses due to multiple tensions and compressions, as well as torsional stresses. In the mean time, the

exposure to cyclic fatigue has a significant effect on the torsional fracture resistance [1]. In the single file technique, the file became weaker and more liable to fatigue at different lengths from the tip according to the magnitude and distribution of the stresses inside the root canal [2]. The instrument fatigue is reflected as deformations or even instrument fracture. The NiTi instruments may fracture suddenly without visible signs of deformation and cause a major problem as separated instruments. Therefore, manufacturers have focused on increasing their resistance to fracturing through surface treatments [3- 4] improved designs, different rotational motions and thermal treatments [5]. So, recent Nickel-titanium (NiTi) rotary instruments are more efficient to prepare curved root canals of molar teeth without clinically critical error [6]. Instruments manufactured from thermally treated NiTi wires have higher strength, flexibility and wear resistance than instruments made of regular NiTi [7]. An example of thermally treated NiTi instruments is m-wires that have increased flexibility and resistance to fatigue [8]. Reciproc, WaveOne and ProTaper Next instruments are made of m-wire, which have high performance in root canal preparation with a lower incidence of fractures [9- 10].

Yared in 2008[11] introduced the concept of a single file technique. Using a single file in a reciprocating motion to prepare root canals has a lower incidence of cyclic and torsional fatigue and prepared the root canals with the same shaping outcomes as full sequence systems in less time [12-13]. Although the concept of a single file system was first linked to reciprocation motion instruments, such as Reciproc and WaveOne, other rotational systems have become available on the market, such as OneShape.

For the single file technique, whether for instruments with reciprocal or continuous rotation, the aim of manufacturers is to enhance the instrument's performance inside the root canal and to decrease the incidence of fracture and deformation as a sign of instrument failure. Although several previous studies evaluated the deformation of different file systems using the single file technique [14-15], no study has compared five different reciprocating and continuous rotating systems in molar teeth in one study.

The aim of the present study was to compare the incidence of deformation and fracture and the time of preparation of molar teeth for five rotatory systems (Reciproc, WaveOne, OneShape, ProTaper Universal and ProTaper Next) utilized as a single file and activated by rotating or reciprocating motion.

The null hypothesis was that there would be no difference in the time and incidence of deformation between the NiTi rotary files activated by rotating or reciprocating motion

## MATERIALS AND METHODS

### Selection and grouping of instruments

The instruments tested for this study were F2 ProTaper Universal (PTU), Primary WaveOne (WO), X2 ProTaper Next (PTN) (Dentsply Maillefer, Ballaigues, Switzerland), R25 Reciproc (RC) (VDW GmbH, Munich, Germany) and #25 OneShape (OS) (Micro-Mega, Besançon Cedex, France). Twenty files from each group with size 25 and 25 mm in length represent a tested group. To compare the incidence of defects and time taken between the rotating and reciprocating motions, the five tested rotary files were redistributed into another two groups according to the type of motion utilized to activate them. The first group is reciprocating group, which include RC and WO (40 files), while the second group is rotating group include PTU, PTN and OS (60 files).

**Teeth selection**

One hundred mandibular molars with 200 separate narrow mesial root canals and 100 distal canals were selected from the pool of teeth. All selected molars have narrow canals with curvatures ranging from 15°-38°, according to Schneider's method (Schneider[16]) and 5-6 mm radius based on the previous technique of teeth selection [(17)]. The specimens were stored in a 0.5% Chloramine-T solution (Sigma-Aldrich, St Louis, MO) until use. Specimens were equally distributed into 5 groups (n=20) according to their curvature degree and tooth type.

**Root canal instrumentation**

One instrument was assigned to prepare one molar. Access to the pulp chamber was performed conventionally. Root canal patency was confirmed by inserting a size #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) through the apical foramen. The size of the apical diameter was measured after coronal flaring with Gates Glidden size #2 (Sybron Endo). The glide path was established by a reconnaissance size #10 K-file through the working length, 1 mm short of the apical foramen. Then, all mesial canals were prepared to size # 15 K- file. The experienced endodontic consultant performed all of the steps of the root canal preparation. One instrument from each system was employed to finish the instrumentation of one molar following the manufacturer's instructions regarding the recommended speed and torque. X-Smart Plus motor (Dentsply Maillefer, Ballaigues, Switzerland) was used to activate all the instruments with a specific preset program for each brand. For the OS group, the PTN program was used at 400rpm speed. The instruments were used in an incremental pecking motion until they reached the working length. The instruments were cleaned, and the canal was irrigated with 2 ml of 2.5% NaOCl after every 3 pecking motions. All of the instruments were ultrasonically cleaned in a glass baker containing absolute alcohol for 5 minutes. The time needed for each instrument to prepare each tooth (including the time required for the irrigation procedures) was recorded using a digital stopwatch.

**Scanning electron microscope examination**

Five new files were randomly selected from each group and were examined using a scanning electron microscope (SEM) (Quanta 250 FEG, FEI, Eindhoven, Netherlands) for manufacturing defects, surface microstructures and machining grooves. The metallurgical microscope (Metallurgical microscope MX7520, MIJI TECHNO, Japan) was used to examine instruments after use to detect deformation (unwinding; rewinding and distortion) and fracture. Subsequently, the SEM was used to examine the defected and fractured instruments at magnification of 200 to 1500x. The fractured segments were exposed to fractographic examination from the longitudinal perspective and fractured faces for the presence of dimples, fatigue striations circular abrasions, crack initiations and propagation sites. The mode of fracture was classified as cyclic or torsional fatigue.

**Data statistical analysis**

The One-way ANOVA was utilized to compare the time of canal preparation taken by each file in the five tested rotary instruments. The independent t-test was used to compare between the total time of canal preparation in rotating and reciprocating groups, while Binomial test was used for testing the proportions of unaffected percentage of instruments in rotating and reciprocating groups. SPSS version 16.0 was utilized for data analysis (SPSS Inc., Chicago, IL, USA), and the significance level was set at 5%.

## RESULTS

### Time for preparation

The results of data analysis for the tested groups are presented in Tables 1 and 2.

There was no significant difference between the RC and PTN ($p>0.05$), and both were significantly faster than the WO and OS ($P<0.05$). The PTU required significantly more time compared to all groups ($P<0.05$). When comparing the reciprocating and rotating groups, reciprocating group was significantly faster than rotating group ($P<0.05$).

### Fracture and deformation incidence

The fracture incidence was zero % in the PTN and OS groups and 5% in the WO and RC groups, while the PTU had (10%) fracture incidence. All of the file separations occurred in the apical part of the canals. The OS had the highest rates of deformation (15%) without fracture followed by the WO (5%), while the PTN, RC and PTU had no deformations. No significance difference was found between the reciprocating and rotating groups regarding the fracture and deformation incidence ($P>0.05$).

### SEM and Fractographic analysis

The SEM photographs of new instruments from each file brand are displayed in Figure 1. Machining grooves were obvious on the surface of all of the brands except OneShape. The grooves were perpendicular to the long axes of the PTU, while the grooves were perpendicular and oblique, with machining defects in the W. In the RC and PTN, deep machining grooves with crack-like defects were noticed near the cutting edge. The PTN had the roughest surface among all of the groups. The OS instruments had a smooth electropolished surface. However, metal protrusions and multiple surface pitting were noticed.

TABLE (1) Time of preparation (mean± standard deviation), % of fractured and deformed instruments for each rotary system

| Rotary System | Time/Sec | Fracture (%) | | Deformation(%) | Motion | Wire |
|---|---|---|---|---|---|---|
| | | Cyclic | Torsional | | | |
| ProTaper Universal | 693.65±20.19 | 10% | 0 | 0 | Rotating | Ni-Ti |
| OneShape | 523.40±14.85 | 0 | 0 | 3 | | |
| ProTaper Next | 330.45±10.97 | 0 | 0 | 0 | | M-wire |
| WaveOne | 407.50±5.67 | 5% | 0 | 5% | Reciprocating | |
| Reciproc | 321.05±8.04 | 0 | 5% | 0 | | |

TABLE (2) Time of preparation (mean± standard deviation), number of fractured and deformed instruments for rotating and reciprocating motion groups.

| Parameter | Rotating motion | Reciprocating motion |
|---|---|---|
| Number of files | 60 | 40 |
| Time/Sec | 515.83±150.43$^{a}$ | 364.28±44.31$^{b}$ |
| Fractured | 2 | 2 |
| Deformed | 3 | 1 |
| Total unaffected percentage | 0.92 | 0.93 |

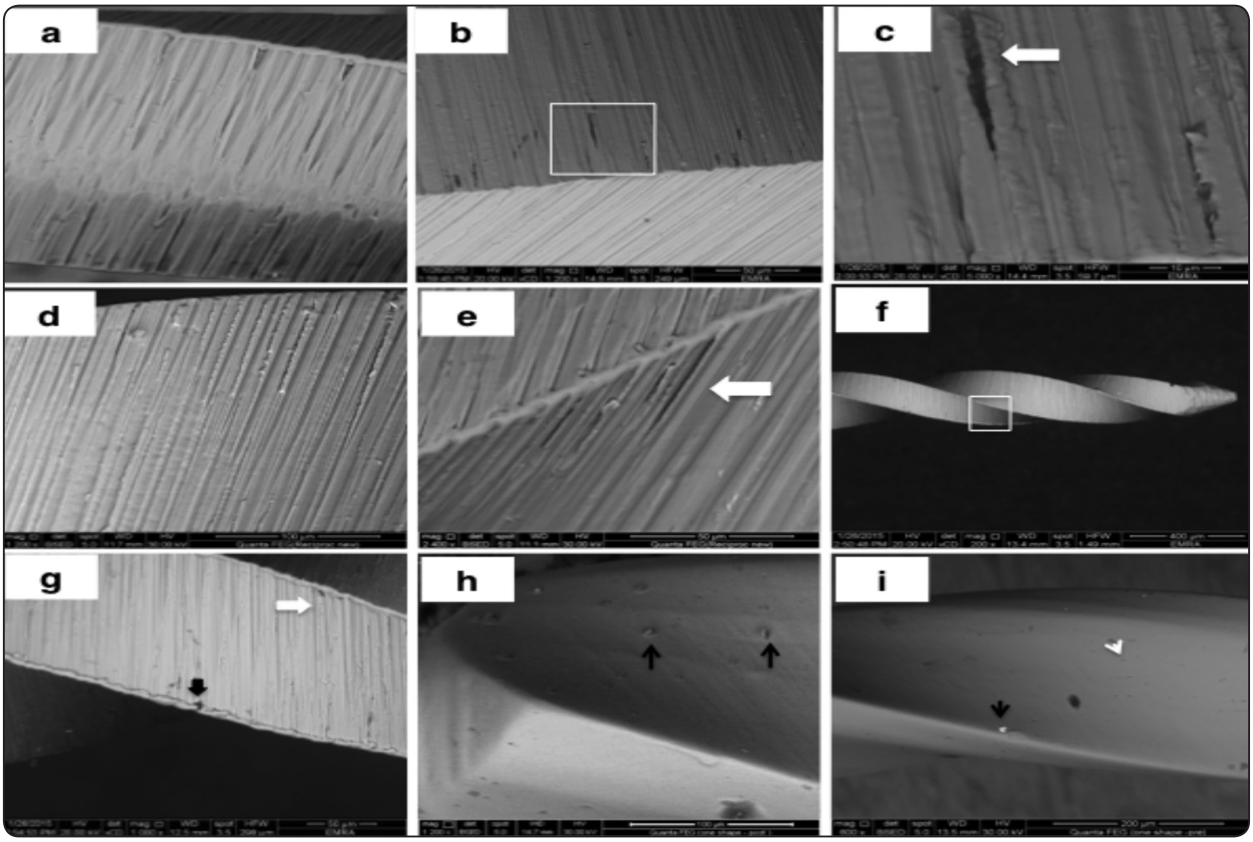


Fig. (1) Scanning electron micrograph of the lateral view of the new instruments showing deep machining grooves with microcracks and defects on the surface of all of the brands except OneShape (white arrow). (a) ProTaper Universal (original magnification, x600). (b) WaveOne (original magnification, x1200). (c) A high magnification of view B (original magnification, x5000). (d) Reciproc (original magnification, x1200). (e) A high magnification of view D (original magnification, x2400). (f) ProTaper Next (original magnification, x200). (g) A high magnification of the selected area in view F showing the rough surface and metal rollover at the cutting edge (black arrow), (original magnification, x1000). (h) OneShape file with a smooth surface and metal protrusions near the tip (original magnification, x1200). (i) Gold metal flashes (black arrow) and surface pitting (white arrow) on the surface of OneShape file (original magnification, x600).

The deformed and fractured instruments showed multiple microcracks that started at the cutting edge and propagated along the machining grooves. In contrast, the OS had tortuous microcracks that faded shortly and were accompanied with surface pitting. Instrument unwinding and rewinding and distortion of the machining grooves were apparent in the WO, and OS. Metal rollover was observed in the cutting edge of the WO and the PTN (Fig. 2).

Microcracks were observed near the fracture site in the majority of fractured specimens of all brands. The magnitude and number of cracks increased near the fracture site. The length of the separated segment in all of the fractured instruments ranged from 4 to 5 mm. Both PTU and WO revealed signs of ductile fractures due to cyclic failure. The WO had a multilevel fracture patterns and abrasion marks due to the friction of surfaces after the fracture. Conversely, the RC instrument displayed typical torsional failure with plastic deformation near the fracture site and distortion of machining grooves (Fig. 3).

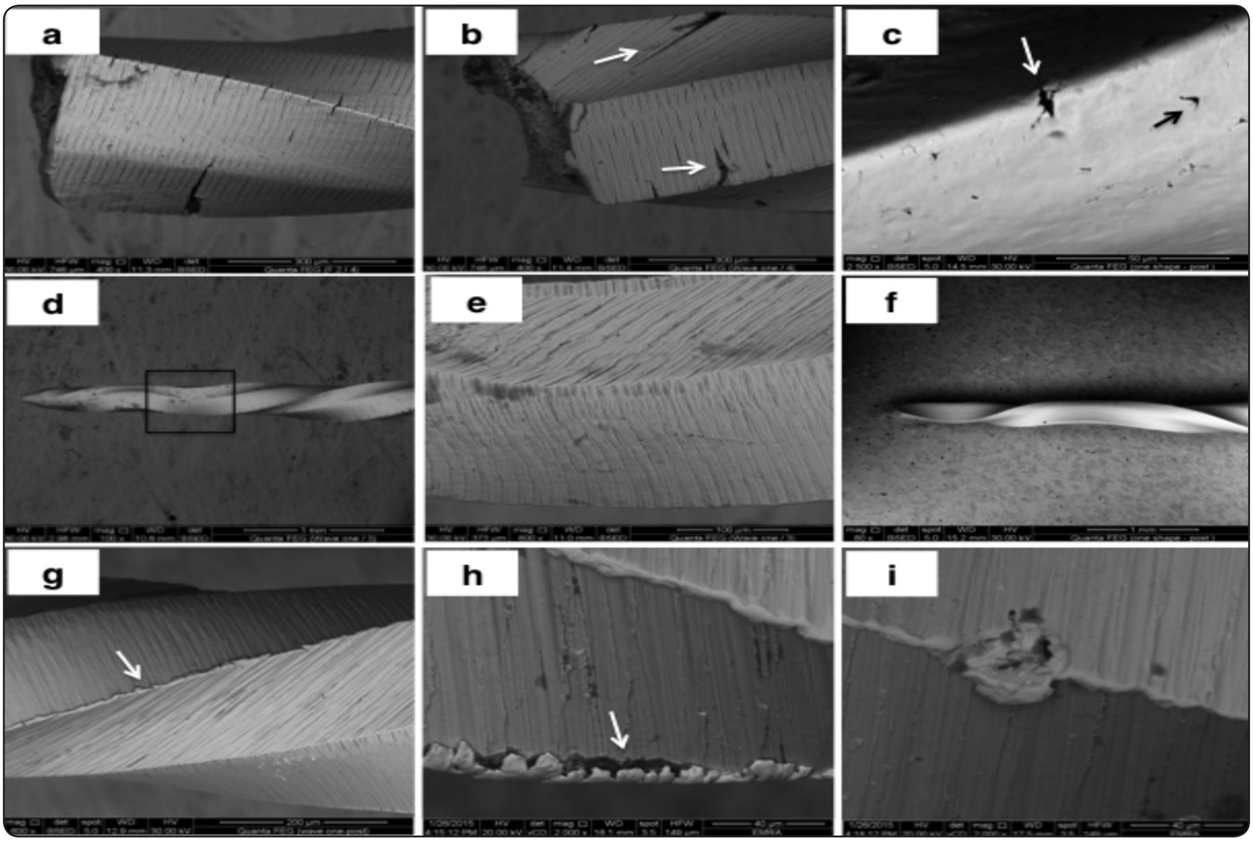


Fig. (2) Scanning electron micrograph of the lateral view of the used instruments. (a) ProTaper had many cracks near the fracture site that started at the cutting edge and propagated through the machining grooves (original magnification, x400). (b) WaveOne had microcrack propagation in two directions (original magnification, x400). (c) OneShape had tortious microcracks at the cutting edge (white arrow) and surface pitting (black arrow) (original magnification, x2500). (d) WaveOne had unwinding (original magnification, x100). (e) Reciproc had distortion along the machining grooves during torsional failure (original magnification, x800). (f) OneShape had unwinding and rewinding (original magnification, x800). (g) WaveOne had metal rollover at the cutting edge(original magnification, x600). (h) ProTaper Next had metal rollover that fractured in some areas with debris accumulation despite ultrasonic cleaning (arrow) (original magnification, x2000). (i) Destruction and separation of some areas at the cutting edge (original magnification, x2000).

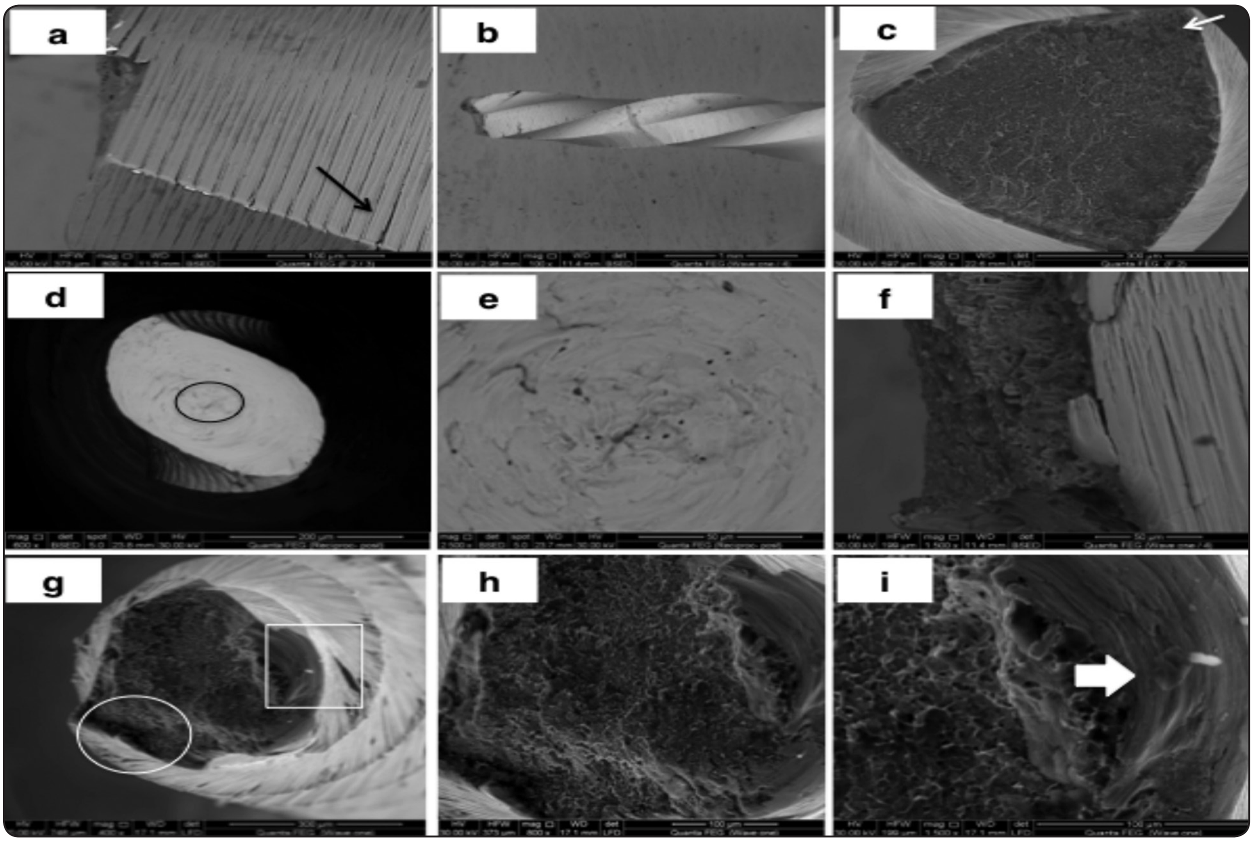


Fig. (3) Scanning electron micrograph of the fractured instruments. (a) ProTaper had deep extensions of the microcracks (original magnification, x800). (b) WaveOne had an increased magnitude and numbers of microcracks near the fracture site (original magnification, x100). (c) ProTaper fracture surface had typical cyclic failure with crack origin (white arrow) (original magnification, x500). (d) Reciproc had typical torsional failure, including circular abrasion marks (original magnification, x600). (e) A high magnification of the selected area in view d showing the central fibrous dimple and many surface voids (original magnification, x2500). (f) WaveOne had two levels of fracture patterns (original magnification, x1500). (g) A cross section of the fractured WaveOne (original magnification, x400). (h) A high magnification of the circled area in view G showing a ductile fracture pattern due to cyclic failure (original magnification, x800). (i) A magnification of the rectangular area in view G showing abrasion marks due to friction of the surface of the segments with different levels of fracturing (arrow) (original magnification, x1500).

## DISCUSSION

The aim of the present study aimed to evaluate the faster instrument with lower instrument fatigue in a condition more similar to the clinical situation. Many studies have evaluated the fracture incidence of rotary files. Most of them were laboratory studies that could not be extrapolated to clinical situations [2, 4,18]. Others were retrospective studies that examined failed files, which were collected from different clinicians and ignored many important factors related to their clinical use [14, 19]. Few studies evaluated the behavior of files in natural teeth, and even fewer studies evaluated the concept of single file technique using different files [2, 20]. Therefore, this study examined the deformation of reciprocating and rotating files during the preparation of molar teeth when using the single file technique.

Multiple and complex factors are responsible for instrument failure. Some factors are related to the instrument design, canal anatomy or operator proficiency [21,22, 23].

In the present study, maximum effort was undertaken to simulate a clinical situation with little variation. The specimens were categorized and equally distributed between the instrument groups, all of the instruments were used once to decrease the risk of fracturing and one experienced operator performed all of the steps (24, 25). Thus, the main variable affecting the results was the type of instrument.

Several mechanical factors may affect the behavior of instrument, including the type of motion, flexibility, cutting efficiency and surface finish. The type of metal used to fabricate the instrument and the cross section of the instrument further control flexibility (26 ,27,28). These factors are not independent; rather, they interact to form the specific behavior of the file. However, some factors may have more significant effects than others (15).

The results of the present study indicated that the RC and PTN files were significantly faster than the other files so, the null hypothesis was rejected. Reciproc has a high cutting ability that is enhanced by the reciprocating motion and the positive rake angle of the S-shaped cross section, in addition to the high flexibility of the M-wire (18). Similarly, PTN is made of M-wire and has a special cutting behavior because alternative points touch the walls of the canals during preparation (9). Altogether, these features enhanced the advancement of PTN into the canals, resulting in fast preparation times without deformation or fracture which came in agreement with Elnaghy & Elsaka (28) who found that PTN has an improvement in resistance to torsional stresses and wear. In the present study, PTN was resistant to deformation and fracture in spite of being used as a single file, which did not follow the manufacture's instructions and subject it to excessive amount of stresses. This resistance to deformation and fracture was attributed to the m-wire, and its swaggreing motion due to its off centered rectangular cross section that enable the instrument to proceed inside the root canal with less resistance (8).

In the present study, the WO and OS files were slower than RC and PTN and were faster than PTU. The WO file has the advantage of reciprocating motion; however, it has a lower cutting efficiency and flexibility than RC due to the convex triangle cross section (26). On the other hand, the OS file has an electropolished surface, which may have retarded its cutting ability in spite of having small cross section (26). In the meantime, PTU was the slowest file of all instruments and this was in accordance with the previous studies (29).

In the present study, defects and deep machining grooves, as well as surface pitting, were observed on the surface of new instruments. In 2015, Caballero *et al.* (30) reported the same observations upon examining the new RC instruments (Caballero *et al.*[30]). These machining defects act as potential crack initiators that subsequently propagate following the machining grooves and lead to failure of the RC, WO and PTU files (3, 31).

Using a single file to prepare a molar tooth subjects the file to torsional and cyclic stresses simultaneously; however, more than one type of failure can be identified on failed instruments (15). Deformation was evident on the OS instruments with no fracture incidence, which could be related to the file flexibility due to small cross section (32) and to the electropolished surface that retarded crack initiation resulting in resistance to fracturing (33).

One RC file experienced a torsion fracture as a direct result of its high flexibility, which was enhanced by its reciprocating motion and high cutting efficiency. These features subject the file to higher torsional stresses during rapid advancement in the canal (10). Plotino *et al.* (34) in 2015 reported that RC as a single file has a very low incidence of fracture and deformation after clinical which came in agreement with the results of the present study but differ in the percentage of fracture due to the different type of teeth prepared in Poltino study as they used all kinds of teeth including anterior teeth.

Interestingly, one WO file had a plastic deformation with two level fractures while the other showed signs of cyclic failure without deformation. This mixed behavior of the WO file may be due to resistance of m-wire and multiple crack origin due reciprocating motion with large cross section [20]. The results of the present study came in agreement with the results of Shen *et al.* [35], who found that the WO files failed after clinical use due to shear stress. The difference in fracture percentage could be attributed to the different type of teeth [35].

In the current study, the PTU file had the highest incidence of fracturing due to cyclic fatigue as a result of low flexibility, which is consistent with the findings of previous studies that reported high cyclic fatigue after the clinical use of PTU F2 files [36, 37]. However, the fracture incidence in the present study was lower than that observed in the previous studies [22]. The present study indicated that instruments activated with reciprocating motion were faster than rotating motion, which came in accordance with the results of the previous studies [12, 38].

The limitation of the present study includes unmatched cleaning and shaping time in the present study with that in the actual clinical situation which might be longer in the clinic.

## CONCLUSSIONS

Within this limitation, The ProTaper Next, Reciproc and WaveOne files, were less vulnerable to fracture and deformation than ProTaper Universal and OneShape files when used as a single file to prepare molar teeth. The ProTaper Next was faster and more resistant to failure than other groups. In addition, the reciprocating motion was faster to finish molar teeth than rotating motion without a significant effect on the defect incidence.

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