

# Influence of kinematics on the cyclic fatigue of ProTaper Gold and WaveOne Gold

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## Abstract

**Introduction:** The aim of the study is to assess the difference in the dynamic cyclic fatigue resistance of ProTaper Gold (PTG) and WaveOne Gold (WOG) files tested in clockwise and counterclockwise continuous rotation against two different reciprocal motions.

**Materials and Methods:** A total of 200 files were tested at 300 rpm. These files were divided into four groups according to direction and type of motion: (A) clockwise continuous rotation, (B) counterclockwise continuous rotation, (C) reciprocal motion with 150° counterclockwise and then 30° clockwise motion, and (D) reciprocal motion with 150° clockwise and then 30° counterclockwise motion. The files were operated in a stainless steel artificial canal with a 60° angle of curvature and a 5-mm radius. A continuous, axial oscillating motion was applied at one cycle/s. The number of cycles to failure (NCF) was recorded. The data were analyzed using two-way analysis of variance.

**Results:** No significant difference in NCF was found between Groups A and B or between Groups C and D in all rotary systems used ( $P > 0.05$ ). However, reciprocal motions exhibited higher cyclic fatigue resistance than continuous rotations ( $P < 0.05$ ). Moreover, PTG showed higher cyclic fatigue resistance than WOG ( $P < 0.05$ ).

**Conclusions:** Reciprocal motions have increased cyclic fatigue resistance, but the direction of the motion had no effect on the fatigue life of the tested instruments. PTG files had higher resistance to cyclic fatigue than WOG files.

**Keywords:** Cyclic fatigue, kinematics, ProTaper Gold, WaveOne Gold

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## INTRODUCTION

Stainless steel instruments have long been used for root canal treatment. Craig *et al.*<sup>[1,2]</sup> demonstrated that stainless steel files were more resistant to cyclic fatigue and had similar or improved resistance to torsional failure than carbon steel instruments. These characteristics and the resistance of stainless steel to corrosion during sterilization procedures led to the use of stainless steel files as the

primary endodontic file.<sup>[3]</sup> However, these files had a tendency to introduce procedural errors that altered the natural canal anatomy. Instrument separation was an additional hazard.<sup>[4]</sup> One reason for the difficulty in maintaining the original canal shape with stainless steel files was because these files had limited flexibility, particularly when exceeding an ISO size of #35.<sup>[1]</sup>

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In the 1960s, Buehler and Wang<sup>[5]</sup> developed a Nitinol wire while working at the Naval Ordnance Laboratory in White Oak, Maryland. They derived the name *Nitinol* from nickel and titanium and NOL for the Naval Ordnance Laboratory. This wire is now more commonly referred to as nickel titanium (NiTi). In 1988, Walia *et al.*<sup>[6]</sup> milled Nitinol orthodontic wires as prototype endodontic files and compared their bending and torsional properties to stainless steel files. In their research, they found that the NiTi files were two to three times more flexible in bending and torsion and more resistant to torsional failure.

Rotary instruments made of NiTi alloys were commonly used in endodontic treatments to shape root canals with challenging anatomies. Cyclic fatigue was the most common cause of fractured NiTi instruments.<sup>[7]</sup>

Fatigue fractures are caused by a repeated cycle of tension and compression at the maximum curved part of the instrument, as this initiates a crack on the surface and then the crack increases.<sup>[7]</sup> Increasing resistance to this cyclic fatigue has been the focus for advancement of rotary NiTi instrument technology. Improvements in the manufacturing process are among the strategies proposed to increase the mechanical properties of these NiTi files.

The motion type and the direction of the movements affect the instruments' fatigue resistance. Most rotary instruments are used in a clockwise continuous rotation, but that motion increases the stresses on the file, particularly in curved and narrow canals.<sup>[7]</sup> Reciprocal movements were introduced to overcome this shortcoming.<sup>[8]</sup>

As proposed by Yared,<sup>[8]</sup> a reciprocal motion is defined as the movement of the file in the clockwise direction followed by a counterclockwise releasing movement. Recent publications have claimed that reciprocation increases the resistance of NiTi files to cyclic fatigue and decreases the incidence of instrument separation during root canal preparation.<sup>[9]</sup> Limited information is available about the influence of clockwise continuous rotation, counterclockwise continuous rotation, and reciprocation on the cyclic fatigue of rotary systems.

The aim of the study was to evaluate the resistance of ProTaper Gold (PTG) and WaveOne Gold (WOG) NiTi files to dynamic cyclic fatigue and to assess the lengths of broken segments in clockwise continuous rotation, counterclockwise continuous rotation, clockwise reciprocal motion, and counterclockwise reciprocal motion.

## MATERIALS AND METHODS

A laboratory experiment for testing the dynamic cyclic fatigue of two different rotary systems was conducted by one operator at a dental biomaterials research laboratory at King Abdulaziz University, Jeddah, Saudi Arabia (Ethical approval number: 016:01–17).

A total of 200 files were tested. The files were divided into four groups according to the directions and the type of motion ( $n = 50$ ):

- Group A: Clockwise continuous motion
- Group B: Counterclockwise continuous motion
- Group C: Reciprocal motion with 150° clockwise and 30° counterclockwise motion
- Group D: Reciprocal motion with 150° counterclockwise and 30° clockwise motion.

Each group was subdivided into two subgroups according to the rotary system used ( $n = 25$ ):

- 1: PTG, F1, tip size # 20 and 7% taper (Dentsply Maillefer, Ballaigues, Switzerland)
- 2: WOG, tip size # 20 and 7% taper (Dentsply Maillefer, Ballaigues, Switzerland).

Each file was examined for defects before the test with a dental operating microscope (PICO, Carl Zeiss, Jena, Germany).

A special setup was assembled for the current experiment using a universal testing machine (MultiTest 2.5-i, Mecmesin, Slinfold, UK) [Figure 1]. A contra-angle handpiece with 1:16 reduction (Sirona, 64625 Bensheim, Germany) and electric endodontic motor (Setelec I-Endo Dual, Acteon, France) was used. The handpiece of the endodontic motor was attached to the moving arm of the universal testing machine. At the lower end of the machine, a stainless steel artificial canal was attached to a chuck vice, which was fixed to a two-dimensional horizontal micropositional stage to precisely align the artificial canal with the descending file [Figure 1].

The artificial canal was made of a laser milled stainless steel block to standardize the testing method. The angle of the artificial canal was 60° with a radius of 5 mm according to Pruett *et al.*'s<sup>[10]</sup> method [Figure 2]. The artificial canal was designed to accommodate the tested rotary files with a tip size of 20 and a 7% taper; the depth of each artificial canal was laser milled to the maximum diameter of the instrument + 0.2 mm, allowing the instrument to rotate freely inside the canal [Figure 2].

A synthetic oil (WD-40 Company, Milton Keynes, England) was used for lubrication as recommended by Nguyen *et al.*<sup>[11]</sup> A drop of oil was used for each rotary file to minimize the friction between the rotating files and the stainless-steel canal wall and prevent temperature elevation. Moreover, the artificial canal was covered with glass to prevent the file and the broken segment from slipping out and for better observation of the rotating file [Figure 3].

All files were 25 mm in length and tested at 300 rpm, according to the manufacturer's recommended speed range.

Twenty-five files in each group were rotated freely in the stainless steel artificial canal. After each file was positioned, a video recording in a high-resolution camera (D3200; Nikon, Tokyo, Japan) was initiated. The time to fracture in seconds was calculated from the videotape and started when the file began to rotate until observing the first sign of fracture. Moreover, instrument fracture was visually detected and timed using a digital stopwatch accurate to 0.01 s.

A continuous axial oscillating motion was applied at one (hertz) cycle/s to simulate a clinical pecking motion. The file was cycled 3 mm above and 3 mm below the starting point, resulting in a net oscillation movement of 6 mm. A special software (Emperor, Mecmesin, Slinfold, UK) was used to control the axial motion.

The number of cycles to failure (NCF) for each instrument was calculated by converting the time (in seconds) required to fracture the instrument into decimal units (in minutes) multiplied by speed.

After removing the glass plate that covered the milled stainless steel block, a Vernier caliper (model 40185; Sears, Roebuck and Co., Chicago, IL, USA) was used to measure the length of the separated instrument's segments.

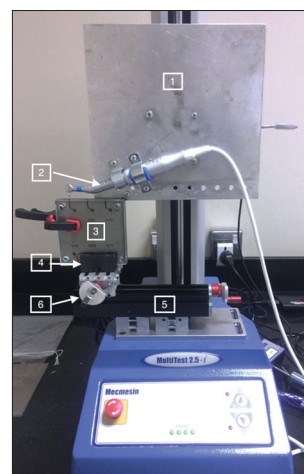
### Statistical analysis

The NCF was analyzed statistically using two-way analysis of variance (ANOVA) followed by *post hoc* pairwise test (SPSS for Mac 11.0; SPSS, Chicago, IL, USA) at a 95% confidence level.

The lengths of fractured segments were analyzed statistically using one-way ANOVA and Mann-Whitney U-tests (SPSS for Mac 11.0; SPSS, Chicago, IL, USA) at a 95% confidence level.

## RESULTS

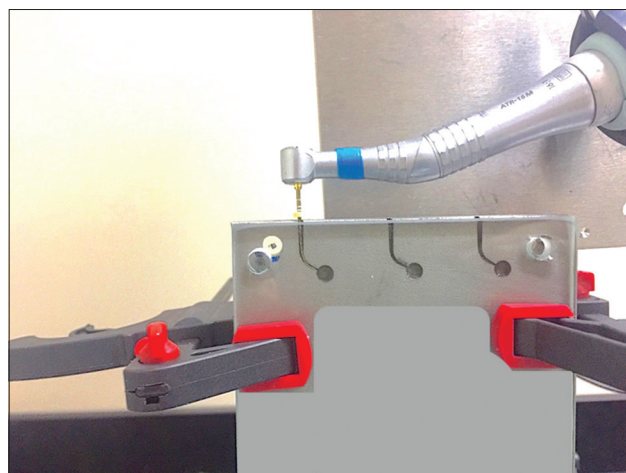
The mean, standard deviation, and statistical analysis of tested groups are presented in Tables 1–3.



**Figure 1:** Universal testing machine (1: The moving arm of the testing machine, 2: A contra-angle handpiece with 1:16 reduction, 3: Stainless steel artificial canal, 4: Chuck vice, and 5 and 6: A two-dimensional horizontal micropositional stage to precisely align the artificial canal with the file)



**Figure 2:** Laser-milled stainless steel block



**Figure 3:** Laser-milled stainless steel block covered by glass

PTG files exhibited a statistically significant higher cyclic fatigue resistance when compared to WOG ( $P < 0.05$ ).



**Table 1: The mean±standard deviation of the number of cycles to failure of the tested groups**

Type of motion	Rotary system	
	PTG	WOG
Group A	A1 1929.20±130.72	A2 1408.80±118.77
Group B	B1 1886.40±179.25	B2 1418.80±102.37
Group C	C1 4078.40±413.24	C2 2791.20±236.97
Group D	D1 4052.20±415.93	D2 2802.20±207.51

Group A: Clockwise continuous rotation, Group B: Counter clockwise continuous rotation, Group C: Reciprocal motion with 150° clockwise and 30° counter clockwise rotation, Group D: Reciprocal motion with 150° counter clockwise and 30° clockwise rotation. PTG: ProTaper Gold, WOG: WaveOne Gold

**Table 2: Pairwise comparisons (post hoc test)**

First group	Mean	Second group	Mean	Mean difference	P
A1	1929.20	B1	1886.40	42.8	>0.05
A1	1929.20	C1	4078.40	-2149.20	<0.01**
A1	1929.20	D1	4052.20	-2123	<0.01**
B1	1886.40	C1	4078.40	-2192	<0.01**
B1	1886.40	D1	4052.20	-2165.80	<0.01**
C1	4078.40	D1	4052.20	26.20	>0.05

The mean, mean difference, and P value of PTG files. \*\*Significant difference ( $P < 0.01$ ). Group A: Clockwise continuous rotation, Group B: Counter clockwise continuous rotation, Group C: Reciprocal motion with 150° clockwise and 30° counter clockwise rotation, Group D: Reciprocal motion with 150° counter clockwise and 30° clockwise rotation. PTG: ProTaper Gold

Moreover, the fatigue life of Groups C and D (Reciprocal motion) were significantly higher than Groups A and B (continuous rotation motion) ( $P < 0.05$ ). The direction of the motion (clockwise versus counterclockwise directions) did not influence the cyclic fatigue resistance in all groups tested ( $P > 0.05$ ).

The average length of PTG fractured segments for all samples was 4.1 mm and 2.6 mm for WOG segments.

The values and a statistical analysis of the fracture fragments length are presented in Table 4. There was a statistical difference between PTG and WOG files ( $P < 0.01$ ).

## DISCUSSION

During root canal cleaning and shaping, choosing the instrument with higher fracture resistance decreases the incidence of instrument separation; therefore, many studies focus on the cyclic fatigue resistance of NiTi files. Manufacturers aim to improve cyclic fatigue resistance by modifying the metallurgy, kinematics, and design of NiTi files.<sup>[12,13]</sup> Therefore, it is crucial for clinicians to understand the different physical properties, kinematics, and designs of recent rotary systems to achieve the maximum benefits of current developments.

**Table 3: Pairwise comparisons (post hoc test)**

First group	Mean	Second group	Mean	Mean difference	P
A2	1408.80	B2	1418.80	-10	>0.05
A2	1408.80	C2	2791.20	-1382.40	<0.01**
A2	1408.80	D2	2802.20	-1393.40	<0.01**
B2	1418.80	C2	2791.20	-1372.40	<0.01**
B2	1418.80	D2	2802.20	-1383.40	<0.01**
C2	2791.20	D2	2802.20	-11	>0.05

The mean, mean difference, and P value of WOG files. \*\*Significant difference ( $P < 0.01$ ). Group A: Clockwise continuous rotation, Group B: Counter clockwise continuous rotation, Group C: Reciprocal motion with 150° clockwise and 30° counter clockwise rotation, Group D: Reciprocal motion with 150° counter clockwise and 30° clockwise rotation. WOG: WaveOne Gold

**Table 4: The mean±standard deviation of fractured instrument fragment length (FI) of the groups tested**

Type of motion	Rotary system Fragment length (mm)	
	PTG	WOG
Group A	4.12±0.16	2.56±0.18
Group B	4.13±0.17	2.58±0.17
Group C	4.14±0.17	2.57±0.17
Group D	4.14±0.17	2.57±0.17

Group A: Clockwise continuous rotation, Group B: Counter clockwise continuous rotation, Group C: Reciprocal motion with 150° clockwise and 30° counter clockwise rotation, Group D: Reciprocal motion with 150° counter clockwise and 30° clockwise rotation. PTG: ProTaper Gold, WOG: WaveOne Gold, FI: Fragment Length

This study evaluated the difference in dynamic cyclic fatigue resistance of PTG and WOG systems tested in different continuous rotation and reciprocal motions. To standardize cyclic fatigue testing and eliminate other contributing factors apart from the cross-sectional design, instruments with a size of 20 and a 7% taper from PTG and WOG were used in this study.

Major drawbacks of laboratory studies testing the cyclic fatigue resistance of NiTi rotary files were the contributing variables that cannot be completely eliminated, which make it difficult to measure the effect of a single variable on its resistance to cyclic fatigue.<sup>[14]</sup> The clinical relevance of these laboratory study results was difficult to assess because the condition differs from clinical intracanal instrumentation in which the file separation might occur due to combined factors (cyclic fatigue and torsional stress) that act simultaneously.<sup>[15]</sup> Yao *et al.*<sup>[16]</sup> stated that “Although the use of extracted teeth simulates clinical situations, they were not anatomically standardized.” Therefore, extracted teeth were not optimal for testing the cyclic fatigue resistance for NiTi instruments. In this study, an artificial canal was used to rule out all the other variables other than the cyclic fatigue variable.

In the literature, the cyclic fatigue resistance of rotary NiTi files has been examined in several static and dynamic

models.<sup>[17-26]</sup> These include rotating the NiTi files against an inclined plane by means of a grooved block or a curved metal tube.<sup>[26,27]</sup> Cyclic fatigue test devices could be used in either static or dynamic modes. In static mode, the instrument rotates in the fixed length in the artificial canal with no axial movement.<sup>[28]</sup> In dynamic mode, the instrument rotates in the artificial canal with axial movement. Dynamic models were reported to simulate clinical situations more realistically than static models.<sup>[19,29]</sup>

In the present study, PTG had a significantly higher resistance to cyclic fatigue than WOG in all types of motion tested. This finding could be due to the differences in the cross-sectional design. WOG files have a parallelogram-shaped design with cutting edges and alternate one-point contact, whereas PTG files have convex triangular cross sections.<sup>[17,30]</sup> Both PTG and WOG files have constant tapers between D1 and D3, which decreases progressively from D4 to D14.<sup>[31,32]</sup> Moreover, both systems were manufactured by gold heat treatment.<sup>[17,30]</sup> A cross-sectional design has been proven to modify the stress distribution produced by a rotary instrument under twisting or tension.<sup>[14,33]</sup> Cheung *et al.*<sup>[14]</sup> conducted a study using a finite elemental analysis and proved that a triangular cross-sectional design showed a higher cyclic fatigue resistance than a square cross-sectional design. They attributed the higher cyclic fatigue resistance of triangular cross-sectional instruments to less metal mass of the files with a triangular cross-section compared to a square cross-section of a similar diameter.<sup>[34,35]</sup> Hence, in this study, the higher resistance to cyclic fatigue of PTG files might be due to the smaller metal mass of the triangular cross compared with more metal in the parallelogram-shaped cross section in the WOG system.

In the present study, the reciprocal motions tested had significantly higher resistance to cyclic fatigue than continuous rotations in both clockwise and counterclockwise directions.

De-Deus *et al.*<sup>[9]</sup> evaluated the cyclic fatigue resistance of ProTaper F2 instruments during continuous rotation and reciprocal motion. They reported that reciprocal motion had significantly higher resistance to cyclic fatigue than continuous rotation motion. The fatigue life is measured by how many times that the initiated crack opens and closes. During one continuous rotation cycle, the crack opens and closes once. According to Yared,<sup>[8]</sup> during one reciprocating movement, the file moved 144° clockwise then moved back 72° counterclockwise, which means that five reciprocal movements will be required to complete one full cycle. In this study, during each reciprocating movement, the files

turned 150° then turned back 30°, which means that three reciprocal movements will be required to complete one full cycle. Hence, it will require at least three reciprocal movements to open and close the initiated crack, which is the reason for a higher resistance to cyclic fatigue in reciprocal motions than in continuous rotation motions.

In this study, the time required for different motions to complete one full rotation with a speed of 300 rotations/min was recorded. For continuous rotation, a 0.216 s was recorded to complete one full rotation. However, for reciprocal motion, a 0.288 s is required to complete one 360° full rotation. In other words, reciprocal motion moves at a lower speed to complete a full rotation compared to continuous rotation. Therefore, reciprocal motion had higher resistance to cyclic fatigue because it required a longer time for the initiated crack to go through one cycle of compression and tension.

However, the present study showed that there was no significant difference in the cyclic fatigue resistance between a clockwise direction and a counterclockwise direction in both reciprocal and continuous rotation motions, and this might be due to identical stress distribution points during bending moments in clockwise and counterclockwise directions.

This study showed that there was no significant difference in the mean length of the fractured segments between each type of motion. Gündoğar and Özyürek<sup>[21]</sup> tested the cyclic fatigue of WOG and Reciproc Blue rotary systems. They reported that there was no significant difference between the mean length of the fractured fragments of the rotary systems used. They attributed that to the precise and reproducible position of each file inside the canal during testing. In this study, the mean length of the fractured segments was not significantly different between all types of motion tested in each rotary file system. This might be because each file tested was accurately positioned inside the canal.

On the other hand, the mean length of fractured segments of PTG files tested in this study was 4.1 mm, which was at the center of the curvature. However, the mean length of fractured segments of WOG files tested in this study was 2.4 mm, which was below the center of the curvature. There was a significant difference in the mean lengths of the fractured segments between PTG and WOG. Kaval *et al.*<sup>[36]</sup> compared the cyclic fatigue resistance of ProTaper Universal and PTG systems. They reported that the mean length of PTG was 5.9 mm, which was significantly higher than the mean length (4.9 mm) of ProTaper universal.

Previous studies attributed the difference in fragment lengths among rotary systems to the physical properties of the alloy and the cross-sectional design of the files, which could modify the distribution of the maximum stress points.<sup>[36-39]</sup>

During cyclic fatigue testing, each point at the curved part of the file was bent and went through compression and tension cycles. During bending moments, the crack was initiated at the point where the maximum stress was located and propagated until fracture occurs. The length of fractured segment gave us an indication of the maximum stress point.

In the present study, the mean length of fractured segments of the WOG files was observed to be shorter than the PTG files, which might be due to different locations of the maximum stress point during compression, and the tension cycles due to the different cross-sectional designs of the PTG and WOG files.

In dynamic mode, the time to fracture scores increased because the stress was distributed along the shaft during back and forth axial movements when compared with static test modes in which the stress was concentrated in a specific area.<sup>[23,28,29]</sup> In this study, the dynamic model for testing cyclic fatigue was used to represent the clinical situation as much as possible.

## CONCLUSIONS

PTG files had higher dynamic cyclic fatigue resistance than WOG files due to the differences in their cross-sectional designs. Reciprocal motion increased cyclic fatigue resistance, but the direction of motion had no effect on the cyclic fatigue resistance of the tested instruments. Kinematics had no influence on the length of separated segments. However, PTG had longer separated segments than WOG due to the differences in their geometrical designs.

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## Conflicts of interest

There are no conflicts of interest.

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