








Cyclic Fatigue and Torsional Strength of a New Thermally Treated Reciprocating System

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ABSTRACT

Objective: This study evaluated the resistance to cyclic fatigue and the torsional strength of Prima One Gold® and WaveOne Gold® reciprocating systems.

Methods: Cyclic fatigue was tested in an artificial canal with 60° curvature, a 5 mm radius of curvature at 22°C (n=10) and 36.5°C (n=10). The torsional strength test followed ISO 3630-1, measuring torque and deflection angle until fracture (n=10). The t-test was used to compare the two groups, and the significance level was set at 5%.

Results: The Prima One Gold group presented greater resistance to cyclic fatigue at room temperature (P=0.001) and body temperature (P<0.001). For the torsional resistance test, the Prima One Gold group had a lower maximum torque value (P=0.029), despite having a greater deflection angle (P<0.001).

Conclusion: The Prima One Gold group showed greater resistance to cyclic fatigue regardless of temperature and a greater deflection angle. The WaveOne Gold group showed a greater maximum torque value than the Prima One Gold group.

Keywords: Alloys, mechanical tests, root canal preparation, shape memory alloys.

HIGHLIGHTS

- New reciprocating instruments Prima One Gold showed greater resistance to cyclic fatigue regardless of temperature;
- Prima One Gold has lower resistance to torsion fracture, and, consequently, movements with lower apical pressure and more control should be performed;
- The results demonstrated changes in the material's behaviour under different temperatures, showing higher resistance to cyclic fatigue at room temperature.

INTRODUCTION

The development of different nickel-titanium (NiTi) alloys revolutionised the endodontic treatment of root canals with marked curvature degrees due to their elastic properties (1). These alloys give the instruments superelasticity and, in addition to heat treatments, the effect of controlled memory (2). Thus, the instruments become more resistant and less susceptible to failures during root canal preparation (3). Additionally, the use of NiTi instruments has some advantages, such as the

ability to be used for more anatomical preparations (4), less transport of the root canal (5), and less risk of perforation in danger zones (6).

Since 2008, instrumentation with reciprocating kinematics has become viable in root canal mechanical preparations (7). This movement is characterised by the oscillation of the rotating file in a counterclockwise direction, returning in a clockwise direction without the instrument completing the initial rotation (8). Compared to rotary systems, reciprocating instruments have greater resistance to cyclic fatigue (9-12). Additionally, in support of reciprocating kinematics, the emergence of single-instrument systems for canal preparation has helped make clinical sessions faster and easier by replacing large sequences of files within the root canal (13).

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A reciprocating system, WaveOne Gold (WOG; Dentsply/Tulsa Dental Specialties), appeared in 2015, with apparent modifications from the previous system (14). These changes were in the cross-section geometry, an increase in the availability of sizes, and the heat treatment related to the advance in the system's behaviour (15). Gold-Wire heat treatment increases the system's elasticity compared to its predecessors (16). This procedure consists of heating the instrument and cooling it at low rate and gives the file its golden colour (17). A new NiTi system, Prima One Gold (POG; Prima Dental Group), was introduced to the market in 2019. It is heat-treated with tips and variable tapers equivalent to the WOG system (20/.v07, 25/.v07, 35/.v06, and 45/.v05). However, there are still no reports in the literature on this new instrument.

Despite the new technologies available, fractures of instruments inside the root canal are still of concern for the clinician. Although reciprocating kinematics generate less stress than rotary movement, a single instrument can cause greater stress when shaping the root canal system (16). Heat treatments and the development of more resistant alloys aim to reduce the incidence of instrument fracture by increasing the resistance against stresses to which instruments are subjected (18).

In curved root canals, the most significant failure is due to decreased resistance to cyclic fatigue. Repeating the movement in a critical space may lead the instrument to fail at its flexion point (19). Another reason for fracture is the instrument's immobilisation within the root canal and the continuous movement without interruption, causing fracture due to torsional fatigue (20).

New systems need to be evaluated because of the additional importance of reciprocating NiTi systems in avoiding file fractures. Thus, this investigation aimed to compare a reciprocating system already established on the market (WOG) with another newly introduced reciprocating system (POG), evaluating the resistance factors to cyclic fatigue by varying the test temperature and torsional fatigue. The null hypothesis was that POG's torsional and cyclical fatigue would be similar to WOG.

MATERIALS AND METHODS

Before starting experimental work, ethical approval was obtained from the institutional ethical committee (CAAE-73430617.9.0000.5083). Sample size calculation was performed using the G* Power version 3.1 for MAC (University of Düsseldorf, Düsseldorf, Germany). The Wilcoxon-Mann Whitney test was selected from the t-test family. An alpha-type error of 0.05 was also established, with the beta power of 0.95 and N2/N1 as 1. The software stipulated eight instruments for each group; however, the sample size was increased by 20% to account for possible losses. Therefore, ten instruments were used for each group for all tests (n=10): Cyclic fatigue resistance test at room temperature (22°C), cyclic fatigue resistance test at 36.5°C, and torsional fatigue resistance test.

Thus, 60 instruments were used for this study, divided into two groups: POG 25/.v07 (Prima Dental Group, Gloucester, United Kingdom) and WOG 25/.v07 (Dentsply/Tulsa Dental Specialties, Tulsa, USA). A preliminary and initial analysis was

conducted by inspection with a stereomicroscope magnification device (Carl Zeiss, Jena, Germany) to detect structural defects before testing.

Cyclic fatigue resistance test at room temperature and 36.5°C

Tests for resistance to cyclic fatigue were performed in two ways, varying only the tested temperature. The tests were performed using a stainless-steel root canal simulation device (13, 21). The test device had an angle of 60° of curvature and a radius of curvature of 5 mm, located 5 mm from the instrument's tip. For activation of the instruments, a VDW Silver Motor (VDW GmbH, Munich, Germany) was used (Fig. 1). Lubrication of the steel canal was done using synthetic oil (Super Oil; Singer Co. Ltd., Elizabethport, USA). The tested program was selected according to each manufacturer's recommendation: for both systems, the "Wave One All" programming was used. The time (seconds) until the fracture of the instrument was counted by two different digital chronometers.

For the test carried out at 36.5°C, the apparatus was immersed in water at a controlled temperature through measurement with an immersed thermometer and instruments (Fig. 2). Time measurement was similar to the test at room temperature (22°C).

Torsional fatigue resistance test

The torsional strength tests were carried out under the International Organization for Standardization (ISO) standard 3630-1 (2019). The final 3 mm of the instrument was clamped to a mandrel and coupled to a motor.

The instrument rotation speed was set at 2 rpm counterclockwise, and, through a computer, the torque and angular deflection values were obtained throughout the test. In addition, at the fracture signal, the maximum torque value and the maximum rotation angle were measured at the rupture moment. All data were obtained through a machine with a specific purpose and interpreted by the Microtorque Software (Analógica, Belo Horizonte, Brazil).

Statistical analysis

For the statistical analysis, the IBM® SPSS® software for MAC (IBM Corp., Armonk, USA) was used. Initially, the Kolmogorov-Smirnov test was performed, which demonstrated normal data distribution. Therefore, the t-test was used for comparisons between the groups. The level of significance was set at 5%.

RESULTS

No instruments were discarded after analysis and inspection in a stereomicroscope before testing. The mean and standard deviation values for cyclic fatigue at room temperature and 36.5°C can be seen in Table 1. There was a statistically significant difference between the groups for resistance to cyclic fatigue at room temperature (P=0.001). The mean value of the POG group for resistance to cyclic fatigue was significantly higher than the mean for the WOG group at room temperature (P=0.001). A similar result was observed for the cyclic fatigue resistance test at 36.5°C, showing a higher average value



Figure 1. The instrument positioned in the cyclic fatigue test device showing the artificial canal with an angle of curvature of 60° and a radius of 5 mm



Figure 2. The apparatus is immersed in water at a controlled temperature (36.5°C)

of cyclic fatigue resistance for the POG group than the WOG group's value ($P < 0.001$). There was a statistically significant difference in comparing the different temperatures for both systems. In both POG ($P = 0.008$) and WOG ($P = 0.004$) groups, higher resistance to cyclic fatigue was observed at room temperature than at 36.5°C.

Table 2 shows the mean and standard deviations of the torsional resistance test. It is possible to observe a statistically significant difference between the groups ($P < 0.05$). Regarding the mean for angular deflection, the POG group had a significantly higher mean value than the WOG group ($P < 0.001$). For the torque values, the WOG group presented a significantly higher mean regarding the resistance to torsional fracture than the POG group ($P = 0.029$).

TABLE 1. Mean and standard deviation cyclic fatigue (time in seconds) of instruments tested (n=10)

Systems	Cyclic Fatigue at room temperature (s)		Cyclic Fatigue at 36.5°C (s)		P
	Mean	SD	Mean	SD	
Prima One Gold	367.7 ^{a,A}	144.9	225.5 ^{a,B}	39.2	0.008
WaveOne Gold	188.7 ^{b,A}	33.7	135.4 ^{b,B}	38.8	0.004
P	0.001		<0.001		

Different lowercase letters represent a significant difference between groups in the same column. Different uppercase letters represent a significant difference between temperatures/tests in the same line by t-test ($P < 0.05$). SD: Standard deviation

TABLE 2. Mean and standard deviation of the deflection angle (°) and torque (Ncm) for the torsional resistance test (n=10)

Systems	Deflection angle (O)		Torque (Ncm)	
	Mean	SD	Mean	SD
Prima One Gold	407.7 ^a	64.2	1.1 ^a	0.2
WaveOne Gold	286.9 ^b	27.3	1.3 ^b	0.1
P	<0.001		0.029	

Different letters in the same column represent a significant difference between groups by t-test ($P < 0.05$). SD: Standard deviation

DISCUSSION

Different reciprocating file systems are available to optimise the treatment of root canals and reduce working time. Although they have the same objective, there are intrinsic differences in the manufacturing processes of instruments, such as the design, cross-section, and heat treatment of the alloy that can modify its behaviour and resistance to failure (19). This investigation aimed to compare a consolidated instrument's performance with another recently launched instrument. The analyses demonstrated that the POG group instruments performed better than the WOG group in the cyclic fatigue tests at the temperatures tested. Additionally, in the torsional fatigue test, the POG system obtained a higher value in its deflection angle; however, less maximum torque value. Therefore, the null hypothesis was rejected since the results differed from the WOG.

Parallel to the technological evolution of file systems for endodontic treatment, mechanical test performance must be consistent to ensure the quality and safety of the instruments. For this study, static tests of resistance to cyclic fatigue were performed. Although there are no norms for test standardisation, they are already well consolidated by the previous literature (18, 21). In addition, another methodology used and previously validated is the torsional resistance test, regulated by ISO 3630-1, to quantify the maximum torque value (Ncm) and deflection angle (°) that the instrument reaches at the time of failure (19). Despite the limitations and difficulties of extrapolation, due to the use of a stainless-steel simulated root canal, the performance tests, as mentioned above, allowed an analysis free of influences, possibly controlling the variables that would alter the results (22).

Evaluating the influence of temperature on materials' mechanical properties is essential in instruments designed for clinical use. This study evaluated the mechanical properties at room temperature and in heated water (36.5°C) to simulate intracanal temperature. The results of the present study demonstrated changes in material behaviour under different temperatures and environments, showing higher resistance to cyclic fatigue at room temperature in dry conditions. These findings align with previous studies that confirm the negative influence of temperature on cyclic fatigue resistance (23-26). Dosanjh et al. (23) evaluated the resistance to cyclic fatigue at four different temperatures: cold water at 3 °C, room temperature at 22 °C, body temperature at 37 °C, and hot water at 60 °C. Their findings allow us to observe that a gradual temperature increase is inversely proportional to the number of cycles the instrument resists until fracture. The same pattern can be observed in Shen et al. (24) study, which detected significant differences in reducing resistance to cyclic fatigue with increased temperature.

However, another study did not detect a difference in cyclic fatigue resistance related to temperature (27). The potential conflict in the results is due to the difference between the temperatures examined. For the present study, temperatures of 22°C and 36.5 °C were compared, and in research carried out by Keles et al., (27) 22°C and 35°C were examined. Additionally, methodological variances may influence the differences in results, as in the apparatus for positioning the samples. These data are essential for determining test performance patterns since most laboratory tests are performed at room temperature, and the results can distort what occurs in the clinical setting. Despite the importance of temperature variation in laboratory tests, the torsion test was performed at room temperature due to a limitation of the device, which is an inability to be submerged in heated water.

According to the result obtained by comparing both systems at different temperatures and with most of the results addressed, it is evident in the laboratory that temperature is an essential factor to be considered in fractures due to cyclic fatigue (23-25). Therefore, it is possible to raise the hypothesis that irrigating solutions at lower temperatures, such as 3 °C, can improve the performance of nickel-titanium instruments, especially in cases of accentuated curvature (23). However, it is essential to emphasise that the POG group obtained better results regarding cyclic fatigue even with a temperature of 36.5 °C, demonstrating that temperature was not a relevant factor between the two instruments. In this context, new clinical studies must be conducted to compare the direct impact with cooled irrigating solutions and at room temperature.

In previous studies, the WOG system, when compared to other systems, such ProDesign Logic, ProDesign R, Reciproc, and Reciproc Blue, presented lower resistance to cyclic fatigue at room temperature ($P < 0.05$), which is confirmed in the present study (21, 28-30). Other studies have reported that this may be related to the taper of the instrument along its length or cross-sections (13, 17). The WOG group's low performance in the test on body temperature ($P < 0.05$) can

also be observed. Previous studies have confirmed the predisposition to the low resistance of the WOG system's cyclic fatigue at higher temperatures (25). Factors intrinsic to the instruments can explain the results of this study, such as heat treatment and the type of NiTi alloy used (28, 30), which varies between manufacturers and is not disclosed in detail. These characteristics can influence the constitution of the material and affect its behaviour (29).

File treatments directly influence the instrument behaviour in the austenite/martensite phases, increasing or decreasing files' elasticity at different temperatures (24, 31-33). A predominance in the instruments' martensitic phase gives them greater flexibility, therefore, greater resistance to cyclic fatigue (18). In the present study, the WOG group had lower resistance to cyclic fatigue regardless of temperature than the POG group ($p < 0.05$). Despite this, previous studies report that the WOG system has less variability at different temperatures (25). This fact can be confirmed in the present study. Thus, it is likely that files in the POG system have a greater proportion of the martensitic phase at room or body temperature, decreasing that phase as the temperature increases. Both files have the same design regarding the central nucleus and cross-section.

The torsional strength test was carried out under ISO 3630-1 on an appropriate machine to assess the deflection angle and the instrument's maximum torque at the time of fracture. The instrument is subjected to high tension and stress, immobilised and twisted counterclockwise at 2 rpm (29). In the clinical routine, it is possible that the instrument can be trapped in some portion of the root canal and remains activated; thus, potential failures will be generated by the low resistance to torsion (22).

For this study, for the values referring to the maximum torsion angle, the WOG group had a lower performance than the POG system ($P < 0.05$). The same result was observed in a similar study, comparing WOG with different systems, with the WOG system obtaining inferior results to the compared groups (21). This finding suggests that the POG group, compared to the WOG group, has a higher threshold of plastic deformation (18). However, when the maximum torque results are evaluated, the POG group performs worse than the WOG group ($P < 0.05$). The torque value of the POG group has lower resistance to torsion fracture; consequently, movements with lower apical pressure and more control should be performed.

For ethical reasons, studies of resistance to cyclic and torsional fatigue of endodontic instruments are impracticable in clinical settings. However, despite the intrinsic limitations of laboratory studies, the present study results are relevant to clinical practice to demonstrate knowledge of instrument properties.

CONCLUSION

The cyclic fatigue test results demonstrate better performance for the POG group regardless of temperature. Additionally, the WOG group had greater resistance in the torsional strength test.

Disclosures

Conflict of interest: The authors deny any conflict of interest.

Ethics Committee Approval: This Experimental Work was approved by the Institutional Ethical Committee (Number: CAAE- 73430617.9.0000.5083).

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