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ORIGINAL ARTICLE

Cyclic fatigue resistance of WaveOne Gold instruments with different amplitudes of axial movement: a dynamic study

ABSTRACT

Aim: *Single-file reciprocating instruments were launched, aiming to diminish the risk of instrument separation. It operates in an in-and-out dynamic with an amplitude of approximately 3-4 mm. This study evaluated the impact of different amplitudes of axial movement in the dynamic cyclic fatigue resistance of the WaveOne Gold reciprocating file.*

Materials and Methods: *Forty-five WaveOne Gold 25.07 were divided into three different groups (n=15) according to the amplitude of axial movement of choice. In the G-2.5 group, the instruments were used in an in-and-out amplitude of 2.5 mm; in the G-5 group, the instruments were used in an in-and-out amplitude of 5.0 mm, and in the G-7.5 group, the instruments were used in an in-and-out amplitude of 7.5 mm. All instruments were tested in a simulated canal notched in metallic block, with 9.04 mm in its cervical portion, 13.3 mm in its apical portion, and curvature of 2.5 mm and 69°. The axial movement was applied with a back-and-forth speed of 2.5 mm/s during the dynamic cyclic fatigue test until the fracture was noticed. All of the tests were performed at a controlled temperature of 36±1 °C and under oil lubrication. Then, the time to fracture (TTF/s), the number of cycles to fracture (NCF), and the length of the separated fragments were registered. The level of significance was set at 5%.*

Results: *The TTF/s was 11.40±9.83, 15.00±7.46 and 22.33±8.76 for G-2.5, G-5, and G-7.5, respectively. The NCF was 57.00±49.13, 75.00±37.32, and 111.67±43.82 for G-2.5, G-5, and G-7.5, respectively. For both TTF/s and NCF, G-7.5 was higher than G-2.5, and G-5.0 was similar to both groups (P<.05). The lengths of the fragments were 10.27±1.07, 10.37±0.66, and 10.58±0.77 for G-2.5, G-5, and G-7.5, respectively. There was no difference among the groups in regards to the length of the fragments (P>.05). The SEM images showed characteristics related to cyclic fatigue.*

Conclusions: *It can be concluded that in-and-out movements affect the dynamic cyclic fatigue resistance of the WaveOne Gold reciprocating instrument. Appropriate pecking motions in the root canals are recommended to prevent the breakage of NiTi reciprocating instruments.*

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Introduction

The introduction of nickel-titanium in modern endodontics resulted in instruments with higher flexibility and cyclic fatigue resistance than the previous hand stainless steel (SS) instruments (1). Recently, the thermic treatment of this alloy resulted in increased resistance and the possibility of creation of controlled-memory instruments. Therefore, its use was indicated, mainly in curved canals (2).

The single-file reciprocating system was emphasized by Yared in 2008 (3), based on the concepts described by Roane et al. for use with SS hand files (4). The reciprocating kinematics reduced the possibility of fracture of the instruments when compared to the rotary kinematics (5). However, fractures in reciprocating instruments still might occur, despite the decreasing risk of instrument separation (6, 7). The removal of such instruments is not always a simple task and has the potential to compromise the outcomes of root canal therapy; therefore, efforts should be made to avoid such occurrence (8).

WaveOne Gold (Dentsply Sirona, Ballaigues, Switzerland) is a single-use instrument presenting a rectangular cross-section and a heat-treated alloy. As only 1 or 2 points of the instrument touch the root canal walls, the screw-in effect is attenuated. This aspect, in conjunction with the heat-treated alloy, decreases the risk of fracture (9). According to the manufacturer, the instrument should advance inside of the root canal in 2 to 3 passes of 3 mm of amplitude in each use.

Usually, cyclic fatigue resistance essays are performed at room temperature (10). However, intracanal temperature is approximately 10 °C higher than room temperature, reaching around 35.1 °C. This difference in temperature might compromise the results of these studies (11). Another variable of interest is that dynamic tests are preferable to static tests for the assessment of cyclic fatigue resistance (12). While fracture of instruments is a complex phenomenon, it can be summarized in fracture by torsion or cyclic fatigue (13). Fracture by cyclic fatigue is particularly affected by the curvature and the location of this curvature within the root canal.

Engine driven files should be used inside of the root canal in an in-and-out or pecking motion fashion (14). Moreover, this dynamic decreases the screw-in effect related to the full rotation of the instrument (10). Incorporating the pecking motion seems to increase the cyclic fatigue resistance because the stress is distributed in the whole extension of the file, rather than in a single spot. This study aimed to assess, at simulated body temperature, the cyclic fatigue resistance of WaveOne Gold instruments at different amplitudes of insertion -2.5 mm, 5.0 mm, and 7.5 mm in simulated metal blocks. The null hypothesis tested is that there is no difference in the cyclic fatigue resistance of the WaveOne Gold 25.07 at different amplitudes of axial movement.

Materials and Methods

Sample size calculation was based on a pilot study using the G*Power 3.1.9.2 software (Heinrich-Heine-Universität Dusseldorf, Dusseldorf, Germany). Considering the minimum difference (10) and the standard deviation of the difference (7.5) to compare the three groups, a minimum of 12 sample units was calculated to achieve the test power of 80% and significance of 5%. Therefore, with a sample number of 15, the study has power above 80%.

Forty-five new WaveOne Gold Primary (25.07) of 25 mm of length were inspected under 25x magnification to discard any signs of distortion. Then, the files were randomly assigned to the three different groups (n=15) according to the different amplitudes of axial movement assessed: G-2.5, 2.5 mm of amplitude; G-5, 5 mm of amplitude, and G-7.5, 7.5 mm of amplitude.

A simulated canal was notched in a metallic block with the following features: a curved segment 2.15 mm long, 69° of curvature, 2.5 mm of radius, presenting 9.04 mm of length in its straight coronal

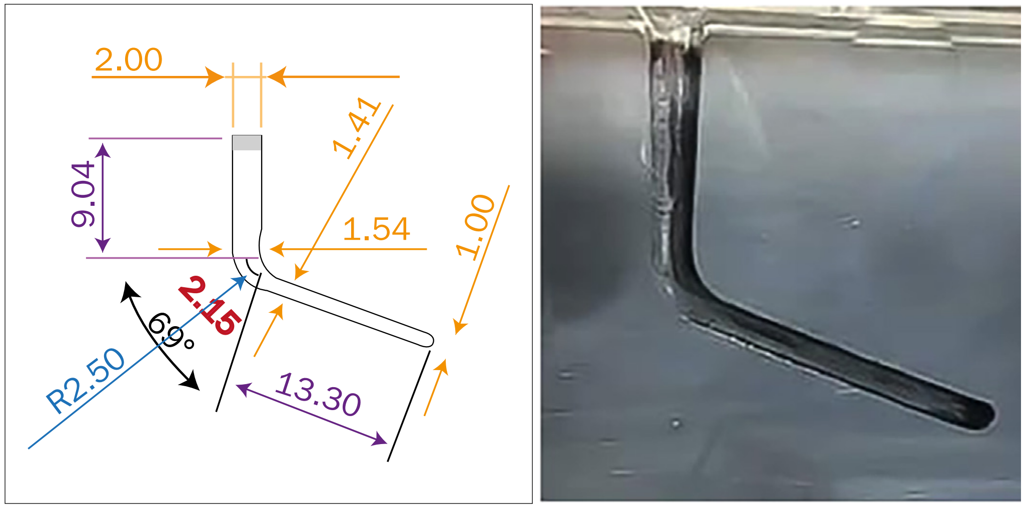

Figure 1
Schematic design of the metallic block simulating a 69° curvature in a root canal.

portion, as well as initial width of 2.0 mm decreasing apically until 1.54 mm of width and 13.3 mm of length in its straight apical portion, with initial width of 1.41 mm decreasing up to 1.00 mm in the apical portion was used for the experiment (Figure 1). The canal was covered with an acrylic plate to prevent the instruments from slipping out and to visualize the reciprocating files.

The metallic block was positioned vertically and kept on a heating plate (Fisatom Co., Sao Paulo, Brazil) that transmitted the temperature to the simulated canal and to the lubricated synthetic oil (Super Oil; Singer Co. Ltd., Elizabethport, NJ, USA) that filled the canal during the time of the experiment. The temperature inside of the simulated canal was kept stable at 36 ± 1° C, confirmed by the use of a digital laser infrared thermometer (Qingdao Tlead Internation, Shandong China) pointing to the inner of the canal; therefore, the synthetic oil was at the same temperature, and this temperature confirmation was performed for each file to be tested.

The instruments were used in a VDW Silver engine (VDW, Munich, Germany) and coupled to contra-angle with a 6:1 reduction (Sirona Dental Systems GmbH, Bensheim, Germany) at the WaveOne "Reciprocating ALL" setting. The handpiece was attached in a mobile unit powered by an electronically controlled motor (SAVOX SC-12 56T69; Savox, Taichung, Taiwan) that regulated the in-and-out amplitude of the insertion of the instrument in a perpendicular direction inside the simulated canal to allow a precise and reproducible continuous up-and-down pecking movement of each file. The in-and-out speed was set at 2.5 mm/s.

All instruments were inserted 22 mm inside the simulated canal; a silicon stop was placed in each instrument to assure the exact 22 mm depth penetration. The mechanical system of axial movement was activated and immediately exerted a 2.5 mm retraction movement (G-2.5) so the file was inserted 19.5 mm into the metal canal (start position); immediately, the file initiated the axial movement 2.5 mm forward and 2.5 mm backward. Simultaneously, the file initiated the reciprocating movement. For the G-5.0 and G-7.5, the mechanical system exerted 5.0 or 7.5 mm of retraction movement, respectively, so the file was inserted with 17 mm or 14.5 mm depth in the canal (start position), respectively and start a 5.0 mm forward and 5.0 backward for G-5.0 and a 7.5 mm forward and 7.5 mm backward for G-7.5.

An IPhone X (Apple Inc, Cupertino, CA) using a 4K recording definition was used to record the movement of the files inside of the simulated canal. All of the films were assessed in the Movie Maker program (Microsoft Co., Redmond, WA), allowing the registration of the beginning of the movement up to the fracture of the instrument with 0.001 seconds precision. The time to fracture (TTF/s) was registered in

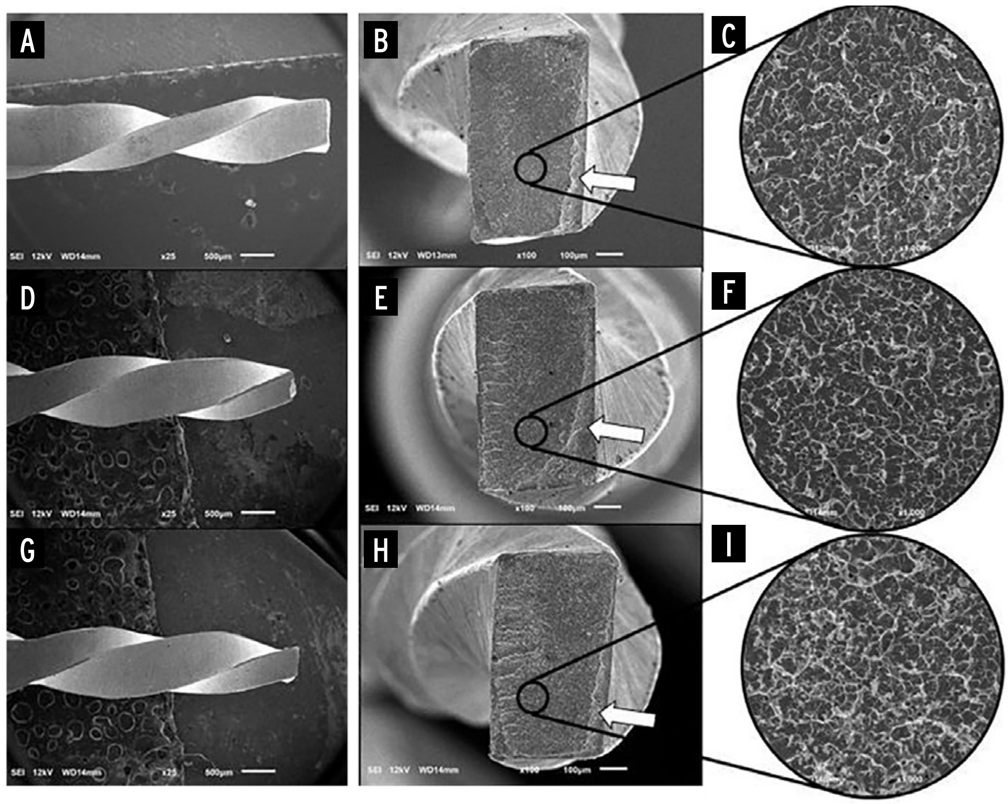

Figure 2
SEM images of the fractured surface of the separated fragments of the instruments in each group: G-2.5 (**A, B,** and **C**), G-5 (**D, E** and **F**), and G-7.5 (**G, H** and **I**). **A, D** and **G**: longitudinal surface of the fractured fragments, no torsional deformation on the helical shaft was noticed (magnification of 25x). **B, E** and **H**: cross section of the fractured fragments with ductile surface fracture morphology and with withe arrows indicating the crack initiation origin (magnification of 100x). **C**, **F** and **I**: higher magnification of **B**, **E** and **H**, respectively, the images show numerous dimples spread on the fractured surfaces, which constitute a typical feature of ductile fracture (magnification of 1000x).

seconds, and the number of cycles to fracture (NCF) was calculated as follows: TTF (s) x 300/60. The apical separated portion of the instruments was collected, cleaned with an ultrasonic bath, and dried for 24 hours at 37 °C. Afterward, the length of the separated fragment was measured with a digital rule with a precision of ±0.03 mm/0.001.

Images from the fragment surfaces were obtained by Scanning Electron Microscopy (SEM, JSM-6010LA, JEOL, Tokyo, Japan) for the assessment of plastic deformation and the pattern of the fracture.

Due to abnormal distribution of data for both TTF/s and NCF, verified by the Kolgomorov-Smirnov test, the Kruskal-Wallis (post-hoc Duncan) was used for statistical analysis. The significance level adopted was P<.05. All tests were performed using the Statistical Package for Social Sciences (SPSS), version 19.0.

Results

The initial inspection of the instruments showed no sign of distortion or fractures; therefore, no instrument was removed from the test.

The time to fracture was 11.40±9.83 sec, 15.00±7.46 sec, and 22.33±8.76 sec for G-2.5, G-5, and G-7.5, respectively. This result was different statistically only between G-2.5 and G-7.5 (P<.05) (Table 1). Similarly, the results of NCF were higher for G-7.5 (111.67±43.82 sec), followed by G-5 (75.00±37.32 sec) and G-2.5 (57.00±49.13 sec); the only statistically significant difference was noticed between G-2.5 and G-7.5 (P<.05) (Table 2).

There was no difference in the length of the fragments in the 3 different groups (Table 3). The SEM images showed no sign of plastic deformation of the fragments, suggesting no torsional fatigue. The cross-section of the fragments presented ductile characteristics and dimples formation related to cyclic fatigue (Figure 2).

Discussion

The study design herein adopted used a simulated canal in a metallic block mimicking a root canal with 69° curvature. In order to diminish confound factors, the block was lubricated with synthetic oil, similarly as in previous studies (5). By using a heating plate, this study aimed to simulate the body temperature, thereby enhancing the similarities with the *in vivo* behavior of the instrument. The dynamic movement of the instrument at 2.5 mm/s in an axial direction is claimed to better simulate the movement of the instrument inside of the root canal (12).

The curvature was located in the middle portion of the simulated canal, and it can be considered severe (15). By doing so, the study aimed to simulate extremely difficult conditions that a file can be submitted *in vivo*. On the other hand, the use of a taper .07 file in severe curvature should be cautiously considered in a clinical setting. It is known that there is a greater challenge in the removal of separated instruments in the apical portion of the canal (16). However, there is a high incidence of curvatures located in the cervical and middle thirds in mesial roots of mandibular and maxillary molars (17). A previous study demonstrated that reciprocating instruments are more prone to fracture when the curvature is located in the middle or coronal third of the canal (18).

The Scanning Electron Microscopy (SEM) images of the apical portion of the instruments showed no signs of plastic deformation of the cutting blades. Moreover, there were clear signs of fatigue striations of the alloy. These features characterize the fracture to be promoted due to cyclic fatigue, which is the aim of the present study (19).

The results of the present study showed higher cyclic fatigue resistance with larger amplitudes of movement. Therefore, the

Table 1
Time necessary for fracture (TTF/s) of the fragments in each experimental group

Group	Mean	SD	Median	Range	p-value
G-2.5	11.40[a]	9.83	9.00	4-46	<0.001
G-5	15.00[a,b]	7.46	12.00	8-35	
G-7.5	22.33[b]	8.76	22.00	10-36	

Different superscript letters indicate statistically significant differences – Kruskall-Wallis (P<.05).

Table 2
Number of cycles to fracture (NCF) in each experimental group

Group	Mean	SD	Median	Range	p-value
G-2.5	57.00[a]	49.13	45.00	20-230	<0.001
G-5	75.00[a,b]	37.32	60.00	40-175	
G-7.5	111.67[b]	43.82	110.00	50-180	

Different superscript letters indicate statistically significant differences – Kruskall-Wallis (P<.05).

Table 3
Mean length of the apical separated fragment (mm) in each experimental group

Group	Mean (mm)	SD	Median	Range	p-value
G-2.5	10.27[a]	1.07	10.00	8.06-12.14	0.154
G-5	10.37[a]	0.66	10.13	9.85-11.95	
G-7.5	10.58[a]	0.77	10.37	9.58-12.05	

Different superscript letters indicate statistically significant differences – Kruskall-Wallis (P<.05).

null hypothesis was rejected. Despite the lack of statistically significant difference when G-5 is compared with G-2.5 and G-7.5, the higher resistance of the instrument in G-7.5 when compared to G-2.5 led to the conclusion that there is an influence in the amplitude on the results. These findings, in a manner, concur with Li et al., as that study also found no difference in cyclic fatigue resistance with variations in pecking motion in the order of 3 mm (10). Another study also found no difference in the forces generated when the variation in the amplitude of movement was as short as 2 mm (20). One possible explanation for this result is that the larger amplitude of movement prevents the narrower area of the instrument from being submitted to tension and compression in the curved area of the block (21). However, as those studies were performed with rotary instruments, care should be taken with the comparisons in relation to the findings of the reciprocating instruments assessed in this study. On the other hand, in the case of shorter in-and-out movements, the stresses are concentrated in a small area of the instrument, which reduces both the TTF/s and the NCF (10).

A recent study assessed the resistance of reciprocating instruments Reciproc Blue (VDW, Munich, Germany), WaveOne Gold, and Prodesign R (Easy Co., Belo Horizonte, Brazil), and found an average time for fracture of 876.5 s; 409.3 s; and 2099.8 s, respectively (22). These results are significantly higher than the findings of the present study. Also, the length of separated instruments ranged from 4.98 to 5.01 mm without statistically significant differences among the files, which differs from the present findings. It is worthwhile to mention that despite the similarities in the curvature – 60° for that study and 69° for the present study – in that study, the curvature was located 5 mm from the apical portion of the simulated canal. This comparison corroborates the hypothesis that curvatures in the middle portion are riskier than apical ones.

The mean length of the fragments in the present study differs considerably from the findings of previous studies, which found 4.51 mm for Edge Taper Platinum, 4.99 mm for ProTaper Gold, and 7.51 mm for Hyflex EDM (19, 23). Also, the mean length found by Alcalde et al. was significantly shorter than the results of the present study (22). While the differences among the files and methods used prevent a straightforward comparison, these findings are clinically relevant. This aspect might be explained by the design of the simulated canal. Moreover, the in-and-out movement is likely to have promoted the fracture in a thicker portion of the file (13). Interestingly, the length of fragments was the same regardless of the experimental groups. Although the different amplitude ranges that resulted impacted the TTF/s and NCF, the area in which the files are submitted to the higher stress remains the same. Considering the characteristics of the simulated canal, and the fact that all files were inserted up to 22 mm, the approximate length in the straight portion of the canal was 10.81 mm, resulting in the fractures occurring in similar areas (means ranging from 10.27 to 10.58), meaning that the separation occurred at the end of the curvature, in the highest area of tension.

Conclusions

While the results of the present study concluded that the amplitude of movement impacts the cyclic fatigue resistance of the instruments, this procedure should be carefully assessed prior to being applied clinically. Further in vitro studies should evaluate, for instance, the possibility of this larger amplitude increasing the debris extrusion, especially in treatments of teeth presenting necrotic pulps.

Within the limitations of an in vitro model, it can be concluded that larger amplitudes of in-and-out movements increase the cyclic fatigue resistance of the WaveOne Gold reciprocating instrument.

Clinical Relevance

Reciprocating kinematics is claimed to diminish the risk of fracture of instruments. These instruments are recommended to be used in an in-and-out fashion with 3-4 mm of amplitude. This study showed that the variation of the amplitude of this movement impacts the risk of fracture of these instruments.

Conflict of Interest

The authors deny any conflicts of interest related to this study.

Acknowledgments

None.

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