Cyclic fatigue and torsional resistance of Gold-type thermally treated reciprocating instruments

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DOI: https://doi.org/10.14436/2358-2545.9.2.036-042.oar

ABSTRACT

Introduction: The aim of the present study was to evaluate the cyclic and torsional fatigue resistance of WA1 and WaveOne Gold instruments. **Methods:** Twenty instruments of the WA1 system (25/0.07v) and twenty instruments of the WaveOne Gold system (25/0.07v) were used. The cyclic fatigue resistance was tested by measuring the time to fracture in a stainless steel curved artificial canal with an angle of 80° and a radius of curvature of 3 mm (n = 10). The maximum torque and rotation angle at instrument failure (n = 10) were measured according to ISO 3630-1. The fracture surface of all the fragments was examined with a scanning electron microscope. The results were statistically analyzed using the student t-test with a significance level of 5%. **Results:** There were no differences in cyclic fatigue life of the tested instruments (P> 0.05). The maximum torsional force of the WA1 instruments was lower than the WaveOne Gold instruments (P <0.05); however, no differences were observed in the maximum rotation angle of both systems (P> 0.05). The scanning electron photomicrographs of the fracture surface revealed similar and typical characteristics of cyclic fatigue and torsional failure for the 2 types of instruments. **Conclusion:** Within the results of the present study, it can be concluded that WaveOne Gold and WA1 instruments had similar behavior regarding cyclic fatigue. However, WaveOne Gold instruments presented greater angular deflection to torsional fracture than WA1 instruments.

Keywords: Endodontics. Dental Instruments. Fatigue. Torsion, Mechanics.

How to cite: Barbosa EM, Costa LGS, Canavezes TCJ, Antunes HS, Vieira VTL, Silva EJNL. Cyclic fatigue and torsional resistance of Gold-type thermally treated reciprocating instruments. Dental Press Endod. 2019 May-Aug;9(2):36-42.
DOI: https://doi.org/10.14436/2358-2545.9.2.036-042.oar

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» The authors report no commercial, proprietary or financial interest in the products or companies described in this article.

Submitted: April 29, 2018. Revised and accepted: June 07, 2018.

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Introduction

Rotary nickel-titanium (NiTi) instruments have been widely used for root canal preparation.[1] Despite their numerous advantages, these instruments present a risk of fracture during their use, especially in curved canals, which might compromise the prognosis of endodontic treatment.[1-4] Many methods have been proposed and tested in order to prevent or reduce the fracture of instruments, such as modifications of activating kinematics[5] and modifications in NiTi alloys.[1,6] The introduction of reciprocating kinematics has been shown to be effective in increasing cyclic fatigue life and torsional stress of NiTi instruments when compared to continuous rotary kinematics.[7,8] In addition, the NiTi alloy heat treatment has been successfully used to improve the mechanical properties of endodontic instruments, increasing fatigue resistance, flexibility, cutting efficiency and canal centralization ability.[1,6,9-11]

The WaveOne Gold system (Dentsply Maillefer, Ballaigues, Switzerland) is the new generation of WaveOne (Dentsply Maillefer) instruments, maintaining the reciprocating kinematics, but with marked changes in its NiTi alloy, dimensions, cross section and geometry. The instruments are manufactured using a heat treatment, which results in a deposition of surface oxides giving a golden coloration to the instrument. The cross section of these instruments was modified to a parallelogram, with 2 cutting edges. In addition, the decentralized design similar to that used in the ProTaper Next (Dentsply Maillefer) instruments is also used in the WaveOne Gold system. Studies have demonstrated superior mechanical properties when these instruments were compared to their predecessors, WaveOne.[12-14] Recently, the WA1 reciprocating instruments (TDKaFiles, Mexico City, Mexico) were introduced into the dental market. These instruments have a design similar to that described above for WaveOne Gold instruments and are also manufactured using a heat treatment that generates an oxide layer on the surface of the instrument and a visually golden appearance. According to the manufacturer of the WA1 system, the heat treatment associated with its innovative design is capable of increasing the flexibility and fatigue resistance of these instruments. However, to date, no study has evaluated the mechanical properties of WA1 instruments.

In view of the availability and easy acquisition of this instrument in the dental market, associated to the absence of scientific studies, the aim of the present study was to evaluate the cyclic and torsional fatigue of WA1 instruments and to compare the results with those obtained by WaveOne Gold instruments. The null hypotheses tested were as follows:

1. There are no differences in the resistance to cyclic fatigue between instruments.
2. There is no difference in the maximum torque for the fracture of the instruments.
3. There is no difference in angular deflection until fracture of the tested instruments.

Materials and methods

Two NiTi reciprocating systems (WA1 with tip 25 and taper of 0.07v, lot number 16100106, and WaveOne Gold primary instrument with tip 25 and taper of 0.07v, lot number 1226916) were used in the present study. All instruments used (n = 40) were 25 mm long, with 10 instruments of each brand used in cyclic fatigue tests and 10 instruments of each brand used in torsional tests. All instruments were inspected under stereomicroscope (OPTZS; Opticam, São Paulo, Brazil) for defects or deformities, before the experiments were performed; no instrument was discarded.

Cyclic fatigue test

The cyclic fatigue test was performed using a custom-made device that allowed a reproducible simulation of an instrument confined in a curved canal, as described previously.[10,11,13,15,16] It consists of an artificial canal with 60° angle of curvature and 5 mm radius of curvature, with a diameter of 0.4 mm in the apical portion and taper of 0.08. The center of the curvature was 5 mm from the tip of the instrument, and the curved segment of the canal was 5.0 mm in length. The artificial canal was open in its upper part and covered with tempered glass to prevent the instruments from slipping out.

Ten WA1 and ten WaveOne Gold primary instruments were activated with a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Alemanha) powered by a torque-controlled motor (Silver Reciproc; VDW), according to the manufacturers´ recommendations ("WAVEONE ALL" mode). The electric handpiece was mounted on a device to allow for precise and reproducible placement of each file inside the simulated canal.

All instruments were driven following the manufacturer's instructions until fracture occurred. The instruments rotated freely within the simulated canal, which was filled with distilled water. All procedures were performed at 37°C inside a cabinet with temperature control. The time was recorded and the experiment stopped as soon as a fracture was detected visually and/or audibly.

Torsional test

The torsional load was applied until fracture to estimate the mean ultimate torsional strength and angle of rotation of the instruments tested using a custom made device produced following ISO 3630-1[17] and previously published studies.[15,18,19] Each file was clamped at 3 mm from the tip using a chuck connected to a torque-sensing load cell; after that, the shaft of the file was fastened into an opposing chuck able to be rotated with a stepper motor. All instruments were rotated in the clockwise direction at a speed of 2 rpm until file separation. The torque load (Ncm) and angular rotation (°) were monitored continuously using a torsiometer (ODEME; Luzerna, SC, Brazil), and the ultimate torsional strength and angle of rotation at failure were provided by a specifically designed computed program (ODEME Analysis TT; ODEME). All procedures were performed inside a cabinet under temperature control (37°C).

Scanning electron microscopic evaluation

A scanning electron microscope (SEM) (JSM 5800; JEOL, Tokyo, Japan) was used to analyze the fracture surfaces of all the tested instruments in order to observe the fracture mode. Different magnifications were used (× 250 and × 900).

Statistical analysis

Because the preliminary analysis of the raw pooled and isolated data revealed a bell-shaped distribution (Shapiro-Wilk normality test), statistical analysis was performed by using parametric methods (student t test). The alpha-type error was set at 0.05. Biostat (Instituto Mamirauá, Tefé, Brazil) was used as analytical tool.

Results

No differences were observed in the cyclic fatigue life between the instruments tested ($P > 0.05$). The maximum torque of the WA1 instruments was lower than the WaveOne Gold instruments ($P < 0.05$); however, no differences were observed in the angular deflection of both systems ($P > 0.05$). The averages and standard deviations of the resistance to cyclic fatigue, maximum torque and angular deflection until fracture of each instrument are presented in Table 1.

Scanning electron microscopy of the fractures surface showed typical characteristics of failure due to cyclic fatigue (presence of micro cavities on all surfaces) and by torsion (presence of microcavities in the core of the instrument and a smooth area generated by the plastic deformation due to the shear stresses) for the 2 types of instruments. The crack initiation area and the catastrophic failure zone for cyclic fatigue fractures and the concentric abrasion marks and fibrous microcavages at the center of rotation for torsional failure can be seen in Figure 1.

Table 1. Mean and standard deviation of fracture time (seconds), torque (Ncm) and angle of rotation (°) of the tested instruments.

Instrument	Time to fracture (sec)	Torque (Ncm)	Angle of rotation (°)
WA1	129 ± 27^{A}	1.4 ± 0.2^{A}	349 ± 40^{A}
WaveOne Gold	149 ± 15^{A}	1.4 ± 0.1^{A}	456 ± 21^{B}

Different letters in the same column represents statistical differences between the groups ($p < 0.05$).

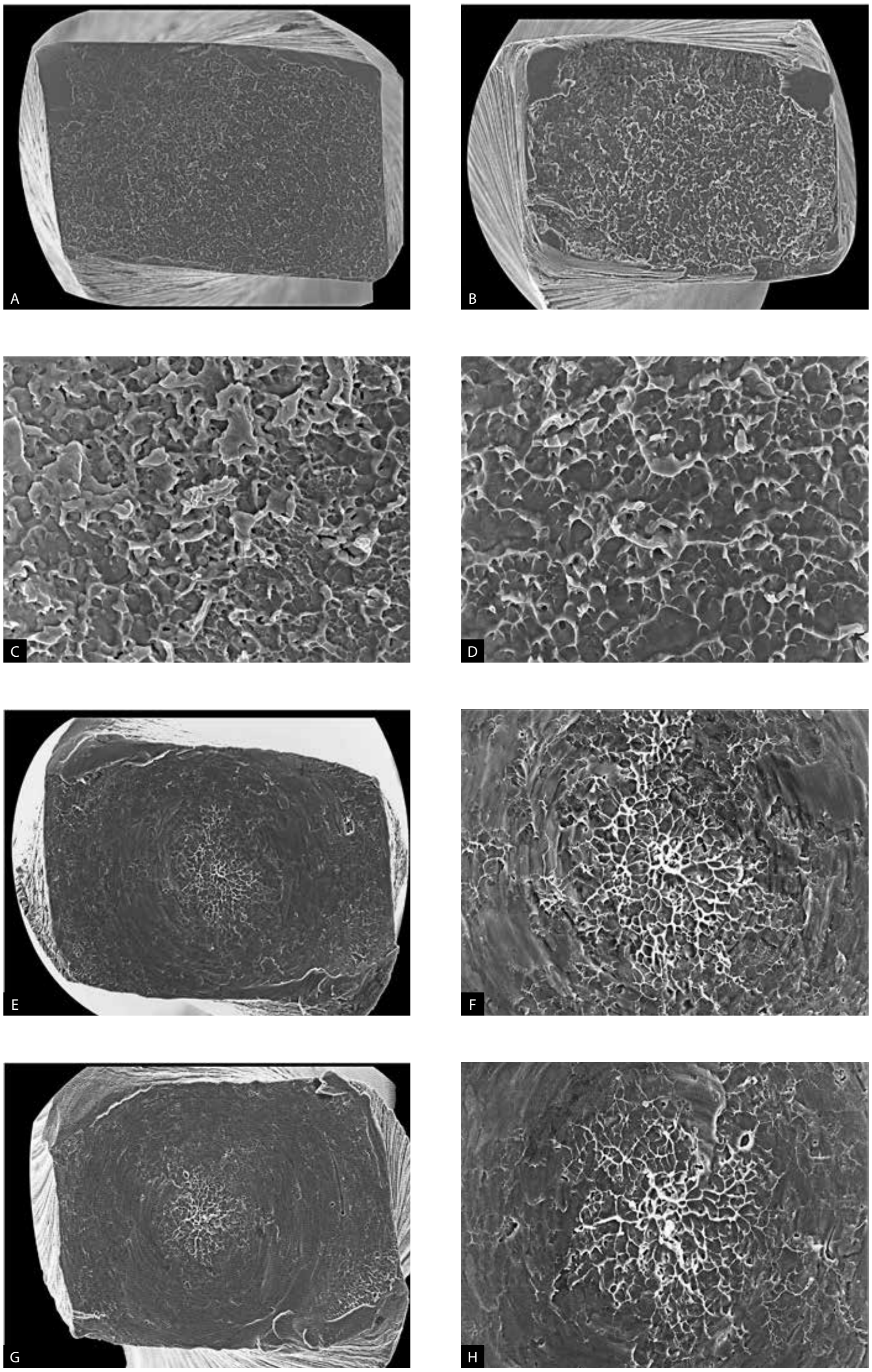

Figure 1. Scanning electron micrographs representative of the fracture surface of the instruments fractured under cyclic fatigue (**A, B, C, D**) and under torsion (**E, F, G, H**). A) WA1 (original magnification, × 250), **B**) WaveOne Gold (original magnification, × 250), C) WA1 (original magnification, × 900) and **D**) WaveOne Gold showing the typical appearance of fatigue failure. The images show areas of crack nucleation and catastrophic failure zones with characteristic ductile microcavity. The transverse micrograph of **E**) WA1 (original magnification, × 250), **F**) WaveOne Gold (original magnification, × 250), **G**) WA1 (original magnification, × 900) and **H**) WaveOne Gold showing the typical appearance of torsion fracture. The images indicate circular abrasion marks and microcapsules located in the instrument core.

Discussion

The fracture of NiTi rotary instruments can occur due to cyclic fatigue or shear stresses.[2,3] In the first scenario, the fracture is produced by normal cyclic and repetitive tensions of compression and traction acting at a point or in an area of the instrument as it rotates in a curved canal. The torsion fracture occurs when the tip of the instrument attaches to the canal, being immobilized while the base of the instrument continues to rotate.[2] Although it is difficult to correlate the findings of laboratory tests with a clinical situation, due to the number of variables that act together clinically to result in fracture of the instrument, access to the mechanical properties of the endodontic instruments is important to present preclinical information valid for the clinician. Such information is important, since the removal of fractured instruments from the root canals is extremely difficult and in some cases impossible. Since fractured instruments may have an adverse effect on the prognosis of endodontic treatment,[4] the reduction of fracture risk is essential from a clinical perspective. The recent introduction of thermally treated NiTi instruments has resulted in improved material properties with increased flexibility and resistance to cyclic fatigue when compared to conventional NiTi.[1,6,9,10-14,18,19] The aim of the present study was to compare two thermally treated NiTi reciprocating systems, WA1 and WaveOne Gold, for cyclic and torsional fatigue.

In this study, the methodology used to evaluate cyclic fatigue has already been validated and used in numerous articles published in scientific journals.[10,11,13,15,16,18,19] It is important to emphasize that there are no international specifications or standards for the evaluation of this property in endodontic instruments of NiTi alloys. A simulated canal was used for both instruments, standardizing possible anatomical variations of the canals that is non-existent in the present study. To ensure that NiTi instruments can travel in an exact and recurring path in terms of radius and angle of curvature, according to Plotino et al,[16] the artificial canal should resemble the tip size and taper of the instruments. In an attempt to reproduce clinical conditions, it was decided to simulate the action of the instruments, in the same simulated canal, in the circumstances closest to the body temperature, therefore, the tests were performed at 37°C.[20]

No differences were observed in the cyclic fatigue life of the WA1 and WaveOne Gold primary instruments ($P > 0.05$). Therefore, the first null hypothesis was accepted. The similar cross-sectional design associated with the same tip size and taper may be related to these results. Although it is not possible to state that the heat treatment carried out on the instruments has been the same, it is expected that both instruments have undergone similar treatments due to the layer of oxide (gold color) present on the surface of the instrument.

The maximum torque for fracture is an important aspect during the choice of an endodontic instrument, especially in constrict canals in which intense contact of the instrument with the root canal is expected. As previously mentioned, this type of fracture occurs when some part of the instrument is immobilized inside the root canal while the rest remains in motion. In this way, a torsional fracture can occur even in straight root canals. This information is not provided by the manufacturers, and in situations where the motor allows torque adjustment, the operator must adjust it below the maximum torque the instrument supports. The methodology used in the torsion test was also reported and validated in previous studies[15,18,19] and is recommended by an international guideline,[17] basically consisting of fixing the tip of the instrument while the body of the instrument is activated. The results of the torsion test did not show differences in the maximum fracture torque of the WA1 and WaveOne Gold primary instruments ($P > 0.05$) accepting the second null hypothesis. These findings indicate that both instruments require the same torque to fracture. The other mechanical property obtained in the torsion test was angular deflection, which showed that WaveOne Gold primary instruments had a significantly higher angle of rotation until fracture than WA1 instruments ($P < 0.05$), rejecting the third null hypothesis. These results indicate that WaveOne Gold instruments have greater elastic and plastic deformation prior to fracture and are therefore more resistant to torsional fracture than WA1 instruments. Angular deflection is a clinically important safety factor because it allows plastic deformation to be visualized on the instrument. Although the instruments have similar design, tip size and taper, small differences in the heat treatment may justify the differences found in the rotating angles of the WA1 and WaveOne Gold instruments. Moreover, in Figure 2 it is possible to clearly observe differences in the surface finish of the tested instruments, which may contribute for such difference of results.

Scanning electron microscopy analysis showed typical characteristics of rotational bending failure and torsion for both instruments evaluated in this study. After the cyclic fatigue test, the instruments

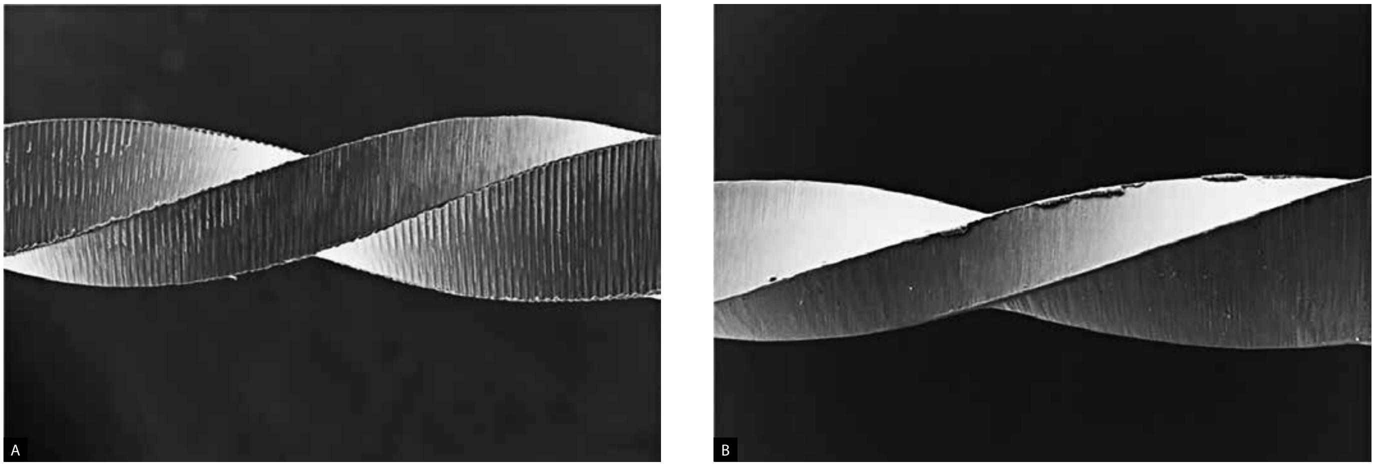

Figure 2. Scanning electron micrographs representative of the side surface of (**A**) WA1 (original magnification, × 250) and (**B**) WaveOne Gold (original magnification × 250) in which differences in finishing surface can be observed.

presented cracking nuclei and overload zones, with numerous microaves ("dimples" or "microvoids") scattered on the fracture surfaces. After the torsion tests, the fractured fragments analyzed showed concentric marks of abrasion (plastic deformation) and microcavity in the center of rotation (core of the instruments), characteristics widely found in the previous endodontic literature.[3,15,18,19]

Conclusion

Within the results of the present study, it can be concluded that the WaveOne Gold and WA1 instruments had similar behavior regarding cyclic fatigue. Both instruments withstand the same torque to fracture under torsion. However, WaveOne Gold instruments presented greater angular fracture deflection than WA1 instruments, which makes it clinically safer.

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