# Comparison of Cyclic Fatigue Resistance of WaveOne and WaveOne Gold Small, Primary, and Large Instruments

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## Abstract

**Introduction:** To compare the cyclic fatigue of resistance of WaveOne (WO; Dentsply Maillefer, Ballaigues, Switzerland) and WaveOne Gold (WOG, Dentsply Maillefer) small, primary, and large instruments in simulated root canals. Each instrument was rotated until fracture occurred. **Methods:** One hundred twenty nickel-titanium endodontic instruments were tested in two different curved artificial canals with different angles and radii of curvatures. WO and WOG small, primary, and large instruments were evaluated ($n = 10$ for each curvature). Each instrument was rotated until fracture occurred. The time to failure was recorded, and the length of the fractured tip was measured. An independent Student'*t* test was used to compare the means between the 2 groups. One-way analysis of variance and Tukey' post hoc tests were used for multiple comparisons ($P < .05$). **Results:** At all the sizes tested and both curvatures, the cyclic fatigue resistance of the WOG instruments was higher than that of the WO instruments of corresponding sizes ($P < .001$). The WOG instruments were approximately twice as resistant to failure as the WO instruments were at a 60° angle of curvature, whereas the WOG instruments were 3 times more resistant at a 90° angle of curvature. The length of the fractured part of the instruments was similar among all the groups ($P > .05$). **Conclusions:** Within the limitations of this study, WOG instruments were more resistant to cyclic fatigue than WO instruments. *(J Endod 2017;■:1–5)*



## Key Words

endodontics, M-Wire, reciprocating instruments, WaveOne Gold


### Significance

To avoid the unfavorable results caused by instrument fractures, clinicians should know the cyclic fatigue resistance of new concepts and designs in NiTi alloys such as WaveOne Gold.

For the past 2 decades, nickel-titanium (NiTi) rotary instruments have been commonly used to shape root canals because of their high flexibility and cutting efficiency (1, 2). However, in root canal treatment, NiTi rotary files can have unfavorable results because of instrument fracture, especially when the root canal is curved or narrow (3, 4). File separation can occur as a result of cyclic fatigue or torsional fracture (5). Cyclic fatigue occurs because of tension-compression stress cycles at the point of maximum flexure, especially when preparing canals exhibiting curvature, finally leading to fracture (6–8). Torsional fracture occurs when part of the instrument is locked to the dentin while the shank maintains to rotate (7). Cyclic fatigue is a major cause of the separation of NiTi rotary instruments during clinical use (9). In general, the cyclic fatigue resistance of NiTi rotary files has been tested using static models because they provide standardized conditions for each tested instrument (10). New concepts and designs in NiTi alloys, including thermomechanical improvements, have improved the cyclic fatigue resistance of NiTi-based instruments (5, 11).

Single-file reciprocation concepts have gained popularity since the introduction of Reciproc (VDW, Munich, Germany) and WaveOne (WO; Dentsply Maillefer, Ballaigues, Switzerland) reciprocating instruments to the market in 2011. Both instruments are manufactured from heat-treated NiTi M-Wire technology. WO is a single-instrument system that uses 2 different working patterns, a counterclockwise motion (cutting direction) and a clockwise motion (release of the instrument), to prepare root canals. When engaging with dentin and advancing in the canal, the instrument uses a large angle of rotation in the cutting direction (counterclockwise). In contrast, in the opposite direction (clockwise), it uses a smaller angle of rotation for safe progression through the canal and to reduce the risk of fractures and so-called "screw-in" tendency (12). Recently, WaveOne Gold (WOG, Dentsply Maillefer) systems have been introduced that use the same reciprocating motion as WO. WOG files have a modified cross section, size, and geometry compared with those of WO files. WO files have a convex triangular cross-sectional design (13). In contrast, WOG files have an off-center, parallelogram design, which provides an 85° active cutting edge, with alternate 1-point contact. WO and WOG files have modified tapers. WOG files are also smaller than those of WO files. WOG files are made using advanced metallurgy, and they are manufactured using heat treatment technology (14, 15). Their unique gold color comes from a thermal cycling procedure (heated and cooled slowly many times). The manufacturer claims that the gold technology design improves the flexibility of the file.

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In the literature, numerous studies have evaluated the cyclic fatigue resistance of WO instruments (1, 16). However, there is limited information in the literature on the cyclic fatigue resistance of WOG instruments (14, 15). The aim of the present study was to compare the cyclic fatigue resistance of WO and WOG (small, primary, and large) files used in reciprocating motions. The null hypothesis was that there would be no difference in the cyclic fatigue resistance of the various groups.

## Materials and Methods

One hundred twenty instruments were tested in this study. The WO and WOG files were evaluated in 2 curved artificial canals, with different angles and radii of curvatures. WO instrument systems with small (21/.06), primary (25/.08), and large (40/.08) files and WOG instrument systems with small (20/.07), primary (25/.07), and large (45/.05) files were selected for the cyclic fatigue resistance test ($n = 10$ in each test). Each instrument was inspected under a dental operating microscope to detect defects or deformities before the experiment. Whole defective instruments were discarded and changed with new ones.

Two simulated canals, one with a radius of 5 mm and a 90° angle of curvature and one with a radius of 3mm and a 60° angle of curvature, were prepared in a metal block as described previously by Larsen et al (10). The working length was adjusted to 19 mm. Synthetic oil (WD-40 Company, Milton Keynes, UK) was used for lubrication, and the stainless steel block was covered with a glass plate to prevent the instruments from slipping out and to observe the files during the experimental procedure. The instruments were allowed to rotate according to the manufacturers' instructions. The instruments were run using the motor (Silver Reciproc; VDW) in the "WAVEONE ALL" mode. For all instruments, the time until occurrence of fracture was recorded in seconds. The length of the fractured tip of the instruments was also recorded using a digital caliper (Digimatic; Mitutoyo Co, Kawasaki, Japan) (Fig. 1).

### Statistical Analysis

The collected data were analyzed with SPSS version 18.0 (SPSS Inc, Chicago, IL). The normal distribution of the variables was tested using the Kolmogorov-Smirnov test. An independent Student '*t* test was used to compare the means between the 2 groups. One-way analysis of variance and Tukey' post hoc tests were used for multiple comparisons. Data are given as the mean ± standard deviation. A $P$ value less than .05 was considered statistically significant (Fig. 2).

## Results

The results for the time to failure and length of the fractured part for each group are presented in Tables 1 and 2. There were statistically significant differences among the groups ($P < .001$). In both artificial canals, the WOG small, primary, and large files resulted in significantly higher cyclic fatigue resistance when compared with that of the corresponding WO small, primary, and large files ($P < .001$). The WOG small files and WOG primary files had the highest time to failure in the simulated canal with a 3-mm radius and a 60° angle of curvature. The WO

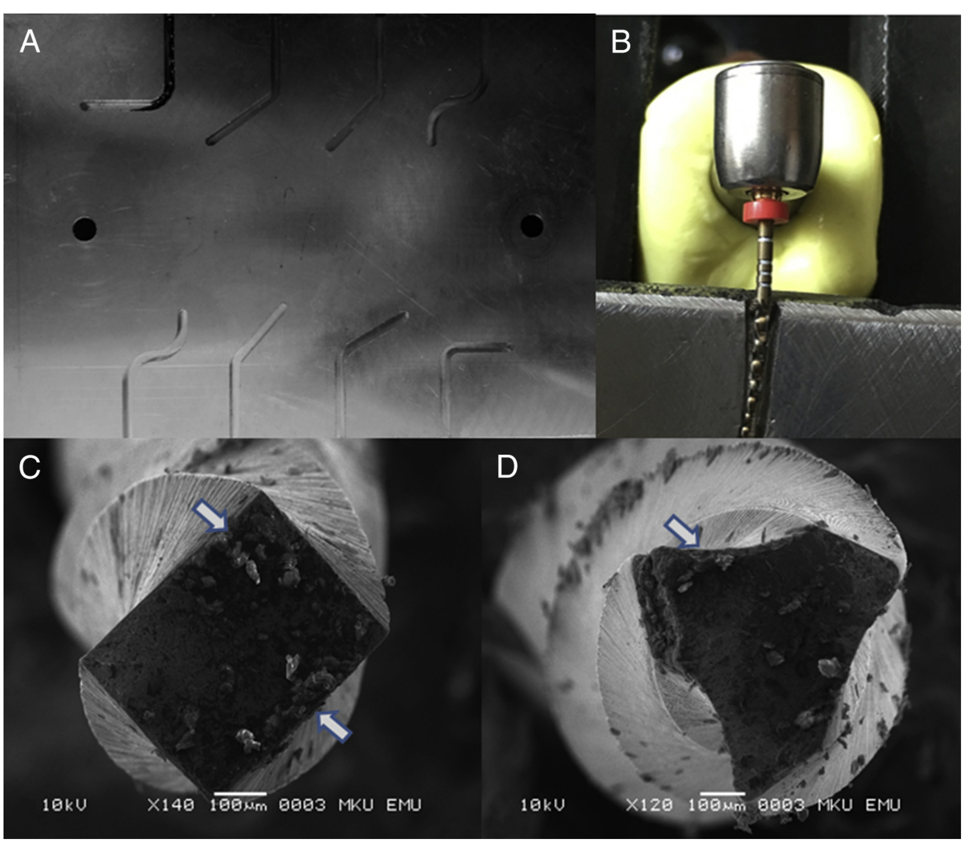


**Figure 1.** (*A*) A photographic image of the canal metal block. (*B*) A photographic image of the cycling testing device used for the fatigue test. (*C*) A representative scanning electron microscopic image of fractured WOG instruments. The *arrows* indicate the crack origin. The presence of fatigue striations and the absence of circular abrasion show the flexural fatigue failure (140×, original magnification). (*D*) A representative scanning electron microscopic image of fractured WaveOne instruments. The *arrows* indicate the crack origin. The presence of fatigue striations and the absence of circular abrasion show the flexural fatigue failure (120×, original magnification).

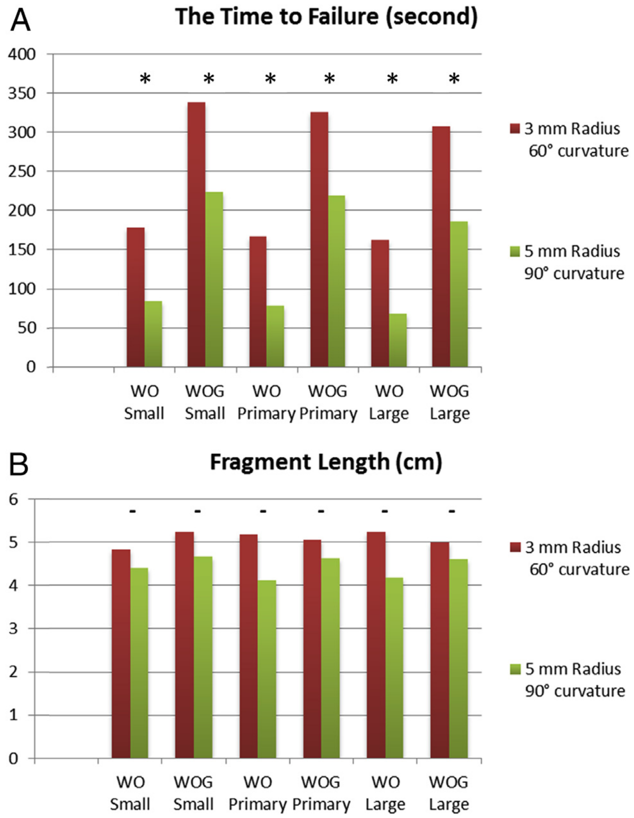


**Figure 2.** (*A*) The results for the time to failure for each group. (*) Significant differences ($P < .001$) arising from independent Student' *t* tests. (*B*) The results for the length of the fractured part for each group. (-) There was no significant difference in the length of the fracture fragment between instruments ($P > .05$).

large files had the lowest time to failure in the simulated canal with a 5-mm radius and a 90° angle of curvature. In addition, the cyclic fatigue resistance of the instruments working in the canal with the 3-mm radius and the 60° angle of curvature was significantly higher than that of the instruments working in the canal with the 5-mm radius and the 90° angle of curvature ($P < .05$). The WOG instruments were approximately twice as resistant to failure as the WO instruments were at the 60° angle of curvature, whereas the WOG instruments were 3 times more resistant at the 90° angle of curvature. The length of the fractured part of the instruments was similar among all groups ($P > .05$).

## Discussion

The design, heat treatment, cross-sectional shape, helical angle, and dimensions of endodontic instruments can have significant effects on their performance and mechanical properties (17–19). It is important that clinicians are aware of how these factors influence file separation. Selecting an instrument with higher fracture resistance could decrease instrumental fracture in clinical conditions (20).

In the literature, the cyclic fatigue resistance of endodontic instruments has been examined in various static and dynamic models. These include rotating the instruments against an inclined plane using a curved metal tube or a grooved block and 3-point bending (21). In cyclic fatigue experiments based on static models, an instrument-fixed working length is bended and then rotated until fracture occurs. Dynamic models are based on cyclic axial motion, which extends the lifetime of rotary files (22). Dynamic models replicate clinical conditions better than static models. However, a tooth can be used only once in these tests, and it is very difficult to ensure standardization and repeatability of the experimental conditions for each instrument. Thus, to eliminate mechanisms of file separation other than cyclic fatigue, the static model was preferred in the present study (23).

The present study compared the cyclic fatigue resistance of WOG and WO file systems. The results confirmed that the cyclic fatigue resistance of WOG small, primary, and large files at both curvatures was superior to that of the corresponding WO small, primary, and large files (Table 1). Thus, the null hypothesis that there would be no difference in the cyclic fatigue resistance of the tested files was rejected.

Currently, there is limited information in the literature on the cyclic fatigue resistance of WOG instruments. Recently, Topcuoglu et al (14) and Ozyurek (15) revealed that WOG primary files exhibited greater cyclic fatigue resistance than Reciproc R25 (VDW) and WO primary files. These reported studies are in accordance with the results of the present study. However, because no comparisons of the effects of WOG small and large file systems on cyclic fatigue resistance have been previously reported, a direct comparison with studies in the literature is not possible. On the other hand, many studies have compared the effect of WO systems and other systems on cyclic fatigue resistance (7, 16, 24). According to 1 study, the reciprocating movement of WO increased the cyclic fatigue lifetime compared with traditional rotary movement (16). WOG file systems use the same motion and kinematics as WO file systems. However, according to the manufacturer, the WOG file systems have numerous innovations.

Some previous studies concluded that the cross section had no effect on cyclic fatigue resistance (21, 25), whereas others came to the opposite conclusion (26, 27). At present, there is no consensus on

**TABLE 1.** Mean Values (± Standard Deviation) for the Time to Failure and Fragment Length (between the 2 Groups)

| Slopes | Groups | *n* | The Time to Failure | Fragment length |
|---|---|---|---|---|
| 3-mm radius 60° curvature | WaveOne small | 10 | $178.7 \pm 16.2^a$ | $4.82 \pm 0.07^a$ |
| | WaveOne Gold small | 10 | $338.4 \pm 25.4^b$ | $5.23 \pm 0.35^a$ |
| | WaveOne primary | 10 | $167.4 \pm 11.9^a$ | $5.18 \pm 0.78^a$ |
| | WaveOne Gold primary | 10 | $325.4 \pm 19.5^b$ | $5.05 \pm 0.71^a$ |
| | WaveOne large | 10 | $162.8 \pm 15.1^a$ | $5.23 \pm 0.28^a$ |
| | WaveOne Gold large | 10 | $307.4 \pm 19.7^b$ | $4.99 \pm 0.98^a$ |
| 5-mm radius 90° curvature | WaveOne small | 10 | $84.1 \pm 10.2^a$ | $4.41 \pm 0.28^a$ |
| | WaveOne Gold small | 10 | $223.3 \pm 15.3^b$ | $4.66 \pm 0.21^a$ |
| | WaveOne primary | 10 | $79 \pm 7.2^a$ | $4.12 \pm 0.28^a$ |
| | WaveOne Gold primary | 10 | $218.7 \pm 18.6^b$ | $4.62 \pm 0.35^a$ |
| | WaveOne large | 10 | $68 \pm 7.5^a$ | $4.17 \pm 0.63^a$ |
| | WaveOne Gold large | 10 | $185.8 \pm 14.3^b$ | $4.6 \pm 0.7^a$ |

Different superscript letters display a significant difference between groups.

**TABLE 2.** Mean Values (± Standard Deviation) for the Time to Failure and Fragment Length (Multiple Comparisons)

| Slopes | Groups | *n* | The Time to Failure | Fragment length |
|---|---|---|---|---|
| 3-mm radius | WaveOne small | 10 | 178.7 ± 16.2[a] | 4.82 ± 0.07[a] |
| | WaveOne Gold small | 10 | 338.4 ± 25.4[b] | 5.23 ± 0.35[a] |
| | WaveOne primary | 10 | 167.4 ± 11.9[a] | 5.18 ± 0.78[a] |
| 60° curvature | WaveOne Gold primary | 10 | 325.4 ± 19.5[bc] | 5.05 ± 0.71[a] |
| | WaveOne large | 10 | 162.8 ± 15.1[a] | 5.23 ± 0.28[a] |
| | WaveOne Gold large | 10 | 307.4 ± 19.7[c] | 4.99 ± 0.98[a] |
| 5-mm radius | WaveOne small | 10 | 84.1 ± 10.2[a] | 4.41 ± 0.28[a] |
| | WaveOne Gold small | 10 | 223.3 ± 15.3[b] | 4.66 ± 0.21[a] |
| | WaveOne primary | 10 | 79 ± 7.2[a] | 4.12 ± 0.28[a] |
| 90° curvature | WaveOne Gold primary | 10 | 218.7 ± 18.6[b] | 4.62 ± 0.35[a] |
| | WaveOne large | 10 | 68 ± 7.5[c] | 4.17 ± 0.63[a] |
| | WaveOne Gold large | 10 | 185.8 ± 14.3[d] | 4.6 ± 0.7[a] |

Different superscript letters display a significant difference between groups.

this topic. The WOG instruments have a parallelogram design with cutting edges and alternate 1-point contact. WO files have a modified convex triangular cross-sectional design. It is possible that the design, including the reduction in the number of touch points between the file and the root canal wall, might result in increased cyclic fatigue resistance. The different cross-sectional designs of the instruments may have influenced the results of the present study (28, 29).

Heat treatment or thermomechanical treatment is 1 of the main ways of influencing the transformation behavior of NiTi alloys. Near-equiatomic NiTi alloys are the result of a single-stage transformation (austenite [A]-martensite [M]) or a 2-stage transformation (A-R-M) depending on the thermomechanical treatment (11). In general, nickel-rich NiTi alloys show a single-stage transformation from A to M. Two-stage A-R-M transformation take places after additional heat treatment, which creates finely dispersed $Ti_3Ni_4$ precipitates in the austenitic matrix. When stress exceeds the critical level, NiTi alloys undergo phase transformation because of superelasticity or pseudoelasticity (11, 15). By modifying the transformation temperatures (austenitic start and austenitic finish) of WOG files, heat treatment can provide a positive impact on the properties of the files. M-Wire is the result of a premanufactured heat treatment process, whereas gold heat treatment is a postmanufacture procedure. The manufacturer claims that this process gives the WOG files more strength and flexibility than WO file systems.

The taper of the files may also explain the superior performance of WOG instruments compared with that of WO instruments. It is well-known that the cyclic fatigue of rotary files decreases with increasing file diameters (30, 31). Decreasing/increasing the diameter and the metal mass of the instrument at the maximum stressed point are important factors in the cyclic fatigue life of rotary instruments (26, 30). In recent years, manufacturers have tended to produce lower taper files to ensure a more conservatively shaped canal. Lower taper files could enhance the fatigue resistance of NiTi endodontic files. The present study tested WO files with 21/.06, 25/.08, and 40/.08 sizes and WOG files with 20/.07, 25/.07, and 945/.05 sizes. Therefore, the results of this study could have influenced the cyclic fatigue resistance of the files.

In this study, we tested the files in 2 curved artificial canals with different angles and radii of curvatures and compared the results. According to the results, the curvature of the artificial canals had a significant influence on the time to fracture of the files. Previous studies reported that the curvature radius and angle of curvature influenced the time to fracture of files (16, 30). Similarly, in the present study, the time to fracture of each of the tested instruments was lower in the canal with the 5-mm radius and the 90° angle of curvature than in the canal with the 3-mm radius and the 60° angle of curvature.

## Conclusions

Within the limitations of this study, the cyclic fatigue resistance of the WOG file system was better than that of the WO file system.

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