BMC Oral Health

RESEARCH

Open Access

# Comparison of cyclic fatigue resistance of three different single-file systems after clinical use

Kübra Gürler[1*], Sehnaz Yilmaz[1], Aysin Dumani[1] and Oguz Yoldas[1]

## Abstract

**Background** Nickel titanium (NiTi) rotary files have drastically altered the treatment protocol in endodontics, allowing for faster and easier preparation and more thorough irrigation of the root canal system. Despite the advantages of the NiTi files, instrument separation still remains a major concern. The aim of this study was to compare the cyclic fatigue resistance of three different single-file NiTi systems after clinical use: WaveOne Gold (WOG, Dentsply Maillefer, Ballaigues, Switzerland), One Curve (OC, Micro Mega, Besancon, France), and Reciproc Blue (RPC Blue, VDW, Munich, Germany).

**Methods** A total of 120 patients requiring endodontic treatment to first or second mandibular molars, were randomly divided into three groups (patient $n=40$) and root canals were prepared with WOG, OC or RPC Blue. Each group consists of 2 subgroups: first use (file $n=10$, patient $n=10$) and third use of file (file $n=10$, patient $n=30$). In control group, files were subjected to cyclic fatigue test without use (file $n=10$). Cyclic fatigue resistance of files was assessed by groove method. The data was evaluated by two-way ANOVA, Games & Howell post hoc and Weibull reliability analyses ($p<.05$).

**Results** RPC Blue files showed the highest failure time value in all groups. In third use group, OC and RPC Blue files showed significantly higher failure time values compared to WOG files ($p<.05$). In general, RPC Blue files show the highest values in terms of number of cycles to fracture (NCF) in all groups, while OC and WOG files follow RPC Blue files respectively. There was statistically significant difference among groups considering the fragment length ($p<.05$).

**Conclusions** Within the limitations of this study, RPC Blue files exhibited highest cyclic fatigue resistance after clinical use.

**Keywords** Cyclic fatigue, Nickel-titanium, Reciprocation, Rotation, Single-file systems

## Background

Instrument fracture during endodontic treatment continues to cause problems for clinicians [1]. The stainless-steel files lack sufficient flexibility, which can lead to iatrogenic errors such as apical transport along with ledge and zip formation, particularly in curved root canals. In order to overcome this issue, nickel titanium (NiTi) files have been developed to minimize the risk of

*Correspondence:
Kübra Gürler
gurlerkubra@hotmail.com
[1] Faculty of Dentistry, Department of Endodontics, Cukurova University, Adana 01330, Turkey

© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

such errors and to facilitate faster root canal shaping [1, 2].

NiTi files can be used to prepare curved canals because of their high corrosion resistance, superelasticity, shape memory, and biocompatibility [3, 4]. Despite the advantages of NiTi files, their main disadvantage is fractures, which occur for various reasons during use [5, 6]. Although there are many reasons for file failure, cyclic fatigue is one of the most important [7, 8]. Cyclic fatigue resistance has been evaluated in vitro with many different test methods, such as three-point, curved groove, and curved surface test methods [9–11]. All these tests are performed when the cutting efficiency of the file is inactive.

Cyclic fatigue resistance studies are frequently conducted with new instruments to maintain standardization and to evaluate the manufacturing processes of files with various kinematic, taper, and cross-sectional designs [12, 13]. Conflicting results can be seen in the literature caused by differences in methodology, despite the use of newly produced files [14].

The Reciproc Blue (RPC Blue; VDW, Munich, Germany), WaveOne Gold (WOG; Dentsply Maillefer, Baillagues, Switzerland), and One Curve (OC; Micro Mega, Besancon, France) are thermomechanically treated NiTi files and single-file systems. RPC Blue is a new-generation reciprocal file produced by a heating–cooling method that results in a Blue color due to the titanium oxide layer [15]. It has an S-shaped cross-section, two cutting edges, and a noncutting tip. It has higher flexibility and lower bending strength than Reciproc files and is twice as resistant to cyclic fatigue [16].

The WaveOne Gold file is produced by Gold-wire technology and subjected to a special thermal treatment that, when slowly cooled, results in its distinctive golden color. At the same time, the durability and flexibility of files have significantly increased. WOG files with a parallelogram cross-section have only one cutting edge in contact with the canal wall during movement, alternating with its noncentral cross-section, reducing the attachment and screwing effect of the file on the canal wall [17].

The OC file, which works with continuous rotation movement, has C-wire technology. C-wire is a new proprietary alloy that is first electropolished and then heat treated. In addition, these files are produced in different cross-sectional designs on the same file in such a way that the apical third remains in the center and debris is removed in the middle and coronal thirds [14].

In their package inserts, manufacturers recommend the single use of NiTi instruments. These recommendations could be related to the cumulative effect of instrument reuse on cyclic fatigue resistance and the conviction that sterilization cannot be achieved. Previously, several researchers assessed the effects of the clinical use of sequenced NiTi rotary files on cyclic fatigue resistance. The authors enlarged each root canal with 5 or 6 files and presented the results for each file by different taper and tip diameters [18, 19]. However, there is limited information about the effect of repeated clinical use on the cyclic fatigue resistance of heat-treated single-file instruments. A cumulative effect on single-file systems, which prepare root canals with one file, could exist. Thus, the aim of the present study was to evaluate the effect of repeated clinical use on the cyclic fatigue resistance of RPC Blue, WOG, and OC NiTi rotary single-file systems produced by thermomechanical methods. The first null hypothesis was that there would be no difference in cyclic fatigue resistance among the tested files. The second null hypothesis was that there would be no difference in the amount of clinical use in relation to the cyclic fatigue life of the tested files.

## Methods

The manuscript of this laboratory study was written according to the Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) 2021 guidelines (Fig. 1).

### Patient selection

Ethical approval was obtained from the Non-Interventional Clinical Research Ethics Committee of the … University Faculty of Medicine (reference no.: IRB/21/2019). As a result of the pilot study, the effect size for the difference between NCF in all experiments of 3 groups was obtained as f = 0.70. Based on this value, the sample size was calculated as a minimum of 10 files per group*experiment and a total of 90 files with 5% error and 90% power.

A total of 120 patients—75 females and 45 males—with a noncontributory medical history who presented to the … University, Faculty of Dentistry, Endodontic Clinic between January 2019 and January 2020—were selected according to the inclusion and exclusion criteria. All patients were aged between 20 and 60 years. All selected teeth were first or second lower molars with 3 canals that were symptomatic or asymptomatic and periodontally healthy. Mature teeth that maintained apical patency employed #15 K type file with no obvious calcification on periapical radiographs were included. The curvatures of the selected teeth (10° or less) were assessed by the Schneider method using periapical radiographs obtained with both parallel and mesially angulated techniques. Teeth with previous root canal treatment or with C-shaped, curved or extra canals were excluded from the study. Pulpal and periodontal status were not considered.

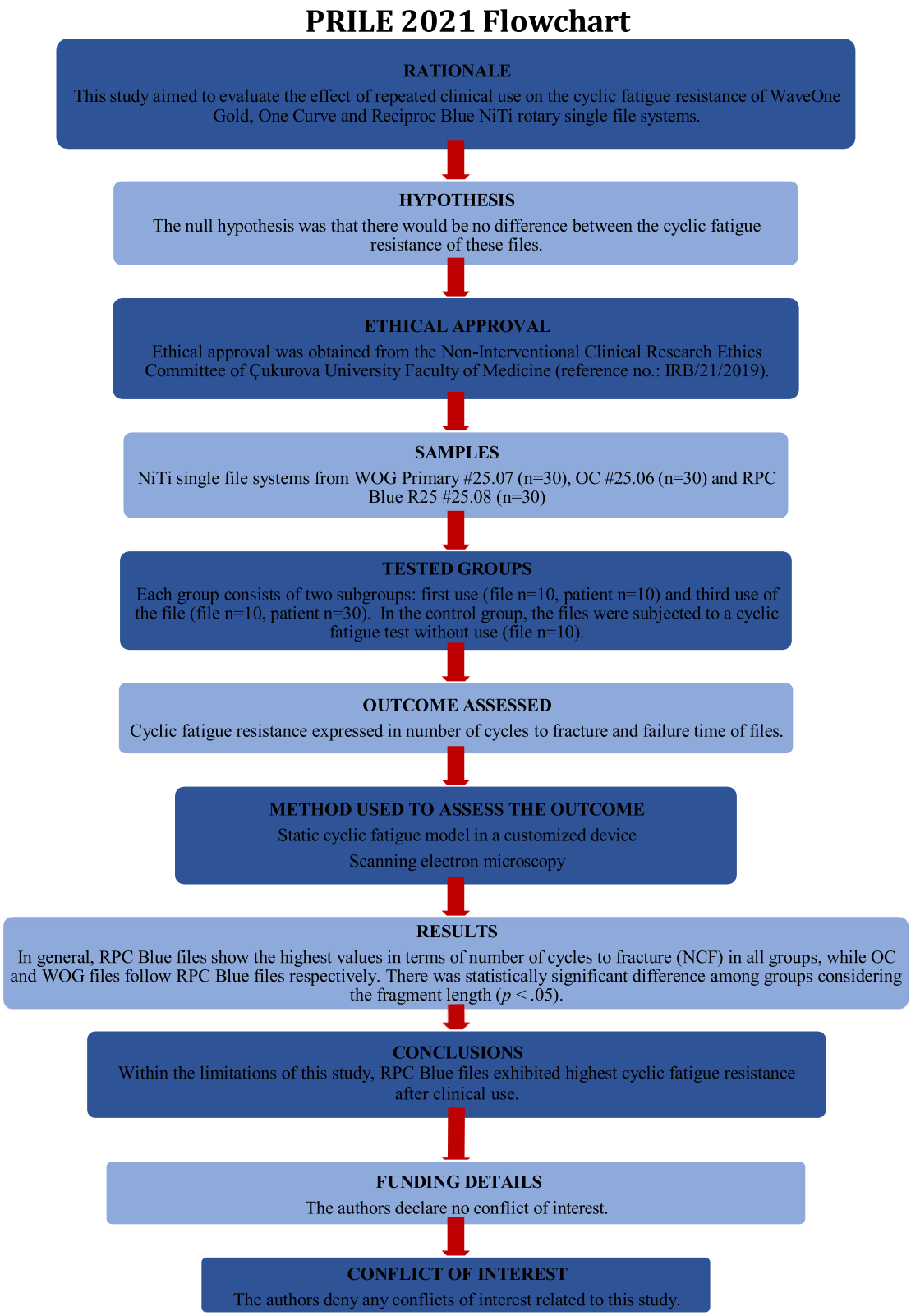



**Fig. 1** PRILE 2021 Flowchart

Pregnant and breastfeeding women were excluded. All patients provided informed consent.

### Group randomization

Thirty WOG Primary (25/0.07), OC (25/0.06) and RPC Blue R25 (25/0.08) files were used for the present study. Each file was numbered according to its own blister, and randomization blocks were created via computer-based allocation (www.randomizer.org). Each file brand was randomly divided into three groups ($n=10$): control, first use and third use. For the control group, files were subjected to a cyclic fatigue test without clinical use. The files were used for patients who were included in the study, according to randomization blocks.

### Clinical procedures

All root canal treatment procedures were performed by an endodontic specialist (K.G). The teeth were isolated using a rubber dam. Caries or coronal restorations were completely removed, and the access cavities were prepared with round diamond burs. Patients were excluded from the study if any variation or canal calcification was detected during the localization of the canal orifices. The working length of the canals was established with a #10 K type file by using an electronic apex locator, Woodpex III (Woodpecker Medical Instrument Co., Guilin, China), and periapical radiographs were taken for confirmation. If there was a discrepancy, an electronic measurement was selected. After determining the working length, a reproducible canal path was created with the #15 K type file, and root canal preparation was completed according to the groups. The WaveOne Gold Primary was used in the WaveOne All mode of the endodontic motor (VDW Silver; VDW, Munich, Germany). One curve was used in the endodontic motor (VDW Silver) at 300 rpm and 2.5 N.cm torque. Reciproc Blue R25 was used in the Reciproc All mode of the endodontic motor (VDW Silver). The files were used with three pecking motions for each insertion, and each insertion was limited to 3 mm during the preparation procedures. The file was removed and cleaned at each insertion, and the canals were irrigated with 2 ml of 2.5% NaOCl solution. These procedures were continued until the files reached the working length. Canal irrigation was completed by using 10 ml of 2.5% NaOCl between the insertions. The final irrigation was performed with 2 ml of distilled water, 17% EDTA and 2 ml of distilled water. The root canals were dried with paper points and then obturated with gutta percha and Adseal (Meta Biomed, Korea) root canal sealers using the cold lateral condensation technique. The teeth were restored with composite resins. The WOG2, OC2 and RPC Blue2 file groups were autoclaved after their first and second use.

### Cyclic fatigue test

The artificial canal used for the cyclic fatigue test was designed in the Autocad program (Autodesk Inc., USA) and was produced from stainless steel blocks by grinding with a computer numerically controlled (CNC) machine. An artificial canal made of stainless steel with an angle of curvature of 60°, radius of curvature of 5 mm and inner radius of 1.5 mm was designed according to the criteria set by Pruett et al. [20]. The starting point of the curvature of the artificial canal is located 5 mm coronal to the apex.

All files were used according to the manufacturer's recommendations at appropriate torque and speed values until they broke within the artificial canal. The time until the file breakage that was detected visually or audibly was measured with a digital chronometer and recorded in seconds. The number of cycles to failure (NCF) for each file was calculated by multiplying the time (seconds) to failure by the rotational speed per minute. The lengths of the broken files were measured with a digital caliper and recorded. The artificial canal was covered with glass to prevent the instruments from slipping. The artificial canal was lubricated with a synthetic lubricant (WD-40 Company, Milton Keynes, U.K.) to minimize friction between the artificial canal walls and the files. The synthetic lubricant in the artificial canal was renewed between each test.

### Scanning electron microscopy analysis

Two randomly selected specimens from each group were examined under a scanning electron microscope (SEM, Quanta™ 650 FEG, FEI, Oregon, USA) to assess the topographic features of the fractured instrument and the mode of fracture. The fractured areas were examined at magnifications of 500× and 2500×.

### Statistical analyses

Statistical analysis was performed with SPSS software version 20.0 (IBM-SPSS Inc., Chicago, IL). The fracture times and fracture lengths of the files are summarized as the mean and standard deviation. The means of the fracture times and fracture lengths between the groups were analyzed by two-way ANOVA. Due to the inhomogeneity of the variances, Games & Howell post hoc analysis was used for pairwise group comparisons. The maximum number of cycles predicted for 99% survival of files was calculated using Weibull reliability analysis. The statistical significance level was set at 5%.

## Results

The mean ages of the female and male patients included in the study were 34.03 and 36.27 years, respectively. No significant differences were found between the sexes of

the patients ($p > 0.05$). Only one RPC Blue file was separated in the canal during the second use. Therefore, cyclic fatigue tests were applied to nine files in the RPC Blue 2 group.

### Time to fracture and segment length

The means and standard deviations (SDs) of the time to fracture (TTF) and segment length are shown in Table 1. The intragroup comparisons of the control, first, and third uses showed no significant differences in segment length among the groups ($p > 0.05$). However, the OC group, which had the lowest segment length, showed significant differences compared to the WOG and RPC Blue groups ($p < 0.05$). A statistically significant difference was found among the groups according to the TTF values ($p < 0.05$). The RPC Blue files showed the highest TTF values, and the WOG files showed the lowest TTF values. The intragroup comparison among the control, first, and third uses showed that the first use had significantly higher mean TTF values than the control and third uses of the RPC Blue files.

### Cycle Numbers (NCF Values) and Weibull analysis

The mean SDs of the NCFs, Weibull moduli, R2 values, Weibull predicted maximum cycles, and failure times for 99% survival are listed in Table 1. Multiple comparisons of the mean NCFs revealed a significant difference among the groups ($p < 0.05$), and the RPC Blue group exhibited higher cyclic fatigue resistance than the OC and WOG groups. The intergroup comparison of the control and first-use files revealed that the RPC Blue group had the highest NCF, followed by the OC and WOG groups ($p < 0.05$). In the third-use group, the WOG had the lowest NCF, followed by the OC and RPC Blue ($p < 0.05$).

As a result of the Weibull reliability analysis, it was observed that as the number of uses of the WOG files increased, the predicted cycles and time to 99% survival decreased significantly, while in the OC files, the predicted cycles and time to 99% survival increased significantly. Considering the RPC Blue files, the number of cycles predicted for 99% survival in the first use increased compared to that in the new file. In contrast, this value decreased in the third use (Figs. 2–3).

### SEM evaluation

Scanning electron microscopy images of the fracture surface revealed the nature of the mechanical characteristics of the cyclic fatigue failure in all the groups. The presence of rough surfaces, micropores and fracture initiation lines in the photomicrographs obtained by SEM analysis indicate that the fractures occurred due to cyclic fatigue. Following the cyclic fatigue test, the files showed crack

**Table 1** Descriptive for fractured segments, lengths, NCF, time to fracture, and Weibull calculations for each group

| Instrument | Experiment | n | Fragment Length (mm) ± SD | Number of cycles to Fracture mean±SD | Time to fracture (sec), mean±SD | Weibull modulus | $R^2$ value | Predicted cycles for 99% survival | Predicted time (sec) for 99% survival |
|---|---|---|---|---|---|---|---|---|---|
| | Control | 10 | 6,57±1,01 [a] | 967,0±171,5 [a] | 165,8±29,4 [a] | 6.58 | 0.91 | 513.03 | 87.95 |
| Group 1 WOG | WOG 1 | 10 | 6,3±0,22 [a] | 941,0±324,2 [a] | 161,3±55,6 [a] | 3.22 | 0.94 | 250.68 | 42.97 |
| | WOG 2 | 10 | 6,19±0,84 [a] | 486,1±376,5 [a] | 83,3±64,5 [a] | 1.13 | 0.99 | 9.31 | 1.60 |
| | Control | 10 | 5,06±0,24 [b] | 1029,4±150,9 [a] | 205,9±30,2 [a] | 7.44 | 0.98 | 589.28 | 117.86 |
| Group 2 OC | OC 1 | 10 | 5,15±0,25 [b] | 1319,4±238,3 [a] | 263,9±47,7 [a] | 6.17 | 0.96 | 671.47 | 134.29 |
| | OC 2 | 10 | 5,25±0,29 [a,b] | 1540,3±276,2 [b] | 308,1±55,2 [b] | 7.37 | 0.81 | 874.15 | 174.83 |
| | Control | 10 | 7,89±0,55 [a] | 2250,0±440,8 [b] | 450,0±88,2 [b] | 5.40 | 0.97 | 1037.60 | 207.52 |
| Group 3 RPC Blue | RPC Blue 1 | 10 | 7,01±1,1 [a] | 3877,2±1106,3 [c] | 775,4±221,2 [c] | 3.70 | 0.89 | 1235.73 | 247.15 |
| | RPC Blue 2 | 9 | 5,45±1,19 [a,b] | 2134,0±1028,9 [b] | 426,8±205,8 [b] | 2.06 | 0.97 | 260.68 | 52.14 |

Each superscript letter denotes a subset of experiment

Different superscript letters indicate significant differences in each column ($p < 0.05$)

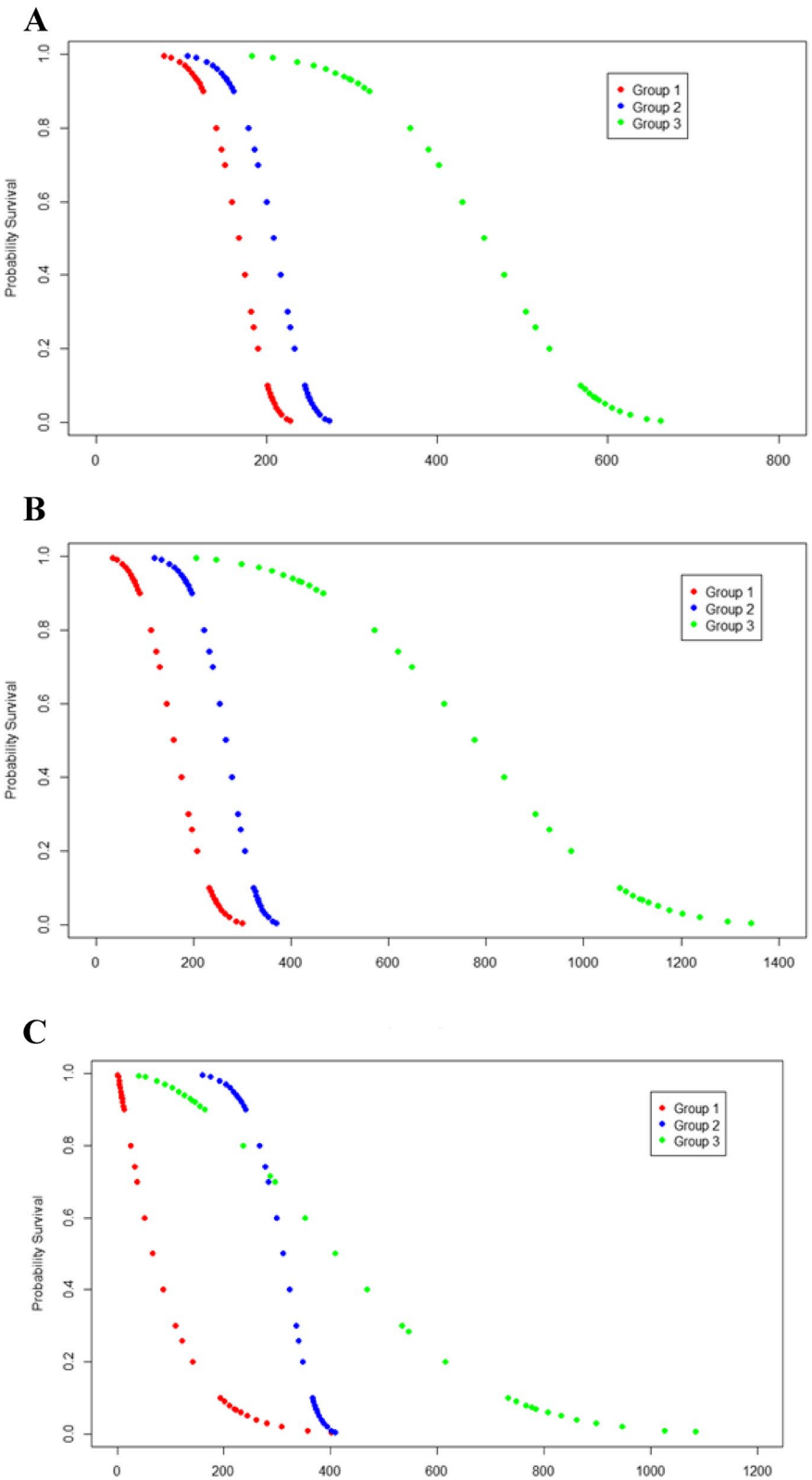



**Fig. 2** Reliability plots for the (**A**) control, (**B**) first-use, and (**C**) third-use groups. The reliability plots were calculated from the Weibull distribution function, which correlated the probability of survival to the failure time

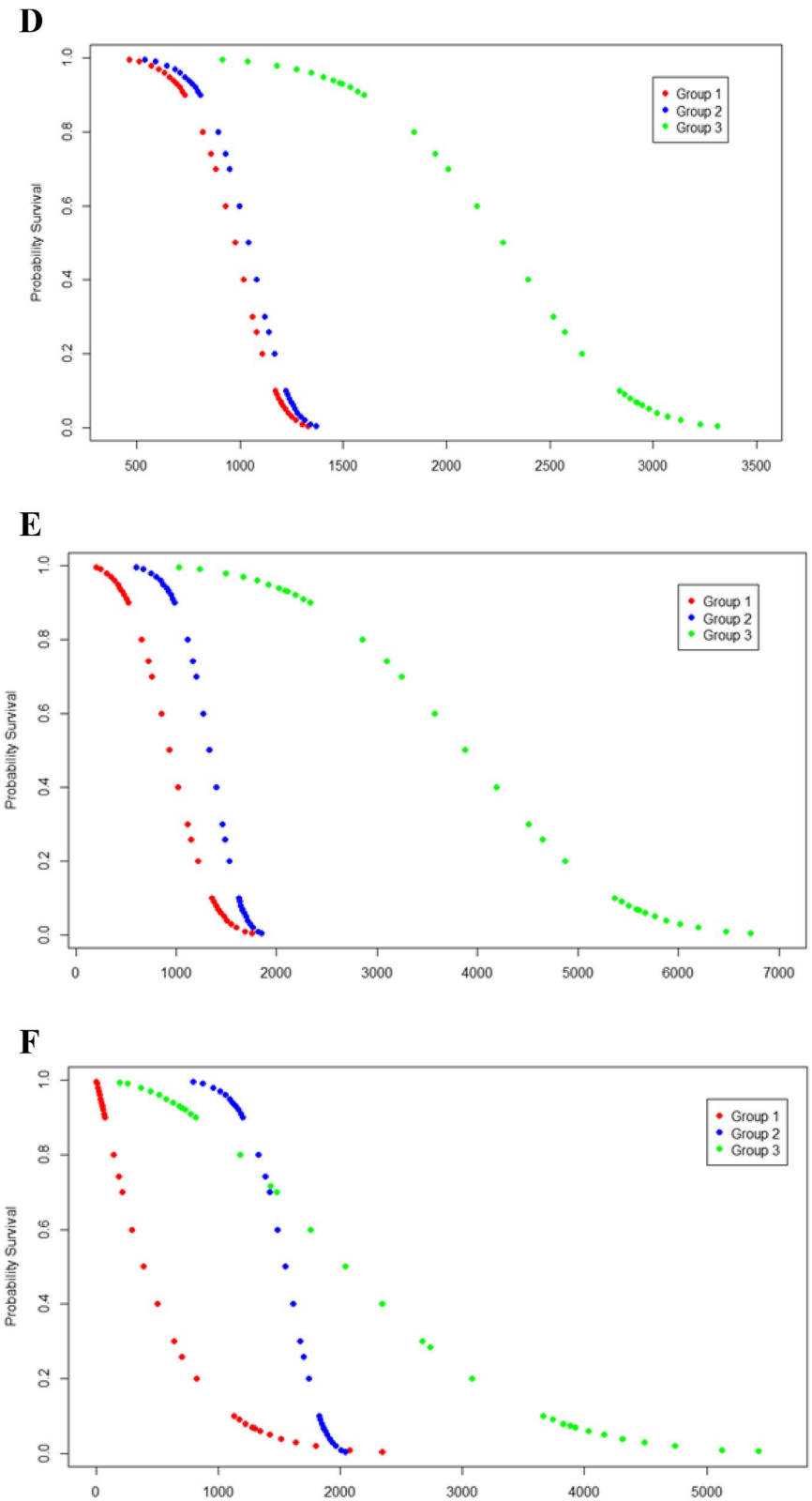



**Fig. 3** Reliability plots for the (**D**) control, (**E**) first-use, and (**F**) third-use groups. The reliability plots were calculated from the Weibull distribution function, which correlated the probability of survival to the NCF

initiation areas and overload zones with numerous dimples spread on the fractured surface (Fig. 4).

## Discussion

This study evaluated the effect of repeated clinical use on the cyclic fatigue resistance of WOG, OC, and RPC Blue single-file systems. According to the results, the RPC Blue files were found to be significantly more resistant to cyclic fatigue than the OC and WOG files. Thus, the first null hypothesis of the present study was rejected.

In in-vitro studies, extracted human teeth or resin blocks were frequently employed to investigate cyclic fatigue resistance of NiTi rotary files [21, 22]. Resin blocks currently provide an acceptable experimental model with standard root canal curvature angle and radius [23]. However, resins have a lower microhardness value than dentin; therefore, the excess debris generated during preparation may lead to file binding and failure, posing challenges in accurately simulating clinical conditions [23–25]. In studies involving extracted teeth, the experimental setups include embedding the teeth in resin blocks with impression material to better reflect clinical conditions. Despite these efforts, the physiological environment; such as body temperature, blood, body fluids, connective and hard tissues of the teeth, and the angle of access for the handpiece, may also differ under clinical conditions [26]. Another important point to consider is the difference in using NiTi rotary files on a patient versus an extracted tooth, as the operator applies varying angles, pressures, and time intervals in clinical settings [18, 19]. All the aforementioned factors may influence the cyclic fatigue of the files; thus, in this study, the tested files were used on patients to more accurately simulate clinical conditions.

The files are subjected to lower tensile and compressive stress operating in reciprocal movement that results employing longer period of time before failure [27]. Thus, this issue positively contributes to the cyclic fatigue resistance of files [28]. In their systematic review, Ferreria et al. concluded that reciprocating movement has an improving effect on the NCF compared to continuous movement [29]. Interestingly, the reciprocating RPC Blue files showed the highest NCF values, while the other reciprocating file, the WOG, showed the lowest NCF values in the present study. Many studies in literature support the conclusions of the current study by finding that RPC Blue files have higher NCF values than WOG files [12, 16, 30].

According to the results of the present study, OC files operating in continuous movement have significantly higher NCF values than reciprocating WOG files as well as showed unexpectedly increasing NCF values with use. An increase in the NCF accompanied an increase in the number of predicted cycles, resulting in a 99% increase in survival according to the Weibull analysis. As stated by the manufacturer of the OC file, C-wire technology increases cyclic fatigue resistance by providing the file more flexibility, the ability to prebend for easier access to the root canal and a controlled memory feature [31]. All the aforementioned factors may explain higher NCF values of OC files.

Martensitic NiTi files are more resistant to cyclic fatigue at body and room temperature [32]. Heat treatments of NiTi alloys strongly influence the martensitic/austenitic transformation behaviour, favouring a different arrangement of the crystalline structure and a higher percentage of martensitic transformation [33]. Thus, the cyclic fatigue resistance and durability of the files can be increased. The austenitic finish (Af) temperature values of the new generation files are higher than traditional NiTi rotary files. Reciproc Blue (Blue wire) and Wave One Gold (Gold wire) have an Af temperature at body temperature (33–38 ∘C) and markedly above (about 47–51 ∘C), respectively [34]. Also, it was concluded that OC files were in a martensitic phase at room and body temperature in a study using differential scanning calorimetry analysis [35]. The issue that files subjected to the heat treatment have higher cyclic fatigue resistance than traditional NiTi rotary files supported by the studies in the literature [14, 30, 36].

There is uncertainty in the literature regarding how many times a file should be used. Although NiTi rotary file manufacturers recommend single use of these files, repeated use after sterilization has become a common practice supported by recent researches [37, 38]. In a prospective clinical study, Bueno et al. concluded that the use of WOG primary and RPC R25 files in up to three cases of posterior teeth produced a low fracture rate, making them a valid option in cost-sensitive environments [26]. Consistent with this study, Moreira et al. assessed the cyclic fatigue resistance of Reciproc files using time to fracture values instead of the NCF, and they reported no significant differences in performance after the first, second, and third clinical uses [39]. For this reason, first and third use of the files were evaluated for cyclic fatigue resistance in the present study. These studies have also concluded that single file systems can be used repeatedly in the clinics in parallel with the outcomes of the present study.

The files tested in the present study feature various cross-sectional designs: WOG has a parallelogram shape, RPC Blue has an S-shaped design, and OC exhibits a variable cross-section, incorporating both triangular and S-shaped elements. Although these designs aim to prevent screwing and torsional failure of the files, in clinical practice the tendency of the stress accumulation on

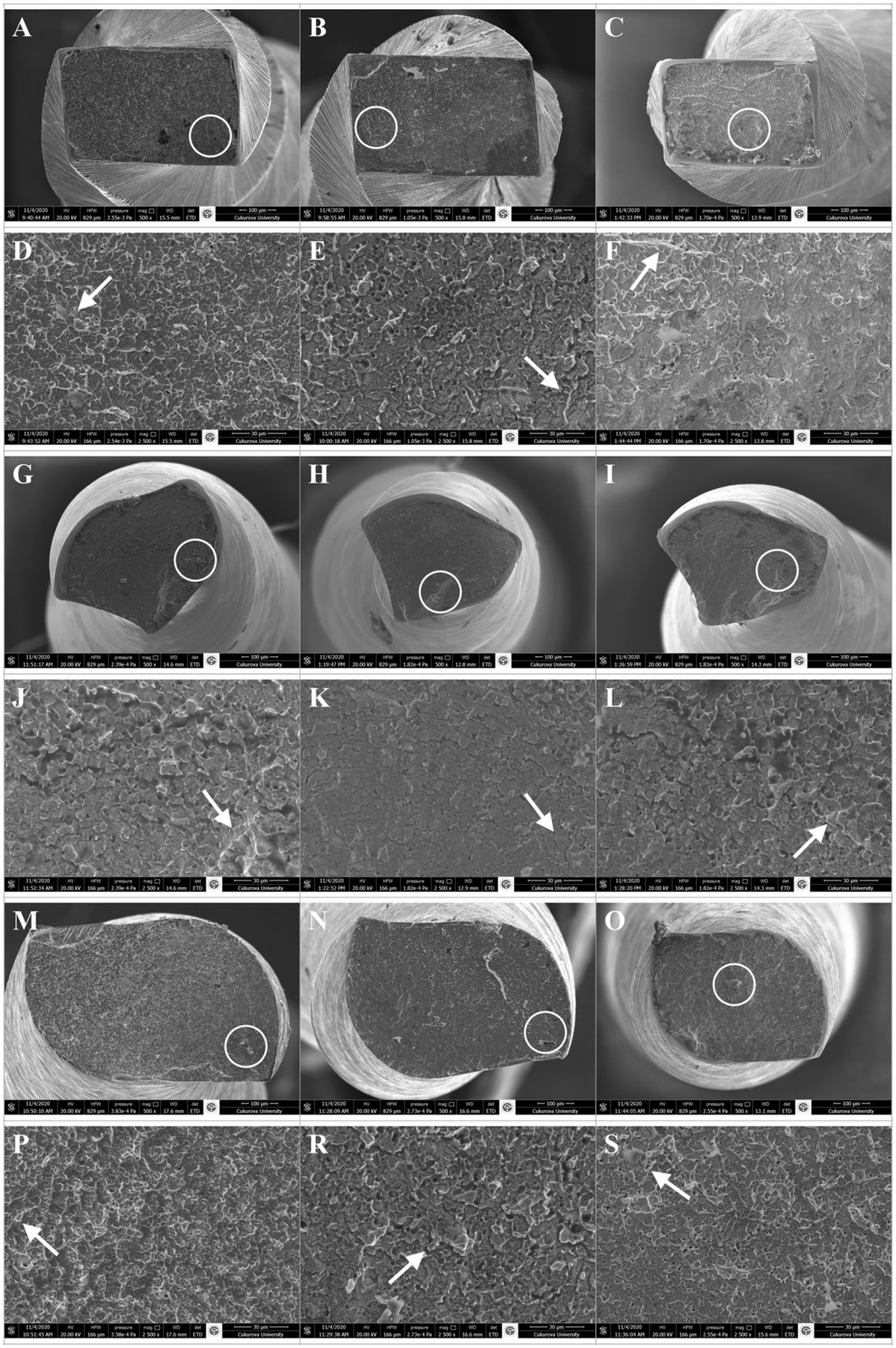



**Fig. 4** Scanning electron microscopy images of the WOG, OC, and RPC Blue files after cyclic fatigue testing. Fracture surface view of the (**A**, **G**, **M**) control, (**B**, **H**, **N**) first use, and (**C**, **I**, **O**) third use groups of WOG, OC and RPC Blue files and a high-magnification view of the (**D**, **J**, **P**) control, (**E**, **K**, **R**) first use, and (**F**, **L**, **S**) third use groups of WOG, OC and RPC Blue files. The crack initiation origin (arrows) and the surface pattern with dimples and cones (circled area) are observed in the fracture surfaces

the file may affect cyclic fatigue behavior. Research shows that reducing the metal mass of the file at the point of maximum stress increases the cyclic fatigue resistance of NiTi rotary files. According to the SEM analysis performed by Alcalde et al., at the D5 level, the RPC Blue 25.08 file had a smaller cross-sectional area than the WOG 25.07 file, and it also exhibited higher cyclic fatigue resistance [12]. The results of that study support the results of the present study which S-shaped RPC Blue and variable shaped OC has higher resistance values to that of WOG which has a parallelogram shape.

Studies have reported that as the apical diameter and taper of files increase, the time until fracture decreases, leading to a shorter failure time for these files [40–42]. In the present study, while all the files used had the same apical diameter, they differed in taper. The Reciproc Blue R25 files, which have the largest taper, generally exhibited higher fatigue resistance. This may be attributed to their superior physical properties, which result from the distinct heat treatment techniques applied during their production or variations in file metallurgy. Furthermore, the results of this study revealed that OC files, which have the smallest taper, demonstrated statistically significant differences when compared to WOG Primary files, particularly in terms of failure time and the NCF ($p < 0.05$). This finding aligns with results reported in other studies within the literature.

In the present study, statistically significant differences were found between and within the groups when the fractured segments lengths of the files were evaluated as a result of the cyclic fatigue test. The reason for the files to fracture at different lengths may be surface cracks and deformations that occur at different levels along the active part of the files as a result of repeated use.

The second outcome of the present study was that the WOG files had decreasing cyclic fatigue with use, and the OC files had increasing cyclic fatigue with use. Additionally, the number of RPC Blue files did not differ between the control and third-use groups, while the highest NCF value was found in the first-use group. Thus, the second null hypothesis was also rejected. In the present study, static cyclic fatigue tests were conducted in simulated artificial canals at room temperature using stainless steel blocks, as reported in previous studies [13, 16, 43, 44]. Therefore, the results of this study may differ from those of other studies that employed dynamic models at body temperature. While dynamic models effectively simulate the clinical pecking motion during root canal preparation, a static model was chosen to minimize variability related to factors such as the amplitude of axial motion and speed, which can be subjective due to differences in how clinicians manually control axial movements [11, 45]. Additionally, the number of pecking motions and the preparation time required to complete the procedure on each tooth could not be standardized in this study. As a result, variations in cyclic fatigue resistance values may have arisen both within and between groups. The testing method and environment temperature used for assessing cyclic fatigue may be regarded as limitations of this study. To better reflect clinical conditions, it is ideal for files to be subjected to cyclic fatigue testing in a dynamic model at body temperature within artificial canals that mimic dentin tissue.

## Conclusion

In particular, single file manufacturers recommend that the files should be used only once. Although single use is recommended, this study revealed that all tested files can be used for up to 3 molar teeth with low curvature. Within the limitations of the present study, the RPC Blue files exhibited highest cyclic fatigue resistance after clinical use.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12903-024-05287-2.

Supplementary Material 1.

Supplementary Material 2.

**Acknowledgements**
This work was supported by the Scientific Research Projects Coordination Center of Cukurova University (Project no. TDH-2019-11919), Adana, Turkey. The authors denied any conflict of interests related to this study. We would like to thank Dr. Ilker Unal for statistical analyses.
This study was recently presented as an oral presentation at the 15th International Turkish Endodontic Society Congress.

**Authors' contributions**
K. G.: Clinical procedures, Writing – review and edit, S. Y.: Investigation; Methodology; Resources; Writing – review and edit, A. D.: Supervision; review and edit, O. Y.: Investigation; Methodology; review and edit.

**Funding**
This work was supported by the Scientific Research Projects Coordination Center of Cukurova University (Project no. TDH-2019–11919), Adana, Turkey.

**Data availability**
No datasets were generated or analysed during the current study.

## Declarations

**Ethics approval and consent to participate**
This clinical study was carried out under the approval of the Ethics Committee of Cukurova University School of Medicine and in accordance with the principles of Helsinki (version 2008) (Approval No. IRB/21/2019). In addition, informed consent was obtained from all individual participants included in the study.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

Received: 6 June 2024 Accepted: 2 December 2024
Published online: 05 December 2024

**References**


1. Haïkel Y, Serfaty R, Bateman G, Senger B, Allemann C. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. J Endod. 1999;25:434–40.
2. Carvalho LA, Bonetti I, Borges MA. A comparison of molar root canal preparation using stainless-steel and nickel-titanium instruments. J Endod. 1999;25:807–10.
3. Schäfer E, Vlassis M. Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus RaCe. Part 2. Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth. Int Endod J. 2004;37:239–48.
4. Schäfer E, Vlassis M. Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus RaCe. Part 1. Shaping ability in simulated curved canals. Int Endod J. 2004;37:229–38.
5. Sattapan B, Nervo GJ, Palamara JE, Messer HH. Defects in rotary nickel-titanium files after clinical use. J Endod. 2000;26:161–5.
6. Martín B, Zelada G, Varela P, et al. Factors influencing the fracture of nickel-titanium rotary instruments. Int Endod J. 2003;36:262–6.
7. Cheung GS, Darvell BW. Fatigue testing of a NiTi rotary instrument. Part 2: Fractographic analysis. Int Endod J. 2007;40:619–25.
8. Gutmann J, Lovdahl P. Problem-solving clinical techniques in enlarging and shaping the root canal. In: Gutmann J, Lovdahl P, eds. Problem Solving in Endodontics Prevention, Identification and Management (5th ed.). China: Mosby; 2011. p. 195–208.
9. Kitchens GG, Liewehr FR, Moon PC. The effect of operational speed on the fracture of nickel-titanium rotary instruments. J Endod. 2007;33:52–4.
10. Larsen CM, Watanabe I, Glickman GN, He J. Cyclic fatigue analysis of a new generation of nickel titanium rotary instruments. J Endod. 2009;35:401–3.
11. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel-titanium rotary instruments. J Endod. 2009;35:1469–76.
12. Alcalde MP, Duarte MAH, Bramante CM, et al. Correction to: Cyclic fatigue and torsional strength of three different thermally treated reciprocating nickel-titanium instruments. Clin Oral Investig. 2018;22:1879.
13. Silva EJ, Rodrigues C, Vieira VT, Belladonna FG, De-Deus G, Lopes HP. Bending resistance and cyclic fatigue of a new heat-treated reciprocating instrument. Scanning. 2016;38:837–41.
14. Staffoli S, Grande NM, Plotino G, et al. Influence of environmental temperature, heat-treatment and design on the cyclic fatigue resistance of three generations of a single-file nickel-titanium rotary instrument. Odontology. 2019;107:301–7.
15. Gündoğar M, Özyürek T. Cyclic Fatigue Resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue Nickel-titanium Instruments. J Endod. 2017;43:1192–6.
16. De-Deus G, Silva EJ, Vieira VT, et al. Blue thermomechanical treatment optimizes fatigue resistance and flexibility of the reciproc files. J Endod. 2017;43:462–6.
17. Webber J. Shaping canals with confidence: WaveOne GOLD single-file reciprocating system. Int Dent – African Ed. 2015;6:6–17.
18. Fife D, Gambarini G, Britto LL. Cyclic fatigue testing of ProTaper NiTi rotary instruments after clinical use. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2004;97:251–6.
19. Gambarini G. Cyclic fatigue of ProFile rotary instruments after prolonged clinical use. Int Endod J. 2001;34:386–9.
20. Pruett JP, Clement DJ, Carnes DL. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod. 1997;23:77–85.
21. Haapasalo M, Endal U, Zandi H, Coil JM. Eradication of endodontic infection by instrumentation and irrigation solutions. Endod Top. 2005;10(1):77–102.
22. Whitworth J. Vital pulp extirpation. In: Orstavik D, eds. Essential Endodontology: Prevention and Treatment of Apical Periodontitis (3rd ed.). Hoboken, NJ: Wiley-Blackwell; 2020. p. 275–312.
23. Schilder H. Filling root canals in three dimensions. Dent Clin North Am. 1967;11(3):723–44.
24. Piasecki L, Al-Sudani D, Rubini AG, Sonnino G, Bossù M, Testarelli L, Di Giorgio R, da Silva-Neto UX, Brandão CG, Gambarini G. Mechanical resistance of carbon and stainless steel hand instruments used in a reciprocating handpiece. Ann Stomatol. 2013;4(3–4):259.
25. Ruddle CJ. Cleaning and shaping the root canal system. In: Cohen S, Burns RC, eds. Pathways of the Pulp (8th ed.). St Louis: Mosby; 2002. p. 231–292.
26. Bueno CSP, Oliveira DP, Pelegrine RA, Fontana CE, Rocha DGP, Bueno CEDS. Fracture Incidence of WaveOne and Reciproc Files during Root Canal Preparation of up to 3 Posterior Teeth: A Prospective Clinical Study. J Endod. 2017;43:705–8.
27. Wan J, Rasimick BJ, Musikant BL, Deutsch AS. A comparison of cyclic fatigue resistance in reciprocating and rotary nickel-titanium instruments. Aust Endod J. 2011;37:122–7.
28. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. Int Endod J. 2008;41:339–44.
29. Ferreira F, Adeodato C, Barbosa I, Aboud L, Scelza P, Zaccaro SM. Movement kinematics and cyclic fatigue of NiTi rotary instruments: a systematic review. Int Endod J. 2017;50:143–52.
30. Keskin C, Inan U, Demiral M, Keleş A. Cyclic fatigue resistance of reciproc blue, reciproc, and waveone gold reciprocating instruments. J Endod. 2017;43:1360–3.
31. One Curve directions for use. 2018. Available from: http://micromega.com/wp-content/uploads/2018/03/Brochure-One-Curve-EN-1.pdf.
32. McKelvey AL, Ritchie RO. Fatigue-crack propagation in Nitinol, a shape-memory and superelastic endovascular stent material. J Biomed Mater Res. 1999;47:301–8.
33. Elsewify T, Elhalabi H, Eid B. Dynamic cyclic fatigue and differential scanning Calorimetry analysis of R-Motion. Int Dent J. 2023;73:680–4.
34. Hou XM, Yang YJ, Qian J. Phase transformation behaviors and mechanical properties of NiTi endodontic files after gold heat treatment and blue heat treatment. J Oral Sci. 2020;63:8–13.
35. Yahata Y, Yoneyama T, Hayashi Y, et al. Effect of heat treatment on transformation temperatures and bending properties of nickel-titanium endodontic instruments. Int Endod J. 2009;42:621–6.
36. Adıgüzel M, Capar ID. Comparison of Cyclic Fatigue Resistance of WaveOne and WaveOne Gold Small, Primary, and Large Instruments. J Endod. 2017;43:623–7.
37. Pirani C, Paolucci A, Ruggeri O, et al. Wear and metallographic analysis of WaveOne and reciproc NiTi instruments before and after three uses in root canals. Scanning. 2014;36:517–25.
38. Ehrhardt IC, Zuolo ML, Cunha RS, et al. Assessment of the separation incidence of mtwo files used with preflaring: prospective clinical study. J Endod. 2012;38:1078–81.
39. Moreira EJL, Antunes HDS, Vieira VTL, et al. Effects of clinical use of NiTi reciprocating instruments on cyclic and torsional resistance, and on roughness. Braz Oral Res. 2021;35:e021.
40. Neal RG, Craig RG, Powers JM. Effect of sterilization and irrigants on the cutting ability of stainless steel files. J Endod. 1983;9:93–6.
41. Miserendino LJ, Brantley WA, Walia HD, Gerstein H. Cutting efficiency of endodontic hand instruments. Part 4. Comparison of hybrid and traditional instrument designs. J Endod. 1988;14:451–4.
42. Tepel J, Schäfer E, Hoppe W. Properties of endodontic hand instruments used in rotary motion. Part 1. Cutting efficiency. J Endod. 1995;21:418–21.
43. Alcalde MP, Tanomaru-Filho M, Bramante CM, et al. Cyclic and Torsional Fatigue Resistance of Reciprocating Single Files Manufactured by Different Nickel-titanium Alloys. J Endod. 2017;43:1186–91.
44. Pedullà E, Lo Savio F, Boninelli S, et al. Torsional and Cyclic Fatigue Resistance of a New Nickel-Titanium Instrument Manufactured by Electrical Discharge Machining. J Endod. 2016;42:156–9.
45. Capar ID, Kaval ME, Ertas H, Sen BH. Comparison of the cyclic fatigue resistance of 5 different rotary pathfinding instruments made of conventional nickel-titanium wire, M-wire, and controlled memory wire. J Endod. 2015;41:535–8.


## Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.