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# Comparative evaluation of sterilization- and temperature-dependent cyclic fatigue resistance of four different nickel-titanium rotary file systems with reciprocal motion

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## Abstract

**Aim:** The aim of this study was to examine the effect of sterilization and temperature differences on the cyclic fatigue resistance of WaveOne Gold, Reciproc, Reciproc Blue, and Twisted File Adaptive rotary file systems.

**Methods:** In total, 160 files and four file systems were used (n = 20). This study was carried out at two different temperatures: 20°C and 39°C. An artificial stainless-steel canal was used for the static cyclic fatigue test. The breaking times of the files were recorded and calculated by multiplying the number of revolutions by the rotational speed. The SPSS 22 program was used for statistical analysis. The Shapiro–Wilk test was used for data with a normal distribution. The Mann–Whitney U test was used for paired groups. The Kruskal–Wallis test was applied to groups with more than two variables where the data did not fit a normal distribution. Tukey's post-hoc analysis was used to determine the source of differences. A value of $p<0.05$ was considered statistically significant.

**Results:** When the lengths of the broken pieces and the numbers of breaks were compared at the two different temperatures, there was a significant difference between all the files. In addition, there was a significant between-group difference between the sterilized files and nonsterilized files ($p < 0.05$).

**Conclusion:** The cyclic fatigue resistance of the Reciproc Blue file was higher than that of the other files. Low temperature increased cyclic fatigue resistance.

**Keywords:** Cyclic fatigue, fracture resistance, NiTi file, sterilization, reciprocal motion

## Introduction

One of the most important stages of root canal treatment is root canal preparation [1, 2]. At this stage, vital and necrotic tissue is removed from the canal together with the infected root dentin. For successful endodontic treatment, the root canal must be widened into a conical form from the apical to the coronal areas during root canal preparation, and the original form of the canal should not be disturbed during the procedure [2].

Endodontic files made of stainless steel are rigid, inelastic, and flat metals. These instruments cannot fully adapt to the inclined root canal, as they must be placed in a straight position [3]. Therefore, the distribution of power in the area in contact with the instrument is uneven [4, 5]. As a result, the possibility of iatrogenic errors such as canal transportation, step, zip, perforation, or instrument fracture increases during the shaping of the curved canals. To prevent undesired changes in the original structure of the root canal, nickel-titanium (NiTi) root canal instruments, which are more flexible than stainless steel files, have been manufactured.

Owing to the low ability of NiTi hand files to cut dentine, the long shaping process has led to the development of NiTi rotary instruments. However, studies have demonstrated that the tendency of NiTi rotary instruments to return to their original forms during shaping may cause changes in canal anatomy [6]. Therefore, thermomechanical processing has been developed to produce more flexible NiTi alloys under clinical conditions.

The biggest disadvantage of NiTi rotary files is that they can fracture during treatment [7]. Fractures may be torsional or caused by cyclic fatigue, which is the predominant mechanism in instrument fractures [8].

Physicians repeatedly use NiTi rotary files despite the risk of fracture for economic reasons [9]. Some studies have found that the repeated clinical use of NiTi rotary files decreases cyclic fatigue resistance [10, 11]. However, studies have also demonstrated that NiTi rotary instruments can be used 10 times or for canal preparation in four molar teeth [12, 13]. As a result, no consensus has been reached in the dental literature about how many times NiTi rotary system files should be used [14].

The effect of sterilization on instrument fractures is uncertain, as no consensus exists in the literature [15, 16]. However, NiTi is considered an important factor in the development of instrument fractures [17].

The aim of this thesis study was to examine the effect of sterilization and temperature differences on cyclic fatigue resistance of the WaveOne Gold, Reciproc, Reciproc Blue, and Twisted File Adaptive rotary file systems.

## Materials and Methods

On the basis of the study conducted by Al-Obaida et al. in 2019, the sample size calculation before the study using the G Power software revealed that 96 files were sufficient to find a significant difference between the five groups, with 80% power (95% confidence interval, $\alpha = 0.05$) [18].

Within the scope of the study, 160 files were used, of which 40 belonged to four different file systems. Recently unpacked materials and materials sterilized once before use were used in each file system. This study was repeated in two temperature environments: 20°C and 39°C (n = 20). An artificial canal, designed with the AutoCAD software, was obtained by etching stainless steel blocks using computer numerical control devices. For the cyclic fatigue system, a stainless-steel artificial channel with an inner diameter of 1.5 mm, a curvature of 60°, and a curvature radius of 5 mm was used. The files were fixed at 19 mm, standardized, and processed. The breaking time of the files was calculated and recorded as the number of cycles obtained by multiplying the number of revolutions by the time to break. The following formula was used to calculate the number of cycles to fracture (NCF) for each file: NCF = [Rotational speed (rpm) × Time (s)]/60.

## Statistical analysis

The SPSS 22 software (IBM SPSS Inc., Armonk, NY, USA) was used for the statistical analysis. Categorical data were expressed as numbers (%), while metric data were expressed as medians and interquartile ranges. The data distribution was assessed in terms of normality using the Shapiro-Wilk test. To compare data that did not fit a normal distribution, the Mann-Whitney U test was used for paired groups, and the Kruskal-Wallis test was used for groups with more than two variables. Tukey post hoc analysis was used to determine the source of the differences. p value<.05 was considered statistically significant.

## Results

In this study, 160 files were used, including 40 Reciproc Blue, 40 Reciproc, 40 WaveOne Gold, and 40 Twisted File Adaptive rotary file systems.When the fracture length of the file was compared according to file type, statistically significant differences were found between the groups ($p<0.001$). This difference was due to the difference between all groups except Twisted File Adaptive and Reciproc Blue.

According to the results, the order of fracture lengths from the longest fracture was as follows: Reciproc > WaveOne Gold > Reciproc Blue = Twisted File Adaptive. When the fracture lengths were compared according to temperature, the fracture length of the files was significantly higher at 20°C than at 39°C (p=0.012). No statistically significant differences were found between the groups in terms of sterilization and fracture length (p = 0.450; Table 1).

When the four file types were evaluated individually, the fracture length was significantly higher at 20°C than at 39°C. In the Reciproc and Reciproc Blue file groups, the fracture length of the sterilized files was significantly higher than that of the unsterilized files (Table 2).

**Table 1.** Comparison of cyclic fatigue resistance according to file type, temperature, and sterilization (Cyclic fatigue resistance was evaluated based on the lengths of the broken pieces).

| | | Broken piece length | | p |
|---|---|---|---|---|
| | | Median | IQR | |
| File Type | Twisted File | 8,06[a] | 7,85-8,22 | <0,001 |
| | WaveOne Gold | 8,60[b] | 7,63-8,80 | |
| | Reciproc | 9,58[c] | 9,07-9,75 | |
| | Reciproc Blue | 7,75[a] | 6,77-8,30 | |
| Temperature | 20°C | 8,58 | 8,10-9,48 | 0,012 |
| | 39°C | 8,00 | 7,15-8,70 | |
| Sterilization | Not sterilized | 8,38 | 7,70-8,78 | 0,450 |
| | Sterilized | 8,37 | 7,80-9,38 | |

* Different supercharacter letters indicate significant difference between groups.

**Table 2.** Comparison of the cyclic fatigue resistance of the four file groups according to temperature and sterilization variables (Cyclic fatigue resistance was evaluated based on the lengths of the broken pieces).

| | | Broken piece length | | p |
|---|---|---|---|---|
| | | Median | IQR | |
| **Twisted File** | | | | |
| Temperature | 20°C | 8,12 | 7,97-8,39 | 0,049 |
| | 39°C | 7,98 | 7,70-8,20 | |
| Sterilization | Not sterilized | 8,08 | 7,88-8,26 | 0,820 |
| | Sterilized | 8,03 | 7,85-8,21 | |
| **WaveOne Gold** | | | | |
| Temperature | 20°C | 8,70 | 8,55-8,83 | 0,007 |
| | 39°C | 7,63 | 7,25-8,70 | |
| Sterilization | Not sterilized | 8,70 | 8,15-8,78 | 0,341 |
| | Sterilized | 8,35 | 7,50-8,83 | |
| **Reciproc** | | | | |
| Temperature | 20°C | 9,63 | 9,50-9,78 | 0,011 |
| | 39°C | 9,07 | 8,68-9,73 | |
| Sterilization | Not sterilized | 9,15 | 8,68-9,68 | 0,021 |
| | Sterilized | 9,65 | 9,50-9,78 | |
| **Reciproc Blue** | | | | |
| Temperature | 20°C | 8,13 | 7,80-8,45 | <0,001 |
| | 39°C | 6,85 | 6,50-7,68 | |
| Sterilization | Not sterilized | 6,93 | 6,53-8,02 | 0,013 |
| | Sterilized | 7,98 | 7,60-8,48 | |

When the NCF was compared according to file type, statistically significant differences were observed between the groups (p<0.001), which was due to the difference between Reciproc Blue and the other three files. Accordingly, the order of the NCF from the highest number was as follows: Reciproc Blue > Reciproc = WaveOne Gold = Twisted File Adaptive. When the NCF was compared according to temperature, the NCF was significantly higher at 20°C than at 39°C (p<0.001). No statistically significant differences in sterilization and the NCF were found between the groups (p = 0.073; Table 3).

When the four file types were evaluated individually, the NCF was significantly higher at 20°C than at 39°C. In the Reciproc and Reciproc Blue file groups, the NCF of the sterilized files were significantly higher than that of the non-sterilized files (Table 4). No statistically significant relationship was found between the fracture length and the NCF of the file (r = −0.090, p = 0.260).

**Table 3.** Comparison of number of cycles to fracture according to file type, temperature and sterilization.

| | | NCF | | p |
|---|---|---|---|---|
| | | Median | IQR | |
| File Type | Twisted File | 540,00[a] | 266,67-820,00 | <0,001 |
| | WaveOne Gold | 448,33[a] | 236,67-580,00 | |
| | Reciproc | 415,08[a] | 184,17-1133,33 | |
| | Reciproc Blue | 1144,67[b] | 858,50-1518,67 | |
| Temperature | 20°C | 670,00 | 382,50-1518,67 | <0,001 |
| | 39°C | 386,67 | 184,17-1255,17 | |
| Sterilization | Not sterilized | 482,50 | 184,17-1286,33 | 0,073 |
| | Sterilized | 553,33 | 260,67-1518,67 | |

* Different supercharacter letters indicate significant difference between groups.

**Table 4.** Comparison of number of cycles to fracture by file types under temperature and sterilization variables

| | | NCF | | p |
|---|---|---|---|---|
| | | Median | IQR | |
| **Twisted File** | | | | |
| Temperature | 20°C | 670,00 | 526,67-820,00 | <0,001 |
| | 39°C | 373,33 | 266,67-666,67 | |
| Sterilization | Not sterilized | 646,67 | 266,67-820,00 | 0,659 |
| | Sterilized | 513,33 | 333,33-733,33 | |
| **WaveOne Gold** | | | | |
| Temperature | 20°C | 491,67 | 433,33-580,00 | <0,001 |
| | 39°C | 350,00 | 236,67-566,67 | |
| Sterilization | Not sterilized | 448,33 | 236,67-580,00 | 0,779 |
| | Sterilized | 441,67 | 280,00-556,67 | |
| **Reciproc** | | | | |
| Temperature | 20°C | 694,17 | 382,50-1133,33 | <0,001 |
| | 39°C | 257,83 | 184,17-473,17 | |
| Sterilization | Not sterilized | 318,75 | 184,17-600,67 | 0,001 |
| | Sterilized | 630,42 | 260,67-1133,33 | |
| **Reciproc Blue** | | | | |
| Temperature | 20°C | 1344,42 | 1068,17-1518,67 | <0,001 |
| | 39°C | 1102,17 | 858,50-1255,17 | |
| Sterilization | Not sterilized | 1116,33 | 1048,33-1286,33 | 0,024 |
| | Sterilized | 1328,83 | 858,50-1518,67 | |

## Discussion

In this study, which was planned considering that sterilization and temperature differences may affect cyclic fatigue, 160 files were used, including 40 Reciproc Blue, 40 Reciproc, 40 WaveOne Gold, and 40 Twisted File Adaptive file systems. The files were classified into groups according to sterilization status and temperature (20°C and 39°C).

When the fracture lengths of the files were compared according to file type, statistically significant differences were found between the groups ($p<0.001$). This difference was due to the difference between all groups except Twisted File Adaptive and Reciproc Blue. According to the results, the order of fracture lengths from the longest length was as follows: Reciproc > WaveOne Gold > Reciproc Blue = Twisted File Adaptive. In a study by Karataşlıoğlu, no statistically significant difference was found between Twisted File Adaptive and Reciproc in terms of fracture length [19]. In a study by Yılmaz et al., the cyclic fatigue resistance and fracture lengths of different file systems at the temperature inside the canal were compared. As a result, no significant difference was found between the WaveOne Gold and Reciproc Blue files in terms of fracture length [20]. In a study by Topçuoğlu et al., three file types (WaveOne Gold, Reciproc, and WaveOne) were compared in terms of cyclic fatigue. As a result, no significant differences were found between the file types in terms of fracture length [21].

In another study conducted by Topçuoğlu et al. in the same year, the cyclic fatigue resistances of Reciproc Blue and Reciproc files were compared. According to this study, the NCF with the Reciproc Blue file was significantly higher than that with the Reciproc file [22]. In their study, Keskin et al. compared three file types (Reciproc, Reciproc Blue, and WaveOne Gold) in terms of cyclic fatigue. As a result, no statistically significant differences were found between the file types in terms of fracture length [23]. In their study, Plotino et al. found no statistically significant difference in fracture length between the Reciproc and WaveOne Primary files [24]. Pedulla et al. also found no statistically significant difference in fracture length between the Reciproc and Reciproc Blue files [25]. In our study, when we compared the lengths of the fractures due to cyclic fatigue, we found statistically significant differences between the groups; however, the maximum numerical difference between the groups was determined <1.83 mm. All files had fractures at 5 mm above the apical area on average at the D4–D6 levels. This level corresponds to almost the center of the canal curvature or to lower or higher values of <2 mm, considering that all files were used at the same length. This point was the area where the file was exposed to maximum stress [26-29].

The reason for the difference in fracture length between the files may be related to the sufficient sample size in the present study. However, further studies with larger samples on this subject matter would prevent this confusion in the literature.

When fracture lengths were compared according to temperature in our study, the fracture length of the files was significantly higher at 20°C than at 39°C. Plotino et al. compared the cyclic fatigues of the ProTaper Gold and ProTaper Universal files at 20°C and 35°C. According to their study, fracture length showed no significant difference between the two temperatures [30]. Our study results differ from those reported in the literature, probably owing to the different reference temperatures and file systems used in our study. To clarify this confusion, studies with the same standardized reference values and file systems are needed.

In our study, when all files were evaluated collectively, we found no statistically significant differences in sterilization status and fracture length. Nonetheless, when examined separately, the fracture lengths of the sterilized Reciproc and Reciproc Blue files were statistically significantly longer than those of the non-sterilized files. However, between the Twisted File Adaptive and WaveOne Gold files, no statistically significant differences in sterilization status and fracture length were found.

In a study by Plotino et al., four different file types (K3, Mtwo, Vortex, and K4 prototypes) were evaluated for cyclic fatigue according to their sterilization status. According to this study, fracture length showed no significant relationship with sterilization status in all files [31]. As in previous studies, when all files were evaluated in our study, the effect of sterilization on fracture length was not significant.

When the files were compared in terms of the number of cycles, a statistically significant difference was found between the groups. This difference was due to the difference between Reciproc Blue and the other three files. Al-Obaida et al. compared cyclic fatigue between WaveOne, WaveOne Gold, Reciproc, Reciproc Blue, and Twisted Files Adaptive and found significantly higher NCF in the Reciproc Blue group, like in our study [18]. In a study by Inan et al. that compared cyclic fatigue between Reciproc Blue and Reciproc, the Reciproc Blue file showed a significantly higher number of break cycles than the Reciproc file [32]. Our study results were similar to those reported in the literature in that they showed that the Reciproc Blue file had the highest number of break cycles. When the NCF were compared according to temperature, the NCF was significantly higher at 20°C than at 39°C.

De Vasconcelos et al. investigated the effects of different file types (Protaper Universal, Hyflex CM, TRUShape, and Vortex Blue) on cyclic fatigue at two temperatures (20°C and 37°C). According to the results of their study, the NCF was significantly higher at 20°C than at 37°C for all files [33]. When the ProTaper Gold and ProTaper Universal files were evaluated individually in the study by Plotino et al., the NCF was significantly higher at 20°C than at 35°C [30]. The results of our study regarding the comparison of the NCF according to temperature were compatible with those reported in the literature.

The effect of sterilization on instrument fractures is uncertain, as no consensus exists in the literature [15, 16]. However, NiTi is considered an important factor in the development of instrument fractures [17]. Plotino et al. evaluated four file types (K3, Mtwo, Vortex, and K4 prototypes) in terms of cyclic fatigue according to sterilization status. As a result, only the sterilized files in the K4 prototype group had significantly higher NCF than the unsterilized files [31]. However, no consensus has been reached on this matter in the literature. One reason for this may be that the setting conditions of the studies were not standardized.

# Conclusion

On the basis of our results, we deduce that cyclic fatigue resistance was higher in the Reciproc Blue file than in the other files. We conclude that although the temperature in the canal or irrigation agents used during root canal preparation decreased, the effectiveness of the NaOCl agent, which is frequently used as irrigation, increased the cyclic fatigue resistance of the NiTi files used.

## Disclosures

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept – B.Ç., F.Ö.; Design – F.Ö., B.Ç.; Supervision – B.Ç.; Materials – B.Ç.; Data collection &/or processing – F.Ö., B.Ç.; Analysis and/or interpretation – F.Ö.; Literature search – F.Ö., B.Ç.; Writing – B.Ç.; Critical review – B.Ç.

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