The Effect of the Niti Alloy Modification and the Taper of Endodontic Instruments on the Cyclic Fatigue Resistance

SUMMARY

Background/Aim: The fracture of engine-driven instruments during root canal treatment has been tried to be eliminated by developing the manufacturing process of the files. The aim of this study was to assess cyclic fatigue resistance (CFR) of the two different rotary files—EdgeSequel™ Sapphire (ES) and Race® Evo (RE)—which are produced by two different manufacturing technologies. Material and Methods: While RE is manufactured from heat-treated NiTi alloy with the electropolished surface, ES undergoes a non-disclosed thermal treatment called FireWire heat treatment. The CFRs of ES and RE comprising of similar tip size and taper (15/.04 and 25/.04) were compared on a cyclic fatigue device with an artificial stainless-steel canal (60° curvature, 5 mm radius, 1.5 mm width, and 3.0 mm depth). The continuous water spray with a syringe at 35.5°C was used to decrease the friction and to simulate in vivo conditions. All procedures were performed at recommended speed and torque for both files until fracture occurred. The time to failure (TF) was recorded and the number of cycles to failure (NCF) was calculated. The Weibull calculations (Weibull modulus, R², predicted cycles, and time for 99 % survival) for NCF and TF were also done. The data were statistically analyzed with the independent two-sample t-test and the paired two-sample t-test. The significance level was set at p < 0.05. Results: Both ES and RE showed a better CFR in 15/.04 tip size than 25/.04 (P < 0.05). The TF of the ES were higher than the RE (P < 0.05). The highest and lowest Weibull modulus values were obtained with RE 15/.04 and RE 25/.04, respectively. Conclusions: Both the tip diameter and alloy modification of the instruments affected the CFR. FireWire heat treatment was associated with longer TF. The bigger the tip diameter, the lower the CFR for both tested products.

Keywords: Cyclic Fatigue Resistance, Edgesequel Sapphire, Nickel-Titanium, Race Evo

Introduction

The usage of NiTi instruments during root canal treatment became very popular in recent years. Thanks to their high flexibility and super-elasticity, shaping the root canal system has become faster and easier². Despite these advantages compared with stainless steel files, the fracture of engine-driven instruments during root canal treatment has still not been prevented due to torsional fatigue or cyclic fatigue². Cyclic fatigue fractures occur abruptly without any prior sign of a deformation². Various alloys, designs, and heat treatments have been applied to instruments to increase their flexibility and fatigue resistance³,⁴.

EdgeSequel™ Sapphire is produced by EdgeEndo company with unique properties caused by heat Treated Fire-Wire™ NiTi ⁵,⁶. These files are produced under the inspiration of Vortex Blue (VB) instruments. According to
the cyclic fatigue analysis of the manufacturer, ES is two times more resistant than Vortex® Blue and eight times more resistant than Vortex® and EndoSequence® 6. It has a triangular cross-section, various tip sizes (15-90), and different constant tapers (.04, .06).

Race® Evo was launched in 2020 as an advanced version of the RaCe rotary instrumentation system (FKG Dentaire–La Chaux-de Fonds–Switzerland), which has proven itself and been used for years7. It is a sequenced version of the RaCe rotary instrumentation system (FKG Dentaire–La Chaux-de Fonds–Switzerland) was used according to the speed and torque instructions of the manufacturers:

Group 1. (n=15) ES 15/.04 instruments rotated at a speed of 500 rpm and 75 g-cm torque.
Group 2. (n=15) ES 25/.04 instruments rotated at a speed of 500 rpm and 104 g-cm torque.
Group 3. (n=15) RE 15/.04 instruments rotated at a speed of 800 rpm and 1.5 Ncm torque.
Group 4. (n=15) RE 25/.04 instruments rotated at a speed of 800 rpm and 1.5 Ncm torque.

The instruments were rotated according to the aforementioned instructions until a fracture occurred. The separation of files was observed visually and audibly, and the separation moment was noted in seconds by the same operator with a digital chronometer (TF). The number of cycles to failure (NCF) was calculated using TF and NCF for the calculation of time to fracture (sec)/60. Weibull reliability analysis was calculated using TF and NCF for the calculation of the probability of survival for the second usage17. Conformity to the normal distribution was evaluated using the Shapiro-Wilk test. Independent two-sample t-test was used to compare the normally distributed NCF and TF values according to the dimensions within the groups. Evaluation of the variability of NCF and TF between samples was performed with Weibull reliability analysis using the Minitab 17 program. Analysis results quantitative data mean ± standard deviation (SD) and median (minimum – maximum). Significance level was taken as $P < 0.05$.

### Statistical Analysis

Data were analyzed with IBM SPSS Version 23. Conformity to the normal distribution was evaluated using the Shapiro-Wilk test. Independent two-sample t-test was used to compare the normally distributed NCF and TF values according to the files. Independent two-sample t-test was used to compare the normally distributed NCF and TF values according to the dimensions within the groups. Evaluation of the variability of NCF and TF between samples was performed with Weibull reliability analysis using the Minitab 17 program. Analysis results quantitative data mean ± standard deviation (SD) and median (minimum – maximum). Significance level was taken as $P < 0.05$.

### Results

The number of cycles to failure and time to fracture are presented in Table 1. The higher NCF means the better CFR.
A significant difference was observed within the groups ($P < 0.05$) regarding TF and NCF. However no significant difference was observed between the groups in NCF values ($P > 0.05$). The NCF and TF of both 15/04 ES and RE were found to be higher than 25/04. While ES 15/04 had the highest mean values of NCF and TF, RE 25/04 had the worst results in these two parameters ($P < 0.05$).

Figure 1a. and Figure 1b. show the Weibull reliability plots with the probability of survival values for NCF and TF, respectively. The Weibull calculations (Weibull modulus, $R^2$, predicted cycles, and time for 99% survival), mean values, and standard deviations are given in Table 2. When the Weibull results of NCF and TF were examined, the highest Weibull modulus value was obtained in RE 15/04 while the lowest modulus in RE 25/04. Although the predicted time for 99% survival was highest in ES 15/04, the predicted cycles for 99% survival were greater in RE 15/04.

### Table 1. Comparison of NCF and TF values between and within the groups

<table>
<thead>
<tr>
<th>EdgeSequel™ Sapphire</th>
<th>Race® Evo</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TF</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15/04</td>
<td>103.4 ± 7.5</td>
<td>63.4 ± 3.0</td>
</tr>
<tr>
<td>25/04</td>
<td>75.4 ± 7.9</td>
<td>44.8 ± 5.2</td>
</tr>
<tr>
<td><strong>NCF</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15/04</td>
<td>861.3 ± 62.6</td>
<td>845.9 ± 39.9</td>
</tr>
<tr>
<td>25/04</td>
<td>628.5 ± 65.7</td>
<td>597.3 ± 68.9</td>
</tr>
</tbody>
</table>

**Discussion**

In this study, two different full-sequenced file systems with the same tip size, length, taper, and cross-section but different heat-treated alloys were compared regarding their cyclic fatigue resistance. The results showed that the bigger the tip size, the lower the CFR for both file systems. Also, time to fracture of FireWire NiTi alloy was higher than medical-grade NiTi alloy. In the light of these results, the first and second null hypotheses were rejected.

It was shown in several studies that the same tip size and taper in the rotary instruments does not mean the
same fatigue resistance\textsuperscript{2,18}. For this reason, researchers have started to focus on the effect of metallurgical properties on the CFR of the NiTi rotary instruments\textsuperscript{2,18,19}. To the best of the authors’ knowledge, there is yet no cyclic fatigue study about EdgeSequel Sapphire (ES) and RaceEvo (RE) files in the literature. These instruments were compared because they have a similar cross-section, tip, and taper size but different alloys which were thought to affect their CFR. As expected, it was observed that the different alloys affected the instruments’ fatigue resistance, in favor of FireWire alloy. Since no study in the literature has compared the CFR of these two instruments, it is useful to look at other studies based on similar logic. Plotino et al\textsuperscript{2} indicated that while Vortex Blue exhibited superior CFR than Profile Vortex for the tip size of 25/.04, no difference was observed between these two for the tip size of 15/.04. Considering the manufacturer says that ES is inspired by Vortex Blue design, it would be logical to compare this study with Plotino’s study\textsuperscript{2}. In this study, the ES outlasted the RaceEvo on both 15/.04 and 25/.04 instruments. The reason for the difference between these two studies may be that Vortex Blue and Profile Vortex files have different treatments on the same material, while ES and RE files have completely different manufacturing technology.

Weibull analysis is a methodology to use for the measurement of the lifespan of the materials through the parameters of R\textsuperscript{2} and Weibull modulus. The higher Weibull modulus shows the increased homogeneity and the consistency of the material\textsuperscript{20}. Although RE 15/.04 has better-predicted cycles for 99 % survival and the highest Weibull modulus, this does not mean it will break later than the other tested files. The reason for this dilemma is the high speed of this instrument, which causes a numeric increase in these parameters. When the results are interpreted accordingly, it makes more sense to consider “predicted time for 99% survival” in terms of extrapolating the results to the clinical practice. In this context, it was observed that the fracture resistance of ES was higher.

The full sequenced rotary file systems usually include both scouting and shaping files. For this reason, the cyclic fatigue performance of these small and big instruments should be evaluated together. In this study, scouting file groups (15/.04) had better fatigue resistance than the shaping files (25/.04) for both instruments. Smaller instruments generally have higher flexibility than the bigger ones\textsuperscript{2,21}. In addition, the 1.5 mm width of the artificial canal may give these small instruments a larger place, and thus the fracture time may be extended due to the reduced friction surface.

When taking into consideration a study\textsuperscript{22} that proved the minimal impact of the clinician on cyclic fatigue failure of an instrument, choosing the proper rotary instrument plays a critical role in the outcomes. This study sheds light on the fact that two instruments with the same design features may outperform one another in clinical use due to their manufactured alloy.

**Conclusions**

Within the limitations of the study, FireWire alloy (ES) showed superior results than medical-grade NiTi alloy (RE), regardless of the tip diameter. However, the findings of the present study should be verified by further in vivo studies.

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**References**


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Correspondence
Ayfer Atav Ateş
Department of Endodontics
Faculty of Dentistry, Istinye University, Istanbul, Turkey
e-mail: carminaayfer@hotmail.com