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Comparison of the cyclic fatigue resistance of VDW.ROTATE, TruNatomy, 2Shape, and HyFlex CM nickel-titanium rotary files at body temperature

Mustafa Gündoğar [1], **Gülşah Uslu** [2], **Taha Özyürek** [3*], **Gianluca Plotino** [4]

[1]Department of Endodontics, Faculty of Dentistry, İstanbul Medipol University, İstanbul, Turkey
[2]Department of Endodontics, Faculty of Dentistry, Çanakkale Onsekiz Mart University, Çanakkale, Turkey
[3]Department of Endodontics, Faculty of Dentistry, Istanbul Medeniyet University, Istanbul, Turkey
[4]Grande Plotino & Torsello - Dental Clinic, Rome, Italy

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Gündoğar M, Uslu G, Özyürek T, Plotin G

***Correspondence to**
Taha Özyürek, DDS, PhD
Associate Professor, Department of Endodontics, Faculty of Dentistry, Istanbul Medeniyet University, Dumlupınar D100 Karayolu No:98, Istanbul 34956, Turkey.
E-mail: tahaozyurek@hotmail.com

ORCID iDs
Mustafa Gündoğar
https://orcid.org/0000-0002-6394-0791
Gülşah Uslu
https://orcid.org/0000-0003-3176-1251
Taha Özyürek
https://orcid.org/0000-0003-3299-3361
Gianluca Plotino
https://orcid.org/0000-0003-3003-8029

ABSTRACT

Objectives: This study aims to compare the cyclic fatigue resistance of VDW.ROTATE, TruNatomy, 2Shape, and HyFlex CM nickel-titanium (NiTi) rotary files at body temperature.
Materials and Methods: In total, 80 VDW.ROTATE (25/0.04), TruNatomy (26/0.04), 2Shape (25/0.04), and HyFlex CM (25/0.04) NiTi rotary files ($n = 20$ in each group) were subjected to static cyclic fatigue testing at body temperature (37°C) in stainless-steel artificial canals prepared according to the size and taper of the instruments until fracture occurred. The number of cycles to fracture (NCF) was calculated, and the lengths of the fractured fragments were measured. The data were statistically analyzed using a 1-way analysis of variance and *post hoc* Tamhane tests at the 5% significance level ($p < 0.05$).
Results: There were significant differences in the cyclic fatigue resistance among the groups ($p < 0.05$), with the highest to lowest NCF values of the files as follows: VDW.ROTATE, HyFlex CM, 2Shape, and TruNatomy. There was no significant difference in the lengths of the fractured fragments among the groups. The scanning electron microscope images of the files revealed typical characteristics of fracture due to cyclic fatigue.
Conclusions: The VDW.ROTATE files had the highest cyclic fatigue resistance, and the TruNatomy and 2Shape files had the lowest cyclic fatigue resistance in artificial canals at body temperature.

Keywords: Body temperature; Cyclic fatigue; Endodontics; Liquid ambient; NiTi instruments

INTRODUCTION

The concept of minimally invasive endodontic treatment has been introduced to increase the preservation of pericervical dentin [1]. According to this concept, the usage of reduced-tapered nickel-titanium (NiTi) files and conservative endodontic access cavity preparation has gained popularity [2,3]. Previous studies suggested that minimally invasive root canal preparation performed using NiTi files with a smaller taper may preserve the root dentin tissue as compared

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

Author Contributions
Conceptualization: Özyürek T, Plotino G; Data curation: Özyürek T; Formal analysis: Özyürek T; Funding acquisition: Gündoğar M, Uslu G; Investigation: Uslu G, Gündoğpar G; Methodology: Özyürek T, Plotino G; Project administration: Gündoğar M, Uslu G; Resources: Uslu G, Gündoğar G; Software: Uslu G, Gündoğar G; Supervision: Özyürek T, Plotino G; Validation: Uslu G, Gündoğar G; Visualization: Özyürek T, Plotino G; Writing - original draft: Uslu G, Gündoğar G; Writing - review & editing: Uslu G, Özyürek T, Plotino G.

with that of large-tapered NiTi files [4] and increase the fracture resistance of endodontically treated teeth [5,6]. Two new NiTi file rotary systems with small tapered designs have recently been launched for conservative root canal shaping: VDW.ROTATE (VDW, Munich, Germany) and TruNatomy (Dentsply-Sirona, Ballaigues, Switzerland). These files include a variety of taper sizes for the preparation of narrow root canals and a coronal taper designed to protect the root dentin and facilitate canal preparation in narrow endodontic cavities with restricted access. VDW.ROTATE files (15/0.04, 20/0.05, 25/0.04) have an S-shaped cross-section, off-centered design, and constant taper [7]. TruNatomy files (17/0.02, 20/0.04, 26/0.04) have a square cross-section, an off-center design, and a variable taper [8]. These files have been undergone different types of heat treatments, which the manufacturers claim to increase the elasticity and resistance to cyclic fatigue of the files [7,8].

In the literature, no studies have compared the cyclic fatigue resistance of these files. Thus, the present study aimed to compare the cyclic fatigue resistance of VDW.ROTATE and TruNatomy files and to compare it with of existing heat-treated NiTi rotary files with similar dimensions (HyFlex CM and 2Shape TS1) at body temperature in artificial stainless-steel canals. The null hypothesis tested was that there would be no difference in the cyclic fatigue resistance of these file systems.

MATERIALS AND METHODS

After a power calculation with G*Power 3.1 software (Heinrich Heine University, Dusseldorf, Germany), 20 NiTi files were included in each group [9]. Thus, 20 files from each brand were included in the present study: VDW.ROTATE (size 25/0.04), TruNatomy Prime (size 26/0.04), 2Shape TS1 (size 25/0.04), and HyFlex CM (size 25/0.04).

All 80 NiTi files were examined under a dental operation microscope (OMG 2350, Zumax, Suzhou, China) at ×20 magnification to exclude the presence of deformation. As no deformation was observed, all the files were included and subjected to static cyclic fatigue testing.

All the instruments were rotated in stainless steel artificial canals with a 60° angle of curvature and a 5 mm radius of curvature, as previously described [10]. All the canals reproduced the exact size and taper of the instruments to be tested. The file tip was located end of the artificial canal. The D5 point of the file was located at the maximum curvature of the artificial canal. Before inserting the instruments into the artificial canals, the artificial canal was immersed in distilled water in a glass container, and the box made of glass was put onto a warm plate that kept the distilled water temperature at 37°C ± 1°C [11]. They were then operated until fracture occurred.

The NiTi files were used according to the manufacturer's recommendations with a torque-controlled endodontic motor (X-Smart Plus, Dentsply-Sirona) in continuous rotation, as follows: VDW.ROTATE size 25/0.04 at 300 rpm and 2.3 Ncm torque, TruNatomy Prime at 500 rpm and 1.5 Ncm, 2Shape TS1 at 300 rpm and 2.5 Ncm torque, and HyFlex CM size 25/0.04 at 500 rpm and 2.4 Ncm torque.

The time for breakage of every NiTi file has been read in seconds via a digital chronometer. The following formula was used to determine the number of cycles to fracture (NCF): NCF = revolutions per minute (rpm) × time to fracture (sec)/60. After this experiment, the fracture tips (FL) of the tested NiTi files have been measured with a digital microcaliper in millimeter. The mean FL was listed to assess the exact positioning of the NiTi files inside the artificial canal that indicates the NiTi files faces with comparable stresses.

Two representative samples from each brand were examined under a scanning electron microscope (SEM) (JSM-7001F, JEOL, Tokyo, Japan) to determine the fracture type, and photomicrographs of fractured surfaces were obtained at 2 magnifications (×100 and ×3,000).

Statistical analysis

To check the assumption of normality, the data were analyzed using the Shapiro-Wilk test. The normality test revealed that the NCF and FL data had a normal distribution. Thus, a 1-way analysis of variance and *post hoc* Tamhane tests were performed for intergroup comparisons of both the NCF and FL data. All the statistical analyses were performed using SPSS 21.0 (IBM-SPSS Inc., Chicago, IL, USA) software. The statistical significance level was set at 5%.

RESULTS

Table 1 shows the mean and standard deviation of the NCF and FL values for all the instruments tested. The NCF values from highest to the lowest were as follows: VDW. ROTATE > HyFlex CM > 2Shape TS1 > TruNatomy Prime (Dentsply-Sirona) ($p < 0.05$). There was no significant difference in the FL values among the NiTi groups ($p > 0.05$) (**Table 1**).

The SEM analysis of the fractured surfaces of the NiTi files showed fatigue striations lines fatigue that indicates that the tested NiTi files fractured due to the cyclic fatigue (**Figure 1**).

DISCUSSION

The present study compared the fatigue resistance of files with small taper sizes designed for use in minimally invasive endodontic treatment. All tests were performed in artificial steel canals. Previous studies reported that artificial canals manufactured according to the tested file dimensions could be used in experiments. The stress that affects the files in these artificial canals was similar to the stress that the file faces in clinical practice [12,13]. The stainless-steel artificial canals used in the present study were manufactured according to the dimensions of the files tested.

Unlike conventional NiTi alloys, NiTi files manufactured using recently produced heat-treated materials have a martensite-austenite transition temperature close to or higher than that of body temperature [14]. Previous studies reported decreased cyclic fatigue resistance of heat-treated NiTi files when the instruments were tested at body temperature rather than

Table 1. Mean and standard deviation of the number of cycles to failure (NCF) and the fragment length (FL) of the tested nickel-titanium rotary files

Group	No.	NCF	FL (mm)
VDW.ROTATE	20	1,840.84 ± 257.62[a]	5.68 ± 0.55[a]
TruNatomy	20	1,110.72 ± 144.32[b]	5.56 ± 0.49[a]
2Shape	20	1,155.53 ± 173.25[b]	5.63 ± 0.54[a]
HyFlex CM	20	1,566.62 ± 250.55[c]	5.61 ± 0.51[a]
p value		< 0.05	> 0.5

Different superscript letters indicate a statistically significant difference ($p < 0.05$).

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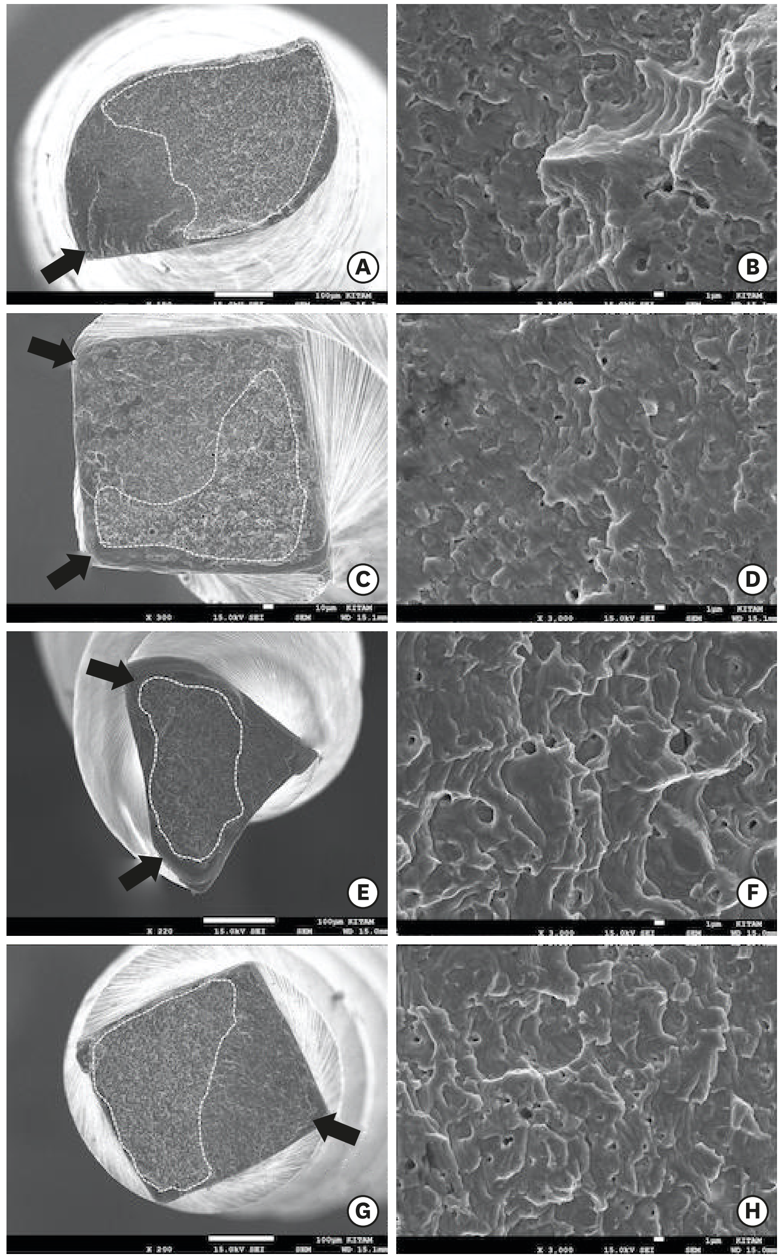

Figure 1. The scanning electron microscope (SEM) images of the tested file's fractured surface. Representative scanning electron microscopic images of the fractured surfaces of the separated instruments after the cyclic fatigue tests. (A, E) VDW.ROTATE, (B, F) TruNatomy, (C, G) 2Shape, (D, H) HyFlex CM. SEM in the left column (magnified ×180 to ×300) shows a cross-section of the fractured instrument. The arrows indicate the crack initiation area and ductile dimpled area outlined with the dotted line indicate overload fast fracture zone. SEM in the right column area (magnified ×3K) shows fatigue striations and fibrous dimples.

room temperature [15-18]. Thus, to better simulate clinical conditions, the NiTi files used in the present study were placed in heated distilled water (37°C ± 1°C) before the cyclic fatigue tests to simulate body temperature. Cyclic fatigue tests do not aim to replicate clinical conditions but only to investigate a particular mechanical property of an instrument [19]. Cyclic fatigue static tests are favored over dynamic tests because the latter cannot replicate real clinical conditions [20,21]. Furthermore, the results of dynamic tests cannot be used to infer aspects of the mechanical behavior of NiTi files [21].

In the present study, the cyclic fatigue resistance values of the tested files were significantly different ($p < 0.05$). Thus, the null hypothesis was rejected. According to the results of the present study, the VDW.ROTATE files had the highest cyclic fatigue resistance. No study compares that compares the VDW.ROTATE and TruNatomy file's cyclic fatigue resistance in the literature. That's why the results of the present study cannot be directly compared with other studies in the literature. Previous studies reported that the heat treatment applied to files and the method used in their manufacturing might affect the fatigue resistance of endodontic instruments [22,23]. Thus, the heat treatment applied to VDW.ROTATE files may have contributed to the superior fatigue resistance of these files.

Previous research demonstrated that the type of horizontal cross-sectional design played an essential role in the cyclic fatigue resistance of NiTi mechanical files [24,25]. NiTi files that have an S-shaped horizontal cross-sectional design had higher cyclic fatigue resistance than the NiTi files with horizontal rectangular and triangular cross-sectional designs [25-27]. Grande *et al.* [25] reported that the volume of metal mass at the maximum curvature point contributed to the fatigue resistance of files. Mtwo files (VDW), which have an S-shaped horizontal cross-sectional design and lower metal mass, exhibited higher fatigue resistance than that of ProTaper files (Dentsply-Sirona), which have a triangular design and greater metal mass [25]. Several studies concluded that files manufactured with an S-shaped horizontal cross-sectional design might show increased fatigue resistance because of a reduction in the metal volume at the maximum curvature point [12,18,28,29]. VDW.ROTATE files an S-shaped horizontal cross-section similar to that of Mtwo and Reciproc (VDW) instruments [30]. This cross-sectional characteristic may have contributed to the enhanced cyclic fatigue resistance of the VDW.ROTATE files in the present study.

In the current study, the fatigue resistance of the HyFlex CM files was significantly higher than that of the 2Shape TS1 and TruNatomy Prime files ($p < 0.05$). The CM-Wire alloy used in the manufacturing of HyFlex CM files might explain their improved fatigue resistance as compared with that of 2Shape TS1 files, which are made of T-Wire alloy, and TruNatomy Prime files, which are produced using a different heat treatment. Özyürek *et al.* [31] found higher fatigue resistance of HyFlex EDM files with a controlled memory feature as compared with that of 2Shape TS1 files and concluded that the alloy properties might have contributed to these results.

A previous study reported higher fatigue resistance values of files with triangular cross-sections as compared with those of files with square cross-sections [32]. This finding might explain why the fatigue resistance of the 2Shape TS1 files in the present study was higher than that of the TruNatomy Prime files (not statistically significant). Özyürek *et al.* [31] reported that 2Shape TS1 files manufactured with a triple helix cross-sectional design exhibited improved fatigue resistance because of their smaller metal mass as compared with that of WaveOne Gold (Dentsply-Sirona) files, which have a rectangular horizontal cross-section. Another study reported that an increase in file size might result in a decrease in fatigue resistance [33]. Thus, the slightly larger tip diameter (0.26 mm) of the TruNatomy Prime files concerning that of the other tested files (0.25 mm) may account for the reduced fatigue resistance of the TruNatomy Prime files in the present study.

Caution is needed in extrapolating the results of this *in vitro* study to clinical conditions because it is difficult to compare the effect of a single factor on the cyclic fatigue resistance of the tested files, as they were produced using different heat-treatment procedures and had various geometric characteristics and designs.

CONCLUSIONS

Under the present study conditions, VDW.ROTATE files exhibited the highest cyclic fatigue resistance among all the NiTi rotary files tested, followed by HyFlex CM, 2Shape, and TruNatomy.

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