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Comparative analysis of torsional resistance among single-file nickel-titanium systems

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Purpose: To evaluate the torsional fatigue resistance of One Curve Mini (OCM), HyFlex EDM (HEDM), WaveOne Gold Primary (WOG), and Reciproc Blue R25 (RPB) rotary and reciprocating nickel-titanium (NiTi) single-file systems.

Methods: Eighty NiTi instruments were tested: OCM (25/.06), HEDM (25/.08), WOG (25/.07), and RPB (25/.08) (n=20 per group). The instruments were fixed at apical 3 mm along their long axis and constant rotation of 2 rpm were applied until fracture occured. Ultimate strength at maximum torque and distortional angle for each file were measured using torsiometer. Statistical analysis was performed with one-way analysis of variance followed by Tukey's post-hoc test, using a 5% significance level ($p<0.05$). All the fractured instruments were scanned using scanning electron microscope to confirm that the instruments were fractured due to torsional fatigue.

Results: Maximum torque values were observed in HEDM and RPB ($p<0.05$) and the minimum values were in OCM ($p<0.05$) files. The torque values of WOG were not statistically different from the other three files ($p>0.05$). The distortion angle was highest in OCM and HEDM and the lowest values were in WOG files ($p<0.05$). RPB files have a similar distortion angle with the other three files ($p>0.05$).

Conclusion: HEDM and RPB were highest and OCM was the least resistant to torsional stress among the tested NiTi file systems.

Keywords: Instrument fracture; nickel-titanium; resiprocating file; rotary file; torsional resistance.

Introduction

Nickel–Titanium (NiTi) files, owing to their elasticity and flexibility, allow for rapid and reliable preparation of curved root canals (1). However, they are prone to fracture under torsional and cyclic fatigue stresses during use, which may adversely affect the treatment prognosis (2). Cyclic fatigue arises from alternating tensile and compressive stresses acting on files in curved root canals. Torsional fatigue is

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induced when the file tip becomes engaged in the canal (3,4). The alloy composition, size, cross-sectional design, and kinematics of NiTi files significantly influence their clinical performance and resistance to fatigue (5,6).

Reciprocating motion of NiTi files, either clockwise or counterclockwise, was introduced to reduce torsional and cyclic fatigue, thereby simplifying root canal shaping and enabling a single-file approach. The single-use recommendation for these systems primarily aims to minimise the risk of cross-contamination, including prion transmission (7). In reciprocating motion, the smaller counterclockwise angle allows NiTi files to operate within their elastic limit, thus reducing the risk of fracture in curved canals (8). The first reciprocating NiTi file systems introduced were Reciproc (RPC; VDW GmbH, Munich, Germany) and WaveOne (WO; Dentsply Sirona, Ballaigues, Switzerland). These systems were later updated to Reciproc Blue (RPC Blue; VDW GmbH, Munich, Germany) and WaveOne Gold (WOG; Dentsply Sirona, Ballaigues, Switzerland), respectively.

RPC Blue files are reciprocating NiTi instruments with similar dimensions and an S-shaped cross-section to the original RPC files. They undergo a proprietary heat treatment that produces a blue titanium oxide layer on the surface, imparting shape memory properties to the instrument. This heat treatment has been shown to significantly increase the cyclic fatigue resistance and flexibility of RPC Blue compared with RPC (9,10). WOG files employ the same kinematics as the WO system, but their dimensions and cross-sectional geometry have been modified. Specifically, the WOG cross-section has been redesigned into a parallelogram with two cutting edges (11), and the instruments undergo a post-manufacturing Gold heat treatment, which enhances flexibility (12). The slow heating–cooling process applied during Gold treatment leads to Ti_3Ni_4 precipitation on the NiTi surface (13), and the martensitic transformation occurs in two steps, thereby increasing file flexibility (11,14).

Hyflex EDM (HEDM; Coltene/Whaledent AG, Altstätten, Switzerland) is a NiTi system that operate in continuous rotation and permit complete root canal preparation with a single instrument. Manufactured from controlled memory (CM) wire using electro-discharge machining (EDM) technology, these files have been reported to exhibit superior mechanical properties (15). The design of HEDM changes along its working length, being quadratic in the apical third, trapezoidal in the middle third, and triangular in the coronal third.

One Curve Mini (OCM; Micro-Mega, Besançon, France) is made from heat-treated C Wire NiTi alloy, which is purported to enhance flexibility and fatigue resistance. Developed as a rotary single-file system, it is intended to shape root canals to the full working length while minimising dentine removal (16).

Preparation of the entire root canal system with a single instrument generates substantial torsional stress (17). Heat-treated single-use files with improved flexibility are less prone to fracture from cyclic fatigue (18,19). Nevertheless, most NiTi file separations occur due to torsional loading (17). Therefore, evaluating the torsional fatigue resistance of single-file systems is critical for ensuring safe clinical use. Accordingly, this study aimed to assess the torsional fatigue resistance of the single-file systems OCM, HEDM, WOG, and RPC Blue. The null hypothesis was that no significant differences would exist among the tested systems regarding resistance to torsional fatigue–related fracture.

Materials and Methods

Sample Selection

Power analysis was performed with G*Power v3.1.9.4 (Heinrich Heine University of Düsseldorf, Düsseldorf, Germany) based on the effect size reported in a previous study (20). A one-way ANOVA (fixed effects, omnibus) from the F-test family was selected, with an alpha error of 0.05 and a beta power of 0.95. The calculation indicated that at least 15 samples per group were required to detect the same effect. Accordingly, 20 NiTi files per group were allocated for torsional resistance testing.

Torsional Resistance Test

A total of 80 files—OCM (25/.06), HEDM OneFile (25/.08), WOG Primary (25/.07), and RPC Blue R25 (25/.08)—were examined under a dental operating microscope (OMS 3200, Zumax Medical, Suzhou, China) at 20× magnification for possible defects. As no deformation was observed, all instruments were included in the torsional resistance test. The tests were conducted in accordance with ISO 3630-1 standards (1992) using a custom-made torsion device, as described in previous studies (17,20).

Before testing, the handles of the files were removed at the shaft junction and secured in a mandrel connected to a geared motor. To prevent slippage during rotation, the apical 3 mm of each file was clamped in another brass mandrel. OCM and HEDM files were rotated clockwise, while WOG and RPC Blue were rotated counterclockwise, all at a constant speed of 2 rpm until fracture occurred. For each file, the maximum torque (N·cm) and angle of rotation (°) at fracture were recorded.

Scanning Electron Microscopic Analysis

All instruments were cleaned in an ultrasonic bath containing ethyl alcohol for 5 minutes prior to scanning electron microscope (SEM) analysis. To examine the topographic features of the fractured instrument surfaces, photomicrographs at different magnifications (x600, x800, x3000) were obtained using a SEM device (FEI Quanta 400 FEG, Hillsboro, OR, USA).

Statistical Analysis

Normality of the data was first assessed using the Shapiro–Wilk test. Subsequently, one-way ANOVA followed by Tukey's post-hoc test was performed. All statistical analyses were conducted with SPSS version 21.0 (IBM-SPSS Inc., Chicago, IL, USA), and the significance level was set at 5% ($p<0.05$).

Results

Figure 1 presents representative SEM micrographs of the fractured surfaces of the tested instruments. The mean and standard deviation values of maximum torque (N·cm) and distortion angle (°) are presented in Table 1. The highest maximum torque values were observed in HEDM and RPC Blue instruments ($p<0.05$), with no significant difference between these two groups ($p>0.05$). The lowest torque values were recorded for OCM instruments ($p<0.05$). The maximum torque of WOG instruments did not differ significantly from those of the other systems ($p>0.05$).

The greatest distortion angles were found in OCM and HEDM instruments, whereas the lowest values were observed in the WOG group ($p<0.05$). The distortion angles of RPC Blue instruments did not differ significantly from those of the other groups ($p>0.05$).

SEM images obtained from the cross-sections of the fractured instrument surfaces revealed typical features of torsional failure. At low magnification, smooth flat areas and concentric abrasion marks were observed, while at higher magnification, centrally located dimpled depressions were evident.

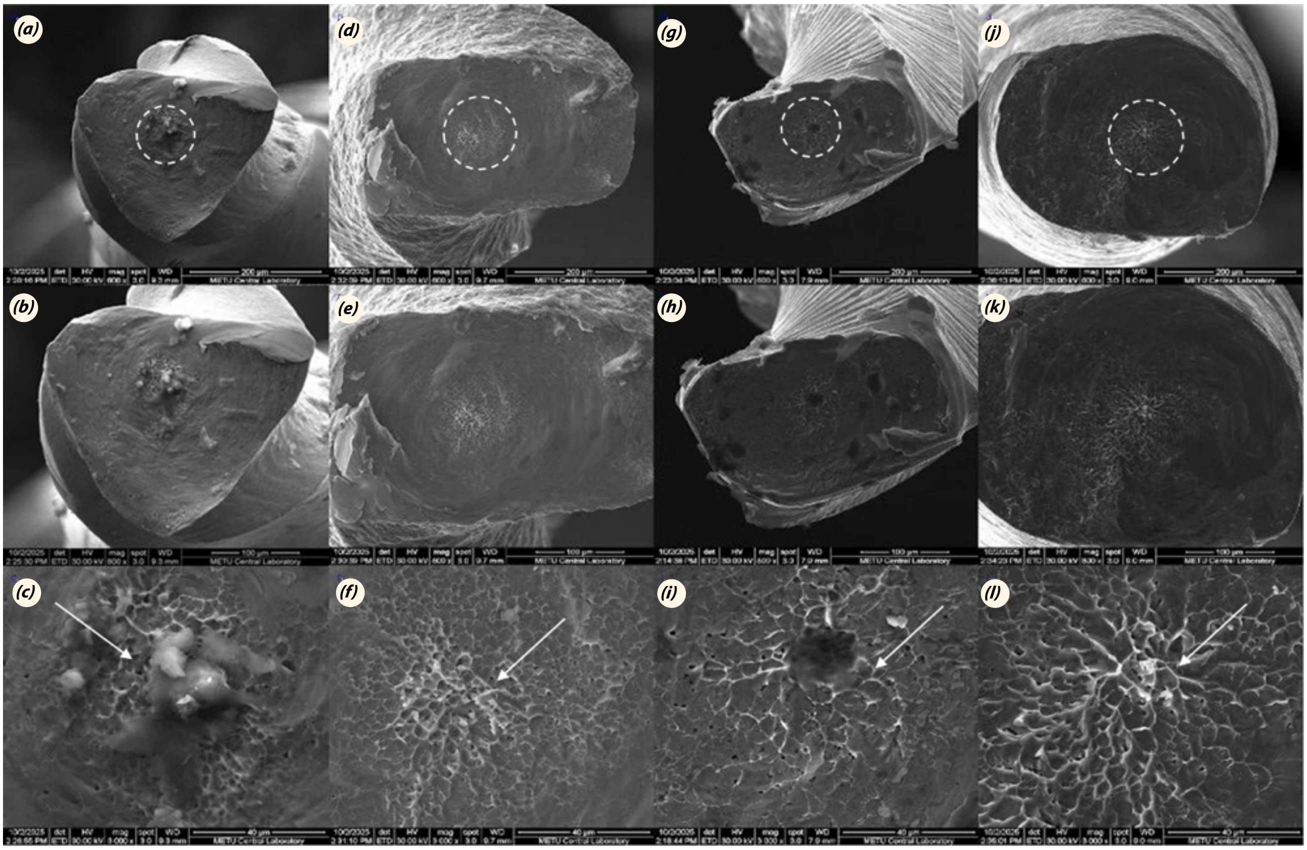

Fig. 1. Scanning electron micrographs of the cross-sections of fractured instrument surfaces. The columns, from left to right, correspond to One Curve Mini **(a, b, c)**, HEDM **(d, e, f)**, WaveOne Gold Primary **(g, h, i)**, and Reciproc Blue **(j, k, l)**, respectively. The rows, from top to bottom, display images captured at ×600, ×800, and ×3000 magnifications, respectively. Scanning electron micrographs of the cross-sections of the fractured instrument surfaces revealed typical characteristics of torsional failure. At lower magnification, smooth flat areas and concentric abrasion marks (indicated by white circles) were observed, whereas at higher magnification, centrally located dimpled depressions (indicated by white arrows) were evident.

Table 1. Ultimate strength at maximum torque (N.cm) and Distortional angle (°) of the tested NiTi file systems (Mean ± Standard Deviation).

NiTi File System	Ultimate strength at maximum torque (N.cm)	Distortion angle (°)
One Curve Mini	1.335±0.16[a]	543.96±70.71[a]
HEDM OneFile	2.195±0.32[b]	559.68±61.56[a]
WaveOne Gold Primary	1.725±0.24[ab]	294.72±44.02[b]
Reciproc Blue R25	2.425±0.31[b]	413.22±67.90[ab]
p-value	<0.05	<0.05

*Different superscript letters indicate statistically significant difference at 5% level ($p<0.05$).

Discussion

The torsional strength of NiTi instruments reflects their ability to withstand twisting before fracture, which is particularly important in narrow or calcified canals where torsional stresses are high (4). Single-file systems used for root canal preparation are subjected to considerable torsional loads; therefore, adequate resistance is essential to minimise the risk of instrument separation (21). Various NiTi systems employing either reciprocating or continuous rotation kinematics currently allow canal shaping with a single file. The present study evaluated the torsional fatigue resistance of OCM, HEDM, WOG, and RPC Blue instruments.

Based on the results, significant differences were observed among the tested systems in resistance to torsional stress, leading to rejection of the null hypothesis. Maximum torque and distortion angle reflect the instruments' fracture resistance and ductility. Instruments with higher ultimate strength also demonstrate greater resistance to torsional fatigue (22). Among the systems evaluated, HEDM and RPC Blue showed the greatest torsional fatigue resistance. Several factors may influence torsional resistance and stress distribution, including cross-sectional design, instrument size, alloy composition, and thermomechanical heat treatments (5,22,23).

The relative dimensions of instruments within root canals strongly affect the torsional stresses generated during use (24). In this study, although the instruments tested differed in design and taper, they all had the same apical tip diameter. However, the larger tapers of RPC Blue and HEDM instruments (.08) compared with WOG (.07) and OCM (.06) may have resulted in a greater metal mass, which could explain their higher resistance to torsional stress (5).

The torsional fatigue resistance of NiTi instruments is also influenced by alloy type and manufacturing method (25). Each system tested in this study was produced using a different alloy and manufacturing technique. In HEDM, EDM technology is used to shape the surface, creating greater hardness without compromising flexibility (26). This may explain the higher torsional resistance and angular distortion observed in HEDM compared with the other systems. The lowest torsional resistance was found in OCM and WOG instruments. Although WOG has an off-centered parallelogram cross-section and OCM a triangular cross-section, alloy properties appear to play a more decisive role in torsional resistance. The Gold heat treatment applied to WOG instruments increases austenite finish temperature and induces a two-step transformation behavior, which enhances flexibility (11) and may have influenced torsional strength. Consistent with these findings, Silva et al. (27) reported lower torsional resistance for WOG compared with RPC Blue, attributing the difference to the higher taper and greater core mass of RPC Blue instruments.

Careful interpretation of the relationship between maximum torque and distortion angle is essential (4,21). While maximum torque represents the instrument's resistance to fracture when subjected to torsional load, the distortion angle indicates the instrument's capacity to undergo plastic deformation prior to fracture, thereby its ductility (5,25). Typically, the literature suggests that stiffer instruments exhibit higher torque values, whereas their distortion angles tend to be lower (16,23). However, in the present study, no linear correlation was observed between these two parameters across the experimental groups. For instance, the HEDM instrument demonstrated both high torsional resistance and a substantial distortion angle. This absence of a direct correlation can be attributed to the confounding effects of distinct manufacturing processes, such as EDM compared with traditional grinding, and proprietary heat treatments including Blue, Gold, C Wire and CM Wire technologies (15,26,28). These treatments alter the phase transformation temperatures and the martensite-to-austenite ratio within the alloy, effectively decoupling the traditional inverse relationship between strength and ductility (13,17,22). Consequently, a file system can be engineered to be both resistant to torsional stress and sufficiently ductile to provide a safety margin, offering the clinician a visual warning in the form of unwinding (3,18).

In the present study, HEDM (CM Wire) and OCM instruments exhibited the highest distortion angles. Previous reports have shown that NiTi instruments manufactured from CM Wire demonstrate higher distortion angles and lower torsional load capacity compared with Blue and Gold alloys. Moreover, lower transformation temperatures have been associated with greater torsional resistance (22). Further studies are needed to clarify the relationship between transformation behavior and torsional resistance of NiTi instruments.

In this study, torsional resistance was measured as the ultimate torsional strength sustained in the cutting direction until fracture, rather than under reciprocating motion. Elsaka et al. (5) reported that the smaller reverse angles of reciprocation reduce instrument stress, indicating that NiTi files are subjected to greater torsional loads in fatigue testing than under clinical conditions. This contextual difference is important when interpreting the results of torsional fatigue studies on reciprocating systems.

This study has certain limitations that must be acknowledged. Firstly, the torsional resistance was evaluated under static conditions according to ISO 3630-1 standards. While this method provides a standardized baseline for comparison, it does not fully replicate the dynamic stresses of clinical practice, where instruments are subjected to simultaneous torsional and cyclic fatigue. Secondly, the tests were conducted at room temperature (21°C±1°C). Given that phase transformation temperatures of heat-treated NiTi alloys are sensitive to thermal changes future studies should consider simulating body temperature (37°C) to better reflect clinical behavior (29).

Furthermore, the torsional tests were conducted at a constant low speed of 2 rpm in accordance with ISO 3630-1 standards to eliminate the influence of inertia. However, in clinical practice, these instruments operate at significantly higher rotational speeds (ranging from 300 to 500 rpm). While some studies suggest that rotational speed may not significantly alter the ultimate torsional strength of certain NiTi instruments (30), the mechanical response of NiTi alloys is known to be strain-rate dependent. Therefore, the torsional behavior observed at low static speeds might not fully capture the dynamic performance of the specific heat-treated files used in the present study.

Clinically, the findings of this study suggest that instruments with higher torsional resistance, such as HEDM and RPC Blue, may offer a safer option in narrow and calcified canals where the instrument tip is prone to locking. High torsional resistance minimises the risk of plastic deformation and subsequent fracture. However, the clinician must balance this with the need for flexibility, as demonstrated by the high distortion angles of OCM and HEDM, which can provide a warning sign of plastic deformation before separation occurs.

Conclusion

Within the limitations of this study RPC Blue and HEDM instruments demonstrated greater torsional fatigue resistance compared with WOG and OCM, whereas OCM and HEDM exhibited the highest distortion angles.

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