

Review Article

Evaluation of Cyclic Fatigue and Torsional Strength of Three Different Thermally Treated Reciprocating Nickel-Titanium Instruments

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Abstract

Objectives: This article's objective was to assess the reciprocating single-file systems Reciproc Blue 25.08 and Prodesign R 25.06's cyclic and torsion fatigue resistance.

Materials and Methods: The systems Reciproc Blue R25 (RB #25.08 taper), Prodesign R (PDR #25.06 taper), and WaveOne Gold (WOG #25.07 taper) (n = 20) were utilized to make sixty reciprocating instruments. The period to breakdown in an artificial stainless-steel canal with a 60° angle of curvature and a 5-mm radius was measured during cyclic fatigue resistance testing (n = 10). The torque and angle of rotation at failure of new instruments (n = 10) were assessed during the torsional test (ISO 3630-1) in the area 3 mm from the tip. Scanning electron microscopy was also used to view each fragment's shattered surface (SEM).

Results: Cycle Fatigue Resistance scores for PDR 25.06 were much higher (P 0.05). Both WOG 25.07 and RB 25.08 showed less resistance to fatigue (P 0.05). Based on the torsional analysis, PDR 25.06 had weaker torsional strength (P 0.05). No changes were found with RB 25.08 and WOG 25.07 (P > 0.05). PDR 25.06 showed higher angular rotation values than RB 25.08 and WOG 25.07. (P 0.05). Greater angular rotation was seen in both WOG 25.07 and RB 25.08. (P 0.05). The cross-sectional area analysis revealed that PDR 25.06 had the smallest cross-sectional areas at 3 and 5 mm from the tip (P 0.05).

Conclusion: In comparison to RB 25.08 and WOG 25.07, PDR 25.06 had the highest cyclic fatigue resistance and angular rotation until fracture. Additionally, torsional strength was higher in RB 25.08 and WOG 25.07 than PDR 25.06. Clinical applicability.

Keywords: Nickel-Titanium; Cyclic Fatigue; Torsional Strength

Introduction

Engine-driven Nickel-Titanium (NiTi) has been used widely in endodontics since it offers safe root canal formation in curved canals due to its high level of flexibility and elasticity [1,2]. Nevertheless, instrument fracture remains a problem for doctors. Numerous new advancements, such as new designs, production methods, kinematics, and heat processes, have been made to improve the mechanical properties of NiTi instruments [1-6]. The reciprocating motion is defined as spinning with a 120° between the two rotations across both counterclockwise and anticlockwise orientations [3-6]. Such kinematics, that reduce the screwing-in effect and mechanical stress on the equipment, allow for the usage of singular instruments for root canal prep [3,4,6]. Furthermore, it has been shown that this movement is better than rotary motion and lowers cyclic and torsional fatigue when used to prepare the roots of curved and constrained root canals [3,4,6,7]. When the instrument rotates in a curved canal, recurring tension compression stress causes cycle fatigue at the location of maximum flexure [8,9]. Torsional fatigue often appears when

the instrument spins while the tip is anchored into the dentin walls during straight root canal preparation, resulting in plastic deformation or fracture [9,10].

Numerous thermally treated NiTi alloys have been developed by manufacturers to improve the mechanical properties of endodontic instruments [1,2,5]. Through a special thermal method known as controlled memory technology, super elasticity is maintained while a specific quantity of Rphase and B19 martensite phase are induced [2]. This treatment greatly improved cycle fatigue resistance and angular distortion capability compared to regular NiTi wire and Martensite wire (M-Wire) [2,11,12]. NiTi Wire. Processing methods have improved both the elastic modulus of rotary files and reciprocating machinery [5,6]. The WaveOne Gold system, a new reciprocating system that uses the very same reciprocating motion as the WaveOne file, was launched in 2015 (Dentsply/Tulsa Dental Specialties) (M-Wire). The WOG devices, meanwhile, are created using a brand-new thermal treatment technique called Gold treatment [13,14]. These device offers various shapes and sizes, with tip sizes of #20, #25, #35, and #45 with tapers of 0.07, 0.06, and 0.05, correspondingly. These tools have 2 sharp edge and a parallelogram-shaped cross-section [13]. In during Gold heat treatment process, the NiTi instruments has a protracted heating-cooling cycle that scatters Ti3Ni4 induces over the the metal's surface [15], causing the martensitic transformation to occur in two phases and enhancing flexibility [13,16,17]. According to past studies [13,14], WOG25.07 has more cycle fatigue resistance than the Reciproc (VDW GmbH, Munich, Germany) (M-Wire) and Wave One (MWire) technologies. In moreover, WOG outperforms Reciproc (M-Wire) in terms of torsional strength until fracture [18]. Reciproc Blue, a new iteration of the Reciproc system, was just unveiled. This reciprocating system's instrument tip diameters, tapers, and S-shaped cross sections match that of the Reciproc (M-Wire) system specifically.

The M-Wire alloy was replaced with the Blue treatment, a new thermal process, by the producers [5]. This high temperature uses a special heating-cooling procedure to produce blue-colored devices because of a titanium oxide coating [5,19]. This method minimizes the formability of the NiTi alloy and results in the occurrence of dynamic recrystallization in two phases, increasing the cycle fatigue resistance and flexibility when contrasted to Reciproc M-Wire equipment [5,19]. A brand-new reciprocating single-file device called the Prodesign R uses controlled memory technology (Easy Dental Equipment, Belo Horizonte, MG, Brazil). Throughout this configuration, two tools-a size 25 tool with a tapered of 0.06 and a size 35 tool with a taper of 0.05 display an S-shaped cross section. According to earlier research, the 25.06 instrument is more resistant to cyclic fatigue than Reciproc (M-Wire) and WaveOne (M-Wire) [21,22]. Despite the criticality of the impact of these thermal procedures on the mechanical properties of NiTi equipment, there haven't been any studies comparing the mechanical characteristics of these unique heat-treated reciprocating equipment.

The Prodesign R 25.06, Wave One Gold 25.07, and Reciproc Blue 25.08 instruments' cyclic and torsional fatigue (maximum torque load and angular rotation) was assessed in this research. The following null hypotheses were put to the test: (1) that there is no difference in the instruments' cycle fatigue resistance; and (2) that there is no difference in the instruments' torsional resistance.

Material and Methods

Even before mechanical characterization, the sample size was calculated using G*Power v. 3.1 with the Wilcoxon-Mann-Whitney test being chosen from the family of t tests. A 0.05 alpha-type error, a 0.95 beta power, and a 1 N2/N1 ratio were also required. The test revealed that the optimal sample size for detecting significant differences was eight samples, four for each group. To make up for potential unusual values that could result in sample loss, we utilized an additional 20% of the total instruments. For this work, a total of 60 NiTi instruments (length: 25 mm) were employed. Reciproc Blue (RB #25, 0.08 taper), Prodesign R (PDR #25, 0.06 taper), and WaveOne Gold (WOG #25, 0.07 taper) were the three groups of samples (n = 20 per system). Well before mechanical characterization, each instrument was examined using a stereomicroscope at a magnification of 16 to look for any potential flaws or abnormalities; none were rejected. test for cyclic fatigue A specially designed apparatus that replicated an artificial canal constructed of stainless steel with a 60° angle of curvature and a 5-mm radius of curvature situated 5 mm from the tip was used to conduct the dynamic cyclic fatigue test [22].

The synthetic oil used to lubricant the artificial canal throughout instrument initialization (Super Oil; Singer Co. Ltd., Elizabethport, NJ, USA). A computerized chronometer was used to track the time to fracture once all of the instruments had been turned on until fracture had taken place. Video records were made simultaneously during the testing, and the tapes were

examined to determine the precise moment the instrument broke. For every reciprocating system, ten instruments attached to a VDW Silver Motor (VDWGmbH) connected to the cyclic fatigue device were employed [10].

Torsional Test

Based on the International Organization for Standardization (ISO) standard 3630-1 (1992), the torsional tests were carried using a torsion machine, as originally explained by other investigations [22-24]. For each reciprocating system, ten instruments totaling 25 mm in length were used. This test was designed to calculate the average torque and maximum angular rotation before instrument fracture. The ultimate torsional load and angular rotation (°) values were provided by a specially constructed machine linked to a computer. The torque and angular rotation were recorded throughout the duration of the test. A particular machine software captured all of the data. Before testing, the handles of all of the instruments were removed at the point where they were attached to the torsion shaft. The 3 mm of the instrument tips was clamped into a mandrel connected to a geared motor. The geared motor operated in the counterclockwise direction at a speed set to 2 rpm for all of the groups.

SEM Evaluation

Following undergoing cyclic and torsional fatigue tests, 30 broken instruments (n = 10 per group) were chosen for SEM analysis (JEOL, JSM-TLLOA, JSMTLLOA, Tokyo, Japan) in order to identify the topographic characteristics of the fragments. The instruments were cleaned for three minutes in an ultrasonic cleaning unit with saline solution before to SEM analysis. Following cyclic fatigue testing, all of the instruments' cracked surfaces were looked at under a magnification of 250. Additionally, the cracked areas of the tools subjected to torsional testing were studied at magnifications of 200 and 1000 in the surfaces' centres. The images of the fractured surfaces obtained by SEM were used to measure the areas of the cross-section configurations at 3 and 5 mm from the tip using software [6,23].

Results

Table 1 displays the averages and standard deviations for the torque maximum load and rotational angle-based cyclic and torsional fatigue testing. PDR 25.06 outperformed all other groups in terms of cycle fatigue resistance (P 0.05). WOG 25.07 and RB 25.08 both displayed significantly lower lifetime values (P 0.05). Table 1 also includes the maximum torsional strength and figures for angular rotation. Of all the categories, PDR 25.06 exhibited the lowest torsional strength (P 0.05). Between RB 25.08 and WOG 25.07, there was no difference (P > 0.05). PDR 25.06 displayed greater values in relation to angular rotation than RB 25.08 and WOG 25.07. Furthermore, WOG 25.07 had lower values than RB 25.08 (P 0.05). Table 2 displays the means and standard deviations for the cross-sectional area and fragment length. Concerning the fragment lengths, there were no appreciable variations across the instruments (P > 0.05). PDR 25.06 had the lowest cross-sectional area of the cohorts, as seen by the area 3 mm from the tip (P 0.05). The difference between RB 25.08 and WOG 25.07 was statistically significant (P 0.05). WOG 25.07 had the biggest area of any of the instruments at 5 mm (P 0.05). In comparison to RB 25.08, PDR 25.06 displayed a considerably reduced cross-sectional area (P 0.05). SEM analysis for all of the instruments put to the test, scanning electron microscopy of the fragment surfaces revealed comparable and characteristic indications of cycle fatigue and torsional failures. All of the broken instrument surface displayed microvoids following the cyclic fatigue test, which are morphologic traits of ductile fractures (Fig. 1). All of the instruments displayed fibrous dimples and abrasion marks near the centre of rotation after the torsional tests (Fig. 2).

Instruments	Cyclic fatigue (s)		Torque (N.cm)		Angle (°)	
	Mean	SD	Mean	SD	Mean	SD
Reciproc Blue 25.08	876.5b	161.30	1.380b	0.1395	306.5b	8.592
Prodesign R 25.06	2099.8a	391.20	1.016a	0.0699	318.7a	8.396
WaveOne Gold 25.07	409.3c	77.24	1.230b	0.1859	296.0c	8.409
Different superscript letters in the same column indicate statistical differences among groups (P < .05) SD, standard deviation.						

Table 1: Mean cyclic fatigue (time in seconds), torque (N.cm), and angle of rotation (°) of instruments tested.

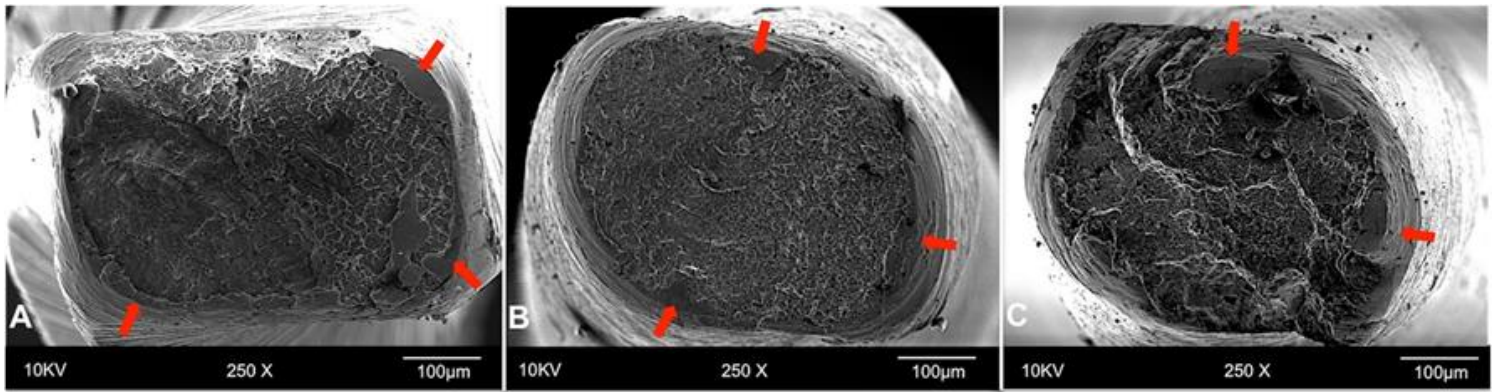


Figure 1: Scanning electron microscopy images of the fractured surfaces of separated fragments of a WaveOne Gold, b Recipro Blue, and c Prodesign R after cyclic fatigue testing. The crack origins are identified.

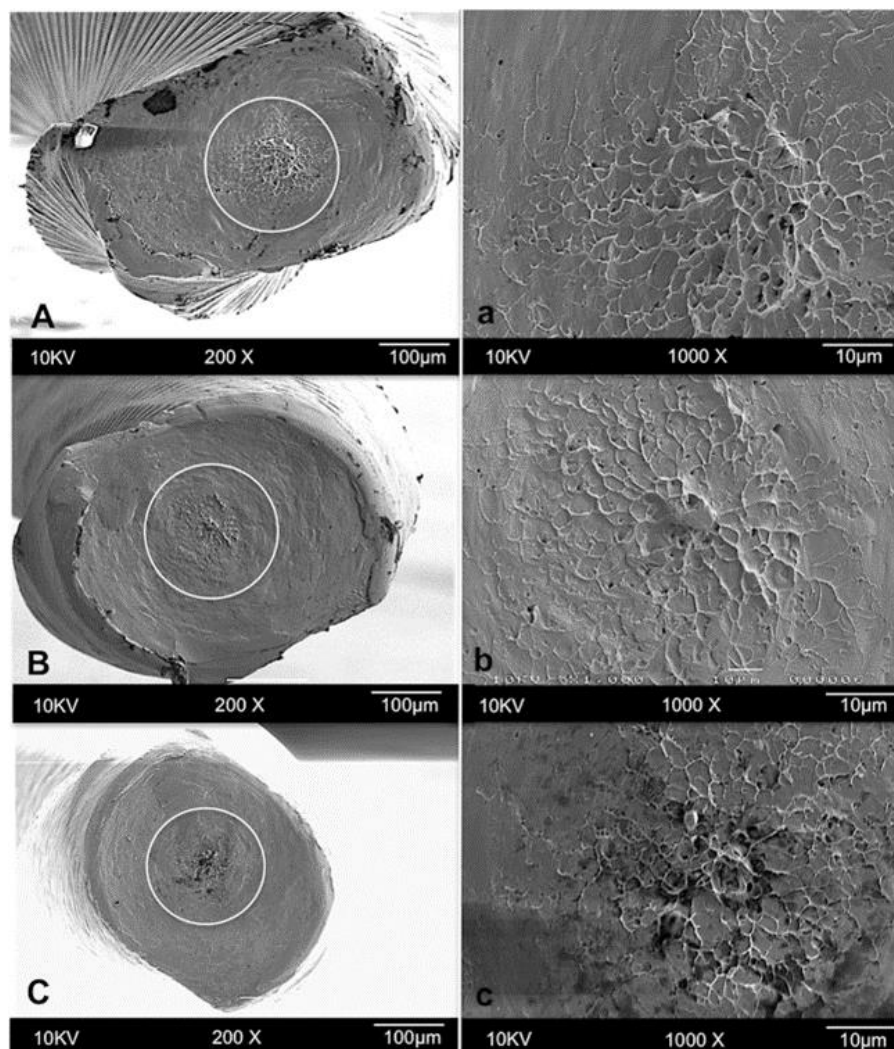


Figure 2: Scanning electron microscopy images of the fractured surfaces of separate fragments after torsional testing (first row: A, a =WaveOne Gold; second row: B, b = Recipro Blue; bottom row: C, c = Prodesign R). The left column shows images with the circular boxes indicating concentric abrasion marks at $\times 200$ magnification; the right column shows concentric abrasion marks at $\times 1000$ magnification; and the skewed dimples near the center of rotation are typical features of torsional failure by red arrows. The images show numerous dimples spread on the fractured surfaces, which constitute a typical feature of ductile fracture.

The martensitic/austenitic conversion behaviour of NiTi alloys is strongly influenced by thermal treatments [15,19,20], which could result in a different arrangement of the crystalline structure and a larger percentage of martensite transformation [2]. According to earlier studies, a larger martensitic phase content in the NiTi alloy encouraged greater flexibility and fatigue resistance [2,18,32]. According to our findings, WOG 25.07 and PDR 25.06 both exhibited stronger cyclic fatigue resistance than the other groups and higher cyclic fatigue time to fracture values than each other. There is a good chance that the various thermal treatments among them could lead to various martensitic phase transformations and various dissipations of the energy necessary for crack development and/or propagation during cyclic thermal cycling fatigue testing [2].

Gündoğar and Zeyrek demonstrated that RB 25.08 had greater cyclic fatigue resistance than WOG 25.07 as a result [33]. Additionally, it has been noted in the past that instruments produced using controlled memory technology have stronger cycle fatigue resistance than instruments produced using Blue and Gold treatments [26,34]. The findings of this investigation are consistent with the findings of the aforementioned experiments, indicating that instruments produced using controlled memory technology are probably higher flexible and fatigue-resistant than those produced using Blue and Gold treatments. Nevertheless, in clinical settings, the reciprocating motion minimises the torsional stress when the reverse motion occurs [6]. In this work, the torsional test examined the maximum torsional load and angular rotation to fracture while the instruments were spinning anticlockwise. As a result, this test tested the instrument's torsional behavior under intense torsional stress [32]. PDR 25.06 had the lowest torsional load when compared to RB 25.08 and WOG 25.07 ($P=0.05$); RB 25.08 and WOG 25.07 did not differ from one other.

Since significant differences were seen amongst three instruments evaluated ($P=0.05$), the secondary null hypothesis was dismissed. PDR 25.06 supported the greatest angular rotation to fracture, followed by RB 25.08 and WOG 25.07. The various cross-sectional designs and thermal treatments were probably responsible for the report's findings.

Prior torsional examination, the cross-sectional structure of each instrument was acquired in D3 by SEM for a second assessment, and the cross-sectional area was measured using software (AutoCAD) [5,15]. The lowest area (98.825 m^2) was displayed by PDR 25.06, followed by WOG 25.07 (108.301 m^2) and RB 25.08 (113.282 m^2) ($P=0.05$). Previous research has demonstrated that torsional loads are generally higher for instruments with larger cross-sectional areas [6,22,23,34].

Additionally, compared to instruments made with Blue and Gold treatments, NiTi instruments made with CM-Wire demanded lower torsional loads and larger angular rotation capacities till fracture [26,35]. Our findings concur with those of the aforementioned research and may assist in understanding the outcomes with PDR 25.06, which had a higher deformation capacity and required less torsional load. Past studies comparing the torsional fatigue resistance of RB 25.08 and WOG 25.07 has not been conducted. The findings indicated that WOG25.07 and RB25.08 both displayed equal torsional stresses but had larger angular rotation values ($P=0.05$).

The Blue process, which may have favoured the higher flexibility and better deformation capability, may have contributed to the higher angular rotation values of RB 25.08. Furthermore, the various core diameters and cross-sectional designs encouraged various torsional stress concentration behaviours, which may have an impact on fatigue susceptibility [25,26,36]. The SEM analysis for the three tested reciprocating files revealed the expected characteristics of cyclic and torsional fatigue. All of the tested instruments had overload zones and crack start sites after the cyclic fatigue test, along with lots of dimples all over the cracked surfaces. After the torsional test, the fragments showed concentric abrasion marks and fibrous dimples at the center of rotation [6,23,29].

The cyclic and torsional fatigue resistance were significantly reduced by the reciprocating motion [4,6]. Practitioners, though, ought to be aware of the variations in mechanical characteristics of the various NiTi reciprocating systems on the market [1]. The current findings revealed that PDR 25.06 and RB 25.08 were safer than WOG 25.07 for the construction of curved canals' root canals due to their higher cyclic fatigue resistance. However, the higher torsional loads of RB 25.08 and WOG 25.07 suggested that they may withstand greater torsional stress during the preparation of confined canals. The findings indicated that PDR 25.06 must be applied in conjunction with glide path preparation to lessen torsional stress and, thus, lower the probability of fracture. In summary, within the constraints of this investigation, the mechanical properties of the NiTi instruments were significantly

influenced by the instrument features, such as cross-sectional design, taper, and thermal treatments. Comparing PDR 25.06 to RB 25.08 and WOG 25.07, our findings revealed that PDR 25.06 had the highest cyclic fatigue resistance and maximum angular rotation values to fracture. But compared to PDR 25.06, RB 25.08 and WOG 25.07 had greater torsional resistance to fracture.

Conflict of Interest

The authors have no conflict of interest to declare.

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