**International Journal of Dental Research**
**www.dentaljournal.net**
**Online ISSN: 2664-9055, Print ISSN: 2664-9047**
**Received: 01-02-2023, Accepted: 19-02-2023, Published: 07-03-2023**
**Volume 5, Issue 1, 2023, Page No. 31-35**

# Evaluation of cyclic fatigue and torsional strength of three different thermally treated reciprocating nickel-titanium instruments

**Dr. Barnojjwal Dutta[1], Dr. Ritika Singh[2], Dr. Anushtha Kushwaha[3], Himanshu Kashyap[2]**
[1] Department of Conservative Dentistry & Endodontics, Institute of Dental Sciences, Bareilly, Uttar Pradesh, India
[2] Institute of Dental Sciences, Bareilly, Uttar Pradesh, India
[3] Department of Public Health Dentistry, Institute of Dental Sciences, Bareilly, Uttar Pradesh, India, Uttar Pradesh, India

## 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). In addition, a supplementary examination was performed to measure the cross-sectional area of each instrument 3 and 5 mm from the tip. The data were analyzed using one-way ANOVA and Tukey's test, and the level of significance was set at 5%.

**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 In endodontic practise, reciprocating instruments that have undergone thermal treatment are used to prepare the root canals of canals that are curved and constrained; as a result, these instruments must exhibit high flexibility and suitable torsional strength to reduce the risk of instrument deformation.

**Keywords:** nickel-titanium**,** cyclic fatigue, torsional strength

## Introduction

Because of its high level of flexibility and elasticity, engine-driven nickel-titanium (NiTi) has been employed extensively in endodontics, offering safe root canal preparation in curved canals [1, 2]. Nonetheless, clinicians continue to struggle with instrument fracture. In order to enhance the mechanical qualities of NiTi instruments, a number of technological advancements have been made, including new designs, manufacturing techniques, kinematics, and thermal treatments [1, 6]. Rotation in both clockwise and anticlockwise orientations with a 120° difference between the two revolutions constitutes the reciprocating motion [3, 6]. The use of single instruments for root canal preparation is made possible by these kinematics, which lessen the screwing-in effect and mechanical stress on the instruments [3, 4, 6]. Additionally, it has been demonstrated that this motion reduces cyclic and torsional fatigue and is safer than rotary motion during root preparation of curved and confined root canals [3, 4, 6, 7]. At the site of maximal flexure, recurrent tension compressive stress leads to cyclic fatigue when the instrument rotates in a curved canal [8, 9]. When the instrument's tip is fixed into the dentin walls during straight root canal preparation and the instrument proceeds to spin, causing plastic deformation or fracture, torsional fatigue typically develops [9, 10].

To enhance the mechanical characteristics of endodontic instruments, makers have created a number of thermally treated NiTi alloys [1, 2, 5]. Controlled memory technology is a unique thermal process that maintains superelasticity while inducing a particular amount of Rphase and B19 martensite phase [2]. When compared to normal NiTi wire and martensite wire (M-Wire), this treatment significantly increased angular deformation capacity [2, 12] and cycle fatigue resistance [2, 11]. (NiTi- Wire). The mechanical characteristics of rotary files and reciprocating equipment have both benefited from thermal treatments [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-WireThe 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. Such devices have a parallelogram-shaped cross-section that has two cutting edges [13]. The NiTi instrument undergoes a lengthy heating-cooling cycle during the Gold thermal process, resulting in Ti3Ni4 precipitates scattered on the NiTi surface [15], which causes the martensitic transformation to take place in two phases and increases flexibility [13,16,17]. WOG25.07 has more cycle fatigue resistance than the Reciproc (VDW GmbH, Munich, Germany) (M-Wire) and Wave One (MWire) systems, as per earlier research [13, 14]. Additionally, WOG has better torsional strength until fracture compared to Reciproc (M-Wire) [18]. Recently, a new generation of the Reciproc system— Reciproc Blue—was introduced. The instruments tip diameters, tapers, and S-shaped cross - sections of this reciprocating system are identical to those of the Reciproc (M-Wire) system. The Blue treatment, a new thermal treatment, was introduced by the manufacturers to replace the M-Wire alloy [5]. Due to a titanium oxide layer, this thermal treatment produces blue-colored instruments using an unique heating-cooling process [5, 19]. When compared to Reciproc M-Wire instruments [5, 19], this treatment increases the cycle fatigue resistance and flexibility by decreasing the formability alloy of the NiTi and causing the occurrence of martensitic transformation in two phases [19, 20]. The Prodesign R is a brand-new reciprocating single-file device that employs controlled memory technology (Easy Dental Equipment, Belo Horizonte, MG, Brazil). Two tools in this setup display an S-shaped cross section: one size 25 with a taper of 0.06 and one size 35 with a taper of 0.05. Previous studies have reported that the 25.06 instrument has higher cyclic fatigue resistance than Reciproc (M-Wire) [21, 22] and WaveOne (M-Wire) [21].

There haven't been any investigations contrasting the mechanical characteristics of these novel heat treated reciprocating instruments, despite the significance of the effects of these thermal procedures on the mechanical properties of NiTi instruments. 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.

## Materials 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 utilised 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).

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

| **Instruments** | **Cyclic fatigue (s)** | | **Torque (N.cm)** | | **Angle (°)** | |
|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD |
| Reciproc Blue 25.08 | $876.5^b$ | 161.30 | $1.380^b$ | 0.1395 | $306.5^b$ | 8.592 |
| Prodesign R 25.06 | $2099.8^a$ | 391.20 | $1.016^a$ | 0.0699 | $318.7^a$ | 8.396 |
| Wave One Gold 25.07 | $409.3^c$ | 77.24 | $1.230^b$ | 0.1859 | $296.0^c$ | 8.409 |

Different superscript letters in the same column indicate statistical differences among groups (P < .05) SD, standard deviation

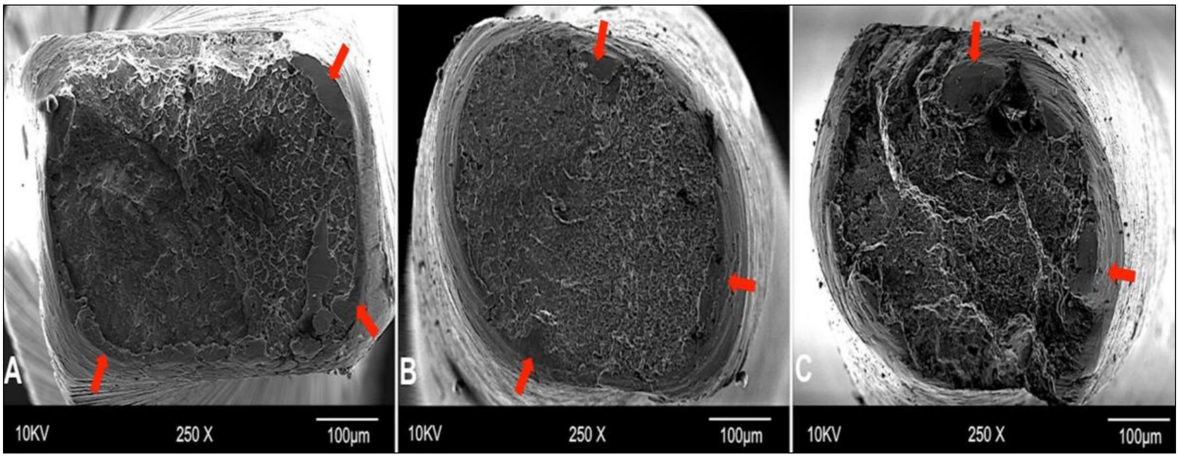

**Fig 1:** Scanning electron microscopy images of the fractured surfaces of separated fragments of a WaveOne Gold, b Reciproc Blue, and c Prodesign R after cyclic fatigue testing. The crack origins are identified

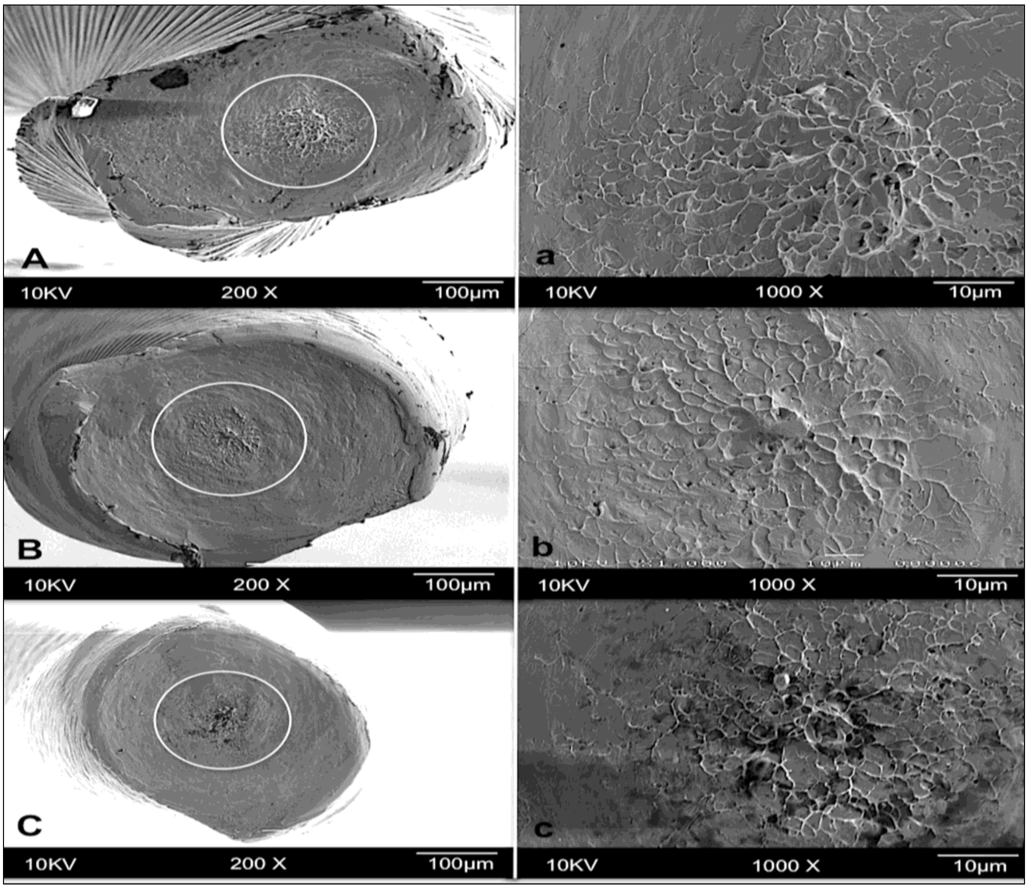

**Fig 2:** Scanning electron microscopy images of the fractured surfaces of separate fragments after torsional testing (first row: A, a =WaveOne Gold; second row: B, b = Reciproc Blue; bottom row: C, c = Prodesign R). The left column shows images with the circular boxes indicating concentric abrasion marks at × 200 magnification; the right column shows concentric abrasion marks at × 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].

Gündoar and zyürek [33] demonstrated that RB 25.08 had greater cyclic fatigue resistance than WOG 25.07 as a result. 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 [34] and Gold treatments [26]. 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 behaviour 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 m2) was displayed by PDR 25.06, followed by WOG 25.07 (108.301 m2) and RB 25.08 (113.282 m2) (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 [35] and Gold treatments [26], NiTi instruments made with CM-Wire demanded lower torsional loads and larger angular rotation capacities till fracture. 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.

## References

1. Gao Y, Gutmann JL, Wilkinson K, Maxwell R, Ammon D. Evaluation of the impact of raw materials on the fatigue and mechanical properties of ProFile Vortex rotary instruments. J Endod,2012:38(3):398-401.
2. Shen Y, Zhou HM, Zheng YF, et al. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. J Endod,2013:39(2):163-172.
3. De-Deus G, Moreira EJL, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. Int Endod,2010:43(12):1063-1068.
4. Karataş E, Arslan H, Büker M, Seçkin F, Çapar ID. Effect of movement kinematics on the cyclic fatigue resistance of nickeltitanium instruments. Int Endod J,2016:49(4):361-4.
5. De-Deus G, Silva EJ, Vieira VT, et al. Blue thermomechanical treatment optimizes fatigue resistance and flex- ibility of the Reciproc files. J Endod,2017:43(3):462-6.
6. Kim HC, Kwak SW, Cheung GS, et al. Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in reciprocation motion: Reciproc versus WaveOne. J Endod,2012:38(4):541-4.
7. Varela-Patiño P, Ibañez-Párraga A, Rivas Mundiña B, Cantatore G, Otero XL, Martin-Biedma B. Alternating versus continuous rotation: a comparative study of the effect on instrument life. J Endod,2010:36(1):157-159.

8. Sattapan B, Nervo GJ, Palamara JEA, et al. Defects in rotary nickel–titanium files after clinical use. J Endod, 2000:26(3):161-165.
9. Pedullà E, Lo Savio F, Boninelli S, Plotino G, Grande NM, la Rosa G, et al. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical dis- charge machining. J Endod,2016:42(1):156-159.
10. Elnaghy AM, Elsaka SE. Torsion and bending properties of OneShape and WaveOne instruments. J Endod,2015:41(4):544-547.
11. Zhou HM, Shen Y, Zheng W, et al. Mechanical properties of controlled memory and superelastic nickel-titanium wires used in the manufacture of rotary endodontic instruments. J Endod,2012:38(11):1535-1540.
12. Peters OA, Gluskin AK, Weiss RA, Han JT. An in vitro assessment of the physical properties of novel Hyflex nickel- titanium rotary instruments. Int Endod J,2012:45(11):1027-1034.
13. Özyürek T. Cyclic fatigue resistance of Reciproc, WaveOne, and WaveOne Gold nickel-titanium instruments. J Endod,2016:42(10):536-539.
14. Topçuoğlu HS, Düzgün S, Aktı A, Topçuoğlu G. Laboratory comparison of cyclic fatigue resistance of WaveOne Gold, Reciproc and WaveOne files in canals with a double curvature. Int Endod J,2017:50(7):713-717.
15. Hieawy A, Haapasalo M, Zhou H, Wang Z, Shen Y. Phase transformation behavior and resistance to bending and cyclic fa- tigue of ProTaper Gold and ProTaper Universal instruments. J Endod,2015:41(7):1134-1138.
16. Webber J. Shaping canals with confidence: WaveOne GOLD single-file reciprocating system. Roots,2015:11(1):34-40.
17. Plotino G, Grande NM, Mercadé Bellido M, Testarelli L, Gambarini G. Influence of temperature on cyclic fatigue resistance of ProTaper Gold and ProTaper Universal rotary files. J Endod,2017:43(2):200-202.
18. Elsaka SE, Elnaghy AM, Badr AE. Torsional and bending resistance of WaveOne Gold, Reciproc and Twisted File Adaptive instruments. Int Endod J,2016:50(11):1077-1083.
19. Plotino G, Grande NM, Cotti E, Testarelli L, Gambarini G. Blue treatment enhances cyclic fatigue resistance of vortex nickel- titanium rotary files. J Endod,2014:40(9):1451-1453.
20. Shen Y, Zhou H, Coil JM, Aljazaeri B, Buttar R, Wang Z, Zheng Y, Haapasalo M. ProFile vortex and vortex blue nickel-titanium rotary instruments after clinical use. J Endod,2015:41(6):937-942.
21. Silva EJ, Rodrigues C, Vieira VT, et al. Bending resistance and cyclic fatigue of a new heat-treated reciprocating instrument. Scanning,2016:38(6):837-841.
22. Alcalde MP, Tanomaru-Filho M, Bramante CM, Duarte MAH, Guerreiro-Tanomaru JM, Camilo-Pinto J, Só MVR, et al. Cyclic and torsional fatigue resistance of reciprocating sin- gle files manufactured by different nickel-titanium alloys. J Endod,2017:43(7):1186-1191.
23. Pedullà E, Lo Savio F, Boninelli S, Plotino G, Grande NM, la Rosa G, et al. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical dis- charge machining. J Endod,2016:42(1):156-159.
24. Bahia MG, Melo MC, Buono VT. Influence of simulated clinical use on the torsional behavior of nickel-titanium rotary end- odontic instruments. Oral Surg Oral Med Oral Pathol Oral Radiol Endod,2006:101(5):675-680.
25. Zhang EW, Cheung GS, Zheng YF. A mathematical model for describing the mechanical behaviour of root canal instruments. Int Endod,2011:44(1):72-76.
26. Kaval ME, Capar ID, Ertas H. Evaluation of the cyclic fa- tigue and torsional resistance of novel nickel-titanium rotary files with various alloy properties. J Endod,2016:42(12):1840-1843.
27. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel titanium rotary instruments. J Endod,2009:35(11):1469-1476.
28. Capar ID, Kaval ME, Ertas H, *et al.* Comparison of the cyclic fatigue resistance of 5 different rotary pathfinding instruments made of conventional nickel-titanium wire, M-wire and controlled mem- ory wire. J Endod,2015:41(4):535-538.
29. Lopes HP, Gambarra-Soares T, Elias CN, Siqueira JF Jr, Inojosa IFJ, Lopes WSP, et al. Comparison of the mechanical properties of rotary instruments made of conventional nickel- titanium wire, M-wire, or nickel-titanium alloy in R-phase. J Endod,2013:39(4):516-520.
30. Arslan H, Alsancak M, Doğanay E, Karataş E, Davut Çapar İ, Ertas H. Cyclic fatigue analysis of Reciproc R25® instruments with different kinematics. Aust Endod J,2016:42(1):22-24.
31. Pedulla E, Grande NM, Plotino G, et al. Influence of contin- uous or reciprocating motion on cyclic fatigue resistance of 4 dif- ferent nickel-titanium rotary instruments. J Endod,2013:39(2):258-261.
32. Kim JW, Ha JH, Cheung GS, *et al*. Safety of the factory preset rotation angle of reciprocating instruments. J Endod,2014:40(10):1671-1675.
33. Gündoğar M, Özyürek T. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc blue nickel-titanium instruments. J Endod,2017:43(7):1192-1196.
34. e Vasconcelos RA, Murphy S, Carvalho CA, *et al*. Evidence for reduced fatigue resistance of contemporary rotary instruments exposed to body temperature. J Endod,2016:42(5):782-7.
35. Pereira ESJ, Amaral CCF, Gomes JACP, Peters OA, Buono VTL, Bahia MGA. Influence of clinical use on physical-structural surface properties and electrochemical potential of NiTi endodontic instruments. Int Endod J,2017:2(1):34-9.
36. Baek SH, Lee CJ, Versluis A, Kim BM, Lee WC, Kim HC. Comparison of torsional stiffness of nickel-titanium rotary files with different geometric characteristics. J Endod ,2011:37(9):1283-6.