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Cyclic Fatigue Resistance, Macroscopic, Microscopic, and Elemental Analysis of Three Reciprocating Systems

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Abstract

Introduction: The aim was to compare the cyclic fatigue resistance and the macroscopic, microscopic, and elemental characteristics of three reciprocating endodontic systems. **Materials and Methods:** An *in vitro* experimental study was conducted with 3 groups (n=20): WaveOne Gold (WOG), Roll Wave Blue (RWB), and TF4 Gold (TF4). Cyclic fatigue resistance was assessed using a custom device with artificial curved canals and an endodontic motor operating in reciprocating motion. The fracture time (FT), in seconds, and the number of cycles to fracture (NCF) were the parameters evaluated in this analysis. Macroscopic analysis was performed using macro photography to assess the pitch, its distribution along the instrument, and the cutting edges. Microscopic analysis was performed using scanning electron microscopy (SEM) to examine surface and cross-sectional features. Additionally, energy-dispersive X-ray spectroscopy (EDX) was used to determine the elemental composition. Data from the cyclic fatigue analysis were analyzed using the Kruskal–Wallis test and Dunn's post hoc test (α=0.05). **Results:** RWB showed the highest resistance to cyclic fatigue, with higher FT and NCF values. The pitch and its distribution differed among all groups. SEM analysis revealed a higher loss of cutting-edge sharpness on TF4 instruments and greater tip deformation on WOG when used. EDX analysis showed no significant differences in elemental composition among the systems. **Conclusion:** RWB demonstrated superior cyclic fatigue resistance. Additionally, the systems had similar chemical compositions but differed in performance, which could be associated with variations in their alloy characteristics, design, and heat treatment.

Keywords: Endodontics; Flexural Strength; Microscopy Electron Scanning; Root canal preparations

Introduction

In the early 2000s, the concept of asymmetric motion was proposed in mechanized endodontics. This kinematics involves the rotation of the endodontic instrument in opposite directions to optimize cutting, debris removal, and fracture resistance [1, 2]. This kinematics, also called reciprocating motion, was based on the "balanced force" concept, which was initially proposed for manual instrumentation and later inspired the kinematics for mechanized systems [3, 4]. Specifically, Yared proposed combining the flexibility of NiTi with asymmetric reciprocating motion. For this purpose, he employed a motor that allowed programming of the reciprocating motion and used a ProTaper F2 instrument with 144° clockwise and 72° counterclockwise rotation. These preliminary observations demonstrated promising results in reducing instrument separation while maintaining the original canal morphology [1].

Following this milestone, the industry began producing specific systems to harness reciprocating motion. This development led to Reciproc (VDW, Munich, Germany) and WaveOne (Dentsply Sirona, Charlotte, NC, USA). These systems were designed with improved alloys, optimized geometries, and electronically controlled motors to apply reciprocating motion in a standardized and safe manner [5].

WaveOne Gold (WOG) (Dentsply Sirona) is the evolution of the WaveOne, and the main distinction from its predecessor is the gold heat treatment, which gives the instrument its characteristic golden color [6]. WOG exhibits higher resistance to cyclic fatigue compared with WaveOne and Reciproc [7]. Its improved flexibility allows it to navigate safely through curved canals, reducing the risk of iatrogenic injuries [8] and maintaining the original canal curvature during instrumentation [9].

Recently, alternative reciprocating systems, also known as replica-like instruments, have been launched on the market and gained popularity because of their lower prices. One of them is TF4 Gold (TF4) (D-Perfect, Shenzhen, China), which, similarly to the WOG, also incorporates a gold heat treatment [10].

Roll Wave Blue (RWB) (Denco Medical, Shenzhen, China) reportedly has a blue treatment, a reciprocating motion, and an optimized tip that facilitates coronal debris removal and reduces the screw-in effect. It has a fixed taper from D0 to D3 and a decreasing taper from D4 to D16 to preserve the dentin in the canal and prevent excessive wear [11].

There is limited evidence regarding both TF4 and RWB. Furthermore, comparisons of their mechanical and metallurgical properties with WOG have not been sufficiently studied. Therefore, this study aimed to compare the cyclic fatigue strength, macroscopic and microscopic characteristics, and elemental analysis of three reciprocating systems. The null hypothesis was that there would be no differences among the three systems in the assessed parameters.

Material and Methods

The sample size estimate for the cyclic fatigue strength assessment was based on a previous study that used replica-like systems [12], and an effect size of 1.049. The G*Power program (version 3.1.9.7) was used, considering a statistical power of 95% and an alpha error of 0.05. The calculation indicated that six instruments per group were required; however, 20 instruments per group were used. All instruments were commercially available at a length of 25 mm and were distributed into the following groups (n=20): RWB group, TF4 group, and WOG group.

Cyclic fatigue resistance

A custom-designed device (Fabristem, Lima, Peru) was used to allow reproducible assessment of instruments rotating freely within a curved artificial stainless-steel canal with a 60° curvature [13]. The radius of curvature was 5 mm, measured on the internal surface of the canal concavity, with the center of curvature located 5 mm coronal to the instrument tip and a curved segment approximately 5 mm long. The X-Smart Plus endodontic motor handpiece (Dentsply Sirona) was mounted on a movable stand that allowed precise positioning of the instrument within the artificial canal, ensuring three-dimensional alignment and stability during testing. A transparent glass plate was placed over the artificial stainless-steel canal, and the instruments were activated until a fracture was detected, using synthetic oil (WD-40 Multipurpose Product, Brazil) to reduce friction.

The programmed reciprocating motion for all groups corresponded to the WOG system, which includes 170° counterclockwise and 50° clockwise movement at 350 revolutions per minute (rpm). It is important to consider that this kinematics is consistent with the manufacturers' recommendations for TF4 and RWB, which are marketed as replica-like systems of WOG. The fracture time (FT) was recorded in seconds, and the number of cycles to fracture (NCF) was calculated using the formula (rpm × time in seconds)/60. The separated fragment of each instrument was retained to allow measurement of the fragment in millimeters (mm).

Macroscopic description

A morphometric analysis of each instrument was performed using standardized macro photography. A professional camera (EOS Rebel T5i, Canon, Tokyo, Japan) equipped with a macro lens (EF 100 mm f/2.8L Macro, Canon) and a ring flash (Macro Ring Lite, Canon) was used. All images were captured with constant exposure parameters: shutter speed 1/30 s, aperture f/5, and ISO 100. The camera, mounted on a 360° rotating tripod, was positioned perpendicularly against a white background at a standardized distance of 30 cm from the instruments, ensuring consistent framing and lighting for each shot. The images were analyzed using ImageJ software (NIH, Bethesda, MD, USA), with a pre-calibrated scale for measuring the active parts of the instruments. The coding for the measurements was established as "P," with "1" assigned at the beginning of the active portion and progressing sequentially across each pitch (defined as the distance between two consecutive cutting edges) to the tip of the instrument. The number of pitches, their distribution along the instrument, and the cutting edges of the active portion of the instruments were described [14].

Microscopic description

Structural analysis was performed using scanning electron microscopy (SEM). Instruments from all systems (n=3), designated as new, were sectioned at 5 mm and 10 mm from the tip using a precision cutting machine (OCP 100 LC, Odeme Dental Research, Luzerna, SC, Brazil). The 5-mm fragment was used for analysis of the active surface of the instrument (cutting edges and tip), whereas the 10-mm fragment was used for cross-sectional evaluation of each instrument.

All fragments were irrigated with distilled water and ultrasonically cleaned for 10 minutes (Cristófoli, Campo Mourão, PR, Brazil). Subsequently, they were individually mounted on metal stubs without metallization and analyzed using SEM (EVO 10MA, Carl Zeiss, Oberkochen, Germany) operated at 20 kV. Additionally, three previously fractured segments, considered "used," approximately 5 mm in length, were randomly selected from the cyclic fatigue test for the same microscopic evaluation. Comparative observations of the active surfaces and instrument tips were performed at different magnifications: 120×, 300× and 700× for active surfaces, tip, and cross-sections analysis, respectively.

Elemental analysis

The instruments (n=3 per group) were also characterized by energy-dispersive X-ray spectroscopy (EDX) using fragments from the active parts of the instruments. EDX analysis was performed with an SEM (EVO 10MA, Carl Zeiss) equipped with an X-act probe (Oxford Instruments, Abingdon, UK) in high-vacuum mode at 20 kV using secondary electrons. Automatic element identification was performed using AZtecOne software (Oxford Instruments), which also employed a dedicated filter for the analysis.

Statistical analysis

The data were analyzed using the open-source software Jamovi (Version 2.3.18.0, Sydney, Australia). The cyclic fatigue resistance data (FT and NCF) were analyzed using descriptive statistics. Normality was assessed with the Shapiro–Wilk test ($W=0.913$; $P<0.001$), and homogeneity of variances with Levene's test ($F (2.57)=9.41$; $P<0.001$). Since data did not meet the assumptions of normality and homoscedasticity, a non-parametric analysis was performed by using the Kruskal–Wallis test followed by Dunn's post hoc test ($\alpha=0.05$).

Results

Cyclic fatigue resistance

The RWB group showed higher FT and NCF compared with the TF4 and WOG groups ($P<0.001$), with no significant differences between the latter two groups ($P>0.05$) (Table 1).

Macroscopic description

The RWB, TF4, and WOG instruments showed morphometric differences among one another. RWB showed a higher number of pitches (eight in total) compared with TF4 and WOG, each of which showed seven pitches in total. A variation in pitch distribution was also identified along the active portion of the instrument. For TF4 and WOG, there was a gradual but more evident reduction in the cervical zone (P1–P4). For RWB, this reduction was concentrated in the apical zone (P5–P8) (Fig. 1A).

Microscopic description

SEM analysis revealed similarities in the design of the active parts. Cyclic fracture-pattern characteristics were observed, including depressions, a dowel pattern, and microscopic striations across the fracture surface. These features are typically located near the crack origin and extend toward the center of the cross-section. All instruments showed different cutting-edge patterns (Figs 2A, 3A & 4A). Examination of the active portions of the used instruments (Figs. 2D, 3D & 4D) revealed loss of cutting-edge sharpness in all groups, with this loss being most pronounced in the used TF4 instrument (Fig. 3D).

Tip analysis revealed that the new WOG instrument had an inactive tip (Fig. 2B), which appeared less rounded after use, showing deformation. The TF4 instrument also had a rounded tip when new (Fig. 3B), which lost sharpness after use (Fig. 3E). The RWB instrument had a fine tip when new (Fig. 4B), which similarly lost sharpness after use (Fig. 4E)

Regarding the cross-sections, the new WOG instrument showed a parallelogram-shaped cross-section (Fig. 2C). The new TF4 instrument also showed a rectangular cross-section but with blunt angles (Fig. 3C), whereas the new RWB instrument had a parallelogram shape (Fig. 4C). The analysis of the cross-sections of the separated instruments (Figs 2F, 3F & 4F) showed that the fracture pattern of the TF4 instrument had multiple irregularities in the metal (Fig. 3F), while WOG and RWB showed more uniform edges (Figs. 2F & 4F).

Elemental analysis

EDX analysis revealed that, although the atomic weight percentages showed slight variations among the instruments (Table 2), all systems exhibited similar proportions of nickel (Ni) and titanium (Ti). Figure 1B presents representative cross-sectional images of each group, including the corresponding elemental distribution peaks.

Discussion

This study aimed to compare the cyclic fatigue strength, macroscopic and microscopic characteristics, and composition of WOG, RWB, and TF4. The null hypothesis was rejected because differences were found among the groups studied, especially in cyclic fatigue resistance.

TF4 and RWB are intended for use with the same WOG reciprocation kinematics [10, 11]. However, subtle manufacturing differences between replica-like instruments and the original may alter the instruments' response to identical kinematics. Consequently, while the present results reflect performance under the manufacturers' recommended motion, they do not exclude the possibility that modified kinematic parameters could further alter cyclic fatigue behavior. Future studies could examine whether minor variations in reciprocation angles or speed influence fatigue resistance across these systems.

Although mechanized systems have improved over the decades, they still separate due to torsional stress or cyclic fatigue, the latter being caused by constant compressive and tensile stress on the instrument in a curved canal [13, 15]. Reciprocating motion has demonstrated higher resistance to cyclic fatigue compared with rotary systems, which may be attributed to the lower concentration of mechanical stresses generated by alternating motion [16, 17].

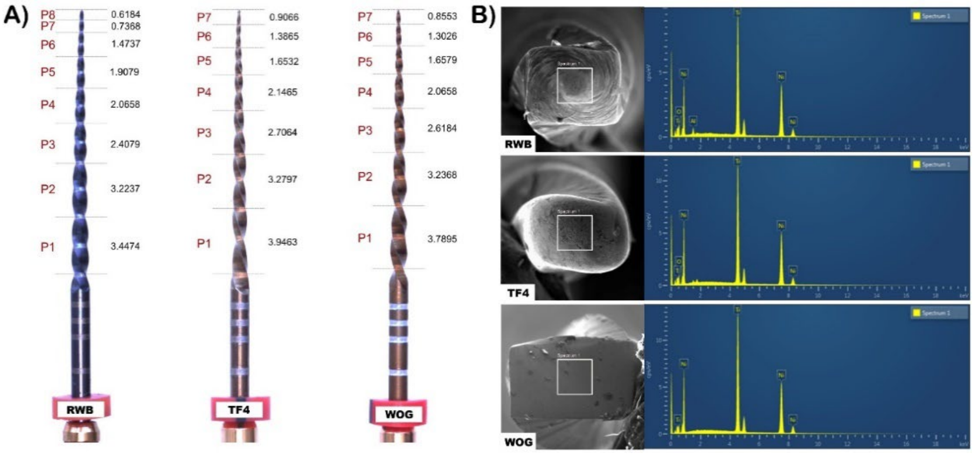

Figure 1. *A*) Macroscopic description of the instruments from the Roll Wave Blue (RWB), TF4 Gold (TF4), and WaveOne Gold (WOG) groups. Pitch distribution can be observed along the instruments from cervical (P1-P4) to apical (P5-P8); *B*) Elemental analysis by energy-dispersive X-ray spectroscopy (EDX) of the RWB, TF4 and WOG groups. Ni: nickel, Ti: titanium, O: oxygen

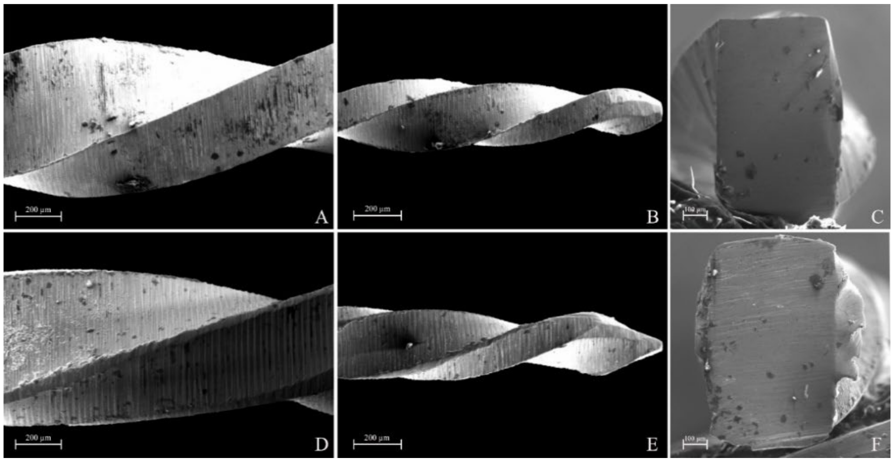

Figure 2. Microscopic description by scanning electron microscopy (SEM) analysis of the WaveOne Gold (WOG) instrument; *A*, *B*) Active part and tip of a new instrument; *C*) Cross-section of a new instrument; *D, E*) Active part and tip of a used instrument; *F*) Cross-section of a separated instrument. The original magnifications are 120× (A, D), 300× (B, E), and 700× (C, F)

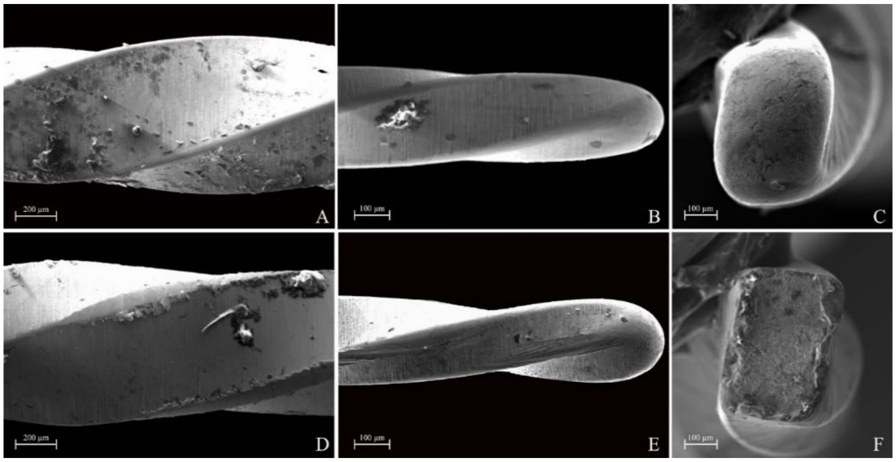

Figure 3. Microscopic description by scanning electron microscopy (SEM) of the TF4 Gold (TF4) instrument; *A, B*) Active part and tip of a new instrument; C) Cross-section of a new instrument; *D*, *E*) Active part and tip of a used instrument; *F*) Cross-section of a separated instrument. The original magnifications are 120× (A, D), 300× (B, E), and 700× (C, F)

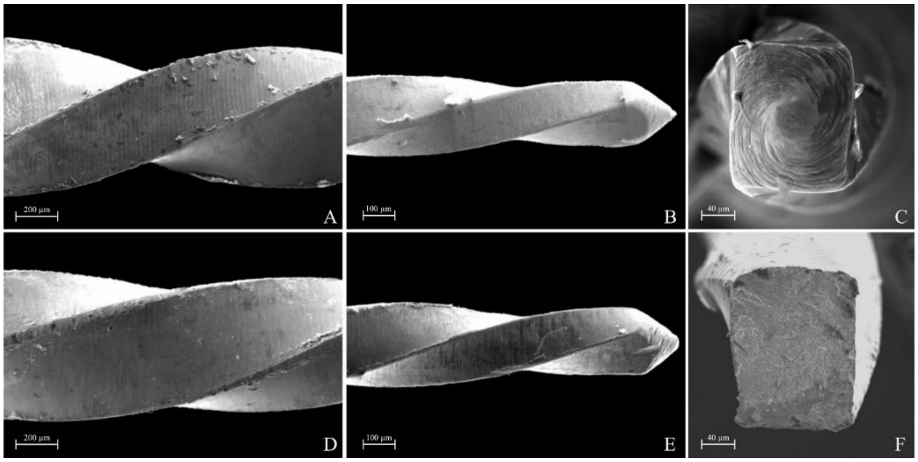

Figure 4. Microscopic description by scanning electron microscopy (SEM) of the Roll Wave Blue (RWB) instrument. *A, B*) Active part and tip of a new instrument; *C*) Cross-section of a new instrument; *D, E*) Active part and tip of a used instrument; *F*) Cross-section of a separated instrument. The original magnifications are 120× (A, D), 300× (B, E), and 700× (C, F)

Table 1. Cyclic fatigue resistance, including fracture time TF4 Gold (TF4) and number of cycles to fracture (NCF), for WaveOne Gold (WOG), Roll Wave Blue (RWB), and TF4 instruments

Groups		FT (seconds) Median (Q1-Q3)	NCF Median (Q1-Q3)
RWB	20	652 (614-715) ^{a}	3804 (3584-4172) ^{a}
TF4	20	166 (134-173) ^{b}	966 (784-1009) ^{b}
WOG	20	134 (103-149) ^{b}	782 (598-872) ^{b}

Values are presented as median (25th–75th percentiles). Different lowercase letters in columns indicate significant differences (Kruskal–Wallis test followed by Dunn's post hoc test; P<0.05)

Table 2. Atomic weight percentages (%) of the elements from WaveOne Gold (WOG), Roll Wave Blue (RWB), and TF4 Gold (TF4) groups, determined by energy-dispersive X-ray spectroscopy (EDX) at 20 kV

Groups	Ti	Ni	O	C
RWB	26.16	25.37	32.44	16.03
TF4	30.19	29.39	23.24	17.18
WOG	32.46	31.89	19.11	16.54

Titanium (Ti), Nickel (Ni), Oxygen (O), Carbon (C)

Another study reported that heat-treated martensitic instruments had higher resistance to cyclic fatigue [18]. In the present study, cyclic fatigue resistance was higher for the RWB group compared with the TF4 and WOG groups. This may be associated with the blue treatment of RWB, unlike the gold treatment used for TF4 and WOG. Both blue and gold treatments consist of a titanium oxide layer, which is thinner in the blue alloy [19].

Blue heat treatment improves the instrument's fatigue resistance by creating a thin titanium oxide surface film, which reduces the shape memory and induces the martensitic transformation into two phases [20, 21], improving mechanical properties during reciprocation [22]. Additionally, a reduced grain size in the blue treatment structure helps to reduce hardness and promote a lower elastic modulus [23]. A previous investigation comparing the Reciproc Blue, Reciproc, and WOG demonstrated that blue treatment combined with a stable martensitic phase significantly increased cyclic fatigue resistance [24]. Another study showed that the Reciproc Blue system had higher cyclic fatigue resistance compared with WOG, which was attributed to its post- machining heat treatment [25]. Heat-treated instruments have been reported to exhibit greater flexibility and strength, factors that are crucial for reducing procedural errors [22]. RWB is manufactured with blue treatment in a martensitic phase, which may have contributed to its improved cyclic fatigue resistance compared with WOG and TF4.

The present findings highlight an important clinical balance between cyclic fatigue resistance and wear behavior. Although RWB demonstrated superior resistance to cyclic fatigue, SEM analysis showed more evident rounding and surface wear at the tip when used, which may reduce cutting efficiency over time. Specifically, WOG exhibited greater apical deformation when used, a feature that may be attributed to the number of uses, which could lead to the formation of microcracks [26]. These observations suggest that higher fatigue resistance does not necessarily correspond to a better canal conformation. Therefore, clinicians should consider that instruments with longer fatigue life may exhibit faster wear, so they need to balance safety and cutting efficiency, depending on the case.

Beyond heat treatment, this study also highlights the importance of instrument design by macroscopic and microscopic analyses. RWB exhibited a greater number of pitches and a reduction in their distribution in the apical zone. A shorter pitch is related to a better distribution of forces on the instrument, improving its performance; while a longer pitch can reduce the contact area and friction, reducing the screw-in effect [27]. Regarding cross-section, WOG has a parallelogram-shaped cross-section, unlike the triangular design of its predecessor, WaveOne [28]. RWB also has a parallelogram-shaped cross-section. TF4 has a rectangular cross-section with blunt angles. It has been described that the cross-section affects the inner core diameter, the cross-sectional area, the moment of inertia, and the mass per unit volume [27]. Even an off-center design, with only two contact points, *i.e.*, a smaller cross-sectional area, is related to greater flexibility [29]. The present macromorphometric analysis found an apically condensed pitch in RWB; combined with its parallelogram type section, this configuration plausibly reduces local stress intensity in the region of maximum curvature, complementing the blue treatment.

SEM analysis revealed typical characteristics of cyclic fatigue fracture, including deep pit zones and herringbone markings. The fractographic appearance of a fatigued metal is characterized by a progression from the crack origin to a zone of fatigue striations, incremental microscopic markings caused by a growing fatigue crack, and finally, a zone of dimple rupture [30]. This is distinct from a torsional fracture, which shows irregular edges, abrupt cracks, and helical markings [30-32]. The present study also showed that although all systems exhibited tip wear after use, this loss was more evident in RWB and TF4. In particular, TF4 exhibited the greatest loss of cutting-edge sharpness and surface micro-defects, which may predispose it to premature failure; however, this requires further investigation. In contrast, WOG exhibited less alteration in its apical structure, which may indicate greater wear resistance. These laboratory results should be interpreted with caution, since it is not possible to directly extrapolate these results to the clinical setting without additional studies assessing other relevant mechanical properties. It is important to emphasize that either SEM and EDX analyses were intended as qualitative and exploratory assessments, using a limited number of instruments per group, which is consistent with previous studies [33, 34]. However, these findings should be interpreted cautiously, and further research with larger samples and quantitative analyses is needed to confirm these observations.

One of the main limitations of this study lies in its *in vitro* nature, which restricts direct extrapolation of the findings to the clinical situation. The cyclic fatigue model applied in the present study has limited clinical applicability; however, the artificial canal allows the assessment in a controlled laboratory environment, to avoid methodological biases [35]. Furthermore, the limited scientific evidence available on RWB and TF4 makes comparison with previous studies difficult and limits the depth of the contextual analysis. Nonetheless, one of the strengths of this investigation is the focus on endodontic instruments that have begun to gain widespread acceptance among clinicians, although the current scientific evidence remains insufficient to support their widespread use.

Overall, beyond the chemical composition of NiTi, the clinical efficacy of instruments is influenced by several parameters, including the alloy characteristics, heat treatment, and geometric design. Although RWB demonstrated higher resistance to cyclic fatigue and WOG showed less tip deterioration after use, further research is needed to evaluate additional parameters related to root canal instrumentation, including studies using natural teeth, torsional fatigue assessment, in vivo evaluations, and complementary analyses of other mechanical properties, to validate these findings and strengthen the available evidence on these systems.

Conclusions

RWB demonstrated the highest resistance to cyclic fatigue, showing a longer time to fracture and a higher number of cycles to fracture compared with TF4 and WOG, which may be attributed to the alloy characteristics and heat treatment used. All reciprocating instruments exhibited similar chemical compositions but differed in performance, which could be associated with variations in their alloy characteristics, design, and heat treatment.

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Conflict of interest

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Authors' contributions

Conceptualization: FCM/WEO/HCL, Data Curation: WEO, Formal Analysis: PCD/MPC/JVZ/WEO, Investigation: JVZ/ADH/HCL, Methodology: PCD/MPC/JVZ/WEO, Project Administration: ADH/FCM. Resources: PCD/MPC/JVZ/FCM, Software: WEO. Supervision: WEO/ADH/FCM/HCL, Validation: WEO/FCM, Visualization: JVZ/HCL, Writing-Original Draft Preparation: PCD/MPC/JVZ/WEO/ADH/FCM/HCL, Writing-Review & Editing: PCD/MPC/JVZ/WEO/ADH/FCM/HCL. All authors read and approved the final manuscript.

References

1. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. Int Endod J. 2008;41(4):339-44.
2. Ribeiro Camargo CH, Bittencourt TS, Hasna AA, Palo RM, Talge Carvalho CA, Valera MC. Cyclic fatigue, torsional failure, and flexural resistance of rotary and reciprocating instruments. J Conserv Dent. 2020;23(4):364-9.
3. Roane JB, Sabala CL, Duncanson MG, Jr. The "balanced force" concept for instrumentation of curved canals. J Endod. 1985;11(5):203-11.
4. de Menezes S, Machado Batista S, Brandão de Magalhães DF, Diana Santana A, de Melo Monteiro GQ. Cyclic Fatigue Resistance of Mtwo

Rotary Instruments with two Different Instrumentation Techniques. Iran Endod J. 2018;13(1):114-9.
5. Plotino G, Grande NM, Testarelli L, Gambarini G. Cyclic fatigue of Reciproc and WaveOne reciprocating instruments. Int Endod J. 2012;45(7):614-8.
6. Ríos-Osorio N, Caviedes-Bucheli J, Murcia-Celedón J, Gutiérrez C, Sierra-Collazo D, Alvarado-Caicedo B, et al. Comparison of dynamic cyclic fatigue resistance of Reciproc® Blue and WaveOne® Gold after sterilization and/or immersion in sodium hypochlorite. J Clin Exp Dent. 2024;16(1):e1-e10.
7. Elnaghy AM, Elsaka SE. Effect of sodium hypochlorite and saline on cyclic fatigue resistance of WaveOne Gold and Reciproc reciprocating instruments. Int Endod J. 2017;50(10):991-8.
8. Fangli T, Maki K, Kimura S, Nishijo M, Tokita D, Ebihara A, et al. Assessment of mechanical properties of WaveOne Gold Primary reciprocating instruments. Dent Mater J. 2019;38(3):490-5.
9. Bürklein S, Flüch S, Schäfer E. Shaping ability of reciprocating single-file systems in severely curved canals: WaveOne and Reciproc versus WaveOne Gold and Reciproc blue. Odontology. 2019;107(1):96-102.
10. Ragozzini G, Abu Hasna A, Dos Reis FAS, de Moura FB, Campos TMB, Bueno CES, et al. Effect of Autoclave Sterilization on the Number of Uses and Resistance to Cyclic Fatigue of WaveOne Gold and Four Replica-Like Endodontic Instruments. Int J Dent. 2024;2024:6628146.
11. Roll Wave Blue Reciprocating File System [brochure].
12. Martins JNR, Silva E, Marques D, Belladonna F, Simões-Carvalho M, Camacho E, et al. Comparison of design, metallurgy, mechanical performance and shaping ability of replica-like and counterfeit instruments of the ProTaper Next system. Int Endod J. 2021;54(5):780-92.
13. Furlan RD, Alcalde MP, Duarte MAH, Bramante CM, Piasecki L, Vivan RR. Cyclic and Torsional Fatigue Resistance of Seven Rotary Systems. Iran Endod J. 2021;16(2):78-84.
14. Faus-Matoses V, Pérez García R, Faus-Llácer V, Faus-Matoses I, Alonso Ezpeleta Ó, Albaladejo Martínez A, et al. Comparative Study of the SEM Evaluation, EDX Assessment, Morphometric Analysis, and Cyclic Fatigue Resistance of Three Novel Brands of NiTi Alloy Endodontic Files. Int J Environ Res Public Health. 2022;19(7).
15. Heck L, Weissheimer T, Souza Calefi PH, Alcalde MP, Vivan RR, da Rosa RA, et al. Effect of A Clinical-Replicable Cooling Protocol on the Cyclic Fatigue Resistance of Heat-Treated Nickel-Titanium Instruments. Iran Endod J. 2022;17(3):132-7.
16. De Pedro-Muñoz A, Rico-Romano C, Sánchez-Llobet P, Montiel-Company JM, Mena-Álvarez J. Cyclic Fatigue Resistance of Rotary versus Reciprocating Endodontic Files: A Systematic Review and Meta-Analysis. J Clin Med. 2024;13(3).
17. Faus-Matoses V, Faus-Llácer V, Ruiz-Sánchez C, Jaramillo-Vásconez S, Faus-Matoses I, Martín-Biedma B, et al. Effect of Rotational Speed on the Resistance of NiTi Alloy Endodontic Rotary Files to Cyclic Fatigue-An In Vitro Study. J Clin Med. 2022;11(11).
18. Silva E, Oliveira de Lima C, Vieira V, Antunes H, Lima Moreira EJ, Versiani M. Cyclic Fatigue and Torsional Resistance of Four Martensite-Based Nickel Titanium Reciprocating Instruments. Eur Endod J. 2020;5(3):231-5.
19. Liang Y, Yue L. Evolution and development: engine-driven endodontic rotary nickel-titanium instruments. Int J Oral Sci. 2022;14(1):12.
20. Shen Y, Zhou H, Coil JM, Aljazaeri B, Buttar R, Wang Z, et al. ProFile Vortex and Vortex Blue Nickel-Titanium Rotary Instruments after Clinical Use. J Endod. 2015;41(6):937-42.
21. Alcalde MP, Duarte MAH, Bramante CM, de Vasconselos BC, Tanomaru-Filho M, Guerreiro-Tanomaru JM, et al. Cyclic fatigue and torsional strength of three different thermally treated reciprocating nickel-titanium instruments. Clin Oral Investig. 2018;22(4):1865-71.
22. De-Deus G, Silva EJ, Vieira VT, Belladonna FG, Elias CN, Plotino G, et al. Blue Thermomechanical Treatment Optimizes Fatigue Resistance and Flexibility of the Reciproc Files. J Endod. 2017;43(3):462-6.
23. Generali L, Puddu P, Borghi A, Brancolini S, Lusvarghi L, Bolelli G, et al. Mechanical properties and metallurgical features of new and ex vivo used Reciproc Blue and Reciproc. Int Endod J. 2020;53(2):250-64.
24. Keskin C, Inan U, Demiral M, Keleş A. Cyclic Fatigue Resistance of Reciproc Blue, Reciproc, and WaveOne Gold Reciprocating Instruments. J Endod. 2017;43(8):1360-3.
25. Oh S, Kum KY, Kim HJ, Moon SY, Kim HC, Chaniotis A, et al. Bending resistance and cyclic fatigue resistance of WaveOne Gold, Reciproc Blue, and HyFlex EDM instruments. J Dent Sci. 2020;15(4):472-8.
26. Marim AZ, Bueno C, Stringheta CP, Pelegrine RA, De Martin AS, Rocha DGP, et al. In vitro study of structural and chemical changes in two reciprocating files after multiple reuses and sterilisation. Aust Endod J. 2024;50(3):502-12.
27. Akkoç H, Keskin C, Aslantaş K. Dynamic analysis of a NiTi rotary file by using finite element analysis: Effect of cross-section and pitch length. Aust Endod J. 2024;50(3):649-57.
28. Adıgüzel M, Capar ID. Comparison of Cyclic Fatigue Resistance of WaveOne and WaveOne Gold Small, Primary, and Large Instruments. J Endod. 2017;43(4):623-7.
29. Galal M, TM H. Evaluation of stress distribution in nickel-titanium rotary instruments with different geometrical designs subjected to bending and torsional load: a finite element study. 2020;44:121.
30. Cheung GS, Darvell BW. Fatigue testing of a NiTi rotary instrument. Part 2: Fractographic analysis. Int Endod J. 2007;40(8):619-25.
31. Drukteinis S, Peciuliene V, Bendinskaite R, Brukiene V, Maneliene R, Rutkunas V. Shaping and Centering Ability, Cyclic Fatigue Resistance and Fractographic Analysis of Three Thermally Treated NiTi Endodontic Instrument Systems. Materials (Basel). 2020;13(24).
32. Sattapan B, Nervo GJ, Palamara JE, Messer HH. Defects in rotary nickel-titanium files after clinical use. J Endod. 2000;26(3):161-5.
33. Martins JNR, Silva E, Marques D, Caramês J, Braz Fernandes FM, Versiani MA. Effect of Clockwise Reciprocation Motion of Optimum Torque Reverse Kinematic on the Cyclic Fatigue Resistance of Nickel-Titanium Rotary Instruments with Different Metallurgical Properties. Materials (Basel). 2026;19(2).
34. Al Jabbari YS, Koutsoukis T, Al Hadlaq S, Berzins DW, Zinelis S. Surface and cross-sectional characterization of titanium-nitride coated nickel-titanium endodontic files. J Dent Sci. 2016;11(1):48-53.
35. Caviedes Bucheli J, Teves Cordova A, Alcalde MP, Munoz HR, Muñoz Alvear HD, Gay MM, et al. Cyclic Fatigue, Torsional Strength and Angular Deflection of Different Reciprocating Instruments: A Critical Analysis of Its Clinical Relevance. Eur Endod J. 2025;10(2):159-72.

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