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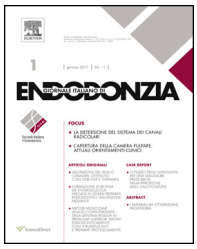

Cyclic fatigue resistance of Nickel-Titanium reciprocating instruments tested with an innovative kinematics

Impatto di una nuova cinematica sulla resistenza in fatica ciclica di strumenti reciprocanti

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KEYWORDS
Cyclic fatigue;
Endodontic instrumentation;
Kinematics;
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Abstract
Aim: To evaluate cyclic fatigue resistance of different Nickel-Titanium instruments tested with an innovative reciprocating kinematics.
Methodology: Eighty Nickel-Titanium reciprocating instruments were tested in cyclic fatigue resistance: WaveOne Primary (n = 20), WaveOne Gold Primary (n = 20), Reciproc R25 (n = 20) and Reciproc Blue R25 (n = 20). The cyclic fatigue of each brand was measured with two different motors and kinematics settings: (1) X-Smart Plus (Denstply Maillefer) used in ''WaveOne All'' or ''Reciproc All'' setting, according to manufacturer's instruction; (2) a 4:1 contra-angle (Cefla, Imola, Italy) with an experimental kinematics (Goldspeed EVOE4 — Cefla, Italy) (EVO) with different rotation angles and based on a sinusoidal acceleration. The time to fracture in an artificial stainless-steel canal (90° angle and a 5-mm radius of curvature) was digitally recorded. Mean life, beta (failure rate) and eta (characteristic life i.e. the number of seconds at which 63.2% of the product has failed) were calculated for each group and compared with Weibull analysis.

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Results: Instruments tested with the kinematics EVO presented higher values of eta in all groups. Reciproc Blue showed the highest eta value (233.05) and Wave One Gold the lower failure probability (46.98%). Wave One instruments showed similar fatigue resistance when tested with EVO or X-Smart.
Conclusion: Tested kinematics with different angles and based on sinusoidal reciprocating acceleration had a positive impact on fatigue lifetime of reciprocating instruments. Present findings suggest the possibility of future improvements in the clinical use of reciprocating files.

PAROLE CHIAVE
Cinematica;
Fatica ciclica;
Strumenti Nichel-Titanio;
Strumentazione endodontica;
Movimento reciprocante.

Riassunto
Obiettivi dello studio: Scopo dello studio è stato quello di valutare l'impatto di una nuova cinematica con differenti angoli di rotazione e controrotazione sugli strumenti disegnati per il movimento di reciprocazione.
Materiali e Metodi: La fatica ciclica di 80 strumenti NiTi reciprocanti è stata misurata in un canale metallico artificiale con angolo di 90° e con raggio di 5 mm, con diverse cinematiche di reciprocazione.

Sono stati testati 8 gruppi di strumenti (n = 10): Gruppo 1: WaveOne Primary in modalità "WaveOne All" utilizzando il motore X-Smart Plus (Dentsply Maillefer); Gruppo 2: WaveOne Gold Primary (Dentsply Maillefer) in "WaveOne All" con X-Smart Plus; Gruppo 3: Reciproc R25 (VDW) in "Reciproc All" con X-Smart Plus; Gruppo 4 Reciproc Blue (VDW) R25 in "Reciproc All" con X-Smart Plus. Altri 4 gruppi degli stessi strumenti sono stati testati utilizzando la nuova cinematica di reciprocazione (EVO E4, Cefla, Imola, Italy) con angoli differenti e basata sul concetto di accelerazione sinusoidale, utilizzando uno specifico motore sperimentale con un contrangolo 4:1 (CEFLA, Imola, Italy). Gruppo 5: WaveOne Primary in modalità "WaveOne" utilizzando il sistema EVO E4 (Cefla); Gruppo 6: WaveOne Gold Primary in "WaveOne" con EVO E4; Gruppo 7: Reciproc R25 in modalità "Reciproc" con EVO E4; Gruppo 8: Reciproc Blue R25 in "Reciproc" con EVO E4.

L'analisi statistica Weibull è stata utilizzata per calcolare e confrontare la media (*mean life*), beta (*failure rate)* e eta (il numero di secondi cui il 63.2% degli strumenti ha fallito).
Risultati: Gli strumenti testati con cinematica EVO E4 hanno dimostrato un tempo medio (*mean life*) di frattura per fatica ciclica superiore agli strumenti testati con le cinematiche convenzionali di reciprocazione, in ogni gruppo. I Reciproc Blue hanno mostrato i più elevati valori di resistenza (233.05 eta) mentre i WaveOne Gold hanno dimostrato la più bassa probabilità di fallimento (46,98%).
Conclusioni: La nuova cinematica di reciprocazione basata su angoli differenti ed accelerazione sinusoidale ha dimostrato avere un impatto positivo sulla resistenza alla fatica ciclica degli strumenti testati. Inoltre è stato confermato che i nuovi trattamenti termici delle leghe migliorano le proprietà meccaniche degli strumenti. I risultati di questo studio aprono nuovi scenari sulle dinamiche di utilizzo dei sistemi reciprocanti ad oggi disponibili.

Introduction

Over last years, several strategies in endodontic instrumentation have been proposed by manufacturers with the aim to reduce procedural errors and fractures of Nickel-Titanium (NiTi) instruments.[1,2]

The use of different movements and kinematics of the files to shape the canals has been studied from sixties and seventies. Also Professor Francesco Riitano contributed in developing an innovative device to reduce errors and fractures during instrumentation procedures.[3,4]

In 2008 Yared[5] relaunched the reciprocating motion (RM) by proposing the use of a ProTaper F2 used for canal preparation in a clockwise (CW) and counterclockwise (CCW) direction. Thereafter several studies had shown a longer lifespan of NiTi instruments used in RM in comparison with continuous rotation.[6–8] In 2011 Wave One (Denstply Maillefer, Baillagues, Switzerland), and Reciproc (VDW, Munich, Germany) have been launched on the market with the intention to simplify and shorten the endodontic procedures.[9,10] Recently, the heat treatment of M-Wire NiTi alloy induced the development of Gold and Blue alloy and consequently the passage from WaveOne and Reciproc to WaveOne Gold (Denstply Maillefer, Baillagues, Switzerland) and Reciproc Blue (VDW, Munich, Germany).

Manufacturers recommend the use of these instruments with a specific motor and pre-set reciprocation modes.

Nevertheless, several possibilities exist for kinematics of RM, and the performances are consequently influenced.[11,12] For example, decreasing the reciprocation range of the instruments results in increased cyclic resistance with less transportation but in longer preparation time.[13] To date, relatively few studies evaluated the differences between several modified kinematics of reciprocation (different speed and/or angles).[11–13]

Recently a new endodontic motor (Cefla, Imola, Italy) has been engineered with different features in terms of engaging and disengaging rotation angles and introducing the concept of sinusoidal acceleration to every rotation reversal of the reciprocating movement. This motor is part of an innovative dental unit (Cefla, Imola, Italy).

To the best of our knowledge, no research had investigated the influence of this new kinematics on the fatigue resistance of NiTi Files. Therefore the aim of this study was to test the cyclic fatigue of different generations of NiTi designed for the reciprocation, assessing the impact of the new kinematics on their fatigue resistance.

Materials and methods

A sample of 80 NiTi reciprocating instruments was tested: WaveOne Primary ($n = 20$), WaveOne Gold Primary ($n = 20$), Reciproc R25 ($n = 20$) and Reciproc Blue R25 ($n = 20$), Instruments were distributed in 8 experimental groups ($n = 10$) as shown in Table 1.

The cyclic fatigue resistance of each brand was measured with two different motors and kinematics settings as reported in Table 1: (1) X-Smart Plus (Denstply Maillefer, Baillagues, Switzerland) endodontic motor used respectively in "WaveOne All" or "Reciproc All" setting, according to manufacturer's instruction; (2) a 4:1 contra-angle (Cefla, Imola, Italy) with the modified kinematics (Goldspeed EVOE4 – Cefla, Italy) (EVO).

A custom-made device, specifically designed for cyclic fatigue tests, was used (Fig. 1). Instruments were tested in a metal block made from stainless steel AISI 300 with a simulated tapered canal (90° angle of curvature and a-5 mm radius). A slipping plexiglass top face cover allowed visualization of the instruments in the canal. The canal was filled with glycerine, reducing friction and heat release. The electric handpiece was mounted on a mobile apparatus providing a precise and standardized placement of each instrument inside the artificial canal. All the files were reciprocated until the occurrence of the fracture and the time to fracture was visually recorded with a digital stopwatch (3 M ESPE, St. Paul, MN, USA).

Table 1 Group ($n = 10$) of the tested instruments with different motors and kinematics settings.

	Instrument	Motor	Kinematics
Group 1	WaveOne	X-Smart	WaveOne All
Group 2	WaveOne	EVOE4	WaveOne
Group 3	WaveOne Gold	X-Smart	WaveOne All
Group 4	WaveOne Gold	EVOE4	WaveOne
Group 5	Reciproc	X-Smart	Reciproc All
Group 6	Reciproc	EVOE4	Reciproc
Group 7	Reciproc Blue	X-Smart	Reciproc All
Group 8	Reciproc Blue	EVOE4	Reciproc

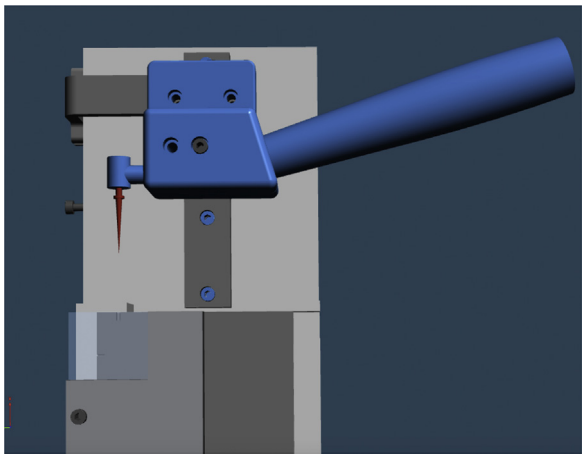

Figure 1 3D reconstruction of the fatigue test device used in the present study.

Mean life, beta (failure rate) and eta (characteristic life i.e. the number of seconds at which 63.2% of the product has failed) were calculated for each group and compared with Weibull analysis.

Results

The mean life, beta (failure rate) and eta (characteristic life i.e. the number of seconds at which 63.2% of the product has failed) were calculated for each group and were compared with Weibull analysis (Table 2). The mean life of instruments tested with the kinematics EVO was generally higher, presenting a greater proportion of instruments with higher values of eta in all groups. Reciproc Blue were significantly the most resistant instruments, irrespective of kinematics, and lasted significantly longer than Reciproc. WaveOne Gold demonstrated a higher resistance than WaveOne with EVO motor, showing also the lowest failure probability (beta) among groups (46.98%). WaveOne instruments showed similar fatigue resistance when tested with EVO or X-Smart Kinematics.

Discussion

In this research the influence of different kinematics on the fatigue life of four different reciprocating instruments was tested. Fatigue resistance of NiTi instruments is associated with the propagation of a superficial crack because of alternating tensile and compressive cycles in curved canal,[14] and is influenced by movement kinematics (continuous or reciprocating motion).[15] RM permits to the instrument to complete one full rotation after more reciprocating cycles (depending on the different angles),[6,11] which means that more time is needed for one entire rotation when compared with continuous rotation. In particular, angles of rotation and contra-rotation, acceleration, deceleration and speed are well-known parameter that may affect the endurance and the preparation time[11–13] of NiTi reciprocating instruments. Findings of the present study demonstrated that kinematics EVO significantly influences the cyclic fatigue resistance of

Table 2 Weibull analysis of fatigue resistance of the tested groups. Mean life, beta (failure rate) and eta (characteristic life, i.e. the number of seconds at which 63.2% of the product has failed) are reported.

Group	Instrument/kinematics	Mean life (s)	beta	eta
Group 1	WaveOne — X Smart	76.482	2.311	85.81
Group 2	WaveOne — EVOE4	81.537	3.666	90.51
Group 3	WaveOne Gold — X-Smart	77.88	8.206	82.38
Group 4	WaveOne Gold — EVOE4	127.71	7.715	136.07
Group 5	Reciproc — X-Smart	126.45	6.181	135.73
Group 6	Reciproc — EVOE4	171.23	2.808	196.70
Group 7	Reciproc Blue — X-Smart	132.73	7.972	136.43
Group 8	Reciproc Blue — EVOE4	215.88	5.651	233.05

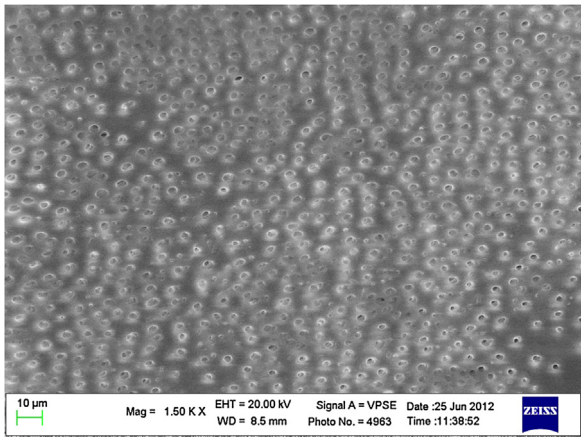

Figure 2 ESEM micrograph (1500×) of the middle third of a root canal instrumented with WaveOne.

tested files. In fact, the mean life of instruments tested with the kinematics EVO was higher and with a greater proportion of instruments with higher values of eta in all groups.

The recently engineered EVO motor by Cefla imparts different engaging and disengaging rotational angles (angles of this motion are patent pending and cannot be fully disclosed) and confers a sinusoidal acceleration during every rotation reversal of the reciprocating movement. The rationale behind this kinematics is to generate a smoother transition between rotation and contra-rotation, permitting a more accurate control of the torque and reducing the stress of the instrument through an incremental angular acceleration of the speed. Further investigations should evaluate the impact of this innovative kinematics on the torsional loads which the instruments are subjected during canal instrumentation and the effect of this reciprocating kinematics on root canal dentinal surface through scanning electron microscope (SEM). In fact, several studies[16–18] confirmed SEM as a suitable method for the comparison of dentin surface morphology after instrumentation, as shown in Fig. 2.

According to other studies,[19,20] in the present research the cyclic fatigue resistance of reciprocating instruments was reported as time to fracture (seconds). This to minimize the errors of questionable data available on the pre-set kinematics from those claimed by the manufacturers, mainly in terms of engaging/disengaging angles and rotational speed.[21] Further studies should deeper investigate the parameters of the tested kinematics to better understand the role of different angles and speed on the cyclic life of reciprocating instruments.

As part of this study, Weibull analysis was conducted with respect to ''life data'', measured in hours, miles, cycles or any other metric, defining the period of successful operation of a particular product.[22,23] This type of analysis focuses on information related to extreme-value distribution and the lower values that may be more crucial for clinicians and has been already used as an adequate model for evaluating the cyclic fatigue resistance of NiTi files.[24,25]

Another interesting aspect of the present study is the comparison of NiTi instruments subjected to different thermomechanical treatments. Is it well known that one of the most successful strategy to improve the mechanical properties of NiTi files is to optimize the microstructure of NiTi alloys through different thermomechanical processes.[24] This determines the characteristics of the microstructural phases and adjusts the transition temperatures of the alloy.[26–30] WaveOne files have been enhanced from M-wire to Gold alloy treatment.[31,32] In this *in vitro* research the comparison between WaveOne Gold and WaveOne resulted in a statistically higher fatigue resistance of WaveOne Gold only with EVO, while no significant differences were found with X-Smart. Even the heat treatment of Reciproc has been changed from M-wire to Blue alloy. According to the literature[33–35] our findings suggested an improved fatigue resistance of the new Reciproc Blue instruments that resulted the most resistant files irrespective of the tested kinematics.

Conclusions

The findings of this *in vitro* research showed the positive impact of new kinematics on fatigue life of reciprocating instruments, suggesting the possibility of future improvements in the clinical use of reciprocating files. Further study should deeper evaluate the kinematics evaluating also the impact of the sinusoidal reciprocating motion on the instruments during canal instrumentation.

Clinical relevance

Present results demonstrated that innovative kinematics has a positive impact on fatigue life of reciprocating instruments, thus suggesting new scenario in the clinical use of NiTi reciprocating files.

Conflict of interest

The authors declare not to have any conflict of interest

References

1. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. *J Endod* 2004;**30**:559—67.
2. Parashos P, Messer HH. Rotary NiTi instrument fracture and its consequences. *J Endod* 2006;**32**:1031—43.
3. Bassi E, Riitano F. Andodontic instrument for concurrent programmed boring, spraying and cleansing of dental root channels. Patent US3747216; 1973.
4. Riitano F. Anatomic endodontic technology (AET) — a crown-down root canal preparation technique: basic concepts, operative procedure and instruments. *Int Endod J* 2005;**38**:575—87.
5. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. *Int Endod J* 2008;**41**:339—44.
6. You SY, Bae KS, Baek SH, et al. Lifespan of one nickel-titanium rotary file with reciprocating motion in curved root canals. *J Endod* 2010;**36**:1991—4.
7. De-Deus G, Moreira EJ, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 Pro-Taper instruments used in reciprocating movement. *Int Endod J* 2010;**43**:1063—8.
8. Pirani C, Ruggeri O, Cirulli PP, Pelliccioni GA, Gandolfi MG, Prati C. Metallurgical analysis and fatigue resistance of WaveOne and ProTaper Nickel-Titanium instruments. *Odontology* 2014;**102**:211—6.
9. Çapar ID, Ertas H, Ok E, Arslan H, Ertas ET. Comparative study of different novel nickel-titanium rotary systems for root canal preparation in severely curved root canals. *J Endod* 2014;**40**:852—6.
10. Generali L, Righi E, Todesca MV, Consolo U. Canal shaping with WaveOne reciprocating files: influence of operator experience on instrument breakage and canal preparation time. *Odontology* 2014;**102**:217—22.
11. Gambarini G, Rubini AG, Al Sudani D, Gergi R, Culla A, De Angelis F, et al. Influence of different angles of reciprocation on the cyclic fatigue of nickel-titanium endodontic instruments. *J Endod* 2012;**38**:1408—11.
12. Arslan H, Alsancak M, Doğanay E, Karatas E, Çapar D, Ertas H. Cyclic fatigue analysis of Reciproc R25® instruments with different kinematics. *Aust Endod J* 2016;**42**:22—4.
13. Saber Sel D, Abu El Sadat SM. Effect of altering the reciprocation range on the fatigue life and the shaping ability of WaveOne nickel-titanium instruments. *J Endod* 2013;**39**:685—8.
14. Sattapan B, Nervo GJ, Palamara JE, et al. Defects in rotary nickel-titanium files after clinical use. *J Endod* 2000;**26**:161—5.
15. Plotino G, Ahmed HMA, Grande NM, Cohen S, Bukiet F. Current assessment of reciprocation in endodontic preparation: a comprehensive review. Part II: properties and effectiveness. *J Endod* 2015;**41**:1939—50.
16. Prati C, Seleghini M, Ferrieri P, Mongiorgi R. Scanning electron microscopic evaluation of endodontic procedures on dentin morphology of human teeth. *J Endod* 1994;**20**:174—8.
17. Pirani C, Feletti G, Cretti R, Acquaviva GL, Marchionni S, Prati C. SEM evaluation of root canal dentin morphology after Ni-Ti instrumentation. *J Appl Biomater Biomech* 2009;**7**:116—22.
18. Bürklein S, Hinschitza K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. *Int Endod J* 2011;**45**:449—61.
19. Kim HC, Yum J, Kwak SW, Cheung GSP, Ko DH, Chung SM, et al. Cyclic fatigue and torsional resistance of two new nickel—titanium instruments used in reciprocation motion: Reciproc versus WaveOne. *J Endod* 2012;**38**:541—4.
20. Pedullà E, Grande NM, Plotino G, Palermo F, Gambarini G, Rapisarda E. Cyclic fatigue resistance of two reciprocating nickel—titanium instruments after immersion in sodium hypochlorite. *Int Endod J* 2013;**46**:155—9.
21. Fidler A. Kinematics of 2 reciprocating endodontic motors: the difference between actual and set values. *J Endod* 2014;**40**:990—4.
22. Weibull W. A statistical distribution function of wide applicability. *J Appl Mech* 1951;**128**:293—7.
23. Life data analysis, http://www.weibull.com/basics/lifedata.htm (accessed 2.3.18).
24. Arias A, Perez-Higueras JJ, de la Macorra JC. Differences in cyclic fatigue resistance at apical and coronal levels of Reciproc and Waveone new files. *J Endod* 2012;**38**:1244—8.
25. Perez-Higueras JJ, Arias A, de la Macorra JC, Peters OA. Differences in cyclic fatigue resistance between ProTaper Next and ProTaper universal instruments at different levels. *J Endod* 2014;**40**:1477—81.
26. Shen Y, Zhou HM, Zheng YF, Campbell L, Peng B, Haapasalo M. Metallurgical characterization of controlled memory wire nickel-titanium rotary instruments. *J Endod* 2011;**37**:1566—71.
27. Pereira ES, Peixoto IF, Viana AC, Oliveira II, Gonzalez BM, Buono VT, et al. Physical and mechanical properties of a thermomechanically treated NiTi wire used in the manufacture of rotary endodontic instruments. *Int Endod J* 2012;**45**:469—74.
28. Hieawy A, Haapasalo M, Zhou H, Wang ZJ, Shen Y. Phase transformation behavior and resistance to bending and cyclic fatigue of ProTaper Gold and ProTaper universal instruments. *J Endod* 2015;**4**:1134—8.
29. Iacono F, Pirani C, Generali L, Bolelli G, Sassatelli P, Lusvarghi L, et al. Structural analysis of HyFlex EDM instruments. *Int Endod J* 2017;**50**:303—13.
30. Iacono F, Pirani C, Generali L, Sassatelli P, Nucci C, Gandolfi MG, et al. Wear analysis and cyclic fatigue resistance of electro discharge machined NiTi rotary Instruments. *Giornale Italiano di Endodonzia* 2016;**30**:64—8.
31. Webber J. Shaping canals with confidence: WaveOne GOLD single-file reciprocating system. *Roots* 2015;**1**:34—40.
32. Özyürek T. Cyclic fatigue resistance of Reciproc, WaveOne, and WaveOne gold nickel-titanium instruments. *J Endod* 2016;**42**:1536—9.
33. Gündogar, Özyürek. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc blue nickel-titanium instruments. *J Endod* 2017;**43**:1192—6.
34. Keskin C, Inan U, Demiral M, Keleş A. Cyclic fatigue resistance of Reciproc Blue, Reciproc, and Waveone gold reciprocating instruments. *J Endod* 2017;**43**:1360—3.
35. 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**:462—6.