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Dynamic Cyclic Fatigue and Differential Scanning Calorimetry Analysis of R-Motion

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ABSTRACT

Introduction: The aim of this study was to assess the dynamic cyclic fatigue resistance of an R-Motion file at simulated body temperature and document corresponding phase transformations compared to OneCurve and HyFlex EDM (HFEDM).

Methods: R-Motion (25/.06), OneCurve (25/.06), and HFEDM (25/.06) files were selected and divided into 3 groups (n = 9) according to the file type. Dynamic cyclic fatigue testing was done with a custom-made artificial stainless-steel canal that had a 90° angle of curvature and a 5-mm radius of curvature. Files were operated continuously at body temperature until fracture in the artificial canal. The time to fracture was calculated. Statistical analysis was performed, and significance was set at 5%. Phase transformation temperatures for 2 instruments of each group were analysed by differential scanning calorimetry (DSC) analysis.

Results: The highest mean time to fracture value was measured in the HFEDM group (277.84 ± 2.51), followed by the R-Motion group (115.09 ± 0.01), whilst the lowest value was found in the OneCurve group (44.28 ± 3.63). Post hoc pairwise comparisons were all statistically significant ($P < .001$). DSC heating curves show austinite start temperatures to be 33.94 °C and 43.32 °C and austinite finish temperatures to be 35.09 °C and 50 °C for R-Motion and HFEDM, respectively. DSC cooling curves show martensite start temperatures to be 27.54 °C and 44.52 °C and martensite finish temperatures to be 29.13 °C and 37.68 °C for R-Motion and HFEDM, respectively. DSC curves of OneCurve failed to demonstrate transformation temperatures within the tested heat range.

Conclusions: Crystalline arrangement of Ni and Ti atoms within the NiTi alloys greatly affects the dynamic cyclic fatigue resistance of the file.

Introduction

Proper root canal disinfection is a critical goal during root canal treatment.[1] This is best achieved through shaping of root canals that increases the efficacy of irrigants and antibacterial medicaments.[2] Limitations of the instruments used in addition to the complexity of the root canal anatomy are considered a great challenge during shaping of root canals. This can lead to canal transportation, perforation, ledge development, or separated instruments.

Instruments separate mainly due to cyclic or torsional failure.[3] When the file rotates freely inside a curved canal, tension and compression will build up in the region of maximum flexure. These repeated stresses will eventually lead to the failure of the file, even if their magnitude is below the elastic limit of the alloy.[4] This limit is affected by root canal curvature,[5] instrument size,[6] taper and cross-section,[7] rotational speed and torque,[8] and alloy type and heat treatment.[9]

Static cyclic fatigue testing models have been used to assess the cyclic fatigue limit of endodontic files. More recently, dynamic models have proved more reliable as the cyclic axial motion mimics the real use of files in the clinical context.[10]

Recently introduced martensite NiTi files show transformation temperatures close to the body temperature. The

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influence of the surrounding temperature at which the file is tested on the cyclic fatigue limit is well documented.[11] Therefore, testing the cyclic fatigue is done at body temperature in order to mimic the clinical context. Phase transformation of NiTi files due to temperature and/or stress greatly affects its properties: shape memory and superelasticity.[12] Differential scanning calorimetry (DSC) is a reliable tool to assess NiTi phase transformation by measuring the transformation latent heat released/absorbed by the tested NiTi file to/from the surroundings.[13]

R-Motion (FKG, Dentaire SA) is a recently launched reciprocating file. R-Motion shows a cross-section of a rounded triangle with sharp cutting edges and an optimised file tip. As claimed by the manufacturer, it has improved flexibility and about 3 times greater resistance to cyclic fatigue due to its proprietary heat treatment.[14]

OneCurve (Micro-Mega) files were launched to operate in full rotation. They are manufactured by C-Wire with a special heat treatment process that helped produce controlled memory (CM) files with high cyclic fatigue resistance.[15] They are pre-bendable with variable cross-sectional design along the working part.[16]

HyFlex EDM (HFEDM; Coltene/Whaledent), a single-file system used in continuous rotation, is manufactured from CM wire using the electric discharge–machining technology. This technique improves flexibility and fracture resistance.[9,17] HFEDM shows a variable cross-section all over the working part and cross-sections that are triangular at the coronal segment, trapezoidal at the middle segment, and quadratic at the tip.[3]

To our knowledge, the dynamic cyclic fatigue (DCF) resistance of R-Motion has not been evaluated yet. Therefore, the aim of the current study was to assess the DCF resistance of R-Motion at simulated body temperature and document corresponding phase transformations compared to OneCurve and HFEDM. The null hypothesis tested is that there is no significant difference amongst the 3 tested NiTi files in DCF.

Materials and methods

Ethical approval

The research proposal was approved by the Faculty of Dentistry, Ain Shams University ethical committee, approval number FDASU-Rec IM092109.

Sample size calculation

A power analysis was performed based on the results of Micoogullari et al[16]; the predicted sample size (n) was found to be a total of (27) samples (i.e., 9 samples per group). Sample size calculation was performed using G*Power version 3.1.9.4

Sample selection and classification

R-Motion (25/.06), OneCurve (25/.06), and HFEDM (25/.06) files were divided into 3 groups (n = 9).

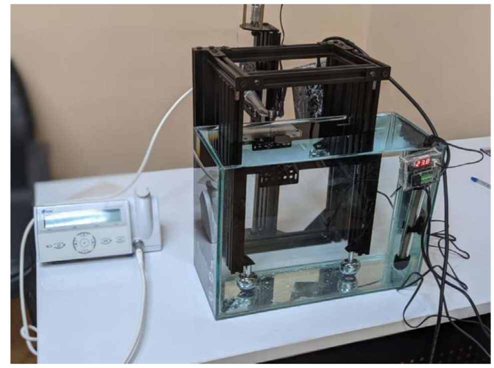

Fig. 1 – Custom-made dynamic cyclic fatigue-testing device used in a water bath at body temperature.

DCF Test

A custom-made DCF testing device was used (Egyptian patent number 265/2021) as shown in Figure 1.[18] AutoCAD software was used to design an artificial stainless canal (25/0.06) plus 0.1-mm relief circumferentially, 16 mm in length. The angle of curvature was 90° with a 5-mm radius of curvature. A cylindrical space with a 5-mm radius was added to the canal tip to allow an easy escape for broken fragments.

DCF testing device was placed in water bath of distilled water at 37 ± 0.5 °C, simulating body temperature. Temperature was controlled via aquatic thermostat connected to heat control and measured via digital thermometer. Manufacturers' recommendations were strictly followed for the speed and torque settings for each group using an endodontic motor (VDW) with a 16:1 reduction handpiece head.

Each file was introduced inside the artificial canal. The whole assembly was immersed inside the water bath. An axial oscillating motion was applied at 1 Hz to simulate the clinical "pecking motion." The file oscillated for a 3-mm amplitude, ±1.5 mm. The file was operated until fracture occurred, and time to fracture was recorded using a stopwatch (Timex). To obtain the exact failure time, magnifying loupes were used at 2.5×. Testing of all files was performed by the second author. Time recording was done by the first author. A digital caliper was used to measure the length of the broken segment.

DSC evaluation

Two new files from each group were cut into segments of 4 to 5 mm in length using a disc mounted on straight handpiece with copious coolant. Specimens weighted 5 to 15 mg.[19]

The DSC analyses were conducted over temperature ranging from 0 to 50 °C using the liquid nitrogen cooling accessory. Each specimen was cooled to 0 °C. Heating curve was obtained through heating from 0 °C to 50 °C. Cooling curve was obtained via cooling from 50 °C to 0 °C. Linear heating/cooling rate was 10 °C/min. DSC cell was purged with dry nitrogen at a rate of 50 mL/min during each analysis.

Universal Analysis software was used to analyse the DSC thermogram plots to determine enthalpy changes and phase transformation temperatures. The intersection point between the maximum gradient line of the lambda-type DSC curve and the baseline indicated the transformation temperatures.[20] Four transformation temperatures were determined for each file, martensite start, martensite finish, austinite start, and austinite finish (Ms, Mf, As, and Af, respectively).

Statistical analysis

Mean and standard deviation values for time to fracture were calculated for each group. Data were parametric and showed variance homogeneity using Shapiro–Wilk and Levene tests. Therefore, data were analysed using 1-way analysis of variance followed by Tukey post hoc test. The significance level was set at $P < .05$ within all tests. Statistical analysis was performed with R statistical analysis software.

Results

Mean and standard deviation time to fracture values for all groups and an intergroup comparison are presented in Table 1. There was a significant difference amongst tested groups ($P < .001$). HFEDM showed the highest mean time to fracture value (277.84 ± 2.51), followed by R-Motion (115.09 ± 0.01) and then OneCurve (44.28 ± 3.63). Post hoc pairwise comparisons were all statistically significant ($P < .001$).

DSC plots show heating and cooling curves. As, Af, Ms, Mf, and latent heat of transformation for R-Motion and HFEDM are shown in Table 2 and Figure 2. OneCurve did not show phase transformation within the tested temperature range.

Discussion

Changing the NiTi alloy, file design, and innovating kinematics of the rotary NiTi files helped improve cyclic fatigue resistance.[21] Applying different machining techniques and different heat treatments of the NiTi files have also claimed to affect DCF resistance. Different crystalline arrangement of the Ni and Ti atoms also affects the DCF resistance.

Unfortunately, we lack a standardised method for DCF testing of endodontic files. Therefore, all efforts have been made to standardise our testing conditions. All the tested files were selected to have the same taper and same tip diameter in order to rule out any difference in the DCF resistance related to the file size. Artificial canals were preferred to natural to teeth for better standardisation as well. A 90° angle of curvature of the simulated canal with a 5-mm radius of curvature were selected in order to test the files in an extreme condition, which will in turn explain the file's behaviour in different clinical situations.[18]

Table 2 – Transformation temperatures and associated latent heat of transformation for different file types.

	Heating			Cooling		
	As (°C)	Af (°C)	Q (J/g)	Ms (°C)	Mf (°C)	Q (J/g)
R-Motion	33.94	35.09	0.5943	27.54	29.13	0.6682
OneCurve	-	-	-	-	-	-
HyFlex EDM	43.32	50	2.549	44.52	37.68	1.1862

As, austinite finish; As, austinite start; Mf, martensite finish; Ms, martensite start; Q, latent heat of transformation.

The DCF testing model better resembles the clinical use than the static model, as the stresses are distributed throughout the instrument's shaft rather than a single point. Therefore, a dynamic model was used in the current study.[16]

Temperature change significantly affects the cyclic fatigue resistance of different heat-treated endodontic NiTi files.[9,11,22,23,24] Raising the temperature will cause phase transformation into more austenite form, which lowers the cyclic fatigue resistance. In order to best mimic the clinical context, testing was performed at body temperature.

The null hypothesis was rejected, as HFEDM showed statistically significant better DCF resistance than R-Motion and OneCurve. The superior results of HFEDM in the current study is in full agreement with numerous previous studies.[3,9,7,17] This superior cyclic fatigue resistance could be mainly attributed to the electrodischarge machining technique of the CM wire.[9] It could be also attributed to the difference in cross-sectional design of the tested instruments. The fracture occurred at D5 to D6, the level at which the HEDM changes from quadratic to triangular cross-section. This cross-sectional design possesses a smaller metal core, which will in turn lead to fewer stresses than the rounded triangle and the triple helix of the R-Motion and OneCurve, respectively.

Another major factor that affects the DCF resistance is the alloy used for instrument manufacturing and NiTi crystalline structure. Superelasticity and/or shape memory depend on transformation of the crystalline arrangement of Ni and Ti atoms. The transformation temperature of the alloy used greatly affects its mechanical properties.[23]

The higher cyclic fatigue resistance of R-Motion compared to OneCurve could be attributed to the different motions used. Previous studies have shown the superiority of the rotational motion in increasing the cyclic fatigue resistance of thermally-treated nickel-titanium files while a lot of other studies have shown the superiority of the reciprocation motion; yet, we believe that the reciprocating motion is superior due to the engagement and disengagement of dentine

Table 1 – Mean time to fracture ± standard deviation values for all groups.

Time to fracture (sec), mean ± SD			Partial eta-squared	*f* value	*P* value
R-Motion	OneCurve	HyFlex EDM			
115.09 ± 0.01^{B}	44.28 ± 3.63^{C}	277.84 ± 2.51^{A}	0.999	19885.00	**<.001***

Means with different superscript letters within the same horizontal row are significantly different.

* Significant ($P < .05$).

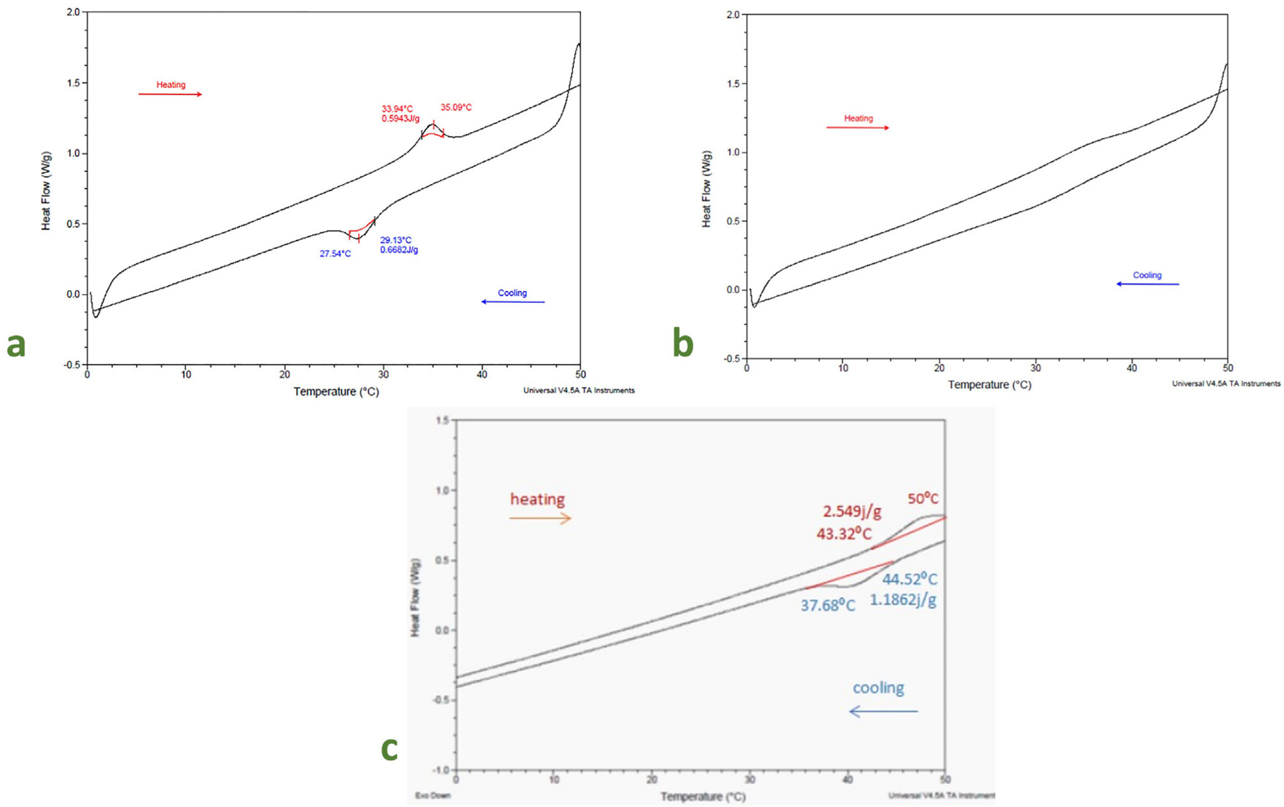

Fig. 2 – Differential scanning calorimetry thermographs of the tested files. A, R-Motion file; B, OneCurve file; C, HyFlex EDM file.

releasing the stresses.[3,7,16,21,25,26] R-Motion uses a reciprocating motion, which improves cyclic fatigue resistance more than continuous rotation. The clockwise-counterclockwise motion leads to engagement and disengagement of dentine, releasing the stresses in the instrument.[3,7,21,26] To our knowledge, cyclic fatigue resistance with R-Motion has not been tested yet; therefore, direct comparison of R-Motion results was not possible.

OneCurve undergoes electropolishing, followed by specific thermal treatment that allows for stabilised martensitic phase at body temperature.[22,23] Nevertheless, OneCurve showed the least cyclic fatigue resistance. Cyclic fatigue resistance is multifactorial.

All tested instruments are heated-treated alloys. DSC results showed that HFEDM and OneCurve have transformation temperatures higher than the body temperature. This means that both files maintained the stabilised martensite structure at body temperature. Martensitic instruments show more flexibility and higher resistance to cyclic fatigue than austenitic instruments.[25] However, R-Motion showed a transformation temperature range below the body temperature. As long as the file is used at the body temperature, then it is used in an austinite form, not a stabilized martensite due to the transformation from martensite to austinite that already took place below the body temperature. This phase transformation could explain the decreased cyclic fatigue resistance of R-Motion compared to HFEDM despite the kinematics effec.

Conclusions

R-Motion showed lower DCF resistance than HFEDM and was superior to OneCurve at a 90° angle and a 5-mm radius curvature. Stabilising martensitic crystalline structure by raising transformation temperature above the body temperature increases DCF resistance of heat-treated NiTi files.

Conflict of interest

None disclosed.

Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.identj.2022.12.007.

REFERENCES

1. Mahfouze AL, El Gendy AA, Elsewify TM. Bacterial reduction of mature *Enterococcus faecalis* biofilm by different irrigants and activation techniques using confocal laser scanning microscopy. An in vitro study. Saudi Endod J 2020;10(3):247–53.
2. Mamede-Neto I, Borges AH, Guedes OA, de Oliveira D, Pedro FLM, Estrela C. Root canal transportation and centering ability of nickel-titanium rotary instruments in mandibular

premolars assessed using cone-beam computed tomography. Open Dent J 2017;11(1):71–8.
3. Thu M, Ebihara A, Maki K, Miki N, Okiji T. Cyclic fatigue resistance of rotary and reciprocating nickel-titanium instruments subjected to static and dynamic tests. J Endod 2020;46 (11):1752–7.
4. Keskin NB, Inan U. Cyclic fatigue resistance of rotary NiTi instruments produced with four different manufacturing methods. Microsc Res Tech 2019;82(10):1642–8.
5. Martín B, Zelada G, Varela P, et al. Factors influencing the fracture of nickel-titanium rotary instruments. Int Endod J 2003;36(4):262–6.
6. Gambarini G. Cyclic fatigue of ProFile rotary instruments after prolonged clinical use. Int Endod J 2001;34(5):386–9.
7. Yilmaz K, Özyürek T, Uslu G. Comparison of cyclic fatigue resistance of one curve, Hyflex EDM, waveone gold and reciproc blue nickel-titanium rotary files at intra-canal temperature. Cumhur Dent J 2019;22(1):42–7.
8. Pedullà E, Plotino G, Grande NM, et al. Influence of rotational speed on the cyclic fatigue of Mtwo instruments. Int Endod J 2014;47(6):514–9.
9. Elsewify TM, Saber SM, Plotino G. Cyclic fatigue resistance of three heat-treated nickel-titanium instruments at simulated body temperature. Saudi Endod J 2020;10(2):131–6.
10. Hülsmann M, Donnermeyer D, Schäfer E. A critical appraisal of studies on cyclic fatigue resistance of engine-driven endodontic instruments. Int Endod J 2019;52(10):1427–45.
11. 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):200–2.
12. Miyai K, Ebihara A, Hayashi Y, Doi H, Suda H, Yoneyama T. Influence of phase transformation on the torsional and bending properties of nickel-titanium rotary endodontic instruments. Int Endod J 2006;39(2):119–26.
13. Kuhn G, Jordan L. Fatigue and mechanical properties of nickel-titanium endodontic instruments. J Endod 2002;28 (10):716–20.
14. Reciprocation redefined. Safe. Easy. Minimally invasive. Available from: www.fkg.ch/r-motion. Accessed 11 Jan 2022.
15. Razcha C, Zacharopoulos A, Anestis D, Mikrogeorgis G, Zacharakis G, Lyroudia K. Micro-computed tomographic evaluation of canal transportation and centering ability of 4 heat-treated nickel-titanium systems. J Endod 2020;46(5):675–81.
16. Micoogullari K S, Kaval ME, Serefoglu B, Kandemir Demirci G, Çalışkan MK. Cyclic fatigue resistance and energy dispersive X-ray spectroscopy analysis of novel heat-treated nickel–titanium instruments at body temperature. Microsc Res Tech 2020;83(7):790–4.
17. Pedullà E, Lo Savio F, Boninelli S, et al. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical discharge machining. J Endod 2016;42 (1):156–9.
18. El-wakeel MSAA, Hashem AAR, Fahmy SH, Saber SM, Plotino G. The impact of composition, core metal mass and phase transformation behaviour on the dynamic cyclic fatigue of Ni-Ti files at different temperatures. G Ital Endod 2022;36 (1):101–9.
19. Iacono F, Pirani C, Generali L, et al. Structural analysis of HyFlex EDM instruments. Int Endod J 2017;50(3):303–13.
20. Yahata Y, Yoneyama T, Hayashi Y, et al. Effect of heat treatment on transformation temperatures and bending properties of nickel-titanium endodontic instruments. Int Endod J 2009;42(7):621–6.
21. Ferreira F, Adeodato C, Barbosa I, Aboud L, Scelza P, Zaccaro Scelza M. Movement kinematics and cyclic fatigue of NiTi rotary instruments: a systematic review. Int Endod J 2017;50 (2):143–52.
22. La Rosa GRM, Shumakova V, Isola G, Indelicato F, Bugea C, Pedullà E. Evaluation of the cyclic fatigue of two single files at body and room temperature with different radii of curvature. Materials (Basel) 2021;14(9):2–9.
23. Staffoli S, Grande NM, Plotino G, et al. Influence of environmental temperature, heat-treatment and design on the cyclic fatigue resistance of three generations of a single-file nickel–titanium rotary instrument. Odontology 2019;107(3):301–7.
24. Arias A, Macorra JC, Govindjee S, Peters OA. Correlation between temperature-dependent fatigue resistance and differential scanning calorimetry analysis for 2 contemporary rotary instruments. J Endod 2018;44(4):630–4.
25. Özyürek T, Uslu G, Yilmaz K. Influence of different movement kinematics on cyclic fatigue resistance of nickel-titanium instruments designed for retreatment. Saudi Endod J 2017;7 (3):151.
26. Tokita D, Ebihara A, Miyara K, Okiji T. Dynamic torsional and cyclic fracture behavior of profile rotary instruments at continuous or reciprocating rotation as visualized with high-speed digital video imaging. J Endod 2017;43(8):1337–42.