In vitro comparison of cyclic fatigue resistance of two rotary single-file endodontic systems: OneCurve versus OneShape

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Abstract

The aim of the present study was to evaluate the difference in cyclic fatigue resistance between OneCurve (OC) and OneShape (OS) endodontic single-file NiTi systems in a severely curved artificial canal. After sample size calculation ($\alpha = 0.01$; $\beta = 0.20$; $\sigma = 20.0$; $\delta = 20.0$), 25 OC and 25 OS files were used. An artificial canal with 60° angle and 5-mm radius of curvature was milled in a stainless-steel block reproducing the size and taper of the files used. The test device was electrically heated to maintain the environmental temperature at 37 °C. All files were rotated until fracture; the time to failure was recorded and the number of cycles to fracture (NCF) calculated. The length of the fractured fragments was measured too. Fractographic examination and cross-sectional area calculation were performed by scanning electron microscopy analysis (SEM). Data were statistically analyzed using an independent sample *t* test. The significance level was set at 0.01. Statistical analysis showed that OC files exhibited significantly greater cyclic fatigue resistance than OS ($p < 0.001$), with 721 ± 89 NCF and 301 ± 38 NCF, respectively. No significant difference was found in the length of the fractured fragments ($p > 0.01$). SEM fractographic analysis confirmed that all the scanned samples separated due to cyclic fatigue. Within the limitations of the present study, OC endodontic instruments resisted to cyclic fatigue better than OS. The improved mechanical resistance of OC could be related to new NiTi alloy used for their manufacturing.

Keywords Continuous rotation · Cyclic fatigue · Nickel–titanium · Single-file system · Scanning electron microscopy

Introduction

Nickel–titanium (NiTi) endodontic files have increased flexibility and strength compared with stainless steel instruments, but they seem to be vulnerable to fracture in clinical situations [1]. Fracture of endodontic instruments usually occurs under two circumstances: torsional and cyclic fatigue [2]. When an endodontic instrument, within its elastic limits, rotates inside a curved canal, a mechanical load occurs, represented by alternating tensile and compressive stresses. The cyclical repetition of these loads leads to instrument fracture through low-cycle fatigue [3]. Cyclic failure is implicated in more than one-third of the instruments fractured clinically and is likely to happen in the region of maximum canal curvature without any previous sign of permanent deformation [4]. Instead, torsional fatigue occurs when the tip of the instrument is locked in the canal while the shank continues to rotate, especially in case of excessive effort during shaping [5]. The manufacturing of endodontic files can improve resistance to cyclic stress but not the torsional one since the latter is more operator-dependent [6]. Because of this, file manufacturers have tried to develop new designs, manufacturing processes and protocols to minimize fracture occurrence [7].

Single-file systems have been recently introduced to simplify instrumentation protocols and to reduce mechanical stress [8]. Moreover, canal preparation with a single-file may be faster than that obtainable with conventional multi-file sequences [9]. Given the above, various endodontic brands have started to introduce single-file single-use systems.

OneShape files (OS; Micro Méga, Besançon, France) were launched into the dental market in 2011 as the first rotary single-file endodontic system. The system consists of only one instrument, which has a noncutting tip of size 25, a constant 6% taper, and an asymmetric cross-sectional

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design that generates traveling waves of motion along the active part of the file [10]. This instrument is made of a conventional austenite 55-NiTi alloy [9]. The variable design involves a triangular cross-section with three sharp cutting edges in the apical and middle part, which progressively changes to two cutting edges near the shaft, resembling an S-shaped design with the aim of preventing the screwing effect [11].

OneCurve endodontic files (OC; Micro Méga) were launched in 2018 as the evolution of OS instruments. OC files are composed of a NiTi alloy that undergoes a patent-protected heat treatment (C.Wire), thanks to which the file is provided with a shape-memory effect and the capability of being pre-curved. OC files share the same tip size (size 25) and the constant taper (6%) of their predecessors but have different shape design. The variable cross-sections with a triangular-shaped at the tip of the instrument and S-shaped near the shaft are claimed to allow effective cutting and centered trajectory.

To date and to our knowledge, the cyclic fatigue resistance of OC and OS endodontic instruments has not been compared yet. Thus, the aim of the present study was to evaluate the cyclic fatigue resistance of these single-file systems testing the null hypothesis that there is no difference in fatigue resistance between them.

Materials and methods

After sample size calculation ($\alpha = 0.01$; $\beta = 0.20$; $\sigma = 20.0$; $\delta = 20.0$), 25 OC files and 25 OS files were inspected at 25 × magnification under a stereomicroscope (Leica MZ10 F, Wetzlar, Germany) to exclude the presence of defects. All 25-mm long OC and OS files were tested following manufacturer's instructions, rotating the files at 300 rpm and 400 rpm, respectively. An endodontic motor was used for cyclic fatigue testing (VDW.Gold Reciproc, VDW, Munich, Germany).

The static cyclic fatigue test was performed using a custom-made device that allowed a reproducible simulation of an instrument confined in a curved canal. An artificial canal was designed by AutoCAD (Autodesk, San Rafael, CA, USA) with a tapered shape corresponding to the dimensions of the instruments tested and milled from stainless-steel; it was manufactured with a 60° angle and a 5-mm radius of curvature, having a total working length of 16 mm (Fig. 1). To reduce the friction of the file as it contacted the artificial canal walls, a synthetic oil (WD-40 Company, Milton Keynes, UK) was applied for lubrication and the prevention of temperature rise. The handpiece was mounted on an adjustable support to allow a reproducible placement of each instrument inside the canal. To standardize the environmental conditions, a hotplate stirrer (Monotherm, Variomag, Daytona Beach, FL, USA) set at

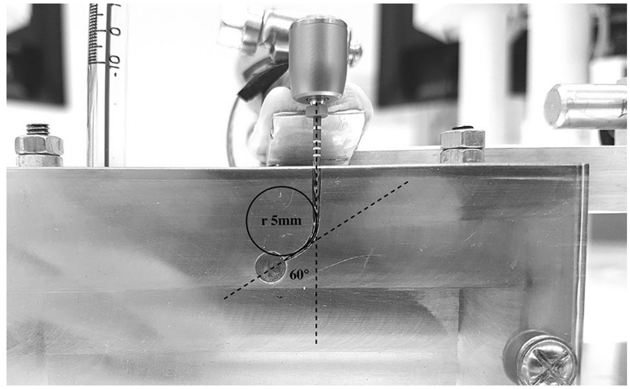

Fig. 1 The artificial stainless-steel canal milled for cyclic fatigue resistance test

37 °C was positioned in direct contact with the stainless-steel block; the temperature was monitored with the aid of a thermometer. All the instruments were led to working length and rotated until fracture occurred. For each instrument, the time to failure (TtF) was recorded in seconds with a digital chronometer (HS-3V-1R, Casio, Tokyo, Japan). The length of the fractured tip was also measured with a digital caliper (Series 500, Mitutoyo, Kawasaki, Japan). The number of cycles to failure (NCF) was calculated by multiplying the TtF by the number of cycles per second.

Five fractured files per group were randomly selected and ultrasonically cleaned in absolute alcohol for scanning electron microscope (SEM) examination (Quanta 250, Fei company, Hillsboro, NE, USA). The fractured surfaces were inspected under 200 × magnification to assess their topographic features and to confirm that the files fractured because of cyclic fatigue. Further, a brand-new file for each instrument type was embedded into epoxy resin (EpoThin 2 Resin, Buehler, Lake Bluff, IL, USA), cross-sectioned with a microtome (Micromet, Remet, Bologna, Italy) at 5.0 mm from its tip, and observed at 250 × at the SEM (Fig. 2). At this level, the cross-sectional area of each file was calculated using image analysis software (ImageJ, US National Institutes of Health, Bethesda, MD, USA).

Collected data were statistically analyzed with dedicated software (Statistical Package for Social Sciences v.15, SPSS Inc., Chicago, IL, USA). All datasets were tested for normality of the distribution and equality of variances with a Shapiro–Wilk and Levene test, respectively. The difference in terms of NCF and fragment length was evaluated with an independent sample t test ($\alpha = 0.01$).

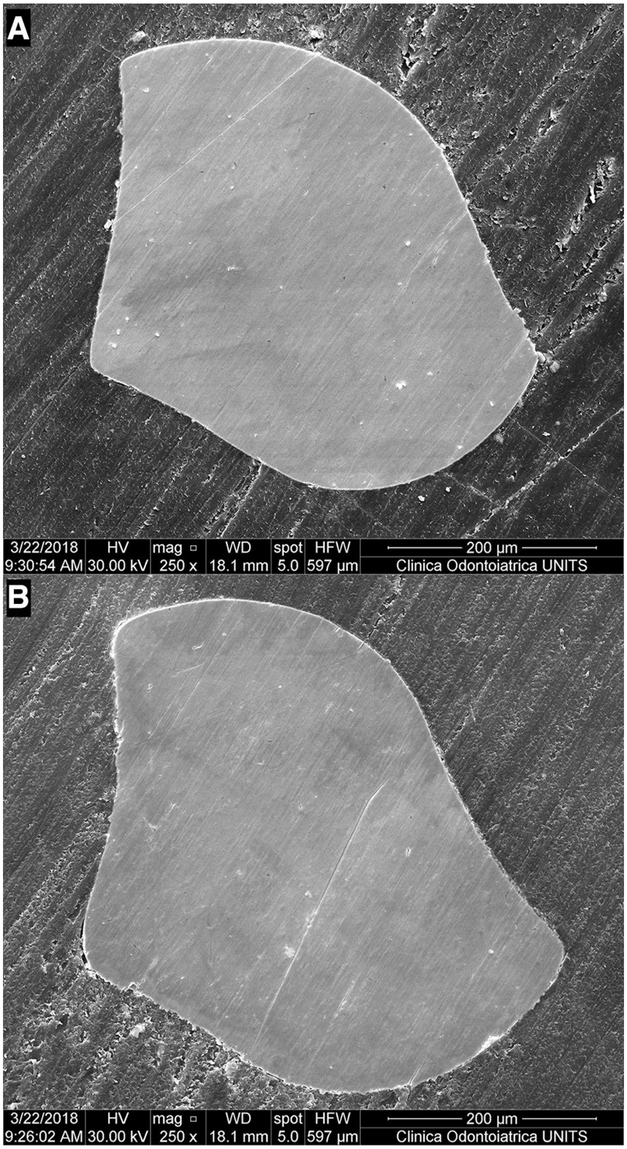

Fig. 2 Cross-sections of OneCurve (**a**) and OneShape (**b**) instruments at 5 mm from the file tip observed at the scanning electron microscope

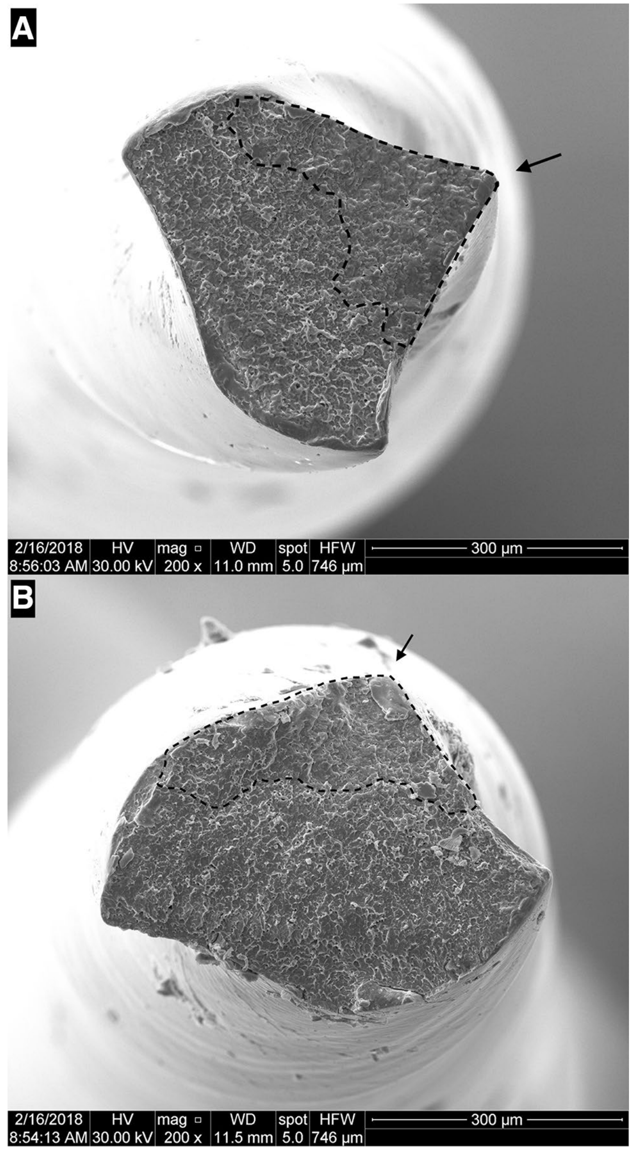

Fig. 3 Scanning electron microphotographs of the fractured surfaces of OneCurve (**a**) and OneShape (**b**) instruments. Crack initiation origin (arrow) and slow fatigue crack propagation (dotted line) are observed in the same fracture surface

Table 1 Means and standard deviations of the time to failure (TtF), number of cycles to failure (NCF) and fragment length (FL) of the tested NiTi files

	n	TtF (s)	NCF	FL (mm)
OneCurve	25	144 ± 18	721 ± 89	4.49 ± 0.32
OneShape	25	45 ± 6	301 ± 38	4.69 ± 0.56
Statistical difference			$p < 0.001$	$p = 0.122$

Results

The results obtained in the cyclic fatigue test are presented in Table 1. The inferential statistical analysis showed that OC files resisted significantly better than OS in the simulated curved canal used in the present study ($p < 0.001$). There was no significant difference ($p > 0.01$) in the mean length of the fractured fragments for all the instruments tested, thus confirming the correct positioning of the files inside the canal.

The calculation of the cross-sectional area of OC and OS instruments was ~ 151,570 µm^2 and ~ 135,220 µm^2, respectively. The SEM microphotographs of the fracture surface of the analyzed instruments revealed similar overload areas and fracture initiation zones (Fig. 3). Typical features of an overload fast fracture zone were observed at the opposite side of the crack initiation area, consistently with the nature of the cyclic fatigue failure.

Discussion

The results of the present study showed that the new OC endodontic instruments resisted cyclic fatigue ~ 2.4 times more than OS files. Basing on the obtained results, the null hypothesis was rejected. The statistical analysis demonstrated that the new patented C.Wire NiTi alloy and the modified design have the potential to improve the mechanical properties of the OC files compared to OS.

The catastrophic fracture of endodontic instruments has been attributed to torsional or cyclic stress. Cyclic failure occurs when the endodontic file rotates freely in a curvature whilst being subjected to repeated cycles of tension and compression, which disintegrate its structure and consequently lead to fracture [12]. The most important factor that leads to separation of NiTi files is metal fatigue, representing the number of cycles that an instrument can resist under a specific loading condition [6]. NCF measurement offers pertinent information regarding the mechanical ability of the instrument design to withstand cyclic fatigue because NCF is cumulative and it relates to the number of compressive/tensile stress occurs in the bend portion of the file [13]. Indeed, TtF cannot always be directly used as a benchmark when the tested files are used with different speed, as was the case of the present study. The instruments will have a mean number of cycles to failure that is determined by specific parameters, and the use of higher rotational speed will consume the useful life of the instrument [14]. Previous studies showed that the TtF is related to the rotational speed, and fracture is then less likely to occur when rotary NiTi instruments are used at lower speeds [15]. Higher speeds could increase the instrument temperature, causing more surface tension and precocious fatigue fracture [14]. Nevertheless, TtF is more clinically relevant, reflecting how the instruments are used in the clinical setting, while NCF is more related to the mechanical property of the file itself, being indicative without considering the speed variable [16]. However, converting the TtF to NCF allows fair comparison regardless of the rotational speed [17]. In the present study, the rotational speeds used were the same recommended by the manufacturer; the authors believe that the improvement of cyclic fatigue resistance can be related more to NiTi alloy features than the variation of rotational speed.

Few studies are available about the cyclic failure of OS instruments, the results of which show huge variability in NCF values. OS files were previously tested in 60°/5-mm radius of curvature artificial canals [18–20] and in 60°/3-mm radius of curvature artificial canals [8, 21, 22]. Unfortunately, it is not possible to directly compare these data with the results obtained in the present study because of a lack of environmental conditions standardization across studies. No study about the cyclic fatigue resistance of OC instruments exists, because they have been recently released to the market, so the present study is one of the first testing this new single-file system and there is no possibility to compare its findings with other data to the best of our knowledge.

The comparison of cyclic resistance between different endodontic instruments must contemplate several variables such as transversal size, taper, cross-sectional design, and manufacturing techniques [23]. However, a major drawback of most studies that have tested the fatigue behavior of NiTi files is that the various contributing factors cannot be totally eliminated and this makes it difficult to quantify the effect of a single variable on fatigue behavior [24]. The production process about the NiTi is important to improve the mechanical features of the root canal instruments. Mainly martensitic files are soft, ductile and have shown a higher flexibility and an improved fatigue resistance compared to conventional austenitic instruments, therefore, manufacturers developed new NiTi alloys [25]. OS instruments are made of austenite 55-NiTi while OC are made of a supposed control memory NiTi wire; control memory instruments are mainly in the martensitic phase and have been manufactured by a thermo-mechanical process that controls the memory of the material and makes the files extremely flexible and resistant to cyclic fatigue [26]. Since the exact properties of the NiTi alloy of OC instruments are not known, further studies are needed to determine the metallurgical features and to compare the resistance given by these instruments. The use of a heat treatment on the manufacturing of superelastic wires should be the reason for the improved cyclic resistance of the latest OC endodontic instruments.

The alloy is not the only factor influencing the mechanical behavior of the file; the diameter and cross-sectional design could affect the metal fatigue [27]. Indeed, some researchers sustained that there is a connection between cross-section and stress resistance whereas the larger the metal volume, the lower the fatigue resistance [28]. Other authors, conversely, found that these factors did not have an impact [29]. The files tested are similar in cross-sectional designs and tip size but the calculation of the transversal area at 5 mm from the file tip revealed that OC files have a smaller area than OS (difference of ~ 16,350 μm^2). Even though the results obtained about cyclic fatigue, the authors believe that the major role for granting greater resistance is played by the processes of NiTi alloys manufacturing, rather than by the low core mass of the OC instruments tested.

Most fatigue resistance studies have been carried out at room temperature, whereas NiTi instruments are called upon to work at body temperature (37 °C). Body temperature may have a significant effect on the cyclic fatigue resistance [30] since increased temperature can negatively affect cyclic resistance [31, 32], also in relation to the previous heat treatment the NiTi alloy has received [33, 34]. In fact, the martensitic transformation, superelastic behavior, and mechanical resistance of heat-treated NiTi can be influenced by the environmental temperature, reducing the fatigue life of an instrument exposed to body temperature [35]. Unfortunately, no study about the differential scanning calorimetry of OC and OS exists, thus calculating the phase transition temperatures is not feasible to predict the alloy behavior of these files under different heat conditions. Therefore, in the present study, the simulation of environmental conditions (i.e. simulation of body temperature) was followed to obtain the most reliable results about cyclic fatigue.

Fractographic analysis was performed on OC and OS files subjected to cyclic fatigue to identify the causes of failure. Wide regions of fatigue striations zone in proximity to the crack origins revealed a slow propagation of the fracture whereas dimples in the central area indicating that on overload caused rapid crack propagation [36]. The SEM images showed typical fractographic appearances of cyclic failure that were similar in both two groups.

Within the limitation of the present study, cyclic fatigue testing demonstrated that the new C.Wire NiTi alloy allows greater cyclic fatigue resistance of OC endodontic instruments compared to their predecessor OS. Further in vivo studies are needed to confirm these results clinically.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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