EGYPTIAN
DENTAL JOURNAL

Vol. 66, 355:364, January, 2020

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics, Dental materials, Conservative Dentistry and Endodontics

www.eda-egypt.org • Codex : 21/2001 • DOI : 10.21608/edj.2020.79111

EFFECT OF DIFFERENT TEMPERATURES ON FLEXURAL CYCLIC FATIGUE RESISTANCE OF 2SHAPE AND ONESHAPE ROTARY ENDODONTIC INSTRUMENTS

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ABSTRACT

Objectives: The aim of the present study was to evaluate the effect of the different temperatures on the flexural cyclic fatigue of 2 Shape and OneShape rotary endodontic files.

Materials and Methods: Forty-rotary endodontic files were divided according to the type of instrument used and the surrounding temperature (n=10); 2Shape and OneShape rotary endodontic files rotated in a custom made simulated canal model block fixed to a beaker containing water with temperature adjusted to either 37 °C or 60 °C. Time was recorded from the beginning of rotation until the fracture was detected, then the number of cycles to failure (NCF) and the length of the fractured segment (FL) were evaluated. Two representative samples were photographed under scanning electron microscopy. Two-way Analysis of Variance (ANOVA) was used to study the effect of the type of instrument used and temperature on the number of cycles to failure and the length of the fractured segment.

Results: 2Shape rotary endodontic files used at 37° C showed statistically significant highest mean of number of cycles to failure compared to 2Shape at 60°C ($P<0.001$), then OneShape used at 37°C, and finally the OneShape used at 60 °C ($P<0.011$).

Conclusions: 2 Shape showed more resistance to flexural cyclic fatigue than OneShape, and high temperature seemed to have a reducing effect on the flexural cyclic fatigue resistance of the both tested rotary endodontic instruments.

KEYWORDS: Flexural cyclic fatigue; OneShape; Model block; 2Shape; Temperature.

INTRODUCTION

Nickel-titanium (NiTi) rotary instruments are considered as essential tools in endodontic treatment as they facilitate the shaping of root canals with complex morphology[1]. NiTi instruments have unique superelastic property (SE), which allow the transformation from austenite to martensite phases when temperature is decreased or stress induced, this phase transformation is reversible during clinical use and responsible for increasing the flexibility of NiTi rotary instruments [2,3].

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NiTi instruments have the ability to maintain the original canal shape and to reduce the risk of mishaps during canal preparation [4]. However, NiTi instruments are not free from unexpected file separation during clinical use [4,5]. There are two causes of instrument fracture, either through flexural cyclic fatigue or torsional overloading, where the flexural cyclic fatigue occurs when the file is rotating in the canal and subjected to repeated tension-compression cycles at the area of maximum root curvature [6].

Many factors can affect instruments fracture inside the root canal such as; the abruptness of the canal curvature including the angle, the radius and the position of the maximum curvature center, addition to ; instrument alloy, design, surface treatment, rotational speed, kinematics, and operator's skill [7-9]. Different attempts have been done to enhance the fatigue resistance of rotary instruments, through improving the alloy itself, cross-section design, manufacturing process, surface treatment and thermal treatment to enhance the mechanical properties [10,11]. Proprietary thermomechanical procedure has been done to provide superelastic NiTi endodontic instruments with martensite phase at room temperature [12], which improves the ductility, resistance to crack growth and provides a higher resistance to cyclic fatigue [4,13, 14].

Recently 2Shape rotary endodontic instruments have been introduced (Micro Mega, Besancon, France) with a proprietary heat treatment (T-Wire) and asymmetrical triple helix cross-section, while the OneShape file (Micro Mega, Besancon, France); is a single-file system, manufactured from conventional austenite 55-NiTi alloy with changing triangular or modified triangular cross sectional shape, 3 cutting edges in the apical and middle thirds and S-shaped cross section with 2 cutting edges, near the shaft [1].

Several Studies have recommended the heating of the sodium hypochlorite (NaOCl) during root canal treatment to increase its antimicrobial activity and tissue-dissolving capacity [16-19] According to literature, there are limited studies evaluating the effect of temperature on flexural cyclic fatigue of endodontic instruments [20-25], thus the purpose of this study was to evaluate the flexural cyclic fatigue resistance of 2Shape and OneShape rotary endodontic instruments at different temperatures. The null hypothesis was that there would be no statistically significant difference in the cyclic fatigue resistance between the two systems at different temperatures.

MATERIALS AND METHODS

Sample size calculation

Sample size calculation was based upon the results of Keskin et al. 2016 [26] and Dosanjh et al. 2017 [22], utilizing number of cycles to fracture as the primary outcome, using alpha (α) level of 0.05 (5%) and Beta (β) level of 0.20 (20%) i.e. power = 80% and effect size 1.786 is expected. The minimum estimated sample size was 7 samples per group. Sample size calculation was performed using IBM® (IBM Corporation, NY, USA.) SPSS® (SPSS, Inc., an IBM Company) SamplePower® Release. 3.0.1. Samples were increased to 10 per group for a total of 40 samples.

Evaluation of the flexural Cyclic fatigue

- ***Fabrication of the custom-made model containing the artificial canal:***

A Custom made simulated canal model was fabricated from stainless-steel to bear friction wear with 60° angle of curvature, 5 mm radius of curvature and 2 mm depth.The angle of curvature and radius of curvature was described according Pruett et al. 1997 [27] method by drawing two straight lines; the first along the long axis of the straight coronal part of the canal, and the second along the straight apical part. There is a point where the canal starts to deviate from each of these straight lines; where the curve starts (point a) and ends (point b). The curved portion of the canal was represented by a circle with tangents at these two points. The length of the radius of this circle in millimeters represents the radius of curvature (r) and the angle (α) formed by the two perpendicular lines starting from point (a) or (b) and intersecting at the center represents the angle of the curvature (Figure 1).

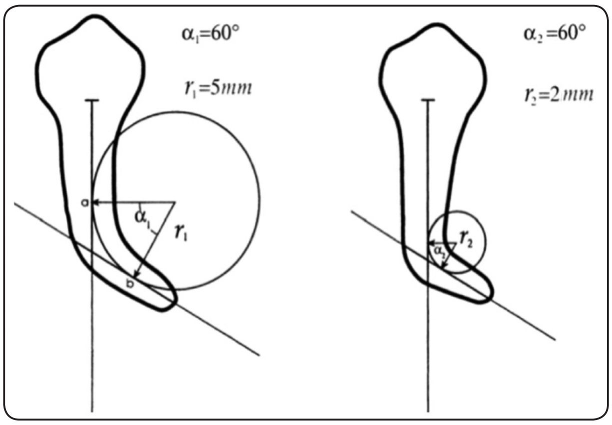

Fig. (1) The method described by Pruett et al for describing canal geometry using two parameters: radius of curvature and angle of curvature.

Canal measurements was manipulated by the help of an AUTOCAD software (Autodesk, San Rafael, CA). Drawing was estimated from the size and tapers of the tested instruments. The simulated canal was designed with a 60° angle of curvature and 5 mm radius of curvature with 11mm straight portion and 5mm curved portion. The design of the canal was based on the dimension of the apical diameter of 0.25 mm at D0 and increase by 0.06 every millimeter up to D16, however the canal was wider than the file with 0.2 mm along its length to reduce the friction and allow the file to rotate freely (D0=0.45mm and D16 =1.41mm). Two millimeter depth was added to the grooves in order to avoid altering the inner rounded cross section topography that adapted to the files shape and to ensure that the files will rotate within the groove without scratching the top glass cover.

The AutoCAD drawing design was entered on a special computer software specifically designed for a 2D laser cutting machine. The main stainless-steel sheet has dimensions of 8 cm length, 4 cm height and 2 mm thickness, then this sheet was backed up with another stainless steel sheet, spot welded by argon flame to the main sheet to form the floor of the canal.Two screw holes were drilled in the lower corners to fix a transparent glass top cover with 3 mm thickness to observe the file while rotating until fracture and to prevent its deviation or slippage during rotation. At the apical end, there was a circular reservoir to collect the fractured pieces of the instruments.

- ***Classification of the samples***

Forty endodontic NiTi files were used, the samples were divided into four groups (n=10), according the type of instrument used and the temperature of the surrounding water. Group I; 2Shape rotary endodontic file (TS2; size 25 and taper 0.06) rotated in the simulated canal model block fixed in a beaker filled with distilled water and the temperature was preset at 37 ± 1°C and in Group II; the same as Group I, except the temperature was preset at 60 ± 1 °C.

Group III: OneShape rotary endodontic file (size 25 and taper 0.06), rotated in the simulated canal model block fixed in a beaker filled with distilled water and the temperature was preset at 37 ± 1°C and in Group IV: the same as Group III, except he temperature was preset at 60 ± 1 °C.

All the files were inspected for any manufacturer defects or deformities before starting the experiment using stereomicroscope (Olympus, SZX9, Tokyo, Japan), and none were discarded.

- ***Cyclic fatigue test***

The testing machine is composed of upper movable compartment and lower fixed base, the contra-angle hand piece of the X-Smart Plus micromotor (Dentsply Maillefer, Ballaigues, Switzerland) was locked in a reproducible position by a custom made jig. This Jig was then attached to adapter that screwed into the upper movable compartment, while the simulated canal model block was fixed in beaker filled with distilled water which was then secured to the lower fixed compartment of the testing machine by tightening screws and the temperature was preset during the testing procedures. Each of the tested files was attached to contra-angle hand piece and then inserted, perpendicular to the orifice of the canal, at the exact depth with the help of the rubber stopper. All the files rotated freely according to the manufacturer's instructions at a rotational speed of 300 rpm and 2.5 Ncm torque.

Time was recorded in seconds from the beginning of the rotation until the moment of fracture was detected visually and/or audibly. Thereafter, the total number of cycles to failure (NCF) for each file was calculated by multiplying the time to fracture in a minute by the number of rotations/min. For each file, the length of the fractured segment (FL) was measured using a digital caliper (Mitutoyo, Tokyo, Japan).

NCF = number of rotations/min (rpm) X time (seconds)/60

Scanning electron microscope examination (SEM) of the fractured files:

The broken files were ultrasonically cleaned in alcohol and then allowed to dry. Two representative samples from each group were photographed under scanning electron microscopy (SEM, Joel 6360 LV, Tokyo, Japan) in lateral and cross-section views at 400x and 550x magnifications respectively.

Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed normal (parametric) distribution. Parametric Data were presented as mean, standard deviation (SD) and 95% Confidence Interval for the mean (95% CI) values. Two-way Analysis of Variance (ANOVA) was used to study the effect of the type of instrument used and surrounding temperatures on the number of cycles to failure and the length of the fractured segment. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS (IBM Corporation, NY, USA) Statistics Version 20 for Windows.

RESULTS

The means and standard deviations (SD) of the NCF values of the four tested groups are shown in (Table 1, Figure 2 and 3) while the means and standard deviations of the FL values were calculated and represented in (Table 2).

The results showed that the type of instrument used and the surrounding temperatures, had a statistically significant effect on the mean number of cycles to failure ($P=0.001$, $P<0.05$). Comparing both types of instruments either at 37 °C or at 60 °C; the OneShape rotary endodontic file showed statistically significantly lower number of cycles to failure than the 2Shape rotary endodontic file ($P=0.001$, $P<0.05$).

Comparing the changes in the number of cycles to failure associated with increasing the temperature from 37 °C to 60 °C using either 2Shape or OneShape rotary endodontic files; a statistically significantly higher mean of number of cycles to failure was observed at 37 °C ($P=0.001$, $P=0.011$, $P<0.05$) than at 60 °C. When comparing 2Shape files at different temperatures, no statistical difference was detected in the mean length of the fractured fragments ($P=0.533$). Also, no difference was observed when comparing OneShape files at different temperatures ($P=0.073$).

The scanning electron microscopic images of the fractured surface revealed features typical to cyclic fatigue failure in all the tested groups, where crack initiation at the cutting edges of the fracture cross-sections, a small smooth area on their edge, associated with slow fatigue crack propagation was observed. The specimens showed small cavities known as dimples and fatigue striations, associated with ductile fracture (Figures 4 and 5).

TABLE (1) The mean, standard deviation (SD) values and the results of two-way ANOVA test for comparing the number of cycles to failure between 2Shape and OneShape rotary endodontic files at different surrounding temperatures (37 °C or at 60 °C)

Temperature	2Shape		OneShape		*P*-value (Between systems)	Effect size *(Partial eta squared)*
	Mean	SD	Mean	SD		
37 °C	1272.1	186.1	616.6	96	<0.001*	0.786
60 °C	885	112.3	463.8	93.2	<0.001*	0.603
P-value (Between temperatures)	<0.001*		0.011*			
Effect size *(Partial eta squared)*	0.560		0.166			

: Significant at P ≤ 0.05.

TABLE (2): The mean, standard deviation (SD) values and results of the two-way ANOVA test for comparing the fragment lenght between 2Shape and OneShape rotary endodontic file at different surrounding temperatures (37 °C or at 60 °C)

Temperature	2Shape		OneShape		*P*-value (Between systems)	Effect size *(Partial eta squared)*
	Mean	SD	Mean	SD		
37 °C	4.92	0.78	4.2	0.44	0.053	0.109
60 °C	5.13	0.69	4.94	1.03	0.580	0.009
P-value (Between temperatures)	0.533		0.073			
Effect size *(Partial eta squared)*	0.011		0.092			

: Significant at P ≤ 0.05.

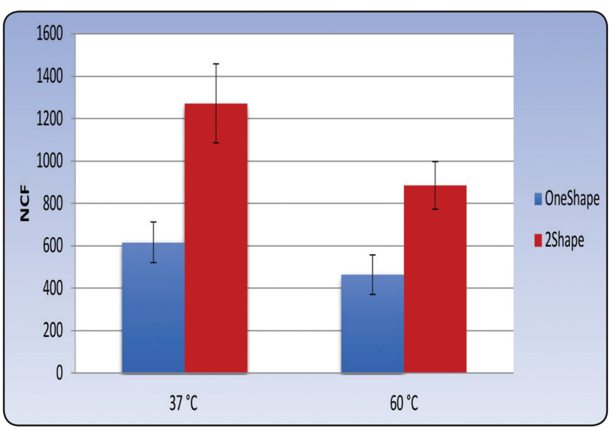

Fig. (2): Bar chart representing the mean and standard deviation values of the number of cycles to failure (NCF) with 2Shape and OneShape rotary endodontic files at different surrounding temperatures (37 °C or at 60 °C).

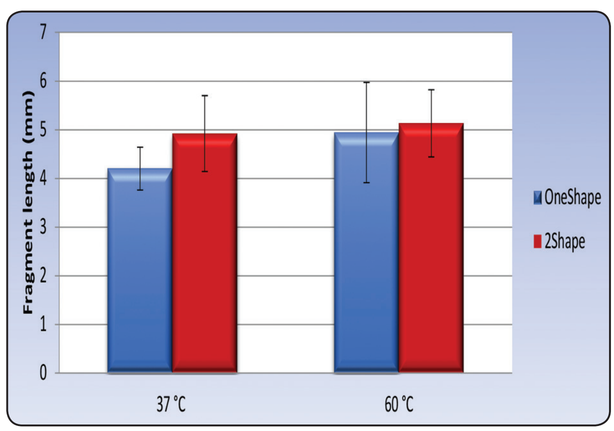

Fig. (3): Bar chart representing the mean and standard deviation values of the fragment length (mm) with 2Shape and OneShape rotary endodontic files at different surrounding temperatures (37 °C or at 60 °C).

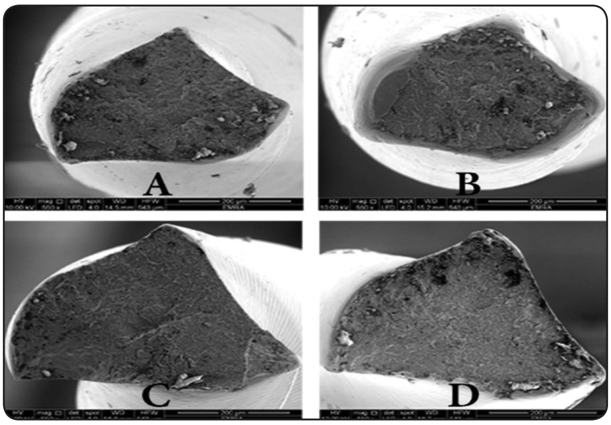

Fig. (4): Representative scanning electron microscopic images of the fracture surface of the broken instruments (A. 2Shape used at 37 °C, B. OneShape used at 60 °C, C. OneShape used at 37 °C and D. 2Shape used at 60 °C) at 550x magnification.

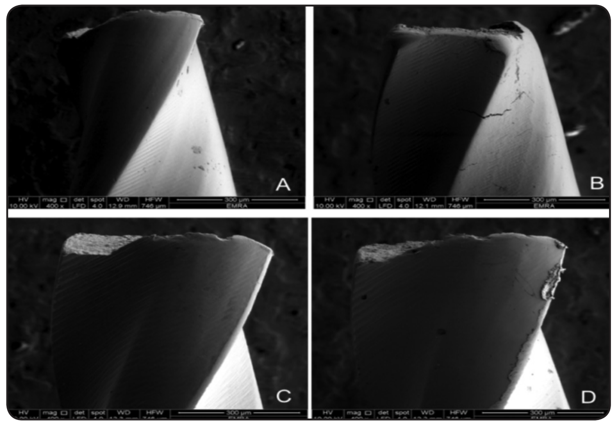

Fig. (5): Representative scanning electron microscopic images of the lateral view of the broken instruments (A. 2Shape used at 37 °C, B. OneShape used at 60 °C, C. OneShape used at 37 °C and D. 2Shape used at 60 °C) at 400x magnification.

DISCUSSION

Fracture of endodontic instruments during root canal preparation is of major concern, where instruments are subjected to great stresses due to the root canal anatomy, the angle of root canal curvature, radius of curvature, size and taper of the instrument, manufacturing design, instrument alloy and the operator experience [27-29].

Up to date, there is no universal protocol or international standard to test cyclic fatigue resistance endodontic instruments to evaluate the flexural cyclic fatigue resistance, yet different methods have been used [30]. Although the extracted human teeth might better reflect the clinical situations [31], they are not anatomically and morphologically standardized (curvature, diameter and radius)in addition, a tooth can only be used once as the shape of the root canal will change during instrumentation, making it impossible to standardize experimental conditions [32]. Thus the use of standardized stainless-steel artificial canals was used to guarantee a fixed radius of curvature, a fixed angle of curvature, a fixed center of maximum curvature and to minimizes the influence of other variables on the file fracture other than the cyclic fatigue [33-36].

The cyclic fatigue testing device permits the instruments to rotate until fracture occurs, allowing the assessment of cyclic fatigue resistance of rotary instruments, which may be affected by instruments diameter, angle severity and radius of canal curvature [27]. In the present study, simulated root canals with 60 degree angle of curvature, 5mm radius of curvature and maximum curvature situated 5mm from the end were used, in accordance with previous reports [35-37] and based on the findings of Pruett et al. [27], where the stress levels induced by curvatures smaller than 5 mm in radius and 30° in angle did not result in instrument separation within the time frame of their study (5 min).

The artificial canal reproduced the instrument size and taper, thus providing the instrument with suitable trajectory to ensure the accuracy of the size of each canal [38, 39]. Extra space of 0.2 mm was added along the canal length according to Plotino et al. [40], who studied the influence of three designs for the artificial canals on the trajectory of the tested file and reported that the artificial canal with a tapered shape, with dimensions increasing than the original dimension (tip size and taper) of the instrument by 0.1 was the best design in representing the parameters of the curvature selected, the second best in their study was increasing the size by 0.3mm, thus in the present study, only an increase of the original size by 0.2 was feasible due to technical limitations and to allow the file to rotate freely in the canal and avoid any torsional stresses that may be developed as a result of locking during rotation.

Flexural cyclic fatigue tests has been performed in several studies at room temperature [41, 42], which is lower than the body temperature and not relevant to the clinical situation, as NiTi instrument is used inside the root canal, surrounded by the periodontium[20], thus performing the experiment at temperature close to the body temperature is more relivent. Moreover, the use of heated irrigating solution during root canal preparation would improve its tissue dissolution capacity and antimicrobial reaction [14,43]. It has been deduced from literature that preheated irrigating solutions would reach a temperature equilibrium relatively quick[44]. Furthermore, human dentin has low thermal conductivity and the intact vasculature with the thermal conductivity of the periodontal membrane and the alveolar bone may also help dissipate the heat rise on the root surface [45].Thus in the present study, the simulated canal model block was fixed in beaker filled with distilled water and the temperature preset at 37±1°C or 60±1°C during the testing procedures to simulate the clinical situations[20-25].

Results showed that 2Shape showed more resistance to flexural cyclic fatigue than OneShape, this was in agreement with Uslu et al. [46] declared that the cyclic fatigue resistance of 2Shape files at the intracanal temperature is higher than that of Twisted File (TF) and EndoSequence Xpress (ESX) nickel-titanium rotary files at intracanal temperature (35°C) and Özyürek et al. 2018 reported no significant difference in the cyclic fatigue resistance between the 2shape, WaveOne gold and Hyflex EDM, in artificial canal with 90° curvature [47]. In addition to Capar et al. 2015 [48] and Gündoğa & Özyürek 2017 [37], reported that the cyclic fatigue resistance of HyFlex file was higher than the OneShape.

This may be attributed to the T-Wire alloy and the proprietary heat treatment used for the manufacturing of the 2Shape rotary endodontic files [47]. It has been reported that thermal heat treatment improved the crystal structure arrangement and the mechanical properties, through increasing the stable martensite phase under clinical conditions, which enhance the flexibility and resistance to cyclic fatigue [42,49], while OneShape rotary endodontic file manufactured from a conventional austenite 55-NiTi , with less ability to resist crack propagation [4, 47].

Moreover, results of the study showed that temperature had an effect on reducing the flexural cyclic fatigue resistance of the 2 Shape rotary endodontic files. This may be attributed to the transition of the 2Shape rotary endodontic files from the martenstic phase to the stiffer austenitic phase by heating, which is more susceptible to fatigue crack propagation [4]. Results also showed that temperature had a reducing effect on the flexural cyclic fatigue resistance of the OneShape rotary endodontic files, which was in agreement with Jamleh et al. 2016 who reported that lower temperatures extend the lifetime of the superelastic NiTi instrument [20].

Results revealed no significant difference in the mean length of the fractured segments, where the fracture of the instrument occurred at approximately 4-5 mm from the tip of the instrument, corresponding to the center of the curvature and the point of maximum flexure of the shaft which confirm that the instruments were correctly positioned within the canal curvature [20, 41].

Flexural cyclic fatigue is related to the repeated cycles of tension and compression that result in structural breakdown of the metal as consequence of stress concentration at the crack origins which were observed at the cutting edge in all files examined under scanning electron microscopy, then crack propagation; represented by striations propagated towards the center. When the crack reach the overstressed point the overload zone appeared as a typical dimple rupture or so-called ductile failure [4, 41].

In conclusion, the 2Shape endodontic files showed more flexural cyclic fatigue resistance than the OneShape endodontic files, furthermore, increasing the temperature surrounding the 2Shape and OneShape endodontic files significantly reduced the number of cycles to failure.

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