Scope
Volume 14 Number 02 June 2024

Thermal Treatment on the Cyclic Fatigue Resistance of Reciprocating Nickel-Titanium Instruments: An Invitro Study

C Champa,[1] Yashashwini B S,[2] Srirekha A,[3] Ashwija Shetty,[4] Sudithi Pal[5], Durga Devi[6]

[1]Professor, Department of conservative dentistry and Endodontics, The Oxford Dental College, Bangalore, India

[2]Post graduate student, The Oxford Dental College, Bangalore, India

[3]Professor and Head of the Department, Department of conservative dentistry and Endodontics, The Oxford Dental College, Bangalore, India

[4] Professor, Department of conservative dentistry and Endodontics, The Oxford Dental College, Bangalore, India

[5] Reader, Department of conservative dentistry and Endodontics,The Oxford Dental College, Bangalore, India

[6]Senior Lecturer, Department of conservative dentistry and Endodontics, The Oxford Dental College, Bangalore, India

Abstract.

Aim: The study aimed to evaluate the effect of thermal treatment using deep cryogenic treatment and autoclaving on the cyclic fatigue resistance of reciprocating nickel-titanium (NiTi) instruments. **Methods:** Thirty primary reciprocating (WaveOne Gold, Dentsply India) nickel-titanium instruments, size 25, 0.07 taper, were divided randomly into three groups: cryo-treated NiTi reciprocating files (Group-A), non-treated NiTi reciprocating files (Group-B) and autoclaved NiTi reciprocating files (Group-C). The instruments of groupA were completely immersed in a cryocan containing liquid nitrogen (-196° C) for 24 h. After 24 h, the instruments were removed from the bath and allowed to gradually return to room temperature. The instruments in group C were autoclaved (121° C) and allowed to gradually return to room temperature. The files were instrumented (at 350 rpm in 150° CCW and 30° CW) in an artificial canal with a curvature of 60° until fracture. The time offracture was recorded with a stopwatch in seconds and subsequently converted several cycles to fracture (NCF). The results were compared using One-way ANOVA and Tukey's post-hoc test at a level of statistical significance of 0.05.**Results:** The mean number of fatigue cycles for the cryo treated group was significantly higher, followed by the non-treated group and the least in the autoclave group. **Conclusion:** Thermal treatment affected cyclic fatigue resistance. Deep cryo treatment enhanced the cyclic fatigue resistance of reciprocating NiTi files.

Keywords: Cyclic fatigue resistance, deep cryogenic treatment, reciprocating files.

Introduction

The removal of vital and necrotic remnants of pulp tissues, microorganisms, and microbial toxins from the root canal system is essential for endodontic success. With the development of nickel-titanium (NiTi) instruments root canal shaping has been enhanced, making them more effective, easier, and faster.[1] Despite all these advantages, the instruments are susceptible to deformation and/or fracture, which can affect treatment prognosis.[2]

When endodontic instruments are applied to curved canals, they undergo both tensile and compressive stress during rotation. Flexural fatigue, regarded as the most destructive cyclic fatigue, is caused by frequent bending and unbending, and is encouraged during instrumentation in curved canals. The constant application of tensile and compressive forces could be a source of potentially destructive load in the area of curvature of the canal where the NiTi rotary instruments are in use.[3] To control these difficulties, new NiTi alloys and different cross-sectional designs have been proposed to optimize the characteristics of endodontic instruments. [4,5]

Thermal processing of NiTi alloys has shown improved instrument fatigue resistance, flexibility, cutting efficiency, and canal-centering ability.[5] In addition to thermal treatment modifications, reciprocating motion kinematics have been shown to expand the lifespan of NiTi instruments and improve fatigue resistance in comparison with continuous rotation movements.[6] WaveOne Gold, is manufactured from a metal alloy treated with a complex heating-cooling treatment which has improved resistance and flexibility.[7]

On the other hand, cryogenic treatment(CT) is an effective heat treatment that can be widely applied to various cutting tools to reduce production costs by increasing cutting tool performance, enhancing wear, abrasion, and corrosion resistance, and reinforcing metals by boosting the degree of NiTi microhardness.[3] CT applied at temperatures between -80 degree Celsius and -140 degree Celsius is shallow cryogenic, while that applied between -140 degree Celsius and -196 degree Celsius is termed deep cryogenic treatment. CT is a two-stage process: (1) submerging the metal in a super-cooled bath that contains liquid nitrogen ($-196^{o}C/-320^{o}F$) and (2) allowing the metal to slowly let the cold out to reach room temperature. The effect of CT on the mechanical behavior of NiTi instruments made of a recently established WaveOne Gold has not yet been evaluated in the literature.

The present study aimed to investigate the effects of deep wet CT and autoclave heat treatment on the cyclic fatigue resistance of the WaveOne Gold file. The null hypothesis states that there is no difference between the cyclic resistance of files treated with or without deep wet CT and those treated after autoclaving.

Materials and Methods

Thirty primary reciprocating Ni-Ti files (WaveOne Gold, Dentsply India) of size 25, 0.07 taper were used in this in vitro study. Before instrumentation, all files were inspected using an optical stereomicroscope under ×20 magnification for morphological and dimensional analysis and for any sign of visible deformations. Files with faults or defects were also discarded. The study protocol and cyclic fatigue testing device used in the present study were based on the method described by Sundaram et al. [8]

All files were randomly assigned into three groups to examine cyclic fatigue:

Group A: Ni-Ti files subjected to deep cryo treatment.

Group B: Ni-Ti files subjected to autoclave.

Group C: Ni-Ti files were not subjected to autoclave or cryo treatment.

Cryogenic treatment protocol

The instruments used in this study were treated cryogenically with liquid nitrogen. They were completely immersed in a cryocan containing liquid nitrogen (-196^{o}C) for 24 h. Then, they were removed from the bath, and stored in 70% of absolute alcohol to gradually return to room temperature. The procedure was similar tothat used by Singh et al.

Autoclaving protocol

Autoclaving cycles were performed at a temperature of 121^{o} C for 30 min using saturated steam under 15 psi of pressure.

Cyclic fatigue examination

The device, developed in the present study to examine the strength of cyclic fatigue, includes a main frame with fixed plastic support to hold the handpiece and a custom-made jig having an artificial curved canal with +0.2 mm deep, 60 ° angle of curvature and 5 mm radius of curvature. Every file is expected to rotate in a precise trajectory as shown in Fig 1. The endodontic micromotor and contra-angle handpiece were placed parallel to the base of the apparatus on the support arm. To ensure correct locking, the file was meticulously secured to the handpiece. Next, as instructed by the manufacturer, the electric motor was calibrated to operate at a speed of 350 rpm. Accurate measurements and instrument placement were guaranteed by file fixation. The micromotor was turned on as soon as the instrument was well-positioned in the canal. Tempered glass was used to cover the artificial canal to stabilize the instrument and allowed to observe the rotating instrument.

The canal was lubricated with synthetic oil to reduce the friction of the instruments. The time taken for the instrument to fracture was recorded with a digital stopwatch. This was a manually operated test, taking from the moment the motor went on to the moment a fracture was detected. This procedure was sequentially repeated by the same operator for all instruments in all three groups.

The time to fracture (TF) was multiplied by the number of rotations per minute to obtain the number of cycles to fracture (NCF) for each instrument.

Statistical Analysis

Once all the tests were administered, each group's mean values were calculated.

Before data analysis, a One-way ANOVA and Tukey's Post Hoc test were done for each group at a statistical significance level of $P < 0.05$.

Results

The mean number of Fatigue Cycles in Cryo treated Group was 2953.84 ± 61.79, for Autoclaved Group was 2338.04 ± 65.65 and in the nontreated Group was 2643.11 ± 37.02. The differences in the mean Cyclic Fatigue values between the three groups were statistically significant at $p<0.001$. (as shown in Fig 2)

Multiple comparisons between groups revealed that the Cryo Treated Group showed the highest mean number of fatigue cycles as compared to the Autoclaved and Non-Treated groups and these differences were statistically significant at $p<0.001$(as shown in Table 2). This isfollowed by the Non-Treated Group, which showed a significantly higher mean number of fatigue cycles than the Autoclave Group and the difference was statistically significant at $p<0.001$. This implies that the mean number of fatigue cycles for the Cryo treated group was significantly higher, followed by the Non-Treated Group and least in the Autoclave Group.Hence, the null hypothesis is rejected. (Figure 3 to 6).

Discussion

The reciprocating working motion has been shown to extend the lifespan of a NiTi instrument, hence providing resistance to fatigue, in comparison with continuous rotation. The M-wire alloy which is used in the development of new instrumentation systems is specifically designed to be used with reciprocating motion: and it offers increased flexibility and cyclic fatigue compared with traditional NiTi. It has a continuously decreasing taper from its shaft and is characterized by different cross-sectional designs over the entire length of the working part. The files have radial lands with a modified convex triangular cross-section at the tip end and a neutral rake angle convex triangular cross-section at the coronal end.

The cyclic fatigue resistance of NiTi rotary instruments has been a subject of great interest in endodontic studies. The impact of torsional fracture, metal fatigue, or fracture of NiTi rotary instruments caused by a combination of torsional stress and accumulation of fatigue is still debated.[9] It has been suggested that cyclic fatigue accounts for 50%-90% of mechanical failures compared to torsional failure. Most of the fractured instruments were analyzed as having flexural failure, implying that cyclic fatigue is the predominant mechanism for material failure.[10]

In this study, canals were simulated with a stainless-steel device that guaranteed a fixed radius of curvature along with a fixed angle of curvature. The protocol used in our study for cyclic fatigue was based on the method described by Li et al. [10] which accurately describes the root canal curvature based on the angle and radius of curvature.

The fracture behavior of rotary instruments might be affected by cold treatment processes which could lead to a potential source of changes in the crystalline alloy structure.[11] Therefore, it is necessary to examine the impact of surface treatment procedures on the performance of NiTi rotary instruments.

In this study, the null hypothesis was rejected and although CT could result in a reduction in the cycles of fracture in the rotary files receiving the process, there was a statistically significant difference in the number of cycles in reciprocating files. Therefore, CT increased the number of cycles ending in the tincture of WaveOne Gold reciprocating files.

Gavini et al. examined the cyclic fatigue resistance of K3 NiTi rotary instruments subjected to nitrogen ion implantation.[12] The results showed that ion implantation was effective in improving the resistance of rotary NiTi instruments to cyclic fatigue.

The present study differed in procedure from that designed by Gavini et al, in that they examined how implantation of the nitrogen ion could affect the properties of the instruments. Implantation occurs within the near-surface layer (below 1 mm deep), hence in this case, implantation becomes a source of compressive residual stress at the subsurface level, which can inhibit the formation and propagation of fracture lines.[12]

However, a study performed by George et al. indicated that the fracture time was significantly higher in three different rotary files (Hero Shapher, RaCe, and K3) after deep dry CT. [3] George et al. concluded that the increase in the level of hardness could be attributed to the alloy completely transforming from the austenitic to martensitic phase. Such a change in phases normally occurs at −195°C and could result in a reduction in the level of internal stress within the alloy owing to plastic deformation.[3]

This study was conducted by George et al. This may be attributed to the CT procedure performed to reduce the occurrence of thermal shock; the nonrecurring thermal treatment was performed at a cooling rate of 1^{o}C/1 min. This improved the microstructure of the NiTi instruments. According to the results of the energy-dispersive X-ray spectroscopy line profile analysis, after CT nitrogen was evenly distributed throughout the entire cross-section of the instrument.[13]

The similarity in the results of the cryo-treated group of the present study with that performed by Gavini et al could be explained by a similar mechanism occurring on CT due to N2 distribution giving similar results. The mechanical behavior of the instruments is highly influenced by the nature of the alloy and the manufacturing process. In addition, even slight changes in the composition, impurities, and heat treatment conditions could have a considerable impact on the mechanical properties of the NiTi alloy.[14] As a case in point, heat treatment (as a part of the manufacturing process) strongly affects superelasticity and shape memory properties.[14]

Under the conditions of the present study, one cycle of autoclave sterilization significantly influenced the cyclic fatigue resistance of reciprocating NiTi files produced by an innovative heat-treated alloy that isWaveOne Gold files (M wire technology). These instruments showed a statistically significant decrease in the number of cycles that caused fractures after sterilization. These results are those obtained by Hilteret al who also reported a significant decrease in the NCF after sterilization exhibited by the group of twisted files suggesting that the enthalpy generated during autoclave processing producedsufficient energy to enable a heat treatment effect that could cause a crystalline phase change with the new manufacturing technique.

Figures

Figure 1- Cyclic fatigue testing device

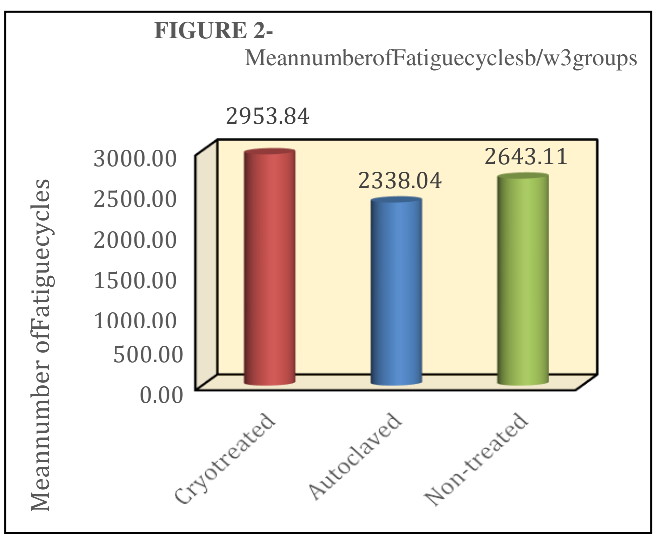


Figure 2- Meannumber of Fatiguecyclesb/w3groups

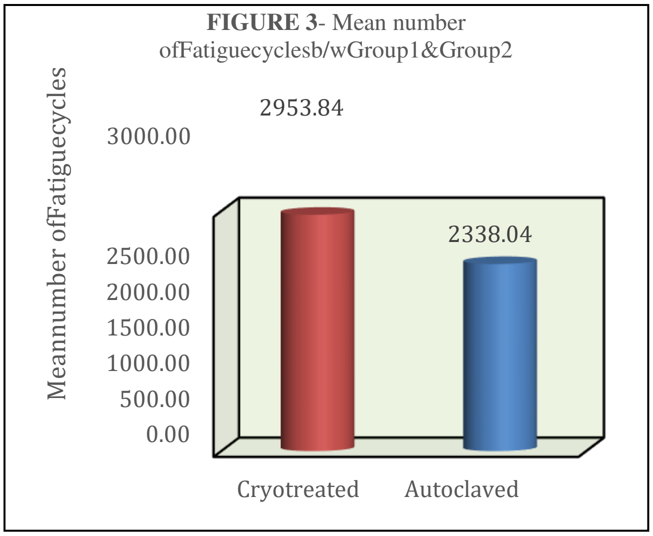


Figure 3- Mean number ofFatiguecyclesb/wGroup1&Group2

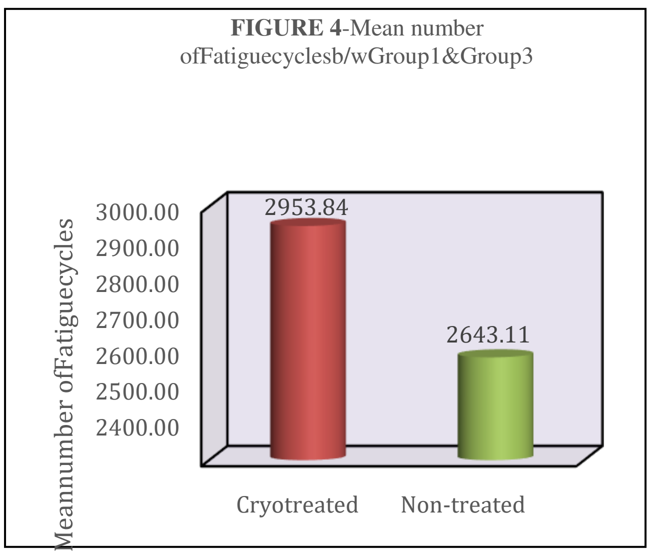
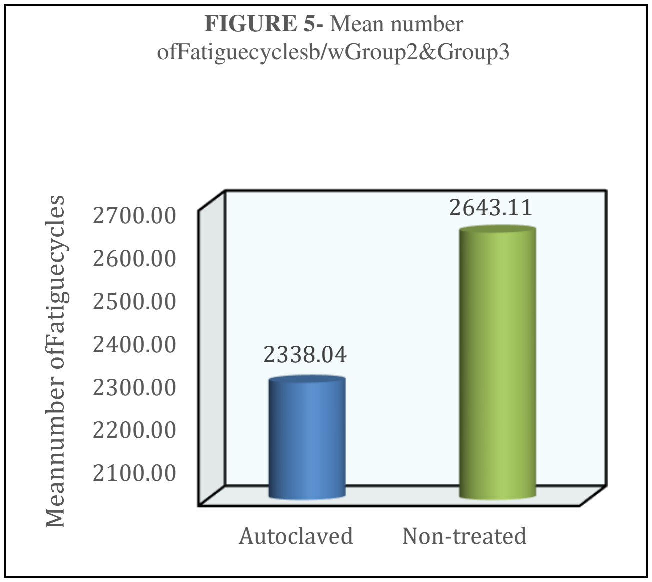


Figure 4-Mean number ofFatiguecyclesb/wGroup1&Group3

FIGURE 5- Mean number ofFatiguecyclesb/wGroup2&Group3



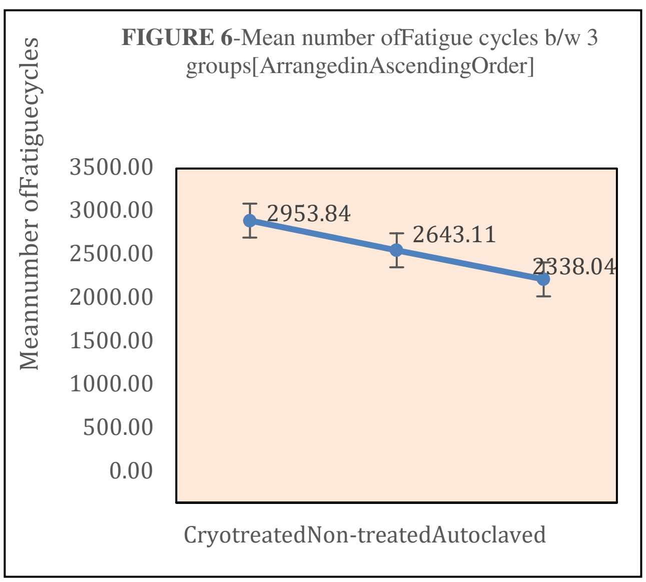


Figure 6-Mean number ofFatigue cycles b/w 3 groups[ArrangedinAscendingOrder]

Tables

Table -1- Comparison of the mean number of Fatigue Cycles between 3 groups using the One-way ANOVA Test

Comparison of the mean number of Fatigue Cycles between 3 groups using One-way ANOVA Test						
Groups	N	Mean	SD	Min	Max	p-value
Cryo treated	10	2953.84	61.79	2850.3	3046.0	<0.001*
Autoclaved	10	2338.04	65.65	2228.3	2413.8	
Non-treated	10	2643.11	37.02	2579.5	2689.2	

*- Statistically Significant

Table-2- Multiple comparisons of mean difference in the number of Fatigue Cycles between groups using Tukey's post hoc Test

Multiple comparisons of mean difference in the number of Fatigue Cycles between groups using Tukey's post hoc Test					
(I) Groups	(J) Groups	Mean Diff. (I-J)	95% CI for the Diff.		p-value
			Lower	Upper	
Group 1	Group 2	615.80	553.41	678.19	<0.001*
	Group 3	310.73	248.33	373.12	<0.001*
Group 2	Group 3	-305.07	-367.47	-242.68	<0.001*

* - Statistically Significant

Conclusions

Thermal treatment affects the cyclic fatigue resistance. Deep cryo treatment enhanced the cyclic fatigue resistance of reciprocating NiTi files. Hence,it is best to use cryo-treated reciprocating files to enhance long-term benefits.

Acknowledgements

I would like to acknowledge and give my warmest thanks to my supervisor Dr. C Champa who made this work possible. Her guidance and advice helped me throughout all stages of writing my project. I would also like to thank my Head of the department Dr. Srirekha A and prof. Dr. Ashwija Shetty, Dr. Suditi Pal and Dr. Durga Devi for letting my research journey be an enjoyable moment, and for their suggestions in performing the study.

I would also like to give special thanks to Dr. Pradeep, Head of the Department, Department of Stem Cell and Regenerative Biology, Mr.Sangeeth, research specialist, Mazumdar Shaw Medical Center, Narayana Health Hospitals, for their extended support in allowing thecryotreatment of reciprocating instruments at their esteemed institute.I would like to thank my co-PGs and family as a whole for their continuous support and understanding when undertaking my research. Your prayer for me was what sustained me.

Funding– No potential financial funding related to this article was reported.

Data access statement- The data provided in the manuscript can be utilized for research and academic purposes.

Author Contributions

Conceptualization: Champa C; Yashashwini B S; Srirekha A; Ashwija Shetty
Data curation: Champa C; Yashashwini B S; Suditi Pal
Formal analysis: Champa C; Yashashwini B S; Durga Devi
Funding acquitisation: Champa C; Yashashwini B S
Investigation: Champa C; Yashashwini B S; Srirekha A; Suditi Pal
Methodology: Champa C; Yashashwini B S; Ashwija Shetty
Project administration: Champa C; Yashashwini B S; Srirekha A
Resources: Champa C; Yashashwini B S; Durga Devi
Software: Champa C; Yashashwini B S; Durga Devi
Supervision: Champa C; Yashashwini B S; Ashwija Shetty
Validation: Champa C; Yashashwini B S; Ashwija Shetty
Visualization: Champa C; Yashashwini B S;Durga Devi; Suditi Pal
Writing - original draft: Champa C; Yashashwini B S;
Writing - review & editing: Champa C; Yashashwini B S; Srirekha A

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

References

1. Hasheminia SM, Farhad A, Sheikhi M, Soltani P, Hendi SS, Ahmadi M. Cone-beam computed tomographic analysis of canal transportation and centering ability of single- file systems. J Endod2018;44:1788-1791.
2. Abu-Tahun IH, Kwak SW, Ha JH, Kim HC. Microscopic features of a fractured fragment of nickel-titanium endodontic instruments by two different modes of torsional loading. Scanning 2018;2018:9467059.
3. George GK, Sanjeev K, Sekar M. An in vitro evaluation of the effect of deep dry cryo treatment on the cutting efficiency of three rotary nickel-titanium instruments. J Conserv Dent 2011;14:169-72.
4. Es-Souni M, Es-Souni M, Brandies HF. On the transformation behavior, mechanical properties, and biocompatibility of two NiTi-based shape memory alloys: NiTi42 and NiTi42Cu7. Biomaterials 2001;22:2153-2161.
5. Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys - a review. Int Endod J 2018;51:1088-1103.Kiefner P, Ban M, De-Deus G. Is the reciprocating movement per se able to improve the cyclic fatigue resistance of instruments? Ind Endod J 2014;47:430-436.
6. Silva EJNL,Vieira VTL, Hecksher F, Dos Santos Oliveira MRS, Dos Santos Antunes H, Moreira EJL. Cyclic fatigue using severely curved canals and torsional resistance of the thermally treated reciprocating instruments. Clin Oral Investig2018;22:2633-2638.
7. Sundaram KM, Ebenezar RA, Ghani MF, Martina L, Narayanan A, Mony B,. Comparative evaluation of the effects of multiple autoclaving on the cyclic fatigue resistance of three different rotary NiTi instruments: An in vitro study. J Conserv Dent. 2013;16:323-6
8. Plotino G, Grande NM, Testarelli L, Gambarini G. Cyclic fatigue of Reciproc and WaveOne reciprocating instruments. Ind EndodJ.2012;45:614-8.
9. Li UM, Lee BS, Shih CT, Lan WH, Lin CP. Cyclic fatigue of nickel-titanium rotary instruments: static and dynamic tests. J Endod. 2002;28:448-51.
10. Kuhn G, Tavernier B, Jordan L. Influence of structure on nickel-titanium endodontic instruments failure. J Endod2001;27:516-20.
11. Gavini G, Pessoa OF, Barletta FB, Vasconcellos MA, Caldeira CL. Cyclic fatigue resistance of rotary nickel-titanium instruments submitted to nitrogen ion implantation. J Endod2010;36:1183-6.
12. Kim JW, Griggs JA, Regan JD, Ellis RA, Cai Z. Effect of cryogenic treatment on nickel-titanium endodontic instruments. Int Endod J 2005;38:364-71.

13. Shen Y, Qian W, Abtin H, Gao Y, Haapasalo M. Fatigue testing of controlled memory wire nickel-titanium rotary instruments. J Endod2011;37:997-1001
14. Hilfer PB, Bergeron BE, Mayerchak MJ, Roberts HW, Jeansonne BG, Multiple autoclave cycle effects on cyclic fatigue of nickel-titanium rotary files produced by new manufacturing methods, J Endod 2011;37:72-4.