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Comparative Evaluation of the Cyclic Fatigue Resistance of Thermally Treated Nickel-Titanium (Ni-Ti) instruments at Varying Temperatures

Isıl İşlem Görmüş Nikel-Titanyum (Ni-Ti) aletlerin Değişen Sıcaklıklarda Döngüsel Yorulma Direncinin Karşılaştırmalı Değerlendirilmesi

Afzal ALİ[1]
[1]Department of Conservative Dentistry and Endodontics, Pacific Dental College and Hospital, Rajasthan, India

Aasima ISHAQ[1]
[1]Department of Conservative Dentistry and Endodontics, Pacific Dental College and Hospital, Rajasthan, India

Sandeep METDUD[1]
[1]Department of Conservative Dentistry and Endodontics, Pacific Dental College and Hospital, Rajasthan, India

ABSTRACT

Objective: This study aimed to evaluate the stationary cyclic fatigue resistance (CFR) of three endodontic instrument systems at varying temperatures (20 ± 1°C and 37 ± 1°C)..

Methods: Ninety endodontic instruments from three instrument systems (HyFlex CM, 2Shape and Hero Gold) of constant tip size and taper (25.04) were selected for this study. These systems were broadly, divided into three groups (n=30): Group 1 (Hyflex CM), Group 2 (2Shape) and Group 3 (Hero Gold). Each group was further subdivided into two subgroups based on the temperature variable used. The endodontic instruments were subjected to stationary cyclic fatigue testing at 20 ± 1°C and 37 ± 1°C using a stainless-steel block with an artificial canal. The number of cycles to failure (NCF) were recorded

Results: Data was analysed using two-way ANOVA and Tukey post-hoc tests at a 95% confidence level. The instrument type and temperature variable significantly affect the NCF values. The observed NCF of the tested instruments was higher at 20±10 °C compared to its values at 37±10 °C and was statistically significant. The HyFlex CM group exhibited the highest CFR at 20±10 °C, while at 37±10 °C the Hero Gold instruments exhibited a higher CFR.

Conclusion: It can be inferred that Hero Gold instruments exhibited superior clinical performance when compared with Hyflex CM and 2Shape rotary instruments at body temperature (37±10 °C). The observed reduction in the NCF when increasing the temperature ranges between 30.29% - 71.27%..

Keywords: Cyclic Fatigue Resistance, Hero Gold, Hyflex CM, Nickel-Titanium, Stationary Fatigue, and 2Shape

ÖZ

Amaç: Bu çalışma, üç endodontik alet sisteminin değişen sıcaklıklarda (20 ± 1°C ve 37 ± 1°C) sabit yorulma direncini (CFR) değerlendirmeyi amaçladı

Yöntemler: Bu çalışma için sabit uç boyutu ve konikliğe (25,04) sahip üç alet sisteminden (HyFlex CM, 2Shape ve Hero Gold) doksan endodontik alet seçildi. Bu sistemler genel olarak üç gruba ayrıldı: Grup 1 (Hyflex CM), Grup 2 (2Shape) ve Grup 3 (Hero Gold). Her grup ayrıca kullanılan sıcaklık değişkenine bağlı olarak iki alt gruba bölündü. Endodontik aletler, yapay kanallı paslanmaz çelik bir blok kullanılarak 20 ± 1°C ve 37 ± 1°C'de sabit döngüsel yorulma testine tabi tutuldu. Arızaya kadar olan döngü sayısı (NCF) kaydedildi

Bulgular: Veriler, iki yönlü ANOVA ve Tukey post-hoc testleri kullanılarak %95 güven seviyesinde analiz edildi. Alet tipi ve sıcaklık değişkeni NCF değerlerini önemli ölçüde etkiler. Test edilen cihazların gözlenen NCF'si 20±10 C'de 37±10 C'deki değerlerine göre daha yüksekti ve istatistiksel olarak anlamlıydı. HyFlex CM grubu en yüksek CFR'yi 20±10 C'de sergilerken, 37±10 C'de Hero Gold aletleri daha yüksek bir CFR sergiledi

Sonuç: Hero Gold aletlerinin vücut sıcaklığında (37±10 C) Hyflex CM ve 2Shape döner aletlerle karşılaştırıldığında üstün klinik performans sergilediği söylenebilir. Sıcaklık artırıldığında NCF'de gözlenen azalma %30,29 - %71,27 arasında değişmektedir.

Anahtar Kelimeler: Cyclic Fatigue Resistance, Hero Gold, Hyflex CM, Nickel-Titanium, Stationary Fatigue, and 2Shape

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Sorumlu Yazar/Corresponding author:
Afzal ALİ
E-mail: abu.ali.4k@gmail.com

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INTRODUCTION

The introduction of NiTi alloy has revolutionized the field of endodontics due to its superior flexibility, shape memory and super elasticity.[1,2] In recent years thermomechanical processing and surface treatment have been employed to further improve the properties of rotary endodontic instruments.[3]

However, instrument fatigue is a major concern associated with endodontic instruments, which can lead to instrument separation. The instrument fatigue can be cyclic or torsional. Cyclic fatigue failure occurs due to repeated compressive and tensile stresses in a curved canal. However, when instrument tip locks and shank continues to rotate exceeding its elastic limit, resulting into Torsional fatigue.[4,5]

Cyclic fatigue tests can be classified as dynamic or static. The dynamic test is performed with a back-and-forth movement simultaneous to the free rotation of the instrument inside the canal. Whereas, the static test does not involve any back-and-forth movement of the instrument. Factors associated with cyclic fatigue include the metallurgy of the instrument, operational setting, core mass, taper of the instrument, cross-sectional area, type of motion and environmental temperature.[6,7]

The HyFlex CM (Coltene/ Whaledent AG, Altstatten, Switzerland) is machined from a Controlled Memory (CM) wire. Its manufacturing process allows for a 300% increase in flexural strength as compared to conventional NiTi alloys. The file sizes 8/25, 6/20, 4/30 and 4/40 have triangular cross-sections while the 4/20 and 4/25 sizes have a quadrangular cross section. The manufacturer recommends a speed of 500 rpm and a torque 2N-cm for operating the HyFlex CM instruments. The shape and strength of the instruments with straightened spirals can be restored with autoclaving.[8] In their study Elnaghy et al.[9] observed the highest number of cycles to failure (NCF) with HyFlex CM when compared with Vortex Blue and TruNatomy.

The 2Shape instruments (MicroMega, Besancon, France) was introduced with a proprietary treatment (T-Wire), and claimed to offer increased flexibility and cyclic fatigue resistance (CFR) by 40%. 2Shape rotary instruments have an asymmetrical triple helix cross-section, two main cutting edges, and one secondary cutting edge which enhances the cutting action and removal of debris. It is available as a two rotary instrument system, TS1 (25/.04) and TS2 (25/.06). The manufacturer recommends a 250-400 rpm speed and a torque 2 N-cm when operating the 2Shape instruments. In a study by Mahmoud and Ismail, 2Shape showed more resistance to flexural cyclic fatigue than OneShape, and at a high temperature had a reducing effect on the flexural CFR of both the tested rotary endodontic instruments.[10]

Hero Gold (Micro-Mega, Becacon, France) is machined with heat treatment technology and has an electropolished surface. It is available either a 4% or 6% taper and has an innovative pitch design that avoids any screwing effects. It has a varied helical pitch and the pitch varies according to the taper of the instruments. The manufacturer recommends a speed of 300-600 rpm and a torque 2 N-cm to operate these instruments [11]. The literature search revealed no studies to date that evaluate the performance of the Hero Gold rotary instruments.

Several studies have assessed the CFR of NiTi instruments at room temperature (20^0 C) and body temperature (37^0 C)[3,12-15]. The results have shown that a decrease in temperature and/or application of stress drastically affects the flexural resistance of NiTi instruments, owing to a phase transformation from austenite to martensite.[3]

To the best of our knowledge none of these studies have compared the CFR of Hero Gold, HyFlex CM and 2Shape (25/.04) rotary instruments at $20±1^0$ C and $37±1^0$ C. Thus, this study aimed to evaluate and compare the CFR of thermally treated NiTi rotary instruments designed with different manufacturing technology at varying temperatures ($20±1^0$ C and $37±1^0$ C). The null hypothesis for the present *in-vitro* study was as follows: there would be no significant differences among the thermally treated NiTi instruments in terms of stationary fatigue and temperature variable.

METHODS

Ethical Approval

Institutional Ethical Committee approval was obtained for this *in-vitro* study (PDCH/20/EC-200).

Instrument's Selection and Groups

Ninety NiTi rotary instruments (25.04) of 25mm in length were tested using 316L series stainless steel metal block with a 1.5 mm wide simulated canal, 7-mm radius of curvature and an angle of 90^0.

Group 1: HyFlex CM instruments (n = 30) developed from proprietary heat treatment technology

Group 2: 2Shape instruments (n= 30) developed from heat treatment T wire technology.

Group 3: Hero Gold instruments (n= 30) developed from controlled memory (CM) wire technology.

Each instrument group was further divided into two subgroups A and B (n = 15), depending on the temperature used ($20±1^0$ C and $37±1^0$ C).

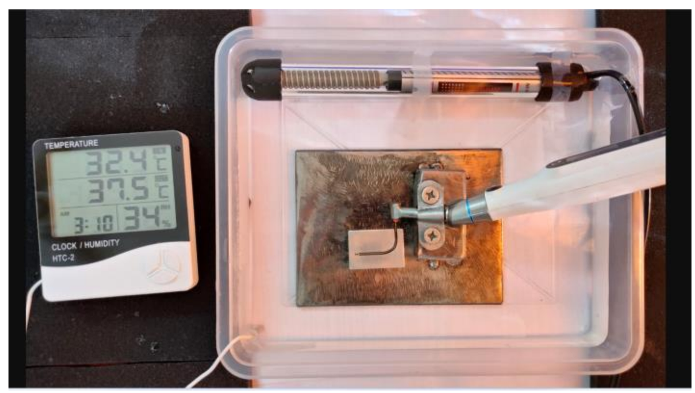

Figure 1. Illustrations showing experimental test assembly for the stationary cyclic fatigue assessment at varying temperatures ($20±1^0$ C and $37±1^0$ C)

Experimental Procedure for the Assessment of Cyclic Fatigue:

The experimental procedure followed for the assessment of CFR was identical to that used by Klymus et al.[3] The stationary cyclic fatigue test assembly was submerged in a container filled with 400ml of deionized water at temperatures of $20±1^0$ C and $37±1^0$ C which were maintained using a thermostat during the stationary cyclic fatigue assessment. The Hyflex CM, 2Shape and, Hero Gold instruments were allowed to rotate at speeds and torques of 500/3, 350/2.5 and, 450 rpm/2 N-cm respectively in a stainless-steel block with an artificial canal, until it fractures, and the time to fracture was recorded using a digital stopwatch. The number of cycles to fracture (NCF) was calculated using a formula [3]:

NCF = rotational speed (rpm) × time to fracture (sec)/60

RESULTS

Data was analysed using two-way ANOVA and Tukey post-hoc tests at a 95% confidence level. The instrument type and temperature variables significantly affect the NCF values (see Table 1). The means and standard deviations (SD) of the NCF are summarized in Table 2. At $20±1^0$

C, the highest NCF was observed with the Hyflex CM instruments (5432.22) followed by the Hero Gold (2756.00) and 2Shape (655.00) instruments. At 37±1^0 C, the highest NCF was observed with the Hero Gold instruments (1811.00) followed by the Hyflex CM (1560.55) and 2Shape (456.55) instruments. The highest mean difference at varying temperatures (20±1^0 C and 37±1^0 C) was observed with the Hyflex CM instruments (3871.66), followed by Hero Gold (945.00) and 2Shape (208.44) rotary instruments (Table 2).

With an increase in temperature to 37±1^0 C, there was a 34.28 % reduction in NCF for the Hero Gold instruments, 30.29 % for 2Shape and 71.27 % for the Hyflex CM instruments.

Table 1. Two-way ANOVA for the main effects and the interaction effects according to NCF data

	F	p	Partial eta squared
Instrument type variable (Hero Gold, 2Shape, Hyflex CM)	950.009	**0.000**	0.916
Temperature variable	918.663	**0.000**	0.958
Instrument type* Temperature	409.770	0.000	0.907

a. R Squared = .977 (Adjusted R Squared = .976)

Table 2. Mean NCF registered at 20±1^0 C and 37±1^0 C during Cyclic Fatigue Testing.

	Instruments			
	Hyflex (Group 1)	2Shape (Group 2)	Hero Gold (Group 3)	Total
Temperature				
20±1˚C (A)	5432.223	655.001	2756.000	1998.336095
37±1˚C (B)	1560.555	456.556	1811.000	620.6607233
Total	3496.389	555.7785	2283.500	

*Statistically significant difference (*P* .05) within and between group

DISCUSSION

Several factors contribute to instrument fracture during root canal preparation owing to torsional failure and cyclic fatigue.[9,16] Studies have reported a higher prevalence of torsional failure (56%) than cyclic fatigue (44%) after multiple use of NiTi rotary instruments.[16]

It has been claimed that thermomechanical technology improves the transformation characteristics and the microstructure of the NiTi instruments.[6,17] Studies have reported a higher cyclic fatigue resistance (CFR) with thermomechanical treated endodontic instruments.[18]

Various studies have been carried out using temperature variables to evaluate the CFR of NiTi instruments.[3,14,19-24] Klymus et al [3] observed a decrease in CFR with an increase in temperature, using Reciproc Blue, Blue file and Wave One Gold Primary rotary NiTi instruments. While verifying the Protaper Universal and Protaper Gold Plotino et al.[17], reported that the latter did not suffer any significant statistical difference in thermal variation between the temperatures of 20^0 C and 35^0 C. Keleş et al. reported no statistically significant difference between Wave One (Dentsply Sirona, Ballaigues, Switzerland) and Reciproc (VDW, Munich, Germany) instruments at temperatures between 22±1^0 C and 35±1^0 C.[23]

Controversially, Keleş et al. [25] reported that the immersion of Reciproc blue instruments in liquid for five minutes at a higher temperature (60^0 C) positively affects CFR. In their study, while the instruments were immersed for five minutes in heated liquids, the tests were performed at room temperature. Such a high temperature (60^0 C) does not reflect a clinical situation.

Thus, it is now well established that instrument fatigue is not only affected by the instrument type but also by the temperature variable employed for the study. The results from this *in-vitro* study showed that CFR is significantly affected by variations in temperature as well as the instrument type (P <.05) (Table 1). A statistically significant difference in CFR was observed with the tested instruments at both 20±1^0 C and 37±1^0 C (Table 2). Thus, the null hypothesis is rejected.

The Hyflex CM (Coltène-Whaledent, Altstätten, Switzerland) instruments produced by thermal treatment offers maintenance of the original root canal curvature during endodontic shaping procedure.[6] Topçuoğlu et al.[26] reported a higher CFR with Hyflex CM when compared with OneShape, ProTaper Universal and, ProTaperNext instruments in the apical curvature of simulated canal. Mario et al.[18] reported no significant difference in NCF between EdgeFile and MTwo, as well as HyFlex CM. In the present *in-vitro* study, Hyflex CM (Group 1A) instruments exhibited the highest NCF at 20±1^0 C. However, at 37±1^0 C, the instruments exhibited intermediate results.

The 2Shape (Micro Mega, Besancon, France) rotary instruments were also introduced to achieve superior results in canal shaping and instrument efficacy.[27] Uslu et al.[27] reported a higher CFR with 2Shape instruments when compared with Twisted and Endo Sequence Xpress rotary instruments.

The Hero Gold (Micro-Mega, Becacon, France) heat treated Ni-Ti file has a smoother electropolished surface. It has a large inner core and three cutting edges. It has an anti-breakage control feature which unwinds the file to indicate the risk of fracture. There is very little literature evaluating and comparing the CFR of Hero Gold with other rotary instruments.

In the present *in-vitro* study the cyclic fatigue results from the 2Shape instruments (Group 2A and 2B) were the lowest at both 20±1^0 C and 37±1^0 C (Table 2).

A statistically significant difference in the CFR was observed with the tested instruments at 20±1^0 C and 37±1^0 C (Table 2). The mean differences obtained at 20±1^0 C and 37±1^0 C for 2Shape, Hero Gold and Hyflex CM instruments were 208.445, 945.000 and 3871.668 respectively (Table 2).

The results from the present *in-vitro* study demonstrate a decrease in the CFR with an increase in temperature. This is in accordance with the studies conducted by Klymus et al.[3], Dosanjh et al.[28], and Shen et al.[22] in which the resistance to cyclic fatigue decreased with an increase in temperature. A statistically significant difference was reported in the NCF at 20±1^0 C and 37±1^0 C for the tested endodontic instruments. This higher NCF at a low temperature (20±1^0 C) could be attributed to its increased flexibility (martensitic phase), as when subjected to heat, the alloy returns to its original shape (Austenitic phase).[14]

At 20±1^0 C, the Hyflex CM instruments (Group 1A) exhibited the highest NCF when compared to all the tested instruments. This could be attributed to the thermal processing of the alloy, the presence of a martensitic phase, and the austenite finish (A_f) temperature. This supports the belief that the more martensitic an NiTi alloy is, the more flexible, and fatigue resistant the instrument becomes. Also, the martensitic phase transformation exhibits damping characteristics, thereby rendering crack propagation difficult.[14]

The 2Shape instruments exhibited the lowest NCF values at both temperatures, possibly due to their metallurgy. The instruments manufactured with the T wire technology (2Shape) had lower fatigue resistance and instrument flexibility than the instruments manufactured with CM wire technology (Hyflex CM). This result is in accordance with the studies conducted by Ozurek et al.[29] and Mustafa Gündoğar et al.[30]

At 37±1^0 C, the Hero Gold instruments (Group 3B) exhibited highest the NCF compared to the 2Shape (Group 2B) and Hyflex CM (Group 1B) rotary instruments.

There is little literature comparing the CFR of Hero Gold instruments with other rotary instruments. Hence, a comparison of the results could not be made between the Hero Gold and other tested instruments. However, it is possible that the proprietary heat treatment technology involved and the cross-sectional design could be responsible for its higher CFR when compared with Hyflex CM instruments at 37±1^0 C.

Thus, the present *in-vitro* study observed a 34.28% reduction in the NCF for Hero Gold, 30.29% for 2Shape and 71.27% for Hyflex CM rotary instruments, with an increase in temperature to 37±1^0 C. This finding suggests that the Hyflex CM instruments underwent large changes in their internal microstructure with an increase in temperature from 20±1^0 C to 37±1^0 C. Differential Scanning Calorimetry (DSC) can be employed to analyze the phase transformation of the NiTi instruments. In this analysis, certain peaks related to the cooling and heating cycles indicate a martensitic (cooling) and austenitic (heating) transformation. The austenitic finish (A_f) temperature for the Hyflex CM was about 44^0 C, which suggests that Hyflex CM has varying degrees of a martensitic condition at 20±1^0 C and moves to austenitic state at body temperature (37±1^0 C).[14]

Thus, the Hyflex CM instruments owing to their austenite finish (A_f) temperature (44^0 C), have austenitic and martensitic content at the intracanal temperature (37±1^0 C). The presence of an austenitic phase at the intracanal temperature (37±1^0 C) causes a decrease in fatigue resistance and instrument flexibility, thereby making it prone to fracture. The highest NCF values of the Hyflex CM instruments at 20±1^0 C cannot be correlated with their superior clinical performance as the intracanal temperature (37±1^0 C) simulation was not achieved.

The results obtained for the Hero Gold instruments could not be compared with results from other studies owing to the lack of literature comparing Hero Gold rotary instruments with other endodontic instruments. This is a limitation of the present study. The body temperature (37^0 C) simulation would not be the only consideration either, for a clinical simulation, factors such as root dentin, irrigating solution among others, need also to be considered when evaluating the CFR. The static cyclic fatigue testing was also performed. Most of the studies have used simulated canal curvatures of 60^0 as compared to 90^0 used in the present *in-vitro* study, this might also affect the CFR.

The preliminary findings of the present *in-vitro* study must be confirmed by further investigation to evaluate the clinically relevant mechanical properties of the instruments. Further *in-vivo* studies need to be performed to investigate similar parameters.[19]

CONCLUSION

The present *in-vitro* study demonstrates how the intra canal temperature can affect the properties of different rotary endodontic instruments including cyclic fatigue. A rise in the temperature increases the presence of the austenitic phase, thereby making the instrument less flexible and more prone to fracture. At 37±1^0 C the Hero Gold instruments demonstrated superior performance compared to the Hyflex CM and 2Shape rotary instruments. However, further analysis needs to be performed to evaluate clinically relevant mechanical properties and the CFR of Hero Gold instruments because these are not explored as much in any other studies.

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Hakem Değerlendirmesi: Dış bağımsız.
Yazar Katkıları: Fikir – A. A, I.A.; Tasarım A. A, I.A.; Denetleme - A. A, I.A.; Kaynaklar - A. A, I.A.; Malzemeler - A. A, I.A.; Veri Toplanması ve/veya İşlemesi - A. A, I.A.; Analiz ve/veya Yorum - A. A, I.A.; Literatür Taraması - A. A, I.A.; Yazıyı Yazan - A. A, I.A.; Eleştirel İnceleme - A. A, I.A., Metgud S.
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Informed Consent: Since this was an in vitro study, patient consent was not obtained
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