Effect of Cryogenic Treatment on Cyclic Fatigue of Nickel-titanium Rotary Files

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Research note

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Abstract

Objective: This study sought to assess the effect of cryogenic treatment on cyclic fatigue of Neoniti and Reciproc nickel-titanium (NiTi) rotary files.

This in vitro, experimental study was performed on 48 Neoniti and Reciproc NiTi rotary files (#25, 6% taper) in two subgroups with and without cryogenic treatment. The files in cryogenic subgroups were stored in liquid nitrogen chamber at -196°C for 24 h. Next, they were placed at room temperature (25°C) to gradually warm up. Stainless steel (SS) blocks were used to standardize the degree of rotation of the files. The SS blocks simulated a root canal with the negative pattern of gutta-percha with 0.08 taper, #25 tip size, and 45° canal curvature. Each endodontic file was rotated in this canal until fracture. The time until fracture was recorded by a digital chronometer. Time to fracture was used to calculate the number of rotations before file fracture as the cyclic fatigue scale.

Results: The mean cyclic fatigue resistance of both Neoniti and Reciproc rotary files in cryogenic subgroups was significantly higher than that in non-cryogenic control subgroups ($P<0.05$). Cryogenic treatment can significantly increase the cyclic fatigue resistance of Neoniti and Reciproc NiTi rotary files.

Introduction

Nickel-titanium (NiTi) instruments preserve their primary shape, and have high corrosion resistance, pseudo-elasticity, flexibility, and fracture resistance as well as low modulus of elasticity and wide range of elastic deformation [1–3]. Despite the favorable properties of NiTi rotary files, they are highly susceptible to permanent deformation and fracture due to continuous rotational movements [2]. Fracture of these files may occur as the result of cyclic fatigue or torsional fatigue [5].

Cyclic fatigue is the cause of fracture of 90% of endodontic files [6, 7]. Several strategies have been proposed to increase the resistance of NiTi rotary files to cyclic fatigue, including surface processing of the files and their cryogenic treatment with liquid nitrogen [8]. In this technique, the metal instrument is stored in a cold chamber containing liquid nitrogen at -196°C and − 320°C for 24 h, and is then allowed to warm up at room temperature. This technique is referred to as cryogenic treatment [9–11]. Unlike other methods that only alter the surface of metal instruments, the main advantage of cryogenic treatment is that italters the entire volume of metal instrument. It also improves the cutting efficiency, wear resistance, and corrosion resistance of instruments. It enhances the overall resistance and hardness of metal, increases its transformation from the austenitic to martensitic phase, and releases the internal stresses of metal. Metals are more flexible and can better tolerate fatiguein the martensitic phase [11, 12]. Thus, this technique can effectively enhance the resistance of endodontic rotary files [13].

Gavini et al. [4] evaluated the effect of cryogenic treatment on cyclic fatigue of NiTi rotary files and showed that cryogenic treatment increased the cyclic fatigue resistance of the files. However, Yazdizadeh et al. [14]demonstrated that cryogenic treatment did not enhance the resistance of rotary files to cyclic fatigue.

Studies on the effect of cryogenic treatment on cyclic fatigue are limited. Given that cryogenic treatment can improve the cyclic fatigue resistance of NiTi rotary files, it can effectively decrease the incidence of intracanal file fracture and improve the prognosis of endodontic treatment. Thus, this study aimed to assess the effect of cryogenic treatment on cyclic fatigue of two types of NiTi rotary files.

Methods

In this in vitro, experimental study, 48 endodontic NiTi rotary files including 24 Neoniti (Neolix; France) and 24 Reciproc (VDW, Germany) files with #25 tip size and 6% taper were selected and assigned into two subgroups with and without cryogenic treatment. The files in the cryogenic treatment subgroups were stored in liquid nitrogen chamber at -196°C for 24 h. Next, they were placed at room temperature (25°C) to gradually warm up. Stainless steel (SS) blocks were used to standardize the degree of rotation of the files. The SS blocks simulated a root canal with the negative pattern of gutta-percha with 0.08 taper, #25 tip size and 45° root canal curvature. The endodontic files rotated in this canal. For this purpose, the files were connected to a low-speed hand-piece (ER64, NSK, Tokyo, Japan) and inserted into the canal until reaching the apex. The hand-piece was connected to a rotary endodontic motor (X-Smart Plus endo-motor; Dentsply, Sirona). The endodontic motor was equipped with torque control. Thus, the files were used with the torque recommended by the manufacturer. According to the manufacturers, the Reciproc and Neoniti files should be used at a speed of 280 rpm with 230 g/cm torque. Each file was rotated in the canal until fracture. The time until fracture was recorded by a digital chronometer. Time to fracture was used to calculate the number of file rotations until fracture as the cyclic fatigue scale using the formula below:

Number of rotations = frequency of rotations per second x time duration

The fatigue time of the two subgroups with/without cryogenic treatment was compared using t-test via SPSS version 25.

Sample size was calculated with Power and Sample Size software using the formula below:

n = (Z1-α/2 + Z1-β)2 ×(σ12 + σ22) / (μ1 – μ2)2

By assessing the number of rotary file cycles, the standard deviation was calculated to be 168 in the control (non-cryogenic) and 278 in the cryogenic treatment group. The mean number of cycles was 11200 in the control and 21300 in the cryogenic group[14]. Thus, considering alpha = 0.05, power of 80%, and 10% error rate, the number of files was calculated to be 12 in each group.

Results

As shown in Table 1, the mean cyclic fatigue resistance of Neoniti rotary files in the cryogenic subgroup was significantly higher than that in the control subgroup (12.75 ± 0.05 versus 9.60 ± 0.41, $P < 0.05$). Also, the mean cyclic fatigue resistance of Reciproc rotary files in the cryogenic subgroup was significantly higher than that in the control subgroup (13.54 ± 0.64 versus 10.38 ± 0.44, $P < 0.05$). The mean cyclic fatigue resistance of Neoniti files subjected to cryogenic treatment was significantly higher than that of Reciproc files subjected to cryogenic treatment ($P < 0.05$). The mean cyclic fatigue resistance of control Neoniti files was significantly higher than that of control Reciproc files ($P < 0.05$).

Table 1
Comparison of cyclic fatigue resistance of Neoniti and Reciproc rotary files with and without cryogenic treatment (n = 12)

File	Subgroup	Mean	Std. deviation	P value
Neoniti	**Cryogenic treatment**	12.7500	.50894	0.001
	Control	9.6042	.41706	
Reciproc	**Cryogenic treatment**	13.5475	.64612	0.001
	Control	10.3817	.44148	

Discussion

Cyclic fracture of NiTi files occurs as the result of their cyclic fatigue in curved root canals [6, 7]. Repeated loading and unloading of NiTi files during endodontic treatment cause their continuous transformation between the austenitic and martensitic phases of NiTi. The austenitic phase is transformed to the martensitic phase under pressure and cold, and vice versa [5, 15]. Metals tolerate higher levels of stress without permanent transformation in the martensitic phase, and return to their original form after bending [16].

The results of the present study revealed that the mean cyclic fatigue resistance of Reciproc files in the cryogenic subgroup was significantly higher than that in the control subgroup (13.54 ± 0.64 versus 10.38 ± 0.44, $P < 0.05$). Also, the mean cyclic fatigue resistance of Neoniti rotary files in the cryogenic subgroup was significantly higher than that in the control subgroup (12.75 ± 0.05 versus 9.60 ± 0.41, $P < 0.05$).

Ujjwal et al, (2017) [5] in their review study reported that cryogenic treatment can increase the fracture resistance of NiTi rotary files. Gavini et al. (2010) [4] reported results similar to the present findings, and demonstrated that cryogenic treatment increased the cyclic fatigue resistance of the files. Increased cyclic fatigue resistance of the files by cryogenic treatment can be due to the fact that complete austenitic to martensitic phase transformation of the alloys that occurs at -196°C temperature releases the internal stress of the alloy due to plastic deformation [16]. Amini et al. [17] explained that presence of residual austenitic phase in an alloy decreases the hardness and wear resistance of instruments. Thus, increased wear resistance and reduction of internal stresses can be named as the most important advantages of cryogenic treatment.

The current results revealed higher longevity and improved fatigue resistance of NiTi rotary files following cryogenic treatment. The present study evaluated two different rotary systems with different chemical compositions, cross-sections, and application protocols.

In line with the present study, Vinothkumar et al. (2016) [15] indicated that cryogenic treatment increased the fatigue resistance by 10%. The present results were also in agreement with those of George et al. (2011) [7]. They reported 20–60% improvement in the number of cycles before fracture of three different rotary files after cryogenic treatment. They used the same rotational speed for all three systems (irrespective of the manufacturers' instructions).

Some other studies, however, reported contrary results. Yazdizadeh et al. (2017) [14] evaluated the effect of cryogenic treatment with liquid nitrogen at -196°C on cyclic fatigue of RaCe and Mtwo NiTi rotary files and concluded that cryogenic treatment did not significantly improve the cyclic fatigue resistance of rotary files.Vinothkumar et al. (2007) [15] reported that cryogenic treatment increased the cutting efficiency of rotary files but had no significant effect on their wear resistance. Bramipour et al. (2001) [18] demonstrated that cryogenic treatment had no significant effect on wear resistance of the files. Controversy in the results of studies may be due to the use of different protocols for cryogenic treatment. For instance, Yazdizadeh et al. [14] used deep cryogenic treatment. Also, canal condition is another important factor influencing the results. A 30° canal curvature results in slower rotation of the file and application of lower compressive forces to the file compared with root canals with 45° curvature. Difference in the type of alloy is another factor that may affect the results, since some alloys may have higher rate of complete martensitic phase transformation [19]. Complete martensitic phase transformation and increasing the ratio of martensitic to austenitic phase in an alloy are among the main mechanisms of cryogenic treatment [20].

Parashoes and Messer evaluated the factors related to fracture of NiTi rotary files and concluded that in addition to the relationship of metallurgy with fracture, some other factors such as the manufacturing process can affect the fracture resistance of NiTi rotary files. Thus, cryotherapy can improve the cutting efficiency and fracture resistance of NiTi rotary files [21].

This study had some limitations. The rotational speed and torque of the two rotary systems were not standardized according to the conditions; although, standardization of these factors is impossible because these files cannot have an ideal performance in conditions other than those recommended by the manufacturers.

Conclusion

The current results revealed that cryogenic treatment can increase the cyclic fatigue resistance of both Neoniti and Reciproc rotary files.

Limitations

Rotation speeds and torques of both systems were not standardized. Standardizing these factors was impossible because these files can not function at their optimum strength under circumstances other than those recommended by the manufacturers. Also clinicians would not use them at other parameters so standardizing them like in some earlier results would render the results unreliable. This was the reason that while the NCF of the files differed greatly, their working times were very close to each other.

Declarations

Ethics approval and consent to participate:

This study was approved by the ethics committee of Hamadan University of Medical Sciences, in the ethic No. IR.UMSHA.REC.1397.481. Informed consent was not applicable.

Consent for publication:

Not applicable.

Availability of data and material:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests

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Author's contributions:

Conception and design: HK, AF and ZP; acquisition of data: HK, AF and ZP; statistical analysis: HK, AF, ZP, FS, SY and SM ; interpretation of data: HK, AF, ZP, FS, SY and SM; drafting of the manuscript: HK, AF and ZP; critical revision of the manuscript for important intellectual content: HK, AF, ZP, FS, SY and SM. All authors read and approved the final manuscript.

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