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Cyclic fatigue resistance of several deep cryogenically treated nickel-titanium endodontic rotary and reciprocating files in artificial canals

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SUMMARY

Objective. Until now no studies were conducted to evaluate the cyclic fatigue resistance of both – rotary and reciprocating – endodontic instruments with and without cryogenic treatment. Therefore, the aim of this in vitro study was to evaluate the effect of cryogenic therapy on the cyclic fatigue resistance of various nickel-titanium rotary and reciprocating endodontic files in an artificial 90º curved canal.

Material and methods. This in vitro study was conducted using 20 rotary and 20 reciprocating nickel-titanium (NiTi) instruments: 10 ProTaper Next, 10 ProTaper Ultimate, 10 Reciproc and 10 Plex RC-ONE. All instruments were divided equally into control and cryogenic treatment groups. Instruments in cryogenic treatment groups were immersed in liquid nitrogen (-196ºC) for 24 hours, after which they were gradually returned to the room temperature. All instruments were tested in an artificial canal with a 90º curvature, and the entire process was recorded till the instrument fracture. Time to fracture was multiplied by the corresponding rotation speed. Statistical analysis was performed using IBM SPSS Statistics software.

Results. The results of this study revealed statistically significant positive effect of cryogenic treatment on the cyclic fatigue resistance of Reciproc system instruments, while no statistically significant effect of cryotherapy was observed in the other instrument groups. When comparing different instrument systems in the cryogenic treatment groups, Reciproc instruments demonstrated statistically significantly higher cyclic fatigue resistance than other instruments in this study.

Conclusions. Our research demonstrated the efficacy of deep cryogenic treatment in increasing the cyclic fatigue resistance of reciprocating endodontic instrument system Reciproc. The study also showed the significantly better Reciproc resistance to cyclic fatigue than rotary ProTaper Next and ProTaper Ultimate instruments.

Keywords: cryotherapy, dental instruments, root canal preparation, materials testing, stress, mechanical.

INTRODUCTION

In endodontic practice, stainless steel instruments have traditionally been used for root canal mechanical preparation. The primary goal of endodontic therapy during the mechanical root canal preparation is the removal of infected tissues, effective shaping of the canal system for proper disinfection with irrigating solutions, and the creation of an adequate space for obturation (1). The advent of Nickel-Titanium (NiTi) rotary instruments significantly improved canal shaping outcomes compared to traditional manual stainless-steel instruments (2). Over the past two decades NiTi rotary instruments have enhanced the quality of root canal shaping. Due to their ability to return to their original shape, these instruments have reduced both the duration of endodontic procedures and the risk of canal transportation (3).

NiTi instruments are characterized not only by high fracture resistance and excellent flexibility, but also by their shape memory and ability to adapt to the curvature of root canals. Because of the complex anatomy of curved root canals, specialized instrument systems are used to ensure thorough

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debridement. To improve the effectiveness of endodontic retreatment, both rotary (used with continuous rotation) and reciprocating (in reciprocating motion) file systems, as well as hybrid instruments capable of operating in both kinematics, are widely used (4).

Reciprocating instruments operate in an interrupted rotation that alternates between counterclockwise (cutting) and clockwise (releasing) directions (5). In curved canals, reciprocating motion helps preserve the original canal anatomy and reduces the risk of apical transportation and other complications, compared to continuous rotary systems (6).

Fig. 1. WaveOne endomotor used in the study

Rotary endodontic instruments rotate in a continuous 360-degree clockwise motion within the root canal system. This mode of operation allows for efficient and precise canal shaping, facilitating the removal of infected tissue and promoting better distribution of irrigants along the canal length. (7)

Instrument separation within the root canal is often an outcome of cyclic fatigue. During cyclic motion within curved canals, instruments are subjected to repeated tension and compression. When these forces exceed the metal's fatigue limit, the instrument may fracture due to cyclic fatigue (8). One of the primary factors influencing the cyclic fatigue resistance of rotary NiTi instruments is the canal anatomy, particularly the angle of curvature. Clinically, canals often present with double curvatures, known as "S-shaped" canals, which pose a significant challenge when using rotary NiTi instruments (9). Meanwhile reciprocating NiTi instruments have shown to minimize the risk of canal transportation compared to continuous rotary systems, thus better maintain the original canal trajectory, especially in curved canals (10).

Studies have shown that NiTi rotary instruments manufactured using different techniques – such as thermal and mechanical processing – exhibit varying levels of resistance to cyclic fatigue (8). These differences are due to the production processes, in which temperature fluctuations play a critical role in influencing the alloy's structure and mechanical properties. One of the most recent innovations is the application of cryogenic treatment. Emerging research indicates that deep cryogenically treated instruments exhibit a longer lifespan, greater reliability, and reduced risk of fracture in complex root canal systems. Cryotherapy is being increasingly applied in the manufacturing of NiTi instruments to enhance clinical safety and efficiency in endodontic practice (11).

Until now, no studies have comprehensively evaluated the cyclic fatigue resistance of both rotary and reciprocating instruments with and without cryogenic treatment. Therefore, the aim of this study was to assess the effect of deep cryogenic treatment on various rotary and reciprocating NiTi instruments within an artificial 90° canal and to compare the cyclic fatigue resistance of rotary versus reciprocating instruments.

Table 1. Study results in different groups and Mann-Whitney U test results

		Instrument systems			
		Rotary		**Reciprocating**	
Cryogenic Treatment		**ProTaper Next**	**ProTaper Ultimate**	**Reciproc**	**Plex RC-ONE**
No (Control)	Mean	209.00	162.67	426.00	341.00
	SD	31.225	32.332	6.000	136.107
Yes	Mean	244.00	206.67	502.00	267.00
	SD	18.083	22.745	32.357	84.481
U test	Asymp. Sig. (2-tailed)	0.127	0.127	0.05	0.513

SD – standard deviation, U test – Mann-Whitney U test., Sig. – significance.

Fig. 2. An instrument an artificial canal

MATERIALS AND METHODS

The study was approved by the Bioethics Center of the Lithuanian University of Health Sciences (Approval No. 2025-BEC2-0555, date of issue 2025-04-09). This in vitro study was conducted using 20 rotary and 20 reciprocating nickel-titanium (NiTi) instruments, which were divided into four main groups (n=10): ProTaper Next 25/0.06 (Dentsply Sirona, Switzerland), ProTaper Ultimate 25/0.06 (Dentsply Sirona, Switzerland), Reciproc 25/0.08 (VDW, Germany), and Plex RC-ONE 25/0.06 (Orodeka Srl, Italy). All instruments were equally divided into subgroups (n=5) – control and cryogenically treated. Instruments in control group (without cryogenic treatment) were kept in the room temperature till the experiment.

Cryogenic Treatment

Instruments assigned to the cryogenically treated subgroups were immersed in liquid nitrogen (-196 °C) for 24 hours. After treatment, they were removed and allowed to gradually return to the room temperature (~25 °C) under ambient conditions.

Cyclic Fatigue Testing

A stainless-steel block with artificial canals was placed on a heating plate and allowed to reach a temperature of 37°C±1°C. Each instrument was carefully inserted into an artificial canal (with 90° angle and 2.5 mm radius of curvature), extending to the full working length. The handpiece of a WaveOne endodontic motor (TR30RAM120, Dentsply Maillefer, Switzerland) was securely fixed in position to eliminate operator variability (Figure 1). An artificial canal was cooled with water (note: sodium hypochlorite was not used due to lack of clarity during testing) to avoid dryness. The instrument rotated freely within the canal, and the entire process was recorded (Figure 2). Once instrument separation occurred, the timer was stopped, the motor was turned off, and filming was concluded.

Operating parameters were set according to the manufacturers' recommendations:

- ProTaper Next: 300 rpm
- ProTaper Ultimate: 400 rpm
- Reciproc: 150° counterclockwise / 30° clockwise at 300 rpm
- Plex RC-ONE: 150° counterclockwise / 30° clockwise at 300 rpm

The number of fatigue cycles (Nf) was calculated by multiplying the time to fracture (in minutes) by the corresponding rotation speed (rpm).

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics software. The Shapiro-Wilk test was used to assess the normality of data distribution. For intergroup comparison, one-way ANOVA with post-hoc Tukey tests and the Mann-Whitney U test were applied. The level of significance was set at $\alpha=0.05$.

RESULTS

The Shapiro-Wilk test confirmed normal distribution of data across the instrument groups ($p>0.05$), while the data in the cryogenically treated group were not normally distributed ($p<0.05$). Thus, one-way ANOVA with post-hoc Tukey test was used to evaluate statistically significant differences between the instrument groups and Mann-Whitney U test to evaluate the impact of cryogenic treatment to the cyclic fatigue resistance of each instrument.

The results of this study are presented in Table 1. The Mann-Whitney U test revealed a statistically significant positive effect of cryogenic treatment on the cyclic fatigue resistance of Reciproc system instruments ($p=0.05$). No statistically significant effect of cryotherapy was observed in the other instrument groups ($p>0.05$). Nonetheless, all cryogenically treated instruments had longer time to fracture than untreated controls.

One-Way ANOVA revealed statistically significant differences between the instrument groups ($p<0.05$). The post-hoc Tukey test showed that Reciproc system instruments had superior cyclic fatigue resistance compared to the other instru-

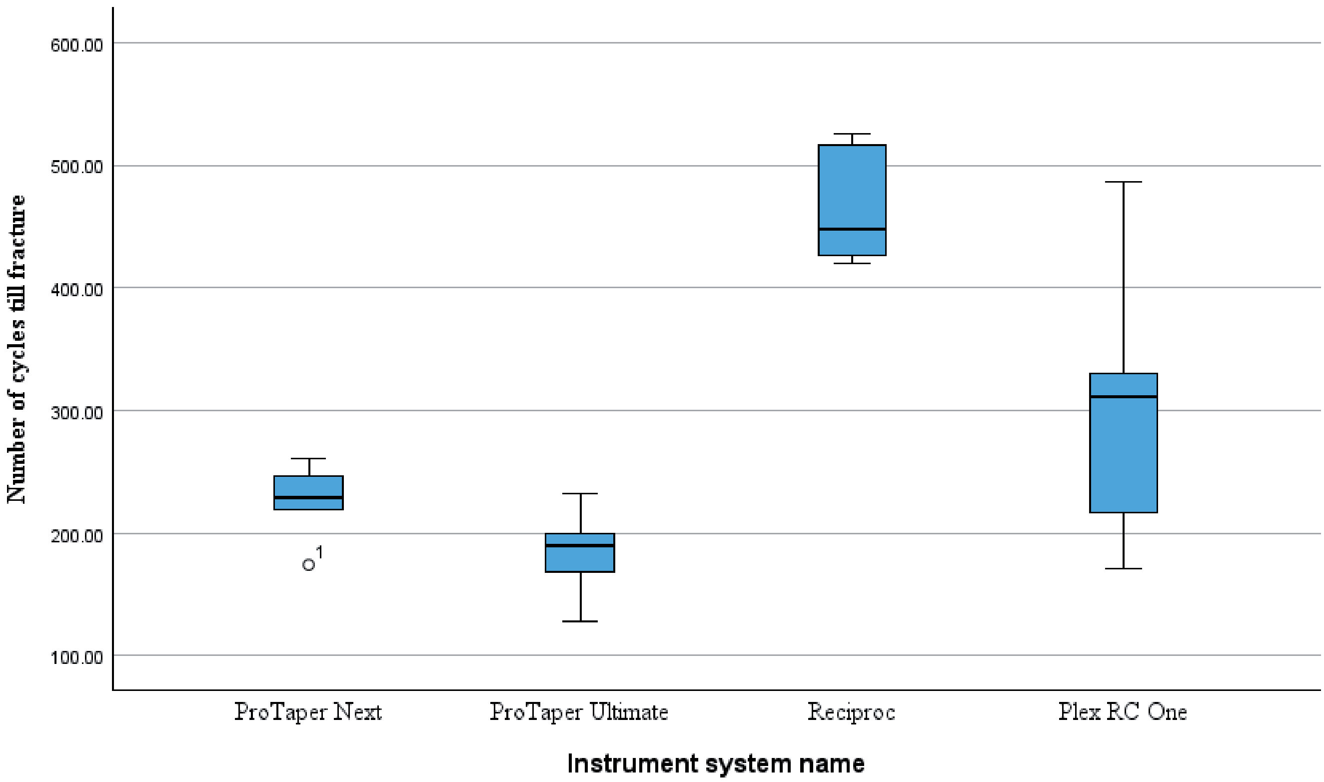

Fig. 3. Number of cycles to fracture of experimental instrument groups

ment groups (Table 2). When comparing different cryogenically treated instruments, Reciproc instruments demonstrated statistically significantly higher resistance to cyclic fatigue than all other instrument groups tested in this study, while in control groups, differences between the reciprocating systems – Reciproc and Plex RC-ONE – were not statistically significant. The distribution of cycles to fracture of all tested instrument groups is graphically represented in Figure 3.

DISCUSSION

Multiple factors contribute to the cyclic fatigue of endodontic instruments, including root canal curvature, the canal radius, the size and tip design of the instrument, motion kinematics within the canal, rotation speed and skills of the clinician. In this in vitro study, all potential variables that could increase the resistance of cyclic fatigue were controlled to minimize their influence. Although many methodologies for assessing the cyclic fatigue of NiTi instruments have been described in the scientific literature, to our knowledge, to date no studies have compared both rotary and reciprocating systems under the cryogenic treatment. Therefore, this study investigated the resistance to cyclic fatigue of two rotary systems made of different NiTi alloys and two different reciprocating systems, using deep cryogenic treatment.

In this in vitro study Reciproc showed statistically significantly better cyclic fatigue resistance

Table 2. Post-hoc Tukey test results

Not cryogenically treated (control)			**Cryogenically treated**		
Instrument system	Instrument system	**Sig.**	**Instrument system**	**Instrument system**	**Sig.**
PTN	PTU	0.857	PTN	PTU	0.774
	Reciproc	0.025		Reciproc	<.001
	Plex RC-ONE	0.189		Plex RC-ONE	0.931
PTU	PTN	0.857	PTU	PTN	0.774
	Reciproc	0.009		Reciproc	<.001
	Plex RC-ONE	0.062		Plex RC-ONE	0.452
Reciproc	PTN	0.025	Reciproc	PTN	<.001
	PTU	0.009		PTU	<.001
	Plex RC-ONE	0.505		Plex RC-ONE	0.001
Plex RC-ONE	PTN	0.189	Plex RC-ONE	PTN	0.931
	PTU	0.062		PTU	0.452
	Reciproc	0.505		Reciproc	0.001

PTN – ProTaper Next; PTU – ProTaper Ultimate; Sig. – significance.

than two widely used rotary systems and one of the newest ORODEKA flexible reciprocating instruments. Several studies can be found in the scientific literature, in which rotary ProGlider and reciprocating WaveOne Gold Glider instruments are compared (12,13). The latter showed better cyclic fatigue resistance of reciprocating endodontic instruments.

To date, no studies have compared rotary and reciprocating instruments under completely identical testing conditions. This underscores the ongoing lack of a standardized methodology that would enable objective evaluation and comparison of the cyclic fatigue resistance of different endodontic instrument systems.

Taking into account that, in the present study, only the Reciproc system demonstrated a statistically significant increase in cyclic fatigue resistance following cryogenic treatment, it can be suggested that the effect of cryogenic treatment is closely related not only to the alloy composition, but also to the instrument's design, manufacturing process, and type of motion (continuous rotation or reciprocation) (14).

CONCLUSIONS

Within the limitations of this in vitro study, our findings demonstrate the efficacy of deep cryogenic treatment in increasing the cyclic fatigue resistance of reciprocating endodontic instrument system Reciproc, as well as the significantly better Reciproc resistance to cyclic fatigue than rotary ProTaper Next and ProTaper Ultimate instruments. Understanding these differences is clinically relevant, as minimizing the risk of instrument fracture during mechanical root canal preparation is essential for improving treatment safety and efficiency. This innovative approach may provide valuable insights for both clinicians and manufacturers. However, further studies are needed to evaluate the effect of deep cryogenic treatment to the different rotary and reciprocating endodontic instruments in different canal curvatures, and to develop practical methods for applying this technology in clinical practice.

STATEMENT OF CONFLICTS OF INTEREST

The authors state no conflict of interest.

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