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The influence of autoclave sterilization on the cyclic fatigue of M-wire rotary endodontic instruments

Uticaj sterilizacije u autoklavu na pojavu cikličnog zamora rotirajućih M-*wire* endodontskih instrumenata

Nenad Stošić*†, Jelena Popović*†, Antonije Stanković*, Aleksandar Mitić*†, Marija Nikolić*†, Kosta Todorović*‡

University of Niš, *Faculty of Medicine, †Clinic of Dental Medicine, Department of Restorative Dentistry and Endodontics, ‡Department of Oral Surgery, Niš, Serbia

Abstract

Background/Aim. The most important moment in modern endodontics is the inclusion of rotating instruments made of nickel-titanium alloy in daily clinical work, which have supplanted stainless steel instruments due to their superior properties. The aim of this study was to investigate the influence of autoclave sterilization on cyclic fatigue (CF) in two types of rotating instruments produced by M-wire technology with different types of rotation. **Methods.** This research included two types of M-wire rotary instruments – 48 ProTaper Next® instruments with full rotation and 48 WaveOne® Gold instruments with reciprocating rotation. Each of the two groups of instruments was divided into four additional groups of 12 instruments depending on the number of cycles of sterilization in the autoclave. The instruments were tested in an artificial canal with a 2 and 5 mm radius of curvature. **Results.** Statistically significantly higher resistance to CF was observed with WaveOne® Gold compared to ProTaper Next® ($p < 0.001$) instruments, both in the non-sterilized group and after their exposure to the first, third, and fifth cycle of sterilization. The third and fifth cycle of sterilization significantly reduced resistance to CF in the WaveOne® Gold ($p < 0.001$) group. There was no statistically significant difference in CF resistance between sterilized and non-sterilized instruments of the ProTaper Next® group. **Conclusion.** Sterilization in an autoclave for instruments based on M-wire technology did not increase resistance to CF.

Key words:
alloys; dental instruments; disinfection; endodontics; equipment failure.

Apstrakt

Uvod/Cilj. Najvažniji momenat u savremenoj endodonciji je uključivanje rotirajućih instrumenata izrađenih od legure nikl-titanijum u svakodnevni klinički rad, koji su zbog svojih superiornijih osobina potisnuli instrumente od nerđajućeg čelika. Cilj ovog rada bio je da se ispita uticaj procesa sterilizacije u autoklavu na pojavu cikličnog zamora (CZ) kod dve vrste rotirajućih instrumenata, izrađenih M-*wire* tehnologijom, sa različitim tipovima rotacije. **Metode.** U istraživanje su bila uključena dva tipa rotirajućih M-*wire* instrumenata – 48 ProTaper Next® instrumenata sa punom rotacijom i 48 WaveOne® Gold instrumenata sa recipročnom rotacijom. Svaka od dve grupe instrumenata podeljena je u još četiri dodatne grupe od po 12 instrumenata u zavisnosti od broja ciklusa sterilizacije u autoklavu. Instrumenti su testirani u arteficijelnom kanalu sa radijusom krivine od 2 i 5 mm. **Rezultati.** Statistički značajno veća otpornost na CZ uočena je kod WaveOne® Gold instrumenata u odnosu na ProTaper Next® ($p < 0,001$) instrumente, kako u grupi nesterilisanih tako i nakon njihovog izlaganja prvom, trećem i petom ciklusu sterilizacije. Treći i peti ciklus sterilizacija su značajno smanjili otpornost na pojavu CZ u WaveOne® Gold ($p < 0,001$) grupi. Nije postojala statistički značajna razlika u otpornosti na CZ kod sterilisanih i nesterilisanih instrumenata u grupi ProTaper Next®. **Zaključak.** Sterilizacija u autoklavu kod instrumenata baziranih na M-*wire* tehnologiji nije povećala otpornost na CZ.

Ključne reči:
legure; stomatološki instrumenti; dezinfekcija; endodoncija; oprema, malfunkcija.

Correspondence to: Nenad Stošić, University of Niš, Faculty of Medicine, Blvd. Dr. Zorana Đinđića 81, 18 000 Niš, Serbia.
E-mail: nenadstosic10@gmail.com

Introduction

The highest quality endodontic therapy, in addition to the experience and knowledge of the practitioner, requires the use of instruments that effectively remove the paracanal layer of dentin and work in highly curved canals. A pivotal moment in modern endodontics was the incorporation of rotating instruments made of nickel-titanium (Ni-Ti) alloy into everyday clinical practice, as they have displaced stainless steel instruments due to their superior properties. Different forms of Ni-Ti alloy possess diverse characteristics, leading to variations in the behavior of instruments during use. With the aim of improving the characteristics of Ni-Ti instruments, various technologies of their production have been developed. Innovative M-wire technology is used to create instruments with remarkably elastic qualities. This process entails applying many heat treatments to the Ni-Ti wire during manufacturing [1, 2].

Subjecting the alloy to thermal treatments and the resulting changes in the alloy structure, manifested in an increased martensitic content, could explain the enhanced resistance to cyclic fatigue (CF) in rotary instruments. This resilience is observed when comparing instruments with full rotation the ProTaper® group, with the highest resistance demonstrated by the ProTaper Next® instrument obtained through M-wire technology [3]. Additionally, the effective performance of reciprocating instruments produced with M-wire technology, including WaveOne® Gold, in removing the paracanal layer of dentin systems has been noted in numerous studies [4].

Regardless of the numerous sets of rotating Ni-Ti instruments produced through various technologies, complications arising from instrument fractures continue to pose a significant challenge during endodontic treatment. These complications impact the procedure's efficiency, prolong treatment times, and require additional efforts from the practitioner to overcome them. While working with instruments, the varied anatomical and morphological characteristics of root canals could lead to the appearance of CF, resulting in instrument fractures [5]. Although instruments are exposed to forces during operation that may cause breakage, processes such as instrument cleaning and sterilization should not be overlooked, as they can indirectly influence the appearance of CF [6].

Single use of Ni-Ti rotary instruments, especially single file systems, ensures better cutting efficiency and reduces the risk of sudden fracture, as instruments almost always have some defects after use, in the form of loss of sharpness of the cutting edges and initial pits and cracks. For economic reasons, which cannot justify discarding the instruments after a single use, many therapists resort to sterilizing these instruments in order to reuse them [7].

Sterilization is a common procedure in medical practice, considering that instruments undergo this process almost daily to prevent the spread of infections and ensure patient safety. Repeated sterilization processes involving extreme temperature variations can contribute to various changes in Ni-Ti alloy. For some types of instruments made from this alloy, heat-induced changes can increase resistance to CF, while for others, sterilization affects a decrease in resistance to CF [8]. By studying the role sterilization plays in the occurrence of CF in specific types of instruments, it is possible to find solutions that effectively overcome this challenge and enhance the overall standard of endodontic treatment.

The aim of this study was to investigate the influence of autoclave sterilization on the CF in two types of instruments produced by M-wire technology with different types of rotation.

Methods

The study included two types of instruments manufactured with M-wire technology: 48 M-wire instruments with full rotation ProTaper Next® (Dentsply Sirona, Ballaigues, Switzerland) (#25, 0.06 taper) and 48 M-wire instruments with reciprocating movements WaveOne® Gold (Dentsply Sirona, Ballaigues, Switzerland) (#25, 0.07 taper). Each type was divided into four groups as follows: group I – 12 instruments that were not sterilized; group II – 12 instruments that have been sterilized once; group III – 12 instruments that have been sterilized three times; group IV – 12 instruments that have been sterilized five times.

For research purposes, sterilization was done in an autoclave (Cliniclave 45M, MELAG, Berlin, Germany) at a temperature of 134 °C for 35 minutes. Immediately after that, the instruments were tested for CF. To remove impurities, the fragments were ultrasonically cleaned and then analyzed using a scanning electron microscope.

The CF test was performed in an artificial canal with a curvature angle of 45° and a radius of curvature of 2 and 5 mm. Instruments were placed on the endomotor (X-smart plus, Dentsply Sirona, Ballaigues, Switzerland) and then put into the artificial canal, where one type (ProTaper Next® – 300 rpm, 2.0 torque Ncm) continuously rotated to the right and the other type (WaveOne® Gold 500 rpm) rotated reciprocally with a certain program.

The number of cycles to failure (NCF) was calculated by multiplying the number of rotations (r) until failure by the time required for the appearance of a crack, expressed in seconds (s), (r×s), and the result obtained was divided by 60. The size of the fractured fragment (FF) of the instrument was measured using a double-legged caliper.

The statistical analysis was conducted using the Student's *t*-test for independent samples and One-Way ANOVA in IBM SPSS version 26.0, with a statistical significance level set at $p < 0.001$.

Results

After testing the NCF value of the first instrument group, which was not exposed to the sterilization process, in an artificial canal with a radius of 2 mm, ProTaper Next® (1,249.50 ± 75.36 r×s) showed a statistically significant ($p < 0.001$) lower resistance to CF compared to WaveOne® Gold (2,223.33 ± 84.36 r×s). After the first and third cycle of sterilization and testing of instruments in the canal under the same conditions, a statistically significantly higher ($p < 0.001$) value of NCF was observed with WaveOne®

Gold (2,192.50 ± 129.67 r×s, 1,498.50 ± 100.01 r×s, respectively) instruments compared to ProTaper Next® (1,242.83 ± 65.55 r×s, 1,223.50 ± 48.44 r×s, respectively) instruments. Testing of the instruments after the fifth cycle of sterilization showed no statistically significant difference between these two types of instruments, given that the NCF values for WaveOne® Gold were 1,342.67 ± 91.71 r×s and for ProTaper Next® were 1,214.50 ± 67.00 r×s ($p = 0.02$) (Table 1).

Testing of instruments in the artificial canal with a 5 mm radius of curvature showed a statistically significant difference in the NCF value between WaveOne® Gold (2,434.00 ± 77.08 r×s, 2,362.00 ± 81.32 r×s, 1,647.83 ± 124.44 r×s, 1,454.83 ± 35.13 r×s, respectively) and ProTaper Next® (1,278.50 ± 52.16 r×s, 1,265.17 ± 33.71 r×s, 1,260.83 ± 66.77 r×s, 1,201.00 ± 94.21 r×s, respectively) instruments in group which was not exposed to the sterilization process, as well as after the first, third, and fifth cycle of sterilization ($p < 0.001$) (Table 2).

The use of the ANOVA test revealed that the sterilization procedure did not significantly affect the reduction in resistance to CF in the ProTaper Next® group. However, it was observed that for WaveOne® Gold instruments, the third and fifth cycles of sterilization significantly reduced resistance on CF compared to the control group and instruments subjected to only one cycle of sterilization (Tables 1 and 2).

The mean value of fragment length after the CF test in a canal with a radius of curvature of 2 mm was statistically significantly higher with WaveOne® Gold compared to ProTaper Next® in all tested groups ($p < 0.001$). Likewise, the same significance was observed for the canal with a radius of 5 mm ($p < 0.001$) (Figure 1).

Table 1

Values of the number of cycles to failure (NCF) of the instruments in the canal with a 2 mm radius of curvature

Number of sterilizations	NCF (r×s)		Independent *t*-test
	ProTaper Next®	WaveOne® Gold	
0	1,249.50 ± 75.36	2,223.33 ± 84.36	$t = 21.09$, df = 10, $p < 0.001$
1	1,242.83 ± 65.55	2,192.50 ± 129.67	$t = 16.01$, df = 10, $p < 0.001$
3	1,223.50 ± 48.44	1,498.50 ± 100.01	$t = 6.06$, df = 10, $p < 0.00$
5	1,214.50 ± 67.00	1,342.67 ± 91.71	$t = 2.76$, df = 10, $p = 0.02$
ANOVA	F = 0.38, df = 3, $p = 0.77$	F = 119.49, df = 3, $p < 0.01$	/
Post hoc Tuckey test $p < 0.001$	/	0 vs.3, 0 vs. 5, 1 vs. 3, 1 vs. 5	/

r – number of rotations; s – seconds; ANOVA – analysis of variance; F – test statistic of ANOVA; df – degree of freedom. All values are shown as mean ± standard deviation.

Table 2

Values of the number of cycles to failure (NCF) of instruments in the canal with a 5 mm radius of curvature

Number of sterilizations	NCF (r×s)		Independent *t*-test
	ProTaper Next®	WaveOne® Gold	
0	1,278.50 ± 52.16	2,434.00 ± 77.08	$t = 30.41$, df = 10, $p < 0.001$
1	1,265.17 ± 33.71	2,362.00 ± 81.32	$t = 30.52$, df = 10, $p < 0.001$
3	1,260.83 ± 66.77	1,647.83 ± 124.44	$t = 6.71$, df = 10, $p < 0.001$
5	1,201.00 ± 94.21	1,454.83 ± 35.13	$t = 6.18$, df = 10, $p < 0.001$
ANOVA	F = 1.65, df = 3, $p = 0.21$	F = 201.71, df = 3, $p < 0.01$	/
Post hoc Tuckey test $p < 0.001$	/	0 vs. 3, 0 vs. 5, 1 vs. 3, 1 vs. 5	/

All values are shown as mean ± standard deviation. For abbreviations, see Table 1.

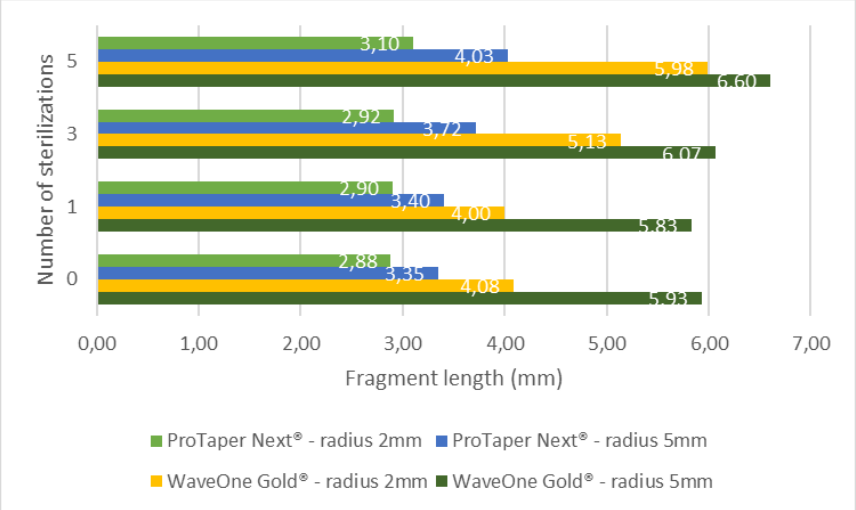

Fig. 1 – Mean values of fragment length after different sterilization cycles in canals with a 2 mm and 5 mm radius of curvature.

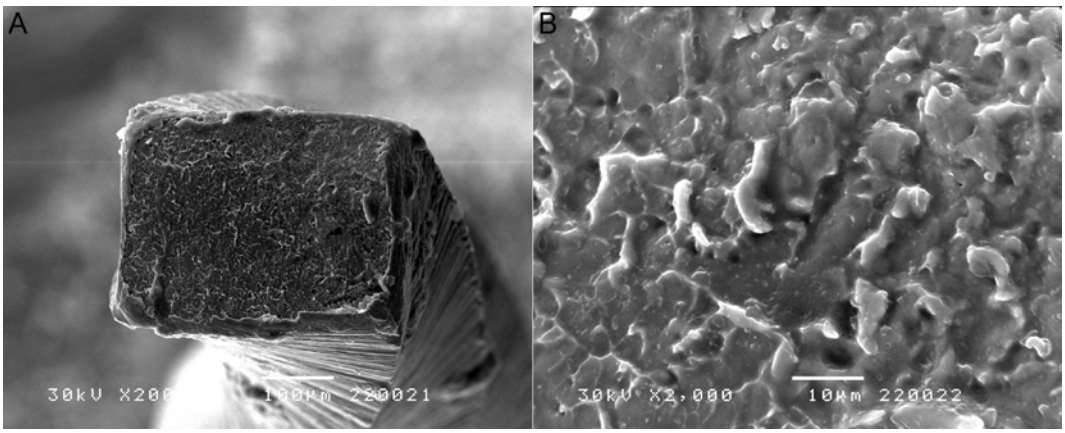

Fig. 2 – Micrograph of the cross-section of the ProTaper Next® fractured fragment after sterilization at A) ×200 and B) ×2,000 magnifications.

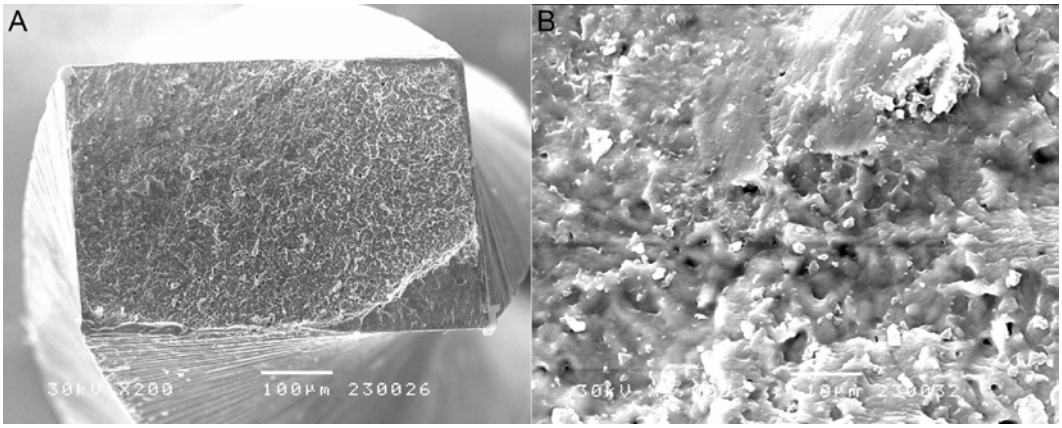

Fig. 3 – Micrograph of the cross-section of the WaveOne® Gold fractured fragment after sterilization at A) ×200 and B) ×2,000 magnifications.

Figure 2 represents the cross-section of the ProTaper Next® FF after autoclave sterilization, while the cross-section of the WaveOne® Gold FF is presented in Figure 3.

Discussion

The high operational costs associated with the use of not-so-affordable rotary endodontic instruments have influenced endodontic clinicians to subject these instruments to sterilization processes in order to prolong their functionality in clinical practice.

Numerous conducted studies have examined the impact of sterilization processes and their repetition on the appearance of microstructural defects on the working surface of instruments. These studies have determined that exposure to multiple sterilization cycles leads to an increased number of defects, consequently raising the risk of instrument fracture during clinical practice [9, 10]. However, there are also quite controversial findings that vary among different types of rotary instruments subjected to specific thermal processes during production [11]. Instruments made using M-wire technology are significantly more elastic and resistant to CF than conventional instruments due to Ni-Ti wire exposion to multiple heat treatments throughout the production process [3].

Nowadays, various tests are employed to assess the resistance of rotary instruments to CF to achieve safe clinical practices in endodontics. In this study, we utilized a static test known for its reliability as it provides valuable insights into the impact of design, taper, and manufacturing processes on CF [12]. Such instrument testing involves placing it in an artificial canal with a specific curvature angle, radius, and length and rotating it through either full rotations or reciprocal movements until the point of fracture.

The analysis of the results revealed a statistically significant difference in the resistance of WaveOne® Gold instruments before and after the third and fifth exposure to the sterilization cycle. With an increase in the number of sterilization cycles, Wave One® Gold instruments exhibited a consistent decline in NCF values. Contrary to these findings, the results of another study by De Ornelas Peraça et al. [13], who investigated the impact of sterilization on Reciproc Blue and WaveOne® Gold instruments, showed that the sterilization cycle did not affect the usage of WaveOne® Gold. Research conducted by Duque et al. [14] in 2020 investigated new and used instruments, including WaveOne® Gold, subjected to sterilization processes, followed by testing for CF. WaveOne® Gold exhibited a significant reduction in CF resistance after simulated clinical use and exposure to sterilization cycles. These findings align with the results of our study.

The obtained results have indicated that autoclave sterilization did not positively impact the CF resistance of the ProTaper Next® rotary instrument, and there was no statistically significant difference in CF resistance observed. The NCF values of ProTaper Next® consistently decreased both in the non-sterilized group and after the first, third, and fifth autoclave sterilization cycles. In contrast to our findings, the results of one study demonstrated an increase in the CF resistance of this instrument after the sterilization process [15]. In a recent study, ProTaper Next® exhibited variable NCF values with a slight increase after exposure to the first sterilization cycle, followed by a decline after exposure to the third and fifth sterilization cycles [16]. Additionally, according to findings from studies where instruments based on M-wire structure were examined, sterilization cycles did not affect fatigue resistance [17, 18].

Results from our study demonstrated a significant CF resistance of WaveOne® Gold compared to the ProTaper Next® instruments in all tested groups. The results of this study correlate with previously conducted studies [19–21]. WaveOne® Gold is a rotating system with reciprocal movements, and its unique parallelogram-shaped working part cross-section may help to explain these results [22]. Consequently, this type of rotational system exhibits different stress distribution behavior and, therefore, fracture patterns. The parallelogram-shaped cross-section of the WaveOne® Gold instrument establishes contact at a single point in the root canal, contributing to its superior resistance to CF compared to ProTaper® [19, 21]. In contrast to WaveOne® Gold, ProTaper Next® is characterized by full rotation movements and a rectangular cross-section that achieves contact at two points [20]. It is also worth noting that both WaveOne® Gold and ProTaper Next® have M-wire as their main structure. Still, WaveOne® Gold is made from a gold alloy as a result of consistent high-temperature heating and gradual cooling after the production process [23]. Therefore, it can be stated that this is one of the main reasons contributing to the higher resistance to CF in WaveOne® Gold compared to ProTaper Next®.

Hanbazaza and Abuhaimed [24], in their assessment of CF resistance for WaveOne® Gold and ProTaper® Gold instruments, employed various rotational directions and concluded that reciprocal movements enhance fatigue resistance for both instrument types. The study noted that WaveOne® Gold exhibited the highest resistance to CF when using movements of 150° counterclockwise and 30° clockwise. Furthermore, it was observed in the mentioned research that different directions of movement did not influence the length of FF. Testing instruments for CF in artificial canals at temperatures of 20° C and 37° C revealed that temperature does not play a role in increasing CF for instruments manufactured using M-wire technology. This is because the temperature used during the production of these instruments is much higher than body temperature [25].

The limitation of this study is reflected in the fact that it was conducted on a static model, which does not replicate a clinical setting. During work in root canals, the instruments are exposed to CF and also to torsional stress, which are the main causes of the file breakage [26]. However, torsional stress was not the subject of this study.

Conclusion

We may conclude from the acquired data that the resistance to cyclic fatigue cannot be increased by autoclave sterilizing rotary endodontic instruments produced by M-wire technology. While autoclave sterilization had a minor impact on ProTaper Next® decline in NCF values, it greatly decreased WaveOne® Gold resilience to cyclic fatigue. Furthermore, the instrument resistance to cyclic fatigue was higher in instruments tested in a larger radius of curvature.

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