RESEARCH

Effect of Chloroform On the Cyclic Fatigue Resistance of Nickel-Titanium Retreatment Instruments

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ABSTRACT

Effect of Chloroform On the Cyclic Fatigue Resistance of Nickel-Titanium Retreatment Instruments

Background: The purpose of this study was to evaluate the cyclic fatigue resistance of 4 different rotary nickel-titanium (NiTi) retreatment instruments after immersion in chloroform solution.

Methods: A total of 120 ProTaper D3, R-Endo R3, D-Race DR2 and Mtwo R2 retreatment instruments were used. Thirty instruments of each system were randomly divided into 2 groups (n=15); Group 1: no immersion and Group 2: immersion in chloroform for 5 min. The instruments were operated in a dynamic cyclic fatigue test device until fracture occurred. The number of cycles to fracture and length of the fractured fragment for each instrument were recorded. Representative samples were examined under a scanning electron microscope. Data were analyzed by using 2-way analysis of variance and Bonferroni tests.

Results: The ProTaper D3 and R-Endo R3 instruments showed the highest cyclic fatigue resistance whether or not immersed in chloroform ($p<0.05$). The immersion in chloroform did not affect the cyclic fatigue resistance of the instruments ($p>0.05$). The Mtwo R2 instruments were more resistant to cyclic fatigue than the D-Race DR2 instruments before and after immersed in chloroform ($p<0.05$).

Conclusion: The immersion in chloroform had no effect on the cyclic fatigue resistance of retreatment instruments. The ProTaper D3 and R-Endo R3 instruments were more resistant to cyclic fatigue than other retreatment instruments regardless of chloroform exposure.

KEYWORDS

Chloroform, Cyclic fatigue, Endodontics, Nickel-Titanium, Retreatment

ÖZ

Kloroformun Farklı Nikel-Titanyum Retreatment Eğe Sistemlerinin Döngüsel Yorgunluk Direncine Etkisi

Amaç: Bu çalışmanın amacı, kloroformun dört farklı retreatment eğe sisteminin döngüsel yorgunluk direncine etkisini değerlendirmektir.

Gereç ve Yöntemler: Bu çalışmada toplam 120 adet ProTaper D3, D-Race DR2, Mtwo R2 ve R-Endo R3 retreatment eğeleri kullanıldı. Her sistemden 30 adet eğe, rastgele 2 gruba ayrıldı (n=15); Grup 1: kloroformda bekletilme yapılmadı ve Grup 2: 5 dakika boyunca kloroformda bekletildi. Eğeler kırılana kadar döngüsel yorgunluk direnci test cihazında çalıştırıldı. Kırılana kadar olan döngü sayısı ve kırık parçaların uzunluğu kaydedildi. Taramalı elektron mikroskobu ile görüntüler incelendi. Elde edilen verilerin istatistiksel analizi iki yönlü varyans analizi ve Bonferroni testleri ile yapıldı.

Bulgular: ProTaper D3 ve R-Endo R3 eğeleri kloroformda bekletilse de bekletilmese de en yüksek döngüsel yorgunluk direncini gösterdi ($p<0,05$). Kloroformda bekletme, eğelerin döngüsel yorgunluk direncini etkilemedi ($p>0,05$). Mtwo R2 eğeleri, kloroform uygulamasından önce de, sonra da D-Race DR2 eğelerinden anlamlı olarak döngüsel yorgunluğa daha dirençliydi ($p<0,05$).

Sonuç: Kloroform, retreatment eğelerinin döngüsel yorgunluk direncini etkilemedi. Kloroform uygulamasından bağımsız olarak, ProTaper D3 ve R-Endo R3 eğeleri diğer eğe sistemlerinden anlamlı olarak daha yüksek döngüsel yorgunluk direnci gösterdi.

ANAHTAR KELİMELER

Döngüsel yorgunluk, Endodonti, Klorofom, Nikel-Titanyum, Yenileme

Nonsurgical root canal retreatment is indicated in case of failure in initial root canal treatment.[1] The primary goal of root canal retreatment is to eliminate microorganisms from the root canal system and establish disinfection. To achieve this goal, previous root canal filling materials must be completely removed, thus the chemomechanical preparation of the root canal system can be performed effectively.[2] Several methods have been introduced to remove filling materials from the root canal including the use of chemical solvents and nickel-titanium (NiTi) rotary instruments.[3]

According to a recent systematic review, the use of a chemical solvent during the mechanical preparation with rotary instruments can enhance the removal of root canal filling materials and accelerate the time required to reach the working length.[4] Among chemical solvents, chloroform is the most popular solution as it can soften root canal filling materials effectively.[5] Although chloroform is also known for its toxicity, it has been shown that the health risk of using solvents during root canal retreatment is negligible.[6]

Some NiTi rotary systems such as the ProTaper Universal retreatment system (Dentsply Maillefer, Ballaigues, Switzerland), the R-Endo retreatment

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system (Micro-Mega, Besancon, France), the D-Race retreatment system (FKG Dentaire, La Chaux-de-Fonds, Switzerland) and the Mtwo retreatment system (VDW, Munich, Germany), are specifically designed for root canal retreatment.[7] The ProTaper Universal retreatment system is comprised of 3 instruments: D1 (30.09) is used for the initial penetration into the filling material, D2 (25.08) is used at the middle part of the root canal, and D3 (20.07) is used at the working length. The R-Endo retreatment system consists of 3 instruments as R1 (25.08), R2 (25.06), and R3 (25.04) that are used at coronal, middle, and apical parts of the root canals, respectively. The D-Race retreatment system also has 2 instruments: DR1 (30.10) is used to clear the access of root canal and DR2 (25.04) is used at the working length. The Mtwo retreatment system has 2 files in sizes 15 and 25, both with 0.05 taper.[7]

Despite having the advantages of reduced treatment time and a low risk of transportation even in curved root canals, the rotary NiTi instruments have the risk of fracture due to torsional or cyclic fatigue.[8] Cyclic fatigue occurs when the instrument rotates in a curved canal and after a number of repeated cycles of tension and compression at the point of maximum flexure, the instrument fracture occurs.[9] The working part of rotary NiTi instruments come into contact for a few minutes with chloroform when it is used as a chemical solvent during retreatment.[8] Such contact may negatively influence the physical properties of rotary NiTi instruments. Since the literature is lacking in this respect, this study aimed to evaluate the cyclic fatigue resistance of ProTaper, Mtwo, D-Race and R-Endo retreatment instruments after immersion in chloroform solution.

MATERIALS AND METHODS

A total of 120 new ProTaper D3 (20.07), Mtwo R2 (25.05), D-Race DR2 (25.04) and R-Endo R3 (25.04) instruments designed for retreatment were selected for this study (n=30). All instruments were inspected under a stereomicroscope (Leica MZ16 A, Leica Microsystems, Wetzlar, Germany) to confirm the absence of any defects. Half of the instruments of each system were directly subjected to cyclic fatigue testing (non-immersion group), while the remaining instruments were tested after immersion in chloroform solution (Merck, Darmstadt, Germany) (immersion group). In the immersion group, the 16 mm working part of each file was exposed to chloroform at room temperature for 5 minutes using small glass bottles. The instruments were removed from the bottles and rinsed with distilled water. All instruments were stored in separate eppendorf tubes until cyclic fatigue testing.

The dynamic cyclic fatigue testing was performed using a specifically developed device (Figure 1), similar to previous studies.[10,11]

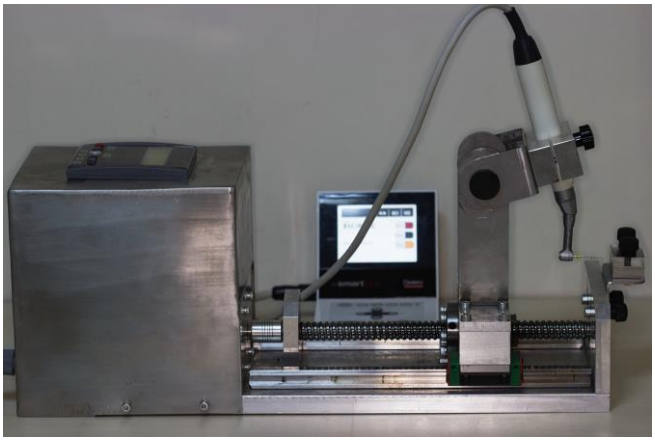

Figure 1

Cyclic fatigue testing device

This device comprised of a stainless steel artificial canal with an inner diameter of 1.5 mm, a curvature angle of 60° and a curvature radius of 5 mm. The handpiece was mounted on a holder that performed the axial movement which was controlled by a sensor placed at the end of the artificial canal. The amplitude of the axial movements was 3 mm, with 1 oscillation every 2 seconds. The instruments were operated at manufacturer's recommended speed and torque (ProTaper D3, 500 rpm and 3 Ncm; D-Race DR2, 600 rpm and 1.5 Ncm; Mtwo R2, 300 rpm and 1.2 Ncm; and R-Endo R3, 300 rpm and 1.2 Ncm) using an endodontic motor (X-Smart Plus; Dentsply Maillefer, Ballaigues, Switzerland). A synthetic oil (WD-40 Company, Milton Keynes, UK) was used for lubrication of the artificial canal.

Each instrument was rotated in the artificial canal until fracture occurred. The time to fracture in seconds was recorded. The number of cycles to fracture (NCF) was calculated according to the following formula: NCF = time to fracture x rotational speed/60. The length of each fractured fragment was measured with a digital caliper (Mitutoyo, Hampshire, UK) and recorded. The fracture surfaces of 2 fractured instruments from each group were examined under a scanning electron microscope (SEM) (JEOL 6400; JEOL, Tokyo, Japan).

The experimental procedures were performed by a single operator to avoid interoperator variability.

Statistical Analysis

All statistical analyses were performed with SPSS 16.0 software (SPSS Inc, Chicago, IL, USA). The data were analyzed using 2-way analysis of variance (ANOVA) and Bonferroni tests. The level of significance was set at $p = 0.05$.

RESULTS

Descriptive statistics of NCF and the length of each fractured fragments of tested retreatment instruments are presented in Table 1.

Table 1.

The number of cycles to failure (NCF) and the length (mm) of fractured fragments of retreatment instruments

	Non-immersion Group				Immersion Group			
	NCF (n=15)		FL (n=15)		NCF (n=15)		FL (n=15)	
Retreatment instrument	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ProTaper D3	727.022[a]	134.082	4.800	0.797	723.356[a]	97.017	5.100	0.870
D-Race DR2	299.833[b]	44.928	4.950	0.158	299.167[b]	49.810	5.050	0.284
Mtwo R2	406.000[c]	55.459	5.167	0.362	406.667[c]	76.501	5.067	0.176
R-Endo R3	672.000[a]	51.471	5.300	0.727	647.333[a]	70.556	4.967	0.481

Different superscript letters indicate statistically significant differences between the groups ($p<0.05$).

The ProTaper D3 and R-Endo R3 instruments showed the highest cyclic fatigue resistance whether or not exposed to chloroform ($p < 0.05$), while there was no significant difference between them ($p > 0.05$). The immersion in chloroform did not affect the cyclic fatigue resistance of the instruments ($p > 0.05$). The NCF of the Mtwo R2 instruments was significantly higher than that of the D-Race DR2 instruments before and after immersed in chloroform ($p < 0.05$).

Analysis of the data regarding the fragment lengths showed that there was no significant difference between the groups in terms of the mean fracture lengths of the retreatment instruments ($p > 0.05$). The immersion in chloroform did not significantly affect the mean fracture length of each retreatment instrument ($p > 0.05$).

According to the SEM analysis, the surfaces of all retreatment instruments in either immersion group or non-immersion group displayed dimples and striation marks indicating the characteristics of ductile fracture (Figure 2).

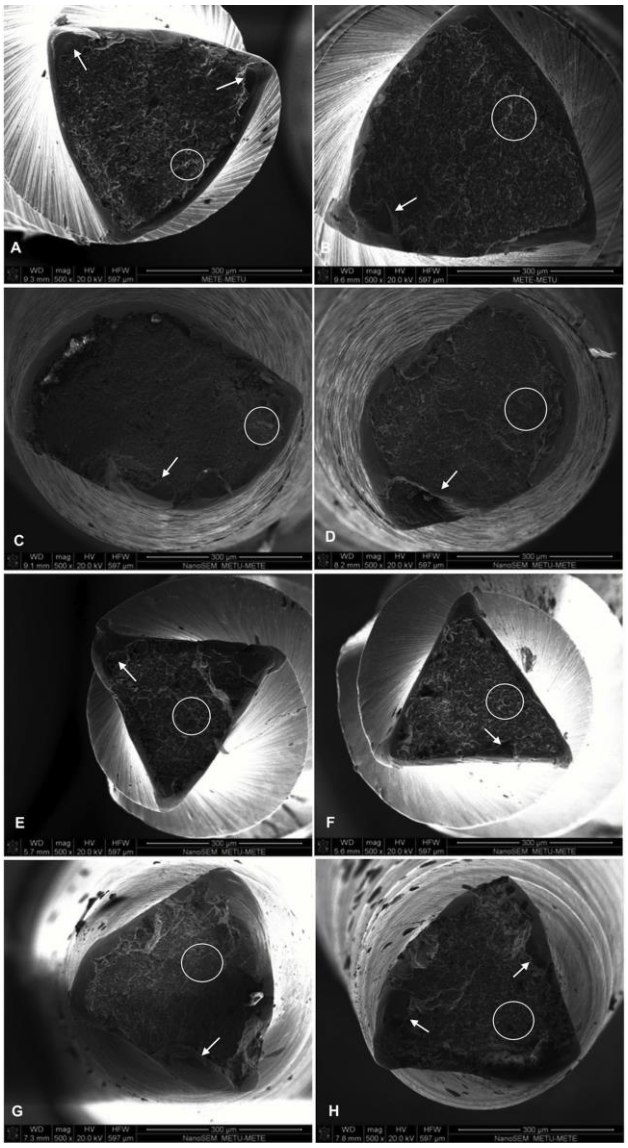

Figure 2

Fracture surfaces of rotary NiTi retreatment instruments (500x magnification). (A) ProTaper D3, non-immersion group, (B) ProTaper D3, immersion group, (C) Mtwo R2, non-immersion group, (D) Mtwo R2, immersion group, (E) D-Race DR2, non-immersion group, (F) D-Race DR2, immersion group, (G) R-Endo R3, non-immersion group, (H) R-Endo R3, immersion group. Crack initiation origin (arrows) and dimples (circled area) can be seen on the surfaces.

DISCUSSION

Chemical solvents are commonly used during root canal retreatment to enhance the penetration of instruments into filling materials.[4] The retreatment instruments should exhibit high fatigue resistance because a well-compacted root canal filling material leads to stress on the instruments.[12] To the best of our knowledge, the present study is the first to investigate the potential negative impact of exposure to chloroform solution on the fatigue resistance of rotary NiTi retreatment instruments.

Based on the present findings, the ProTaper D3

(20.07) and R-Endo R3 (25.04) instruments exhibited higher cyclic fatigue resistance than the Mtwo R2 (25.05) and D-Race DR2 (25.04) instruments whether or not immersed in chloroform. On contrary, in previous studies, the ProTaper D3 instruments were associated with lower cyclic fatigue resistance than the R-Endo R3 and D-Race DR2 instruments due to its greater taper.[3,12,13] This result can be explained by the fact that in the current study a dynamic model was used during fatigue tests while a static model was used in those studies.[3,12,13] In the static model, stresses are concentrated in a particular area of the instrument because the instrument does not move axially. These cumulative stresses may lead to changes in the microstructure of the instrument. On the other hand, in the dynamic model, stresses are distributed along the shaft of the instrument because the instrument moves axially along the curvature.[10] The differences in the distribution of stress concentration between the static and dynamic test models may affect the cyclic fatigue resistance of instruments.

The higher cyclic fatigue resistance of the ProTaper D3 and R-Endo R3 instruments compared to the other retreatment instruments can be attributed to their mechanical properties such as design, geometrical shape and flexibility. The R-Endo R3 instruments were found to be more flexible and have smaller pitch distance compared to the Mtwo R2 and ProTaper D3 instruments.[14] In general, a smaller pitch distance provides higher fatigue resistance to the instruments.[15] On the other hand, it was reported that the tip diameter and angle of the ProTaper D3 instruments were smaller than those of the Mtwo R2 and R-Endo R3 instruments[14] and this may have affected the fatigue behavior of the ProTaper D3 instruments positively during dynamic experiments.

Each tested retreatment instrument has a different cross-sectional design. The ProTaper D3 instruments have a convex triangular cross-section[3] while the R-Endo R3 instruments have a triangular cross-section with three equally spaced cutting edges and no radial surfaces.[8] The D-RaCe DR2 has a triangular cross-sectional design with alternating cutting edges,[7] while the Mtwo R2 instruments have S-shaped cross-section with a constant helical angle.[16] The convex triangular cross-sectional design of the ProTaper D3 instruments causes its internal mass to be larger than other retreatment instruments[17] and this might have contributed to its high cyclic fatigue resistance. Despite the differences in the cross-sectional design, the instruments within all groups showed ductile fractures. Based on this result, it can be concluded that the cross-sectional design of NiTi retreatment instruments has no effect on the fracture type.

The immersion of NiTi instruments in chemical solvents may cause metal corrosion, change metallurgical properties and affect the fatigue resistance of instruments. Based on the present findings, the exposure to chloroform had no effect on the fatigue resistance of rotary NiTi retreatment instruments. Similar to the present results, the immersion in chloroform was found to cause no significant surface deteriorations on the retreatment instruments previously.[8]

In the present study, the retreatment instruments were placed in small glass bottles containing chloroform to obtain the contact between the solution and instruments similar to previous studies.[13,18] The present experimental design does not simulate the exact clinical condition because in clinical practice the instruments are in contact with the solutions in the small volume of a prepared root canal. However, this methodology was preferred due to the ability to standardize the solution volume and to allow analysis without being affected by other confounding factors such as friction caused by the dynamic immersion in the root canals of extracted or artificial teeth.[18] According to previous studies, the retreatment instruments remove filling materials from the root canal in about 5 minutes.[19-21] Therefore, a period of 5 minutes was determined as the immersion time of the instruments in the solution to simulate the clinical conditions.

Several methodologies have been used to evaluate the cyclic fatigue resistance of NiTi instruments. In most of the studies, stainless steel canals were used to avoid wearing of the canal walls during instrumentation.[3,11-13,18] In the present study, a device consisting of a stainless steel canal with a 5 mm radius was used to simulate an abruptly curved canal. The use of such devices allows the standardization of the canal dimensions during the experiments.[10] In this study, all tested instruments fractured at the center or just below the curvature, which confirmed the standardization of the instrument position in the test device. Because each instrument was rotated in the same artificial canal, the difference between the tapers and lengths of the tested retreatment instruments might be criticized. However, identical sizes of the retreatment systems are not commercially available, and according to the manufacturers, these systems can be used safely in all canals with different curvature, shape, or length.[12]

In conclusion, the immersion in chloroform did not affect the cyclic fatigue resistance of rotary NiTi retreatment instruments. The ProTaper D3 and R-Endo R3 instruments were more resistant to cyclic fatigue than the Mtwo R2 and D-Race DR2 instruments regardless of chloroform exposure.

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