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Effect of Cryogenic Treatment on Fracture Resistance of Nickel Titanium Rotary Instruments a Systematic Review

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ABSTRACT

Introduction: Endodontic instruments upon rotation are subjected to both tensile and compressive stresses in curved canals. This stress is localized at the point of curvature. It has been demonstrated that the continuous cycle of tensile and compressive forces in the area of curvature of the canal to which (Nickel Titanium) NiTi rotary instruments are subjected produce a very destructive form of loading, causing cyclic fatigue and eventually fracture of the instrument.[2] The aim of this study is to conduct a systematic review on the effect of cryogenic treatment on fracture resistance of nickel titanium rotary instruments.

Methods: Two Internet sources of evidence were used in the search of appropriate papers satisfying the study purpose: the National Library of Medicine (MEDLINE PubMed) and Google Scholar, Google and manual search using DPU college library resources. All cross reference lists of the selected studies were screened for additional papers that could meet the eligibility criteria of the study.

Results: Preliminary screening consisted total of 54 articles out of which 24 articles were selected. The papers were screened independently by two reviewers. At first the papers were screened by title and abstract. As a second step, full text papers were obtained when they fulfilled the criteria of the study aim. Any disagreement between the two reviewers was resolved after additional discussion. Finally 3 articles were included in this study.

Conclusions: Within the limitations of this study we can conclude that the cryogenic treatment increases the fracture resistance of nickel titanium rotary instruments.

Key Words: Treatment, Fracture Resistance, Nickel-Titanium Rotary Instruments

INTRODUCTION

Nickel-titanium alloy exhibits the unique properties of shape memory (SM) and pseudoelasticity.[1] It is well known that instrument separation occurs either by brittle fracture (cyclic fatigue) or by ductile fracture (torsional fatigue). Endodontic instruments upon rotation are subjected to both tensile and compressive stresses in curved canals[2]. This stress is localized at the point of curvature. It has been demonstrated that the continuous cycle of tensile and compressive forces in the area of curvature of the canal to which NiTi rotary instruments are subjected produce a very destructive form of loading, causing cyclic fatigue and eventually fracture of the instrument[2]. Despite the extreme flexibility,[4] these thermomechanically processed NiTi instruments undergo permanent plastic deformation, especially while reusing the smaller size instruments[5,6] due to inadequate martensite content. Cryogenic treatment is a supplementary procedure of subjecting stainless steel[7,8] and superelastic NiTi[3] to subzero temperatures that affects the entire bulk of the material rather than the accessible surface alone. One of the mechanisms proposed behind the improvement in properties following cryogenic treatment is the complete martensitic transformation from the austenite phase.[9] It has been proved that deep cryogenic treatment (DCT) at a soaking temperature of up to −185°C increases the martensite content of SM NiTi alloys by a similar mechanism.[10] Previous studies have been done evaluating the effect of cryogenic

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treatment on the fracture resistance of nickel titanium rotary instruments. However, no systematic review comparing the effect of cryogenic treatment on fracture resistance of nickel titanium rotary instruments have been conducted. The aim of this study is to conduct a systematic review on the effect of cryogenic treatment on fracture resistance of nickel titanium rotary instruments.

METHODS

Inclusion criteria:

i. Articles in English or those having detailed summary in English.
ii. In vitro Studies published between 1st January 1985 and 31st June 2016.
iii. New packet of Nickel-Titanium rotary files.
iv. Cryogenic treatment modality.

Exclusion criteria:

i. Used nickel-titanium rotary file.
ii. In vivo studies, reviews, case reports were excluded.

PICO:

P – Product: Nickel-titanium rotary files.

I - Exposure: treatment modalities.

C -Comparison: between cryogenically treated and non treated nickel titanium rotary instruments.

O - Outcome: increase in the fracture resistance of treated nickel-titanium rotary files.

Two Internet sources of evidence were used in the search of appropriate papers satisfying the study purpose: the National Library of Medicine (MEDLINE PubMed) and Google Scholar, Google and manual search using DPU college library resources. All cross reference lists of the selected studies were screened for additional papers that could meet the eligibility criteria of the study. The databases were searched up to and including 31st June 2016 using the search strategy.

RESULTS

Preliminary screening consisted total of 54 articles out of which 24 articles were selected. The papers were screened independently by two reviewers. At first the papers were screened by title and abstract. As a second step, full text papers were obtained when they fulfilled the criteria of the study aim. Any disagreement between the two reviewers was resolved after additional discussion. Finally 3 articles were included in this study. (Fig no.1)

STUDY SELECTION

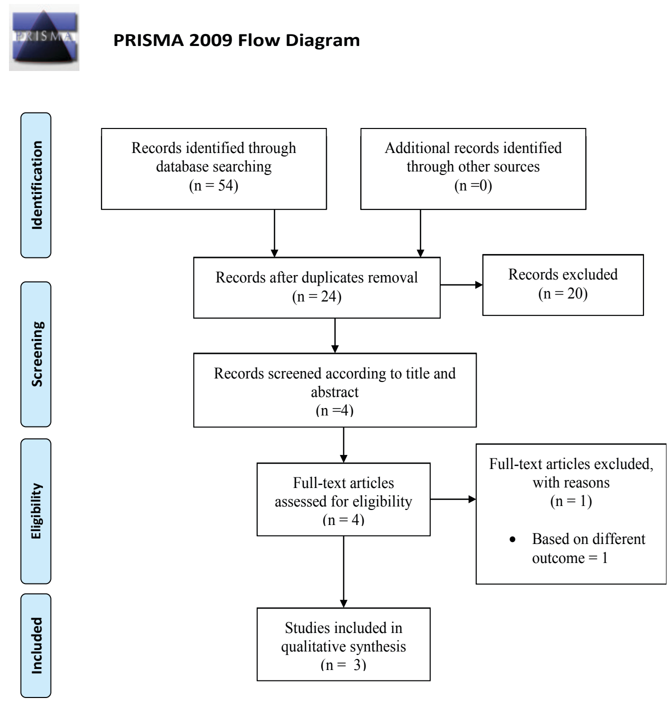

Figure 1: Summarizing the article selection process.

DISCUSSION

Biomechanical preparation has been considered the most important step in root canal therapy.[15] Advent of rotary NiTi instruments has aided endodontists in cleaning and shaping of root canals. Civjan et al in 1975 suggested the use of NiTi alloy for fabrication of hand and rotary endodontic instruments.[15] The extraordinary characteristics of super elasticity and shape memory of the NiTi alloy have made it possible to manufacture rotary instruments.[1]

Endodontic instruments upon rotation are subjected to both tensile and compressive stresses in curved canals.[2] This stress is localized at the point of curvature. It has been demonstrated that the continuous cycle of tensile and compressive forces in the area of curvature of the canal to which NiTi rotary instruments are subjected produce a very destructive form of loading, causing cyclic fatigue and eventually fracture of the instrument.[2] It has been suggested that cyclic fatigue has accounted for 50–90% of mechanical failures.[2]

Cryogenic methods have been used to increase the wear, abrasion, corrosion resistance, and to improve the strength of metals. Cryogenically treated NiTi instruments have shown increased microhardness. Deep cryogenic treatment involves suspending the metal over a super-cooled bath containing liquid nitrogen at −196°C or −320°F and then allowing the metal to slowly warm to room temperature.[16]

Methods like boron ion implantation,[17]thermal nitridation,[18] physical vapor deposition of titanium nitride[19] and electropolishing[20] have been used for increasing the cutting efficiency of rotary NiTi instruments. Anderson et al in 2007 showed that electropolished instruments performed significantly better than non-electropolished instruments in both the cyclic fatigue testing and static torsional loading, which is likely to be caused by a reduction in surface irregularities that serve as points of stress concentration and crack initiation in nickel titanium.[21]

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Kim et al 2005[22] studied the effect of cryogenic treatment on nickel-titanium endodontic instruments.30 size 25 nickel-titanium K-files (NTO2525; Dentsply-Tulsa Dental) were embedded in epoxy resin (811-563-103 and 811-563-104; Leco, St Joseph, MI, USA) mixed according to the manufacturer's instructions. 15 control instruments and 15 cryogenically treated instruments were used. Each instrument was cut at the handle and then placed within a mounting ring (20-8161-010; Buehler, Lake Bluff, IL, USA). The mounting rings were brushed with releasing agent (20-8185-032; Buehler) and placed upon a flat surface. The resin and hardener were then mixed until clear in appearance and was then poured into each mounting ring. The epoxy resin was left to cure for 8 h. The resin blocks were then removed from the mounting rings and ground to reveal a cross-section of the instruments and polished flat using a grinder/polisher (Phoenix Beta; Buehler). Silicon carbide polishing papers (240, 320, 400, 600 and 1200) were used in succession followed by Al_2O_3 powder/H_2O suspensions (1.0, 0.3 and 0.05μm particle sizes) for final polishing. A Vicker's indenter was used to make two indentations adjacent to the edge of the instrument cross-section (FM-7; Future Tech, Tokyo, Japan). A 9.8 N indentation load was applied for a 15 s dwell time. Both indentation diagonals were measured, and the Vicker's microhardness (VHN), was calculated from the size of the indentation. According to the equation

$$VHN = 0.1891F/ d^2$$

Where, F is the indentation load having unit (N) and d is the average diagonal length of indentation having unit (mm).

It was concluded that there was an increase in the microhardness following cryogenic treatment. Non treated instruments had a mean VHN of 339.3 ± 23.0, and treated instruments had VHN of 346.7 ± 20.6 (Fig. 2). A Student's t-test showed this to be a statistically significant difference ($P < 0.001$; $\beta > 0.999$).

Mahalaxmi Sekar et al 2011[16] studied the effect of deep dry cryotreatment on the cutting efficiency of three rotary nickel titanium instruments. 20 NiTi instruments of RaCe (FKG Dentaire, Switzerland), K3 (Sybron Endo, CA, USA) and Hero Shaper (Micro Mega, France) of size 25, 21mm length and of 0.06 taper, were used for this study. The files were randomly divided into two groups for evaluating the cyclic fatigue as follows:

Group A: untreated NiTi rotary files and Group B: cryotreated NiTi rotary files. These were further divided as the follows.

Group A1: 10 untreated RaCe rotary files : Group A2: 10 untreated K3 rotary files:Group A3: 10 untreated Hero Shaper rotary files.

Group B1: 10 cryotreated RaCe rotary files: Group B2: 10 cryotreated K3 rotary files: Group B3: 10 cryotreated Hero Shaper rotary files.

Mean number of cycles required to fracture in Group B1 (405 ± 3) was significantly higher than that of Group A1 (352 ± 2) ($P < 0.0001$). Mean number of cycles to fracture in Group B2 (708 ± 4) was significantly higher than that in Group A2 (452 ± 3) ($P < 0.0001$). Mean number of cycles to fracture in Group B3 (359 ± 10) was significantly higher than that in Group A3 (268 ± 7) ($P < 0.0001$). Groups B1, B2, and B3 showed significantly higher number of cycles to fracture than Groups A1, A2 and A3 ($P < 0.0001$).

The results of this study showed an increase in the fracture resistance of NiTi files which were treated as compared to untreated files. This could be attributed to the fact that the complete transformation of the austenitic phase of the alloy to martensitic phase, which could have occurred at −195°C, would have decreased the internal stress within the alloy due to plastic deformation. Amini et al [15] have explained in their study that the presence of residual austenite phase in an alloy decreases hardness and also reduces the wear resistance of the tool. Thus, increasing resistance to wear, reduction of internal stresses can be regarded as the most important benefits of using cryogenic treatment. It was observed that by decreasing the temperature of cryogenic environment, better properties were obtained. The deep dry cryogenic treatment (DCT) has been seen to affect the entire cross section of the instrument rather than just the surface, with no change in the elemental crystalline composition of the alloy.

T.S.Vinothkumar et al 2016[14] studied mechanical behavior of deep cryogenically treated martensitic shape memory nickel–titanium rotary endodontic instruments. The martensitic

SM NiTi instruments made from controlled memory wire (HyFlex® CM; ColteneWhaledent Inc., Cuyahoga Falls, OH, USA) of size 25, 0.06 taper were selected for this study. A total of 75 instruments were randomly divided into three groups of 25 each as follows: DCT 24: Soaking temperature −185°C, soaking time 24 h, DCT 6: Soaking temperature −185°C, soaking time of 6 h, number of cycles to failure (NCF) for each instrument. The NCF is directly proportional to the cyclic fatigue resistance of the instrument. They concluded that the maximum NCF of each HyFlex® CM rotary endodontic instrument following rotation in artificial root canals with 30° angle of curvature was observed in DCT 24 group followed by DCT 6 and control.

Despite the extreme flexibility of HyFlex® CM SM NiTi instrument, supplementary cryogenic treatment would further increase the volume of martensite resulting in superadded benefits, especially for smaller size instruments. Cryogenic treatment can be classified based on the soaking temperature as deep (−185°C) and shallow (−80°C).[9,19,20] Deep soaking temperatures are effective in increasing the martensite content of SM NiTi alloys than the conventional shallow cold treatments. Consequently, DCT significantly reduces the hardness and increases the wear resistance of the SM NiTi alloy. Therefore, the objective of this study was only to evaluate the role of DCT soaking time with respect to the constant cooling and warming rate. The advantage of the dry DCT facility used in this study is to gradually increase or decrease the temperature in order to avoid thermal shock to the instrument that would make it brittle.

CONCLUSION

This systematic review summarizes that the cryogenic treatment of NITI Rotary endodontic instruments increases the fracture resistance of the instruments. It could be attributed to the complete transformation of the austenitic phase to martensitic phase.

LIMITATIONS

Search strategy may not be complete due to limited accessibility.

IMPLICATIONS FOR FUTURE RESEARCH

Cryogenic treatment appears to be a promising supplementary method in the manufacturing of nickel titanium endodontic instruments. Cryogenic treatment significantly increases the fracture resistance of nickel titanium alloy. Further investigations are required to evaluate the impact of cryogenic treatment on fracture resistance of nickel titanium rotary instruments.

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Abbreviations:

1. NITI – Nickel Titanium
2. SM - Shape Memory
3. DCT – Deep Cryogenic Treatment
4. VHN – Vicker's Hardness Number
5. NCF – Number of Cycles to Failures

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