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Original Article

A novel approach to determine the effect of irrigation on temperature and failure of Ni-Ti endodontic rotary files

Sayed Ali Mousavi[1], Vida Kargar-Dehnavi[2], Sayed Amir Mousavi[3]

[1]Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, [2]School of Dentistry, Khorasgan branch, Islamic Azad University, [3]Department of Endodontics, School of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran

ABSTRACT

Background: Nickel-titanium (Ni-Ti) rotary instrument files are important devices in Endodontics in root canal preparation. Ni-Ti file breakage is a critical and problematic issue and irrigation techniques were applied to decrease risk of file failure root. The aim of the present study was to compare the temperature gradient change of different irrigation solutions with Ni-Ti rotary instrument system during root canal preparation and also to define their effects on the file failure.
Materials and Methods: A novel computerized instrumentation was utilized and thirty standard (ProFile #25/.04) files were divided into three groups and subjected to a filing in the root canal test. Changes in temperature on teeth under constant instrumental conditions with custom-designed computerized experimental apparatus were measured by using a temperature sensor bonded to the apical hole. A rotary instrument for canal preparation in three series of solution was used and the changes in temperature after each solution were compared. Finally, the file failure results were mentored according to each step of test. Comparisons were performed between group status clinically by using ANOVA (*t*) test, once the sample showed up normal and differences of $P<0.01$ were considered significant. All data collected were computerized and analyzed for frequency, distribution, and statistical description.
Results: There was a decrease in the temperature of the instruments, which were immersed in 5% NaOCl, when compared with the water group ($P<0.01$). There was also a decrease in the temperature of the instruments immersed in water, when compared with the no solution group ($P<0.01$). Test results showed that sodium hypochlorite, water, or air of root canals does alter the properties of gradual temperature change and contributes to the failure of the instruments.
Conclusion: By immersing the file in 5% NaOCl, the temperature gradient decreased and instrument failure was reduced.

Key Words: File failure, instruments, Ni-Ti, solution, temperature

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Address for correspondence: Dr. Sayed Ali Mousavi, Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran
E-mail: sayedali_mousavi@yahoo.com

INTRODUCTION

In Endodontics, root canal preparation for the tooth is a challenging task. Stainless steel and nickel-titanium (Ni-Ti) rotary instruments have been used for canal preparation purposes. In recent years, Ni-Ti rotary instruments have allowed much improvement in Endodontics canal preparation. Ni-Ti instruments are known to be more superelastic and flexible in bending and torsion than stainless steel files. Often, depending on the dentist experience, they are replaced before reaching their elastic limit.[1] Despite the advantages of Ni-Ti instrumentation, unexpected instrument failure occurs during clinical use, in relation to mechanical root canal properties.[2] Cyclic fatigue and torsional stress are two main reasons for instrument failure. Several researchers conducted researches using a specially designed torque-testing apparatus,

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later detailed torque and force values present in clinical situations and the conditions that may lead to instrument failure depending on preloading and instrument movements.[3,4] Under the normal use, when the instruments reach near their endurance limit, failure may occur. In addition, the temperature of files which increases due to the instrument's thermodynamical situation will promote instrument failure.[5] Irrigation solutions which are used during root canal preparation can decrease the instrument temperature and consequently decrease the chance of instrument failure. The revolution speed of the instruments inside the root canal also interferes in the heat production and its transmission to the external surface since speed is directly proportional to heat.[6] Research has revealed that the anatomical diameter of the root canal and the amount of remaining dentine are factors that can contribute to the higher or lower temperature dissipation.[7] Research has been performed on the (Pro Instrument #0.6, Dentsply Tulsa, Switzerland) rotary instrument failure in the presence of sodium hypochlorite.[8] The effect of temperature on the viscosity of the root canal material as well as the root temperature gradient has also been studied.[9] The use of sodium hypochlorite (NaOCl) to irrigate root canals is currently the standard and one of the best irrigation to achieve tissue dissolution and disinfection.[10,11] In a study evaluating the effects of irrigation on cutting efficiency K-files, tap water and 2.5% sodium hypochlorite solutions increased the cutting efficiency compared with dry conditions.[12] One additional factor potentially limiting the resistance to fatigue and torsional fracture is corrosion that may occur in the presence of NaOCl solution.[13,14]

A rise in temperature was reported in the root surface of human teeth during post-space preparation at a point 6 mm from the apex of the tooth using a thermocouple attached to a chart recorder. Hence, it was suggested that the use of Ni-Ti rotary instrument to prepare post channels in the teeth will generate heat that may cause tissue damage, and caution should be exercised during their use.[15] There was no statistically significant difference between temperature elevations recorded *in vitro* and those measured *in vivo*, which validates *in vitro*.[16] Research was conducted at temperature elevations far above body temperature, which may be sufficient to cause bone tissue injury.[17] The demonstration stress and strain analysis of Ni-Ti instrument indicated that torsional and flexural stresses are important causes in instrument failure.[13] Cyclic fatigue is a common problem in endodontics instrument failures. Additionally, temperature could be considered as one of the major factors which influence fatigue, fracture, and instrument failure.[18]

When using Ni-Ti rotary instruments for canal preparation, the continuous tensile and compressive stress cycles in the canal region of maximum curved lead to mechanical fatigue. Thus, Ni-Ti fatigue resistance is the parameter that determines, in most cases, the applicability of the device.[19] In general, fatigue-crack growth resistance has been reported to increase with decreasing temperature, such that fatigue thresholds were higher and crack-growth rates slower in martensite compared with austenite and superelastic austenite.[20] Separate studies have shown that the temperature of Ni-Ti wire increases under low-cycle and high-amplitude fatigue conditions, which are caused, apparently, by the martensite–austenite phase transformation in each cycle.[21] Fatigue of metals is influenced by a number of factors and described by the Coffin–Manson equation[22] which is as follows:

$$N_f = \left(\frac{a}{\varepsilon_a}\right)^b \quad (1)$$

where, a and b are considered empirical material constants. It has been considered that these instrument failure parameters a and b are influenced by additional operational and environmental parameters such as C (specific heat transfer). In another study, it was also found that the number of instrument failure increases and lifetime variability decreases with increasing C (Relative Specific Heat).[23]

Physically, this means that the ability of solution to absorb the heat generated by the cycling Ni-Ti rotary instruments proportionally correlates with its lifetime. The specific heat of Ni-Ti is ($C_{Ni\text{-}Ti}$=0.20 cal/g°C.); thus, when Ni-Ti instruments are rotated in an environmental fluid such as water (C_{water}=1.00 cal/ g°C), or NaOCL (C_{NaOCL}=0.94 cal/g°C), the fluid acts as an efficient heat absorber and attracts the energy generated by transforming Ni-Ti without an appreciable increase in temperature.

In contrast, when the Ni-Ti rotary instrument is rotated in a non-irrigated environment (C_{air}=0.24 cal/g°C), the solution surrounds the rotating Ni-Ti instrument that reduces heat dissipation and thus decreases the number of rotation leading to failure.[24,25] The aforementioned possibility justifies the need for a better understanding of rotary Ni-Ti file rupture in order to devise possible methods to increase file fatigue life according to a constant temperature which has been the subject of some bench studies.[26,27] The number of cycles caused fracture for Ni-Ti files at four different temperatures with a single irrigation solution which have been also investigated in separate.[28] In the light of above mentioned reports, it is evident that the controlled impacts of real-time experimental constant parameters such as RPM, force, torque, etc. *in vivo* which affects the file failure have not yet been investigated with computerized intelligent control system.

The current study is therefore conducted to determine the Ni-Ti instrument lifetime as a function of temperature that can be controlled and quantified by a computerized control system in a clinical setting. The lifetime has been deliberately considered as a function of the properties of the solution in which Ni-Ti instrument fatigue occurs. The aim of the present study was to compare the temperature gradient change of different irrigation solutions with Ni-Ti rotary instrument system during root canal preparation and also to define their effects on the file failure.

MATERIALS AND METHODS

Experimental design apparatus

The major components of the system, as illustrated in Figure 1, are as follows:

1. Microcontroller,
2. Database,
3. Hardware/Software interface, and
4. Graphical User Interface (GUI).

A computerized engine-driven rotary endodontic instrument was designed to record the dynamic thermal changes during each cycle of the test sequence by keeping parameters constant. A biocompatible, water-resistant device with a temperature sensor (PT100-Pico, china) ranging from 0 to 200°C was used for recording data. The apices of the prepared teeth were sealed with a temperature sensor. The wire leads from the temperature sensor were embedded into the resin blocks to prevent accidental detachment. An apex locator (NSK, Japan) was used as an online position sensor which provided file position inside root canal which allowed determining the distance of files to apex of roots. The Hardware/Software interface is a part of software which controlled hardware components through computer and microcontroller [Figure 2]. The Microcontroller device was programmed to execute, record, and send the signals received from the temperature sensor to the computer. A microcontroller monitors the current of the motor, RPM, torque, force, and temperature. A pressure sensor was used to determine the apical force caused by the endodontics hand force. RPM, torque, and apical force were recorded in different stages and the computerized control system maintained them constant during operation. The rotary instruments were operated with controlled apical force (10 N) and constant force control system was applied via microcontroller. The test was conducted in low-strain amplitude condition. This was followed by a torque control at 3 NCm and file rotation speed at 350 RPM. Graphical User-friendly Interface (GUI) was designed for the integration of all aforementioned components, which allowed the dentist to interact with the entire system. ICE (Intelligent Control System for Endodontics) is software developed for integration and implementation of the designed

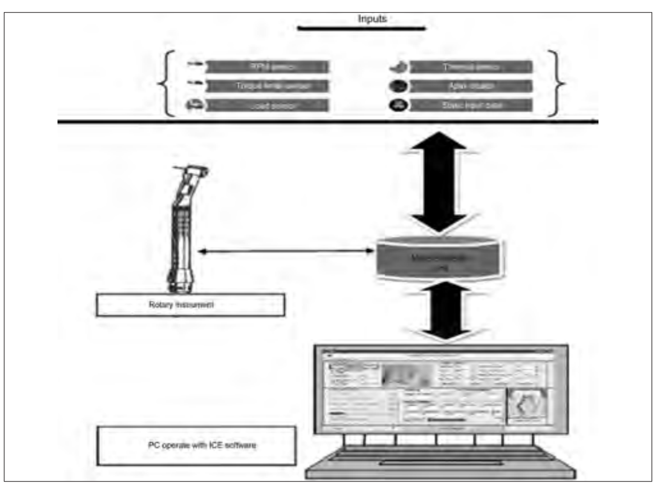

Figure 1: Experimental apparatus

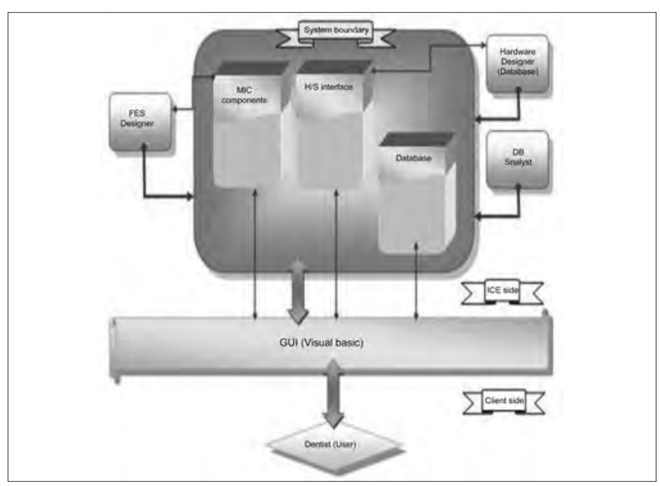

Figure 2: Software architecture

system collectively. ICE is comprised of the following steps. Data collected by sensors, stored in database system, were used for statistical analyses. Data which were recorded in each test stage of the experiment were saved and recorded as a Microsoft access. Experiment was conducted to quantify and evaluate the process variables during rotary instrument canal preparation for statistical analyses. Measurement of temperature and failure of the Ni-Ti instrument were preceded using thirty instruments (ProFile #25/.04). They were employed to prepare root canal filled with one of the irrigation solutions. The 5% solution of sodium hypochlorite was used in this study which represents extreme concentration which is commonly used in clinical settings. Water was used as a standard neutral solution, which is not considered as a suitable solution for canal preparation.

Several tests were conducted to measure and compare temperature change and determine file failure during canal preparation. The effect of three irrigation condition including sodium hypochlorite (NaOCl, 5%), water, and no irrigation (air) on the temperature gradient and failure of instruments (ProFile #25/.04) were evaluated, respectively. The solution in the canal was renewed frequently during the filling process. The 10 CC standardized solution regime for each test instrument was prepared and the temperature change was monitored every second at each stage. The total operation time for each irrigation system was thirty minutes. Each tooth underwent the irrigation process with the same manner. Ten distal canals from mandibular molars teeth with completely formed apices and presenting curvature between (1 - 20 degrees) were selected with radiographic picture using the method described by Schneider (Schafer and Florek 2003).[29] The teeth were stored in 100% humidity for one week to allow the resin, adhesives, and varnish to set completely. These teeth, selected with single and mature root canals, were used after temporary storage in 2% formal-saline. All teeth were crack-free when examined under a stereo microscope (Arska, 45´ Binocular AY11232).

In order to reach the root canal, the crowns were removed 3 mm above prior to canal preparation. An oval access preparation was made and the canals prepared to a standard flare with an apical size of 2 mm. Each instrument was placed in the root canal and aligned vertically over the center of the access preparation. Statically, studies of irrigation group scores were classified into three scores, the *P* value of score 1 (ANOVA test) was .01, score 2 (ANOVA test) was .01 and score3 (ANOVA test) was .01. The level of significance was set to 0.01.

RESULTS

The numbers of rotations for each treatment stage and for each tested tooth which finally resulted in instrument failure and consequently file fracture were determined by using our designed novel control system. The total number of rotations causing file failure under air, water, and NaOCl irrigation conditions is illustrated in Figure 3. The mean values of number of rotations to failure received from hardware under different environment were analyzed using a single-factor analysis of variance (ANOVA). As shown in Figure 3, the number of rotations to failure under NaOCl was significantly greater than that of air and water ($P<0.01$). Similarly, the number of rotations to failure under water was significantly greater than that of air ($P<0.01$).

The mean values of file temperature generated under different irrigation-tested solutions at different time points are depicted in Figure 4. The difference between mean values at each time point was performed by ANOVA. The file temperature values for the NaOCl group at all time points were significantly less than those of water ($P<0.01$) and non-irrigation circumstances. Statistical analysis revealed that there was a significant difference ($P<0.01$) between temperature of the air and non-irrigation conditions. Temperature differences between the 5% sodium

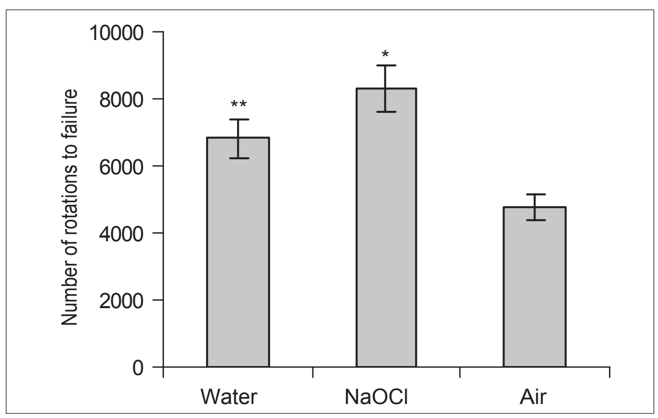

Figure 3: Diagram presenting means (standard deviation) of rotations to failure. Experimental conditions (air, immersion in 5% NaOCl and water). Significant differences (analysis of variance with ANOVA tests) are indicated by horizontal bars. *significantly different from water and air. **significantly different from air

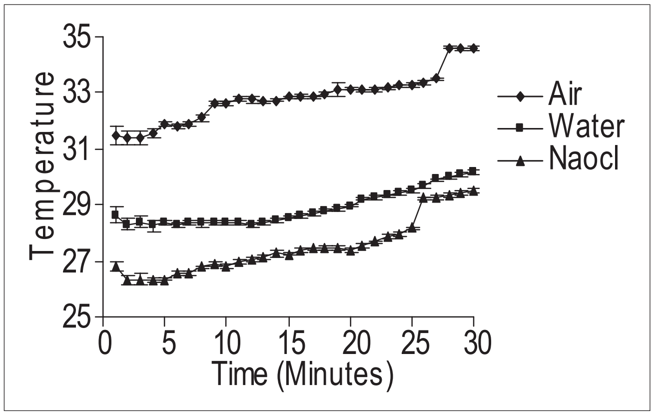

Figure 4: Temperature changes with time under three different irrigation conditions including air, water, and NaOCl. Data are presented as Mean ± SD

hypochlorite group and the water and air groups were found to be statistically significant; there appears to be an increase in temperature values from the no irrigation and water solution with comparison with sodium hypochlorite. By using the Q-square, it was shown that there were differences ($P<0.01$) between the three groups for solution.

DISCUSSION

The current research assessed the effects of irrigation of ProFile Ni-Ti rotary files in different solution and found a marked reduction of file failure and temperature with computerize control system.

Number of rotations to failure under different irrigation are in agreement with a recent study on ProTaper (Dentsply, Maillefer) files which indicated that with increase number of rotation this with correlation with file failure.[30] However, it contradicts the reports that resistance to fatigue of ProFiles was unaltered after immersion in NaOCl for 24 hours to be stable. Control of testing temperature is of paramount relevance since structural state of Ni-Ti alloy depends on temperature, as shown by D.S.C assays.[31]

This study was divided into two quite separate but related sections. The first section evaluated the effect of different solution on temperature gradient of instruments and the second part allowed observation of the effect of such solution on instrument failure that causes fracture during root canal preparation. The rotary instruments used in the test behaved as smart materials during testing. Thus, it was important that the machine was set to record temperature, RPM, and failure parameters that can cause fracture fatigue accurately. Temperature changes for files have been reported between 25°C to 34°C. The rotary instruments test machine used in this study was set to work on constant environmental condition. Irrigation solution has been recommended for the use of Ni-Ti rotary instrument; beneficial effects such as reduction of temperature or elimination of instrument fractures have not been conclusively demonstrated in particular in *in-vivo* status. This is a novel computerized control system *in vivo* approach designed to evaluate the effect of temperature changes on file failure with different solutions used during engine-driven rotary root canal preparation. It was suggested that cutting efficiency of Ni-Ti instruments in the presence of different irrigation was increased.[32,33] This was attributed to the ability of irrigation to remove debris from the canal. The promotion of cutting efficiency could be a reflection of a decrease in temperature. In the present study, irrigation solutions such as water and NaOCl were generally more effective than the non-irrigation condition in decreasing file and canal temperature. Whilst irrigation condition depends mainly on film formation and reversible physical surface modification, it is also possible to chemically modify the surfaces that are subjected to friction.

Previous studies involving the effect of irrigation systems on the resistance, fatigue, and corrosion on the files do not completely mirror actual clinical situation including high temperature, contact time, etc. Longer exposure times may increase the chemical effect on file mechanical and thermomechanical properties (i.e., corrosion phenomena), which results in reduced number of rotations to failure for Ni-Ti files.[34] Heating NaOCl solutions up to 60°C has been suggested to increase reactivity and antimicrobial and tissue-dissolving action.[35,36] However, the increase in reactivity may also enhance the corrosive potential of commercial NaOCl solutions and adversely affect mechanical properties of Ni-Ti rotary files. However, there is apparently no consensus whether or not corrosion presents a clinical problem. It needs to be pointed out that NaOCl is not only an indispensable endodontic solution[11,12] but may be used to decontaminate files during reprocessing before sterilization.[37,38]

In addition to the two variables "torque" and "force" that have been used previously to describe the action of endodontic files in rotary motion, in the current study, most of the factors such as RPM, force, canal condition, torque, file type, and strain amplitude that effects file fatigue and failure were significantly controlled and maintained constant in accordance with clinical conditions.[39,40]

Much smaller changes were registered for temperature change for all irrigation conditions, but these values may also reflect canal properties and the reaction of the instrument to the irregularities. Therefore, it seems likely that testing conditions in this research were relatively better than cited studies.

There was a slight increase in temperature paralleled by a reduction in number of rotation that caused file failure after immersion in NaOCl. This effect is variable in different solution conditions and most likely clinically significant. A possible reason for this effect may be formation of a brittle surface layer during immersion of superelastic Ni-Ti alloys.[29] Under the conditions of this *in vitro* study, ProFile rotaries showed a reduction in temperature cause less files failure. There was a high difference in the temperatures generated by the rotary instruments with different solution system, and the changes in temperature were directly related to the amount of wear and solution materials. They can also absorb the heat generated by device to increase the device lifetime. On the other hand, solution material acts as a heat absorber and increases the life of the instrument and prevents fracture of the instrument. Note that increased specimen temperature is one important parameter of fatigue but is not the only factor causing fatigue. The effect of thermal fatigue and creep also could be considered and would be a good subject for future research. The lifetime of Ni-Ti instruments can be increased by using 5% NaOCl solution rather than water or air. The number of cycles that instruments can withstand prior to fracture was increased according to solution used during canal preparation. The use of other solution methods like sodium hypochlorite (5%) and ethylenediaminetetraacetic acid (EDTA) (17%) and their effects on temperature and failure of files could be considered in future researches.

CONCLUSIONS

In conclusion, there appears to be a risk of file failure of Ni-Ti rotary files without irrigation, especially when non-irrigation conditions are used. The results of the current study suggest that liquid irrigation in fact reduce temperature and act as thermal heat absorber, and NaOCl irrigation solution is more suitable in comparison with water and air conditions. Furthermore, it is clear how wetting properties and phase transformation ability of Ni-Ti may be affected by the temperature and the application modalities present in this *in vivo* study. More research is needed to identify suitable lubricants that do decrease the file temperature and that are adequate for different Ni-Ti instrument size. The effect of other mechanical failure characteristics such as tribology could be considered in future researches.

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