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Effect Of Irrigation On Surface Roughness And Fatigue Resistance Of Rotary NiTi Files - An Atomic Force Microscopic Study

Research Article

Niha Naveed[1], James David Raj[2], Pradeep S[3*]

[1] Department of Conservative Dentistry and Endodontics, Saveetha Institute of Medical and Technical Science, Saveetha University, Chennai 600077, India.
[2] Reader, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Science, Saveetha University, Chennai 600077, India.
[3] Reader, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Science, Saveetha University, Chennai 600077, India.

Abstract

Aim: To investigate the effect of irrigation on the surface roughness and fatigue resistance of two rotary systems -ProTaper (Dentsply Sirona Endodontics,York,USA) and M-two (VDW GmBH, Munich,Germany).
Materials And Methods: New ProTaper F2 and M-two files of 25mm length (n=30) were investigated under an operating microscope (20×) and files with defects were discarded. Five new files of each group were analysed using AFM as the controls. Twenty-five files from each group were dynamically immersed using an endomotor in 3% NaOCl solution for 15 minutes at 37°C. This was followed by AFM analysis. The roughness average and root mean square values were analysed statistically using a paired sample t-test. Sixty endodontic study models (Nissin,Japan) were used for studying the fatigue resistance of irrigant-soaked instruments. Files from both the groups were inserted into the canal and rotated at 400 rpm using a 16:1 reduction handpiece at a torque of 2.5Ncm. The instruments were rotated freely until fracture occurred and timing was noted. The time was converted into a number of rotations to failure(Nf). The Nf of various groups were analysed using the one-way analysis of variance.
Results: For ProTaper files, the Ra and RMS values significantly increased ($P<0.05$) after the immersion when compared to the M-two files. The resistance to cyclic fatigue of both ProTaper and M-two files significantly decreased ($P<0.05$) by immersing in 3% NaOCl solution.
Conclusion: Under the limits of this study, immersing in NaOCl, the surface roughness of the files increased which in turn reduced the fatigue resistance.

Keywords: Atomic Force Microscopy; Fatigue Resistance; Irrigation; Sodium Hypochlorite.

Introduction

Nickel-Titanium (NiTi) instruments have become very popular in endodontics over the past decade. Their properties of shape-memory and superelasticity offer benefits over hand instrumentation in preparing curved root canals. They have significantly reduced the operating time with fewer chances of canal transportation. [1] However, fracture of NiTi files limits the prognosis of root canal treatments. [2] The fracture of rotary NiTi instruments are known to occur either as a result of cyclic flexural fatigue and torsional failure or a combination of both. [3]

Torsional fracture happens when the tip of the instrument becomes locked in the canal while the shank of the instrument continues to rotate. When the elastic limit of the metal alloy exceeds its threshold, it subsequently leads to the fracture of the file. Instruments that fracture as a result of torsional failure, reveal signs of plastic deformation such as unwinding, straightening, and

***Corresponding Author**:
Pradeep S,
Reader, Department of Conservative Dentistry and Endodontics, Saveetha Dental College and Hospitals, Saveetha Institute of Medical and Technical Science, Saveetha University, Chennai 600077, India.
Tel: 9710404482
E-mail: pradeeps@saveetha.com

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twisting. [4]

Flexural fatigue happens when the instrument continuously rotates freely in a curved canal producing tension or compression cycles at the point of maximum bending, which eventually leads to fracture. It has been proposed that repeated tension-compression cycles caused by the rotation within curved canals increases cyclic fatigue of the instrument over time.[4, 5] Cyclic fatigue fracture occurs primarily due to overuse of the metal alloy. Other factors potentially contributing to cyclic fatigue include corrosion and changes caused by thermal expansion and contraction.

According to certain studies [4-6], it was reported that the majority of instruments fractured due to cyclic fatigue thereby implying that overuse was the most significant mechanism of failure. On the contrary, other studies [7] stated torsional fracture as the dominant mode of fracture suggesting that it was the result of using excessive apical force during instrumentation or due to excessive curvature of the canal.

The factors affecting the fatigue resistance of NiTi rotary files include inherent material properties, cross-sectional design, surface treatments, and metallurgical characterization. [8] Root canal irrigants, an additional factor is known to affect the physical properties of NiTi files potentially. Root canal irrigants are constantly in contact with the endodontic files in the pulp chamber and root canal during biomechanical preparation.[9]

Recently, the atomic force microscope (AFM) has been recommended as a valuable research tool for probing the topography of various endodontic instruments.[10] An AFM uses a cantilever with a very sharp tip to scan over a sample surface. As the tip approaches the surface, an attractive force between the surface and the tip causes the cantilever to deflect towards the surface. As the cantilever approaches the surface, such that the tip comes in contact with it, there are increasing repulsive forces between the two and hence the cantilever deflects away from the surface. A laser beam is used to detect such deflections of the cantilever, towards or away from the surface. An incident beam is reflected off the flat surface of the cantilever, such that any cantilever deflection will cause slight alterations in the direction of the reflected beam. These changes can be detected by a position-sensitive photodiode (PSPD). The elevated and depressed characteristics on the sample surface influence the deflection of the cantilever, which is recorded by the PSPD. By using a feedback mechanism to control the height of the tip above the surface, constant laser position is maintained, so that the AFM can generate an accurate topographic map of the surface features [9-11].

The purpose of this study is to evaluate the effects of sodium hypochlorite (NaOCl) on the nanostructure surface of two widely used rotary systems- the ProTaper and M-two using AFM analysis and also evaluate its impact on fatigue resistance of the files.

Materials And Methods

The following files were studied: ProTaper F2 (Dentsply Sirona Endodontics, York, USA) and M-two (VDW GmbH, Munich, Germany) files, size 25 at the tip, a taper of 0.06 and a length 25 mm, were compared (Figure 1). The irrigant used was 3% NaOCl (Prime Dental Products Pvt Ltd, India). The new files of each group were investigated under a dental operating microscope (DOM) at ×20 magnification before the testing and files with defects were discarded. Thirty files of each brand were assigned to two groups. Group 1 (the control group) was composed of new instruments not immersed in solutions. Groups 2 were dynamically immersed in 3% NaOCl solution.

Five new files of each brand were chosen as the control group. Then, twenty-five instruments from each brand were dynamically immersed in 3% NaOCl solution for 15 minutes at 37 °C. For dynamic immersion, the endodontic instruments were attached to an endodontic motor (Dentsply Maillefer X-smart Endomotor, Dentsply Sirona) and rotated freely at a constant speed of 400 rpm. The same torque (2.5 Ncm) was applied to a small plastic tube containing a solution of 3% NaOCl. This was sufficient for contact with the instruments, but not the shaft, thus avoiding the galvanic action between the instrument and its handle. Immediately after removing from the immersion, all the files were rinsed with distilled water to neutralize the effect of irrigation and dried.

Atomic force microscopy (AFM)

By placing the files on the specimen stage of the AFM device with the handle always in the same position (Figure 2), the same selected areas were observed for the five new files (controls) as well as the twenty-five files immersed in 3% NaOCl. The files were attached to a glass plate using a double-sided adhesive tape. Each sample was placed on the AFM, and then 20 points were scanned along a 3 mm section of the tip of each file. The AFM images were recorded in the contact mode under ambient conditions with a 1.98 μm s-1 scanning speed. AFM probes (curvature radius <10 nm) mounted on cantilevers (250 μm) with a spring constant of 0.1 Nm -1 were used. The scanned areas were 1 ×1 μm2 squares. Three-dimensional (3D) images (512 × 512 lines) were processed using AFM analysis software. The roughness average (Ra) and root mean square (RMS) parameters were selected to investigate the vertical surface topography of endodontic files. An increase in Ra and RMS values meant alterations of the instrument surface caused by the irrigants.

Testing the fatigue resistance

To standardize the experimental conditions, the fatigue test was conducted in sixty endodontic study models of the maxillary first molar (Nissin, Japan) (Figure 3). The instruments of the control group and the instruments immersed in 3% NaOCl, of both the brands were subjected to rotational bending in the curved mesiobuccal canal of the endodontic study models. The files were rotated at 400 rpm using a 16 : 1 reduction handpiece powered by an electric motor at a torque of 2.5 Ncm. The file was rotated synchronized with timing by using a stopwatch. The instruments were rotated freely until fracture occurred. The timing was stopped when a fracture was detected visually and audibly. The time was then converted into a number of rotations to failure (Nf).

Statistical analysis

The data are presented as the means and standard deviations (SD). The Ra and RMS values between new instruments and irrigation immersed files were analysed statistically using a paired sample t-test. The number of rotations to failure (Nf) for the various groups was analysed using the one-way analysis of variance. The significance level was set at $P < 0.05$. The statistical analysis was performed using the SPSS version 20.0 software.

Results And Discussion

Figure 4 shows the three-dimensional AFM images of the ProTaper and M-Two files. The 3D AFM images of the surfaces of all the ProTaper and M-Two NiTi instruments including the new and those immersed in 3% NaOCl showed topographic irregularities at the nanometer scale.

Table 1 shows the mean roughness average (Ra) and root mean square (RMS) values of all the ProTaper and M-Two NiTi instruments including the new and those immersed in 3% NaOCl. The immersion of ProTaper and M-Two instruments in 3% NaOCl solution for 15 minutes demonstrated a significant increase ($P < 0.05$) in the mean values of Ra and RMS compared to the control groups. The ProTaper files showed more variation in surface topography in terms of Ra and RMS values after immersion in 3% NaOCl when compared to the M-Two files.

A total of 10 new NiTi instruments and 50 NiTi instruments after immersing in 3% NaOCl for 15 minutes were tested in the curved mesiobuccal canal of the upper first molar study model (Table 2). The resistance to cyclic fatigue of both ProTaper and M-two files significantly decreased ($P<0.05$) following immersion in the 3% NaOCl solution. The fatigue life of M-Two files was higher than that of ProTaper files irrespective of whether it was immersed in the irrigant.

In order to have proper disinfection of the root canal system, complete elimination of microorganisms is mandatory. For doing so, we have to rely on instrumentation and root canal irrigants. NaOCl is an effective antimicrobial with tissue-dissolving capabilities. The use of NaOCl to irrigate root canals is currently the

Table 1. The surface roughness of ProTaper and M-Two files before and after irrigation (p<0.05).

		ROUGHNESS AVERAGE Ra (nm)		ROOT MEAN SQUARE VALUE RMS (nm)	
	GROUPS	MEAN ± SD	P	MEAN ± SD	P
PROTAPER FILE	NEW	1.78 ± 0.82	0.008*	8.56 ± 4.26	0.023*
	NaOCl	8.96 ± 4.37		75.86 ± 24.01	
M- TWO FILE	NEW	0.28 ± 0.12	0.006*	6.69 ± 2.15	0.006*
	NaOCl	5.44 ± 3.12		53.48 ± 22.42	

Table 2. The number of rotations to failure (Nf) for new instruments and those immersed in different solutions.

	IMMERSION	N	MEAN (Nf)	SD	P
PROTAPER FILE	NEW	5	1257	372	0.006*
	NaOCl	25	1045	298	
M- TWO FILE	NEW	5	1649	145	0.023*
	NaOCl	25	1524	203	

Figure 1. 1a- ProTaper F2 (Dentsply Sirona Endodontics, York, USA); 1b- M-two (VDW GmBH, Munich, Germany).

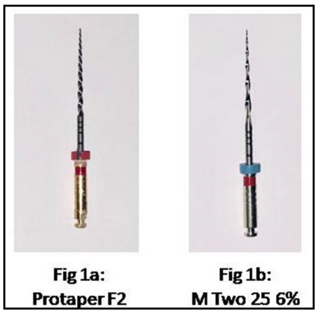


Figure 2. 2a- Atomic force microscope; 2b- Setting up the instrument for AFM analysis.

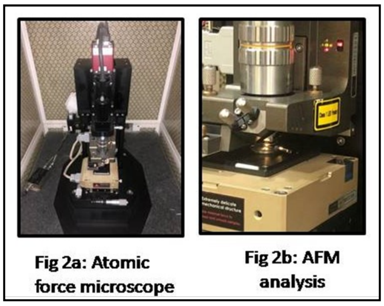


Figure 3. 3a- Endodontic study models of maxillary first molar (Nissan, Japan); 3b- Setup for Fatigue resistance test.

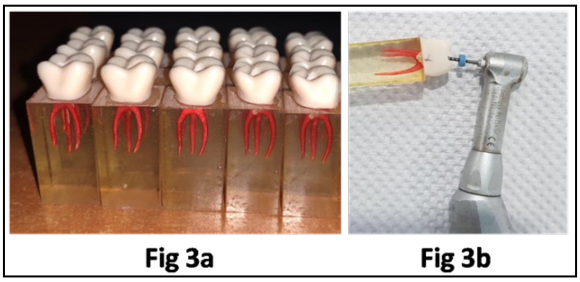
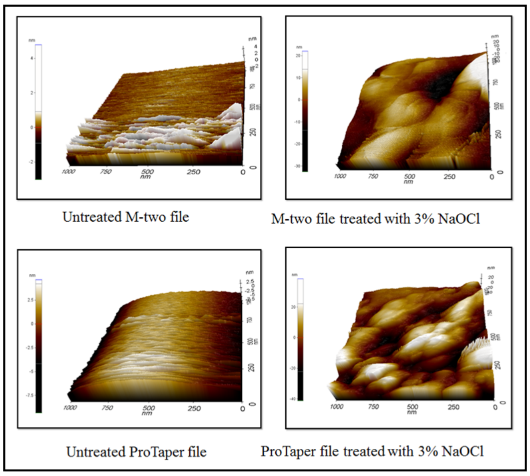


Figure 4. 3D AFM images of the surfaces of ProTaper and M-Two NiTi instruments including the new and those immersed in 3% NaOCl.



gold standard to achieve tissue dissolution and disinfection. Thus, rotary NiTi instruments come in contact with the solution during the chemomechanical preparations or cleaning procedures. [12] Many studies have been done to evaluate the effect of NaOCl on fracture properties and corrosion of nickel titanium (NiTi) files. But this is the first study to compare its effects on the ProTaper and M-Two files.

The ProTaper files represent a new generation of NiTi endodontic instruments for shaping root canals. The ProTaper system comprises three Shaping files- Sx, S1 and S2, and three Finishing files F1, F2 and F3. A unique feature of the ProTaper file is that each instrument has a changing percentage of tapers over the length of its cutting blades. This progressively tapered design serves to improve flexibility, cutting efficiency and safety significantly.[13] Another feature of the ProTaper instruments is their convex, triangular cross-section which enhances the cutting action. It also decreases the rotational friction between the blade of the file and dentin. ProTaper files have a changing helical angle and pitch over their cutting blades which reduces the potential of an instrument from inadvertently getting trapped into the canal. Each file has a noncutting, modified guiding tip which allows each instrument to safely follow the secured portion of the root canal while the small flat on its tip enhances its ability to find its way through the soft tissue and debris. In this study, we used the ProTaper F2 because it has been shown to possess lower resistance to fracture because of cyclic fatigue than the other instruments in the ProTaper series.

M-two endodontic instruments are a new generation of NiTi rotary instruments that have recently gained popularity. This system includes four basic instruments with variable tip sizes ranging from #10 to #25 and tapers ranging from 0.04 to 0.06. (size 10/0.04 taper, size 15/0.05 taper, size 20/0.06 taper, size 25/0.06 taper). The cross-section of M-two is an 'italic S' with two cutting blades. The rake angle of M-two is slightly negative which enhances the instrument's cutting effectiveness. The tip is non-cutting. The blade pitch of the instrument determines the helical angle. A shorter blade pitch will determine a closer helical angle while a longer one will result in a more open helical angle. This determines a greater cutting efficiency for the bigger sizes and a greater mechanical resistance together with a tendency to advance in the canal for the smaller ones. The flutes are deeper from the tip to the handle, thus increasing the capacity to remove debris coronally. [13, 14] All these features enable M-Two files to be highly efficient in preventing canal transportation. [14]

In this study, we have studied the effect that NaOCl has on the surface characteristics of ProTaper and M-Two files during chemomechanical preparation of the root canal and whether it has an influence on the fracture resistance of these instruments. Previous studies have proved that NaOCl is corrosive to many metals. It is known to selectively remove nickel from NiTi alloy. [11, 15-17] Not just as an irrigant, but it is believed to cause micropitting of the metal when used as a disinfectant to clean endodontic NiTi files. [12, 18-21] In our study, we observed the surface roughness of the files increased when immersed in NaOCl for 15 minutes at 37 °C. This may be attributed to the galvanic corrosion induced by the presence of dissimilar metals in the instrument, where one acts as the cathode of a galvanic couple, established when the instrument is immersed in NaOCl solution. The NiTi alloy may act as the anode and thus undergoes corrosion.[11, 21-24] Several investigations have demonstrated that NiTi files exhibit an inferior resistance to rotational fracture when compared to stainless steel files [9-11, 24-27] The phenomenon of early fracture in NiTi files may be due to the corrosion of files or due to other factors like the curvature of the canal in which they rotate. In our study, the surface roughness of ProTaper was found to be increased more compared to M-Two when they were immersed in NaOCl. This difference may be due to the dissimilarities in the surface finish of the instruments. This is the first report to correlate surface topography following irrigant contact and fatigue fracture as well as time to fracture. When subjected to cyclic fatigue, the ProTaper files fractured much earlier than the M-Two files irrespective of whether or not they were immersed in NaOCl. This difference may be attributed to various factors like the instrument cross-section or surface treatments.

To investigate the differences in the surface topography of the files, we used AFM analysis. Scanning electron microscope (SEM) had been the most widely used instrument to evaluate surface characteristics of different NiTi instruments. Recently AFM analysis was introduced to provide qualitative and quantitative information on the topography of various materials including endodontic files. [13, 14, 28, 29] previously in our university we had done several researches on root canal anatomy, canal disinfection and obturation techniques. [29] Several studies have now been performed using AFM as a reliable means of evaluating surface characteristics of NiTi files. [30] While the SEM could only provide a photographic image of the surface topography, thus giving us only qualitative data, the AFM provided a complete qualitative and quantitative analyses. In addition, AFM provided good contrast in details.

In summary, fracture of NiTi instruments has a complex and multifactorial etiology, primarily involving instrument cross-section and root canal curvatures. Our study provides interesting insights that another factor - surface topographical alterations by chemical agent contact- could play an important role in predisposing file separation. However, further studies are needed to evaluate the effect of different irrigant concentrations and sequences of files with and without surface treatments.

Conclusion

Immersion in sodium hypochlorite influences the roughness of root canal instruments differently. Immaterial of the change in surface roughness, immersion in NaOCl decreases the cyclic fatigue resistance of both the instruments investigated in this work. Thus we recommend not using the files under the given conditions for not more than 3 minutes for the ProTaper file and 4 minutes for the M-two file in a continuous manner inside the root canals.

Clinical Significance

Root canal irrigants are known to be a factor potentially affecting the physical properties of endodontic files, when in contact within the pulp chamber and root canal during instrumentation. Therefore, this study focuses on the effect of root canal irrigation on the nanostructure surface of various endodontic files under an atomic force microscope.

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