Cyclic Fatigue Resistance of Three Different Nickel-Titanium Instruments after Immersion in Sodium Hypochlorite

Eugenio Pedullà, PhD, DDS, Nicola M. Grande, PhD, DDS,† Gianluca Plotino, PhD,† Alfio Pappalardo, DDS,* and Ernesto Rapisarda, MD, DDS**

Abstract

Introduction: The purpose of this study was to assess the resistance to cyclic fatigue of three nickel-titanium (NiTi) files after the immersion in sodium hypochlorite (NaOCl) solution in conditions similar to those used in clinical practice. **Methods:** A total of 150 new Twisted Files (SybronEndo, Orange, CA), Revo S SU files (Micro Mega, Besancon, France), and Mtwo files (Sweden and Martina, Padova, Italy), size 25.06, were tested. Fifty files of the same brand were randomly assigned to five groups (n = 10) and submitted to the following immersion protocol in 5% NaOCl at 37°C for 16 mm: no immersion (control), 5 minutes statically, 1 minute statically, 5 minutes dynamically (300 rpm/min), and 1 minute dynamically. Resistance to cyclic fatigue was determined by counting the numbers of cycles to failure in a 60° curve with a 5-mm radius. Data were analyzed by two-way analyses of variance. **Results:** Resistance to cyclic fatigue of the same NiTi file was not significantly affected by immersion in NaOCl ($P > .05$). The Twisted File showed a higher resistance in all groups than Revo S SU ($P < .001$). The comparison between the same groups of Twisted Files and Mtwo files or between Mtwo and Revo S files did not show significant differences ($P > .05$) except for two cases: group 2 of the Twisted Files and Mtwo files and group 5 of the Mtwo and Revo S SU files ($P < .05$). **Conclusions:** Static or dynamic immersion in NaOCl for 1 minute or 5 minutes did not reduce the cyclic fatigue resistance of NiTi significantly. However, the type of instrument influences cyclic fatigue resistance. In our study, Twisted Files were more resistant followed by Mtwo and Revo S SU files. *(J Endod 2011;37:1139–1142)*

Key Words

Corrosion, cyclic fatigue, nickel-titanium, rotary instruments, sodium hypochlorite

The goals of root canal treatment are to achieve a high standard of disinfection of the root canal system through chemomechanical instrumentation and fill the canal to prevent reinfection (1, 2). Canal preparation requires a continuous and progressively tapered shape so as to allow irrigants to be delivered to the apical section of canal and perform its bactericidal action (3, 4) and to dissolve organic substances (5). Over the last 2 decades, nickel-titanium (NiTi) rotary files have become increasingly popular for this task (6). There is clear experimental and clinical evidence that the use of NiTi files, compared with stainless steel K-files, promotes canal shapes that follow the original canal path with less procedural errors (6, 7). On the other hand, *in vitro* studies have suggested that NiTi rotary files fracture more often than stainless steel files (8). The fracture of instruments used in rotary motion occurs in two different ways: torsion and flexural cyclic fatigue (9, 10). Torsional fracture occurs when an instrument tip or another part of the instrument is locked in a canal while the shank continues to rotate (11). Fracture caused by fatigue through flexure occurs because of metal fatigue. The instrument does not bind in the canal, but it rotates freely in a curvature, generating tension/compression cycles at the point of maximum flexure until the fracture occurs. This repeated tension-compression cycle, caused by rotation within curved canals, increases cyclic fatigue of the instrument over time and may be an important factor in instrument fracture (6, 12). Efforts are ongoing to identify factors that impact NiTi rotary fracture resistance (eg, file sequence, torque-limiting motors, cross-sectional file design, and file surface treatments as electropolishing and magneto-electropolishing processes) (13, 14). One additional factor potentially limiting the resistance to fatigue and torsional fracture is corrosion that may occur in the presence of NaOCl solution (15–17). Sodium hypochlorite (NaOCl) is the most common irrigant used in root canal treatment. It has a very unpleasant odor; it tends to discolor (18) and corrode surgical instruments (19). NiTi instruments come into contact with NaOCl during disinfection (20) or when the solution is present in the pulp chamber and root canal during instrumentation (21), and for this reason the time course and extent of corrosive action of NaOCl on NiTi surfaces are currently unclear (22). The corrosion patterns, involving selective removal of nickel from the surface, can create micropitting (23). It is supposed that these microstructural defects can lead to areas of stress collection and crack formation, weakening the structure of the instrument (24). The corrosive effect of NaOCl on endodontic NiTi instruments has been studied previously. Haikel et al (25) used hand instruments totally immersed in a 2.5% solution for 24 to 48 hours and detected no obvious corrosion. Busslinger et al (26) used 5% NaOCl for 30 or 60 minutes and Lightspeed rotary instruments and found corrosion patterns, even if the authors were not sure of the clinical implications (Discus Dental, Culver City, CA). However, these studies provide a contact of endodontic instruments with hypochlorite solution only in static mode and for different times from what occurs in clinical conditions. In fact, the working part of endodontic instruments contacts dynamically the NaOCl solution only for a few minutes during endodontic

From the *Department of Surgery, University of Catania, Catania, Italy; and †Department of Endodontics, Sapienza University of Rome, Rome, Italy.
Address requests for reprints to Dr Eugenio Pedullà, Via Cervignano, 29, 95129, Catania, Sicily, Italy. E-mail address: eugeniopedulla@gmail.com
0099-2399/$ - see front matter

doi:10.1016/j.joen.2011.04.008

therapy. If present, corrosion may negatively affect physical properties of NiTi files (22). Therefore, the aim of the present study was to assess resistance to cyclic fatigue of three NiTi files after immersion in NaOCl solutions in conditions similar to those used in clinical practice.

Materials and Methods

A total of 150 new Twisted Files (SybronEndo, Orange, CA), Revo S SU files (Micro Mega, Besancon, France), and Mtwo files (Sweden & Martina, Padova, Italy), size 25.06, were tested. Fifty files of the same brand, all from the same production lot, were randomly assigned (using a random numbers table) to five different groups of 10 each. Group 1 (the control group) was composed of new instruments not immersed in solution. Instruments of groups 2, 3, 4, and 5 were immersed in 5% NaOCl (Niclor, OGNA Laboratory, Milan, Italy) at 37°C for 16 mm. For that purpose, files were placed in small separate glass containers. Files of groups 2 and 3 were statically immersed in NaOCl solution for 5 minutes and 1 minute, respectively; instruments of groups 4 and 5 were dynamically (300 rpm) immersed in solution for 5 minutes and 1 minute, respectively. For the dynamic immersion, the endodontic instruments were attached to an endodontic motor and rotated freely at constant speed (300 rpm) in a small glass container with the amount of the NaOCl solution necessary to contact 16 mm of instruments. Immediately after removal from immersion, all files were rinsed by bidistilled water to neutralize the effect of NaOCl, dried, registered with an ID number, and stored in glass vials. The instruments of all five groups of three brands were then subjected to cyclic fatigue test using a mechanical device (Fig. 1) specifically developed for the purpose and already used in previous studies (27–29). The apparatus was connected to an endodontic motor and enabled the instrument to rotate freely within a stainless steel artificial canal at a constant pressure. The artificial canal was manufactured by reproducing an instrument's size and taper. It provided the instrument with a suitable simulated root canal with a 60° angle of curvature and a 5-mm radius of curvature. The center of the curvature was 6 mm from the tip of the instrument, and the curved segment of the canal was approximately 6 mm in length. The instruments were rotated at a constant speed of 300 rpm using a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled electric motor (VDW Silver, VDW GmbH–Dentsply International Inc, Munich, Germany). Torque was set at 2 N/cm. To reduce the friction of the file as it contacted the artificial canal walls, a special high-flow synthetic oil designed for the lubrication of mechanical parts (Super Oil; Singer Co Ltd, Elizabethport, NJ) was applied. For each instrument, the time in seconds from the start of the test until the moment of breakage was recorded with a chronometer to an accuracy of 0.1 seconds, and the number of cycles to failure (NCF) were calculated to the nearest full number multiplying the seconds by 5 (number of cycles for second using 300 rpm). The Kolmogorov-Smirnov for normality test revealed a nonnormal distribution of fatigue data in all groups of the same brand, and, therefore, nonparametric statistical analysis was chosen. A two-way analysis of variance and Scheffè post hoc tests at 0.05 (MedCalc Software, Mariakerke, Belgium) were used to evaluate the effect of immersion in hypoclorite solution on fatigue resistance. The number of rotations to fracture was dependent variables, whereas the brand of files and immersion conditions were independent measures.

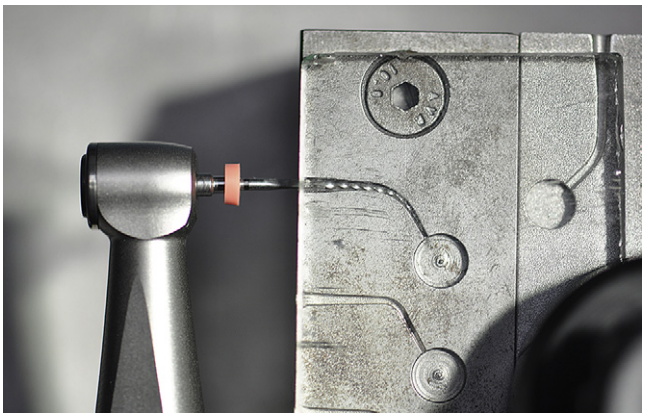

Figure 1. The Twisted File instrument inserted in the cyclic fatigue testing device.

Results

Descriptive statistics are summarized in Table 1 and Figure 2. The mean NCFs of all Twisted File groups are greater than that of Mtwo and Revo S. The inferential analysis revealed no statistically significant differences between the five groups of the same brand, considering the immersion conditions as the independent variable (two-way analysis of variance, $P = .71$; interaction = 0.84), but there were statistically significant differences between the same group considering the brand as the independent variable (two-way analysis of variance, $P < .0001$). Post hoc analysis revealed a significantly higher resistance to cyclic fatigue in all groups of Twisted Files when compared with respective groups of Revo S ($P < .05$ for each comparison). The comparison between the groups of Twisted File and Mtwo or Mtwo

TABLE 1. Descriptive Statistics of Cyclic Fatigue Resistance: NCF for Instruments

Brand	Group	n	Mean (seconds)	Median	Standard deviation	Standard error of mean	Min	Max
Twisted File	1	10	742.5	750	87.38	27.63	555	865
	2	10	729.5	720	121.7	38.5	575	915
	3	10	703	735	92.26	29.18	520	795
	4	10	802.5	807.5	84.73	26.79	710	975
	5	10	755	767.5	138.9	43.92	450	915
Revo S SU	1	10	395.5	375	72.17	22.82	315	565
	2	10	417.5	452.5	124.3	39.32	155	540
	3	10	392	390	92.14	29.14	275	545
	4	10	390	367.5	92.33	29.2	260	530
	5	10	382	390	35.76	11.31	305	420
Mtwo	1	10	560	540	107.5	33.99	450	730
	2	10	533	480	122	38.59	380	700
	3	10	563	512.5	145.5	46.01	435	905
	4	10	579.5	552.5	113	35.73	450	800
	5	10	571.5	572.5	145.8	46.12	415	840

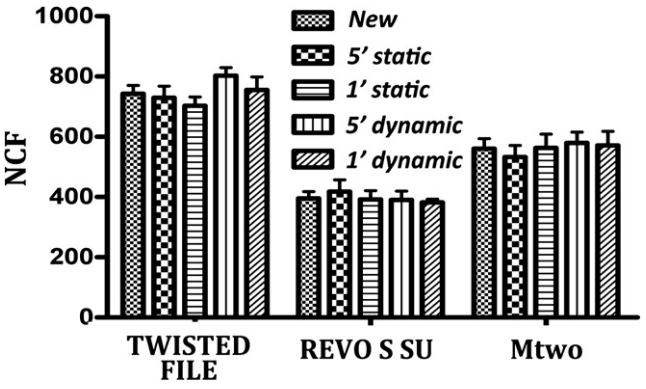

Figure 2. A column bar plot of NCF for instruments by groups.

and Revo S did not show statistically significant differences ($P > .05$) except in two cases. Group 2 (files statically immersed in NaOCl for 5 minutes) of the Twisted File was more resistant to cyclic fatigue than the same group of Mtwo, and group 5 (files dynamically immersed in NaOCl for 1 minute) of Mtwo was more resistant than the same group of Revo S ($P < .05$).

Discussion

This study aimed to assess the resistance to cyclic fatigue of three NiTi files after immersion in NaOCl solutions in conditions similar to the clinic. Different times and static or dynamic immersion were used. Many studies have considered the effects of NaOCl on NiTi alloys. Berutti et al (30) immersed ProTaper rotary instruments in 5% NaOCl solution at 50°C for 5 minutes and found corrosion effects afflicting the cyclic fatigue fracture resistance, especially when the instrument was completely immersed in solution, because of galvanic corrosion phenomena caused by the different composition of the working part and the shaft of ProTaper (Dentsply Maillefer, Ballaigues, Switzerland). Peters et al (22) investigated the effect of immersion in 5.25% NaOCl for 1 or 2 hours at temperatures of 21°C and 60°C on torque and fatigue resistance of 25.04 ProFile (Dentsply Maillefer) and RaCe (FKG Dentaire, La Chaux-de-Fonds, Switzerland) files and found that NiTi rotary files exhibit reduced resistance to cyclic fatigue after contact with heated NaOCl, so they should be considered single-use instruments (22). However, Darabara et al (16) found no signs of corrosion after immersion for 1 hour in 5.25% NaOCl and 17% EDTA heated to 37°C. Possible explanations for these conflicting findings are the different test and immersion protocols used. Immersion varied substantially (between 5 minutes and 48 hours) provided that the instrument was totally and statically immersed in the solution. These conditions, which mimic those used during cleaning procedures of the instruments involving NaOCl as a disinfectant agent, are very unlikely in clinical practice when the shaft is completely lodged within the head of the endodontic handpiece and the endodontic file rotates during root canal therapy. In order to get closer to clinical conditions, the protocol of this study provides static or dynamic (300 rpm) immersion in 5% NaOCl solution at 37°C for 1 or 5 minutes only of the working part (16 mm) of 25.06 endodontic NiTi rotary files of three different brands. Considering that the mean life of instruments in group 1 (control group) in the test conditions was between 1 minute 16 seconds (382 NCF, Revo S SU) and 2 minutes 51 seconds (755 NCF, Twisted File), it was decided to choose 1 minute and 5 minutes as the contact time of the instrument with the solution so as to remain within realistic times for clinical practice. NaOCl solution was used at 37°C to simulate the body temperature. Only 16 mm from the tip of instruments was immersed in solution to avoid galvanic corrosion phenomena that are induced when two (or more) dissimilar metals are coupled in a corrosive electrolyte (such as NaOCl solution) (31). However, the clinicians should consider that the use of heating NaOCl (50°C or 60°C) or its use as a disinfectant agent of NiTi files as well as the onset of galvanic corrosion during endodontic therapy (the presence of NaOCl solution in pulp chambers of teeth with restorations of different metal such as amalgam restorations, gold crowns, and so on) trigger corrosion processes as shown in other studies (22, 30) and might further reduce the cyclic fatigue resistance of file. In these experimental conditions, static or dynamic immersion in NaOCl for 1 minute or 5 minutes did not reduce significantly the cyclic fatigue resistance of NiTi files. These findings may be because of the type of analysis. The cyclic fatigue device generates the maximum stress at the center of the simulated curve (about 6 mm from the tip), so if a corrosive zone was present at that level, the instrument could break early. However, if the corrosive attack hits the instrument in a different area from that of maximum stress generated by the testing device, the resistance to cyclic fatigue of the instrument will probably not be reduced. Under the conditions of this *in vitro* study, statistically significant differences were found between the three different NiTi files tested; Twisted Files were more resistant to cyclic fatigue than Mtwo and Revo S SU. These differences are probably because of the different type of alloy and production processes used for these instruments. In fact, Twisted File instruments were produced by heating and twisting, whereas Mtwo and Revo S SU were produced by traditional grinding methods. Moreover, it has been shown that the different cross-section and cutting flutes design of the three NiTi instruments used in this study do not influence the fatigue resistance of files that are of the same size (32–34). In conclusion, under these experimental conditions, static or dynamic immersion in NaOCl for 1 minute or 5 minutes did not reduce significantly the cyclic fatigue resistance of NiTi files. However the type of instrument influenced cyclic fatigue resistance. In our study, Twisted Files were more resistant than Mtwo and Revo S SU.

Acknowledgments

The authors deny any conflicts of interest related to this study.

References

1. Schilder H. Filling root canals in three dimensions. Den Clin North Am 1967;11:723–44.
2. Schilder H. Cleaning and shaping the root canal. Den Clin North Am 1974;18:269–96.
3. Best M, Springthorpe VS, Sattar SA. Feasibility of a combined carrier test for disinfectants: studies with a mixture of five types of microorganisms. Am J Infect Control 1994;22:152–62.
4. Rutala WA, Weber DJ. Uses of inorganic hypochlorite (bleach) in health-care facilities. Clin Microbiol Rev 1997;10:597–610.
5. Koskinen KP, Stenvall H, Uitto VJ. Dissolution of bovine pulp tissue by endodontic solutions. Scan J Dent Res 1980;88:406–11.
6. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30:559–67.
7. Pettiette MT, Metzger Z, Phillips C, Trope M. Endodontic complications of root canal therapy performed by dental students with stainless-steel K-files and nickel-titanium hand files. J Endod 1999;25:230–4.
8. Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P. Mechanical root canal preparation with NiTi rotary instruments: rationale, performance and safety. Status report for the Am J of Dentistry. Am J Dent 2001;14:324–33.
9. Sattapan B, Nervo GJ, Palamara JEA, et al. Defects in rotary nickel-titanium files after clinical use. J Endod 2000;26:161–5.

10. Ullmann CJ, Peters OA. Effect of cyclic fatigue on static fracture loads in ProTaper nickel-titanium rotary instruments. J Endod 2005;31:183–6.
11. Martín B, Zelada G, Varela P, et al. Factors influencing the fracture of nickeltitanium rotary instruments. Int Endod J 2003;36:262–6.
12. Parashos P, Gordon I, Messer HH. Factors influencing defects of rotary nickel titanium endodontic instruments after clinical use. J Endod 2004;30:722–5.
13. Rapisarda E, Bonaccorso A, Tripi TR, et al. The effect of surface treatments of nickel-titanium files on wear and cutting efficiency. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:363–8.
14. Praisarnti C, Chang JW, Cheung GS. Electropolishing enhances the resistance of nickel-titanium rotary files to corrosion-fatigue failure in hypochlorite. J Endod 2010;36:1354–7.
15. O'Hoy PYZ, Messer HH, Palamara JEA. The effect of cleaning procedures on fracture properties and corrosion of NiTi files. Int Endod J 2003;36:724–32.
16. Darabara M, Bourithis L, Zinelis S, Papadimitriou GD. Susceptibility to localized corrosion of stainless steel and NiTi endodontic instruments in irrigating solutions. Int Endod J 2004;37:705–10.
17. Sonntag D, Heithecker K. Korrosion von Nickel-Titan-Instrumenten. Endodontie 2006;15:23–30.
18. Basrani BR, Manek S, Sodhi RN, Fillery E, Manzur A. Interaction between sodium hypochlorite and chlorhexidine gluconate. J Endod 2007;33:966–9.
19. White RR, Hays GL, Janer LR. Residual antimicrobial activity after canal irrigation with chlorhexidine. J Endod 1997;23:229–31.
20. Savage NW, Walsh IJ. The use of autoclaves in the dental surgery. Aust Dent J 1995; 40:197–200.
21. Bystrom A, Sundqvist G. Bacteriologic evaluation of the effect of 0.5 percent sodium hypochlorite in endodontic therapy. J Oral Surg 1983;55:307–12.
22. Peters OA, Roehlike JO, Baumann MA. Effect of immersion in sodium hypochlorite on torque and fatigue resistance of nickel-titanium instruments. J Endod 2007;33: 589–93.
23. Sarkar NK, Redmond W, Schwaninger B, Goldberg AJ. The chloride corrosion behaviour of four orthodontic wires. J Oral Rehabil 1983;10:121–8.
24. Oshida Y, Sachdeva RC, Miyazaki S. Microanalytical characterization and surface modification of TiNi orthodontic archwires. BioMed Master Eng 1992;2:51–69.
25. Haikel Y, Serfaty R, Wilson P, Speisser JM, Allemann C. Mechanical properties of nickeltitanium endodontic instruments and the effect of sodium hypochlorite treatment. J Endod 1998;24:731–5.
26. Bussliger A, Serner B, Barbakow F. Effects of NaOCl on nickel-titanium light speed instruments. Int Endod J 1998;31:290–4.
27. Grande NM, Plotino G, Pecci R, et al. Cyclic fatigue resistance and three-dimensional analysis of instruments from two nickel-titanium rotary systems. Int Endod J 2006; 39:755–63.
28. Gambarini G, Grande NM, Plotino G, et al. Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. J Endod 2008;34:1003–5.
29. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel-titanium rotary instruments. J Endod 2009;35:1469–76.
30. Berutti E, Angelici E, Rigolone M, Migliaretti G, Pasqualini D. Influence of sodium hypochlorite on fracture properties and corrosion of ProTaper rotary instruments. Int Endod J 2006;39:693–9.
31. Angelini E, Zucchi F, Caputo A. Degradation processes on metallic surfaces. In: Barbucci R, ed. Integrated biomaterial science. Dordrecht: Kluwer Academic–Plenum Publishers; 2002:308–23.
32. Cheung GS, Darvell BW. Low-cycle fatigue of NiTi rotary instruments of various cross-sectional shapes. Int Endod J 2007;40:626–32.
33. Testarelli L, Grande NM, Plotino G, et al. Cyclic fatigue of different nickel-titanium rotary instruments: a comparative study. Oper Dent J 2009;3:55–8.
34. Chaves Craveiro de Melo M, Guiomar de Azevedo Bahia M, Lopes Buono VT. Fatigue resistance of engine-driven rotary nickel-titanium endodontic instruments. J Endod 2002;28:765–9.