REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
30-01-2012

2. REPORT TYPE
Scientific journal publication

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
The effect of autoclaving on torsional moment of two nickel–titanium endodontic files

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
J. B. King, H. W. Roberts, B. E. Bergeron & M. J. Mayerchak

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Tinker Air Force Base, Oklahoma City, OK

Keesler Air Force Base,
Biloxi, MS

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
International Endodontic Journal, doi:10.1111/j.1365-2591.2011.01958.x
Wiley Blackwell Publishing,
111 River Street Hoboken, NJ 07030-74

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Aim To evaluate the effects of repeated autoclaving on torsional strength of two nickel–titanium (NiTi) rotary endodontic files: Twisted Files (SybronEndo, Orange, CA, USA) and GT Series X files (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA). Methodology Four groups of 20 GT Series X (size 20, .06 taper) and four groups of 20 Twisted Files (size 25, .06 taper) were subjected to 0, 1, 3 or 7 autoclave cycles. The nonautoclaved files served as controls. Failure in torsion was recorded using a torsiometer according to ANSI/ADA 58 and ISO 3630-1 standards. Mean results were analysed using analysis of variance (anova) at a 95% confidence level. Dunnett's procedure was used for post hoc analysis. Results There was no significant difference in torsional moment between the number of autoclave cycles for Twisted Files. However, the mean torque at failure was significantly lower for GT Series X files after three ($P < 0.001$) and seven ($P < 0.001$) autoclave cycles. For Twisted Files, there was a significant increase ($P < 0.001$) in mean number of degrees of rotation to failure with more autoclave cycles compared to nonautoclaved files. For GT Series X files, there was no significant association ($P = 0.527$) between the number of autoclave cycles and the degrees of rotation to failure. Conclusions Repeat autoclaving of unused GT Series X files between three and seven times resulted in a significant reduction in torsional strength, whilst there was no effect observed for Twisted Files.
. International Endodontic Journal, 45, 156–161, 2012.

15. SUBJECT TERMS
autoclave, nickel–titanium, rotary endodontic, torsion.

16. SECURITY CLASSIFICATION OF: unclassified			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Howard W Roberts, Col
a. REPORT unclassified	**b. ABSTRACT** unclassified	**c. THIS PAGE** unclassified		5	**19b. TELEPHONE NUMBER** *(include area code)* (228) 376-5190

International Endodontic Journal

doi:10.1111/j.1365-2591.2011.01958.x

The effect of autoclaving on torsional moment of two nickel–titanium endodontic files

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Abstract

King JB, Roberts HW, Bergeron BE, Mayerchak MJ. The effect of autoclaving on torsional moment of two nickel–titanium endodontic files. *International Endodontic Journal*, **45**, 156–161, 2012.

Aim To evaluate the effects of repeated autoclaving on torsional strength of two nickel–titanium (NiTi) rotary endodontic files: Twisted Files (SybronEndo, Orange, CA, USA) and GT Series X files (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA).

Methodology Four groups of 20 GT Series X (size 20, .06 taper) and four groups of 20 Twisted Files (size 25, .06 taper) were subjected to 0, 1, 3 or 7 autoclave cycles. The nonautoclaved files served as controls. Failure in torsion was recorded using a torsiometer according to ANSI/ADA 58 and ISO 3630-1 standards. Mean results were analysed using analysis of variance (ANOVA) at a 95% confidence level. Dunnett's procedure was used for *post hoc* analysis.

Results There was no significant difference in torsional moment between the number of autoclave cycles for Twisted Files. However, the mean torque at failure was significantly lower for GT Series X files after three ($P < 0.001$) and seven ($P < 0.001$) autoclave cycles. For Twisted Files, there was a significant increase ($P < 0.001$) in mean number of degrees of rotation to failure with more autoclave cycles compared to non-autoclaved files. For GT Series X files, there was no significant association ($P = 0.527$) between the number of autoclave cycles and the degrees of rotation to failure.

Conclusions Repeat autoclaving of unused GT Series X files between three and seven times resulted in a significant reduction in torsional strength, whilst there was no effect observed for Twisted Files.

Keywords: autoclave, nickel–titanium, rotary endodontic, torsion.

Received 15 May 2011; accepted 28 August 2011

Introduction

Nickel–titanium (NiTi) is an alloy with increased flexibility and shape memory capabilities, and continued research into different NiTi manufacturing methods has been hallmarked with the goal of improving the physical and mechanical properties of the NiTi rotary endodontic file (Thompson 2000). These fabrication techniques are usually targeted towards increasing file flexibility and strength, which are promoted to enhance treatment efficiency and reduce the rate of iatrogenic errors (Gambarini 2001, Gambarini *et al.* 2010). The aetiology of instrument fracture during root canal preparation is complex; however, cyclic fatigue and torsional failure have been frequently implicated (Gambarini 2001, Xu *et al.* 2006). Cyclic fatigue conditions involve forces imparted on the rotating endodontic file as it repeatedly bends around a curved canal, often causing failure independent of torsional (twisting) forces acting on the file. Additionally, friction encountered during the negotiation of narrow root canals can cause files to bind, which can lead to fracture if the mechanical properties of the NiTi alloy are exceeded (Xu *et al.* 2006).

A recently marketed NiTi file system, the Twisted File (SybronEndo, Orange, CA, USA), is said to be fabricated using a unique, proprietary process involving heating, cooling and twisting of a NiTi wire blank (SybronEndo Literature 2010). This process is said to induce changes in the NiTi molecular phase structure, which in turn is

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advertised to optimize the Twisted File's physical properties (SybronEndo Literature 2010). According to manufacturer's promotional literature and nonscientific publications, the Twisted File is alleged to possess three to four times the resistance to the effects of torsion and cyclic fatigue, and in most root canal configurations, a single file is advertised to be used to prepare and shape the entire tooth (Sybron Endo Literature 2010).

The GT Series X file (Tulsa Dental Specialties, Tulsa, OK, USA) is based on M-wire technology and is said to be based on a proprietary NiTi composition combined with a reduced core mass design (GT Series X Brochure 2009). Accordingly, the reduced core is described as achieved by reducing the number of cutting flutes combined with wider and increased blade angle to produce a slimmer instrument that is advertised to create a more flexible, yet strong design for increased cutting efficiency (GT Series X Brochure 2009).

Manufacturer's instructions for GT Series X files state they are intended exclusively for single-patient use (GT Series X Brochure 2009), whilst the use of Twisted File is dependent on canal conditions, clinical demands placed upon the file and critical file inspection before and after each use (Sybron Endo Literature 2010). The Twisted File manufacturer's instructions also state that the file should not be used if the file becomes deformed, looses cutting efficiency or fails to function normally (Sybron Endo Literature 2010). Whilst physical evidence of file deformation is evident, assessment of rotary file's cutting efficiency and function is more subjective in nature and may tempt clinicians to use the Twisted File to prepare and shape more than one treatment case. This creates a situation in which a rotary endodontic file may be subject to multiple autoclave sterilization cycles. Furthermore, in addition to autoclaving before prior use, practitioners also may prefer using prearranged packages of selected files of which not all may be used during a single treatment. This could involve unused rotary files that might be subjected to multiple autoclave cycles for subsequent cases.

The effects of autoclaving NiTi files have generated contrasting reports: some studies suggest that sterilization may increase NiTi torsional strength (Silvaggio & Hicks 1997), whilst other investigations have reported increased susceptibility to cyclic fatigue and decreased torsional moment (Canalda-Sahili *et al.* 1998, Viana *et al.* 2006). Additional research suggests repeated NiTi autoclave sterilization negatively affects the mechanical properties and leads to premature instrument failure (Eggert *et al.* 1999, Rapisarda *et al.* 1999, Schäfer 2002, Alapati *et al.* 2005, Valois *et al.* 2008).

The purpose of this study was to observe the effect of 1, 3 and 7 autoclave cycles on the torsional failure of Twisted Files and GT Series X files. The hypothesis was formed that autoclave conditions would not have an effect on either NiTi file system (null hypothesis).

Materials and methods

Eighty GT Series X (size 20, .06 taper) files and eighty Twisted Files (size 25, .06 taper) were each divided into four groups ($n = 20$). The control group was not subjected to autoclaving. Groups 1, 2 and 3 were subjected to autoclave sterilization (STATIM 5000; Sciscan USA, Canonsburg, PA, USA) one, three and seven times, respectively. Each autoclave cycle consisted of a peak temperature of 132 °C for 6 min, and all cycles were performed according to manufacturer's instructions. For Groups 2 and 3, instruments were cooled to room temperature, removed from the sterilization packaging and repackaged prior to subsequent autoclave cycles. After the annotated autoclave cycles were complete, groups were subjected to torsional testing.

Torsional testing was accomplished in accordance with ANSI 58 and ISO 3630-1 standards using a microprocessor-controlled torsiometer (Torsiometer/Memocouple; Sabri Dental Enterprises, Downer's Grove, IL, USA). Prior to respective file placement in the torsiometer, the handle was removed at the point of shaft attachment with wire cutters, with the shaft end secured in a chuck connected to the torsiometer's rotating motor. The file's distal three millimetres was then secured into the torsiometer's torque sensor. Each file was then rotated in a clockwise direction as viewed from the shank end at a speed of two rotations per minute until file tip fracture (Best *et al.* 2004) with torsional moment and rotational degrees to failure recorded. Mean results were evaluated using analysis of variance (ANOVA) at a 95% level of confidence. Dunnett's procedure was used for *post hoc* analyses.

Results

Mean torsional testing results are shown in Table 1. A significant difference ($P < 0.001$) in file failure torque was identified within the GT Series X files, with files undergoing three and seven autoclave cycles demonstrating significantly lower failure torque as compared to control ($P < 0.001$). In contrast, no significant

Table 1 Mean (SD) maximum torque at failure (Nm). $n = 20$.

Autoclave cycles	Twisted file	GT series X
0	51.40 (6.46)^A	97.95 (11.04)^A
1	46.32 (5.84)^A	94.75 (8.84)^A
3	43.25 (7.28)^A	85.67 (9.59)^B
7	48.70 (4.73)^A	78.10 (7.36)^B

Values within columns annotated with same letter are statistically similar ($P = 0.05$).

Table 2 Mean (SD) rotational degrees to failure (degrees). $n = 20$.

Autoclave cycles	Twisted file	GT series X
0	586.55 (64.18)^A	445.65 (62.39)^A
1	670.63 (59.74)^B	441.80 (47.30)^A
3	672.65 (103.16)^B	483.11 (66.57)^A
7	702.25 (80.64)^B	430.75 (66.49)^A

Values within columns annotated with same letter are statistically similar ($P = 0.05$).

difference was identified within the Twisted File groups ($P = 0.563$).

Results of rotational degrees to failure are listed in Table 2. A significant difference ($P < 0.001$) in rotational degrees to failure was found within the Twisted Files with all autoclaved samples demonstrating significantly higher rotational degrees to failure compared to control. A significant difference was not identified ($P = 0.527$) within the GT Series X file groups.

Discussion

The torsional properties of NiTi files have been attributed to file design (Turpin *et al.* 2000, Kim *et al.* 2009a,b), alloy composition, as well as manufacturing thermomechanical processes (Kell *et al.* 2009). Furthermore, other reports ascribe the most decisive influence concerning NiTi file stress distribution and torsional behaviour to be the cross-sectional configuration of a particular file (Turpin *et al.* 2000, Berutti *et al.* 2003, Xu *et al.* 2006, Kim *et al.* 2009b, Zhang *et al.* 2010).

The effects of autoclave conditions on the surface characteristics and mechanical properties of NiTi alloys and endodontic instruments have been reported. It has been identified that NiTi alloys display higher corrosion rates with increased temperature (Pun & Berzins 2008) whilst that repeated autoclaving conditions altered the surface concentrations of nickel, titanium, oxygen and carbon in NiTi alloys (Shabalovskaya & Anderegg 1995). Furthermore, the latter report stated that nickel surface concentrations decreased with autoclave exposure time, which led the authors to propose that oxidation was taking place (Shabalovskaya & Anderegg 1995). Auger spectroscopy analysis identified increasing parallel amounts of both surface oxygen and titanium deposits on autoclaved endodontic NiTi files, which suggested the presence of titanium oxides (Rapisarda *et al.* 1999). Additionally, atomic force microscopy found that rotary NiTi files demonstrated increases in file surface irregularities after autoclaving, which were attributed to corrosion processes (Canalda-Sahili *et al.* 1998).

An evaluation of NiTi rotary files that failed during clinical use identified that the predominant failure mode was file fracture owing to crack propagation through grain boundaries that initiated at oxide formations. Even though the rotary files evaluated had undergone an average of six to eight clinical uses (inferring repeat autoclaving conditions), the authors ascribed the identified oxides were attributable more to NiTi file manufacturing and preparation process (Alapati *et al.* 2005).

However, another study reported that five autoclave cycles did not negatively affect the fatigue properties of Profile size 25 and size 30, .06 taper files (Viana *et al.* 2006), and this somewhat corroborated an earlier investigation which found that autoclave cycles of 1, 5 and 10 times increased both torsional flexibility and rotational flexibility for Profile Series 29, .04 taper NiTi files (Silvaggio & Hicks 1997). Contrastingly, another investigation indentified that 10 autoclave cycles resulted in an overall decreasing trend of torque resistance with Nitiflex (Dentsply Maillefer, Ballaigues, Switzerland) and Naviflex (Brasseler, Savannah, GA, USA) files (Canalda-Sahili *et al.* 1998), and a recent report found that repeat autoclaving significantly reduced cyclic fatigue resistance of size 25, .06 taper Twisted Files but not the size 25, .04 taper Twisted Files and Profile GT Series X files (Hilfer *et al.* 2011).

The torsional values of baseline GT Series X files found during this evaluation corroborate well with results published in two recent studies (Kell *et al.* 2009, Kramkowski & Bahcall 2009). Interestingly, the conditions of this study resulted in a significant decrease in torsional moment resistance in the GT Series X files after three and seven autoclave cycles as compared to control. There was no significant difference noted after one autoclave cycle. However, repeat autoclaving did not induce any change in the rotational degrees to failure of GT Series X file. These findings are contrasted by those of Kell *et al.* (2009) who found a transient increase in torque at failure and a decrease in rotational degrees to failure for GT Series X files. However, their dissimilar results were the product of a differing protocol, as Kell *et al.* (2009) used an innovative method that included controlled functional use of the rotary files in standardized resin blocks followed by autoclaving. Because of these added conditions, the authors suggested that the initial increase in torque at failure could be possibly the outcome of work hardening.

The results of the Twisted File testing are worthy of note. In contrast to the GT Series X results, the number of autoclave cycles did not significantly affect the torsional moment of the Twisted File, whilst rotational degrees to failure significantly increased. However, the mean torque values at failure for the Twisted File under the conditions of this study consistently accord with those recently reported by Gambarini *et al.* (2010) for Twisted Files without a surface deoxidation finishing process. This recent study is the first to the author's knowledge that describes in detail the Twisted File surface treatment process (Deox) as the ageing for an extended period of time the newly twisted NiTi rotary files in a heated salt bath. Furthermore, according to Gambarini *et al.* (2010), the Deox process is not equivalent to a surface electropolishing finishing technique but is designed to enhance file durability via stabilizing the metallic crystalline structure and reducing surface defects (Gambarini *et al.* 2010). Additionally, Gambarini *et al.* (2010) confirmed the value of this Deox treatment by reporting that Twisted Files with Deox treatment had 90% greater torque failure values as compared to Twisted Files with no deoxidation treatment. The results of Gambarini *et al.* (2010) compared with the results of this study reasonably allow the present authors to assume that the Deox procedure is a relatively new processing technique introduced by the manufacturer.

Studies based on clinically fractured NiTi instruments suggest that fracture usually occurs owing to a single overloading event under torsion, tensile or bending–loading forces (Alapati *et al.* 2005, Parashos & Messer 2006, Spanali-Voreadi *et al.* 2006). The cause of failure owing to these forces either individually or in combination continues to be a source of debate (Parashos *et al.* 2004). Some maintain that metal fatigue is the predominant failure mechanism (Cheung *et al.* 2005, Peng *et al.* 2005), whilst other investigators report that torsional failure accounts for the majority of clinical failures (Sattapan *et al.* 2000, Alapati *et al.* 2005). Regardless of the mechanism, mechanical loading will eventually lead to deformation and file survival could be largely dependent on cross-sectional configuration (Kim *et al.* 2008, 2009a, Ounsi *et al.* 2008, Arbab-Chirani *et al.* 2011) as well as the inherent fracture toughness (McKelvey & Ritchie 1999, Plotino *et al.* 2009).

Unfortunately, crack propagation resistance of NiTi alloy has been reported to be lower compared to those of other alloys of similar strength; therefore, once a microcrack is initiated, it may quickly propagate to result in catastrophic failure (McKelvey & Ritchie 1999, Plotino *et al.* 2009). Investigations into clinically fractured NiTi files suggest that a predominant number of failures are attributable to crack propagation initiated from grain boundaries, oxide particles and/or surface imperfections (Alapati *et al.* 2005, Alexandrou *et al.* 2006, Shen *et al.* 2009). As autoclave conditions have been suggested to induce corrosion with some NiTi endodontic files (Rapisarda *et al.* 1999, Valois *et al.* 2008), perhaps increased surface corrosion could potentially explain the torsional results of the GT Series X files. Unfortunately, ultrastructural evaluation of file surfaces after autoclave cycles was not possible.

The results of this study corroborate the recommendations of the Twisted File manufacturer, as Sybron-Endo allows clinician discretion in terms of the instrument use/reuse. Furthermore, this study should provide sufficient data to allow clinicians to autoclave an unused GT Series X file before clinical use, as recommended by the manufacturer. Direct comparison of the results of this study with those of previous NiTi torsional study reports may be only accomplished in general as both files evaluated in this study involve newer manufacturing techniques. When feasible, future research should include functional forces as well as file failure analysis involving ultrastructural examinations.

Conclusion

Under the conditions of this study, repeat autoclaving of unused Twisted Files did not affect their torsional strength. However, the same conditions were found to significantly reduce the fracture strength of GT Series X files after three autoclave cycles.

Acknowledgements

None of the authors involved in this study have any financial interest in any materials used in this study. This research was supported by the American Association of Endodontics Foundation. Additionally, the authors gratefully appreciate the manufacturer's donation of the files used in this study. The opinions expressed in this work are those of the authors only and do not represent the official opinion of the United States Air Force, Department of Defense or the United States Government.

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