Torsional fatigue and endurance limit of a size 30 .06 ProFile rotary instrument

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Abstract

Best S, Watson P, Pilliar R, Kulkarni GGK, Yared G. Torsional fatigue and endurance limit of a size 30 .06 ProFile rotary instrument. *International Endodontic Journal*, **37**, 370–373, 2004.

Aim To evaluate the torsional cyclic fatigue characteristics and specifically the endurance limit (EL) of a nickel–titanium rotary instrument.

Methodology Size 30 .06 taper ProFile instruments were evaluated. The equipment was assembled according to the ANSI/ADA Specification No. 28. The motor was programmed to repeatedly rotate to a selected deflection angle (DA) and then return to zero (cycle). Testing started at 200° and was continued at decreasing angles until 10^6 cycles were reached without instrument fracture. Ten instruments were tested at each DA. The mean log number of cycles to fracture and standard deviation were determined for each DA at which fracture occurred. The DA at which 10^6 cycles were reached without instrument fracture corresponded by definition to the EL. Analysis of variance and pairwise comparisons using Duncan's multiple range test were performed to detect significant differences among the mean log number of cycles of the different DA. Significance was determined at the 95% confidence level.

Results Instruments cycled at larger DA consistently demonstrated fewer cycles to fracture than those cycled at smaller DA. The differences among the mean log number of cycles of the different DA were statistically significant ($P < 0.001$). Cycles of 10^6 were completed without instrument fracture at 2.5°.

Conclusions A torsional fatigue profile was generated for a specific NiTi rotary instrument. The EL was 2.5°.

Keywords: endurance limit, nickel–titanium, torsional fatigue.

Received 11 September 2003; accepted 6 February 2004

Introduction

Root canal preparation with nickel–titanium (NiTi) rotary instruments is easier and faster than with hand instruments (Glosson *et al.* 1995). Despite the increased flexibility and strength compared with stainless steel instruments (Walia *et al.* 1988), NiTi rotary instruments can fracture unexpectedly (West *et al.* 1994).

Instrument fracture occurs if the forces applied on the instrument exceed its ultimate strength. It can also result from flexural and/or torsional fatigue (Serene *et al.* 1995, Sattapan *et al.* 2000). In flexural or torsional fatigue, the material fails after being subjected to repeated cycling at stress or strain levels below those that cause failure upon monotonic loading. Accordingly, cyclic fatigue evaluation is performed by repeatedly loading a material to specific levels of stress or strain until failure occurs. The fatigue life of a material is the number of cycles required to cause failure. The endurance limit (EL) of a material is by definition the level of stress or strain at which a material can be subjected to 10^6 cycles (cycle: loading stress or strain and releasing) without failure (Lindeburg 1999). At the EL, continued cycling (beyond 10^6 cycles) of the material is unrestricted, would not decrease the strength of the material any further and would not

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lead to the failure of the material. With respect to the fatigue of endodontic instruments, an instrument would have an infinite fatigue life if the stress or strain were kept below the EL.

Flexural fatigue of NiTi rotary instruments has been evaluated extensively (Pruett *et al.* 1997, Haikel *et al.* 1999, Yared *et al.* 1999, 2000). However, information on torsional fatigue is not available. Repeated locking of the rotary instruments during canal preparation (Blum *et al.* 1999) and use in narrow canals could subject these instruments to higher torsional stress (Peters *et al.* 2003) leading to torsional fatigue.

The purpose of this study was to evaluate the torsional cyclic fatigue characteristics and specifically the EL of a selected NiTi rotary instrument.

Materials and methods

ProFile .06 taper, size 30 instruments (Stock No. PIT063025) (Tulsa Dental Products, Tulsa, OK, USA) were evaluated. A digital torque meter memocouple (Model RTS-50; Transducer Techniques, Temecula, CA, USA) measured torque with an accuracy of ±1 gcm and angle of rotation with an accuracy of ±2°. Prior to testing, each instrument's handle was removed with a suitable wire cutter at the point where the handle was attached to the instrument shaft. The shaft end was clamped in a chuck connected to a reversible geared computer controlled motor (BM250; Aerotech, Pittsburgh, PA, USA). Three millimetres of the tip of the instrument were clamped in another chuck with brass jaws connected to the digital torque meter. A jig was constructed to ensure reproducible positioning of the tip of the instrument in the chuck. The equipment was assembled according to the ANSI/ADA (1988) Specification No. 28 (Fig. 1). The torque-sensing device was mounted with ball bearings on a horizontal track, to allow its free movement towards or away from the motor. The electrical signal from the torque-sensing device was amplified (Type S7DC; RDP Electronics Ltd, London, UK), converted by a data acquisition card (Model DAQPad-6020E; National Instruments, Austin, TX, USA) and sent via a connector block (Model CAEE78; National Instruments) to a computer. LabView Software (Version 6.0, National Instruments) was used to specifically design a platform (Advanced Measurements, Calgary, AB, Canada) for cyclic torsional fatigue testing, and to analyse the data. The motor was programmed to repeatedly rotate to a selected angle, defined as the deflection angle (DA) and then return to zero (rest). Each rotation was defined as one cycle. Instruments were tested at approximately 50 cycles min^{-1}. Testing started at a DA of 200°, and was continued at decreasing selected angles until 10^6 cycles were reached without instrument fracture. Ten instruments were tested at each of the following DA: 200, 150, 100, 50, 25, 10, 5, 2.5°. The experiment was stopped at the DA at which 10^6 cycles were reached without fracture of the instrument. The mean number of cycles to fracture and standard deviation were determined for each DA at which fracture occurred. The DA at which 10^6 cycles were reached without instrument fracture corresponded to the EL. A logarithmic transformation of the number of cycles was carried out to facilitate the analysis. Analysis of variance and pairwise comparisons using Duncan's multiple range test were carried out to detect significant differences among the mean log number of cycles of the different DA. Significance was determined at the 95% confidence level.

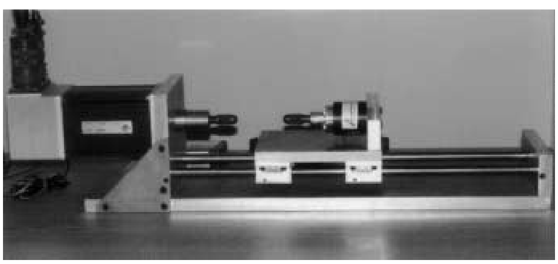

Figure 1 Torque testing device.

Results

The DA and the corresponding log number of cycles to fracture are presented in Table 1. Cycles of 10^6 were completed without instrument fracture at the DA of 2.5°. Instruments cycled at larger rotational DA consistently demonstrated fewer cycles to fracture than those cycled at smaller DA. The differences among the mean log number of cycles of the different DA were statistically significant ($P < 0.001$).

Discussion

This appears to be the first study to evaluate torsional fatigue of an endodontic NiTi rotary instrument.

In the absence of guidelines for fatigue testing, the experimental set-up was adapted from ANSI/ADA (1988) Specification No. 28. Fatigue tests are

Table 1 Mean log number of cycles (±SD) for the different angles of deflection

Angle of deflection (°)[a]	Mean log number of cycles (±SD)
200.0	0.1 ± 0.01
150.0	2.2 ± 0.03
100.0	2.8 ± 0.02
50.0	3.2 ± 0.01
25.0	3.5 ± 0.02
10.0	4.3 ± 0.02
5.0	4.7 ± 0.02
2.5	5.7 ± 0.01

[a]Ten instruments were tested at each angle of deflection.

frequently conducted using stress or strain control of the sample materials (Tapley 1990). In the present study, selected angular deflections (strain) were used to repeatedly cycle the instruments to fracture. Previously described models for torsional testing (Blum *et al.* 1999, Peters *et al.* 2003) can also be used to conduct torsional fatigue studies.

Only one instrument size was evaluated in the present study. The evaluation of one instrument required at 5° approximately 14 days until fracture occurred, and at 2.5° approximately 21 days until 10^6 cycles were reached without instrument fracture. The size 30 .06 ProFile was selected for two reasons: it is the middle size of a series of instruments, and smaller instruments (sizes 15 and 20) tend to slip in the chuck connected to the digital torque meter during similar testing procedures.

A preliminary study showed that at a deflection of 200° a low number of cycles to fracture convenient to start fatigue evaluation could be obtained. Therefore, 200° was selected as the highest DA.

The cycling frequency was 50 cycles min^{-1}. As a general rule, in a torsional loading model, the strength of a material and therefore its failure are independent of the twisting rate (cycling frequency) (Bailey 1985).

Regarding the use of endodontic rotary instruments, fatigue can include flexural and torsional components (Turpin *et al.* 2000). A material subjected to flexion or torsion is subjected to a combination of forces: tension is the force that pulls the structure of the material apart; compression is the force that pushes the structure of the material together; and shear causes one part of the material to slide over another part (Tapley 1990). In both flexural and torsional cyclic fatigue, fracture can occur although the load amplitude may be much less than the yield strength of the material (Kuhn *et al.* 2001). Using simulated root canals of varying curvature, Pruett *et al.* (1997) examined the influence on cyclic flexural fatigue of the angle and radius of canal curvature. They concluded that an increasing angle and a decreasing radius of canal curvature significantly decreased the number of rotations the instrument could withstand before fracture occurred. Their data indicated that the higher the tension–compression–shear cycle, the greater the fatigue effect. In the present study, a similar result was obtained when the instruments were repeatedly loaded in torsion: the more severe the angular deflection (i.e. greater tension–compression–shear forces) the lower the number of cycles to fracture. Kuhn *et al.* (2001) observed a high incidence of machining marks and other defects on the surface of new NiTi rotary instruments. Under repeated cycling, these defects would grow into cracks that propagate and cause fatigue failure. The larger DA, and consequently the greater tension–compression–shear forces, would lead to a faster propagation of the cracks and an earlier fracture (lower number of cycles to fracture).

Fatigue strength is the resistance of a material to frequent applications of a load. An instrument will have an infinite life if the deflection is kept at or below the EL level, where cycling is unrestricted (Lindeburg 1999). For a .06 taper ProFile size 30 NiTi instrument, the EL, in torsion, was established at a DA of 2.5°.

It is difficult to make any clinical correlation from the obtained data due to the apparatus design. The results of the present study will be used as the baseline for future torsional fatigue testing using the same model. Instrument selection should be based on the information available from different types of investigations, including torsional fatigue studies. The present study provided the torsional fatigue characteristics for a .06 taper ProFile size 30 instrument. Similar fatigue investigations of other instrument designs and sizes would be expected to provide characteristic curves. In addition, there may be potential clinical applications of such fatigue studies. Although the ProFile instruments are not designed to cut in both directions, several other instrument systems can be used in a reciprocating motion. Information, other than the EL, derived from fatigue studies may have practical implications for such systems. For instance, the present results showed that a .06 taper ProFile size 30 instrument could be reproducibly subjected to an angular deflection of 50° over 1400 times. Programming a reciprocating system with a specific DA for each size and type of instrument, that would balance cutting efficiency and exposure to torsional fatigue, may prove safer than an arbitrary rotational angle set for all instruments.

Conclusions

A torsional fatigue profile was generated in this study for a specific endodontic NiTi rotary instrument, predicting an EL reflective of a particular angular deflection (2.5°). A model for torsional fatigue testing was also demonstrated.

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