Cyclic fatigue of NiTi rotary instruments in a simulated apical abrupt curvature

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Abstract


Aim To evaluate the cyclic fatigue resistance of five NiTi rotary systems in an abrupt apical curvature.

Methodology Cyclic fatigue testing was performed in stainless-steel artificial canals with a 2-mm radius of curvature and an angle of curvature of 90° constructed to the dimensions of the instruments tested. The middle of the simulated curvature was 2.5 mm from the tip of the instrument that was placed at full working length. All instruments were new and 25 mm in length. Ten ProTaper Universal F2 (Dentsply Maillefer, Ballaigues, Switzerland); FlexMaster (VDW, Munich, Germany) tip size 25, taper 0.06; Mtwo (Sweden & Martina, Padova, Italy) tip size 25, taper 0.06; ProFile tip size 25, taper 0.06 from Dentsply Maillefer (Ballaigues, Switzerland); and ProFile tip size 25, taper 0.06 from Dentsply Tulsa (Tulsa, OK, USA) were rotated passively at 300 rpm until fracture occurred, and the number of cycles to failure (NCF) recorded. Length of the fractured tip was measured. Data were analysed by one-way ANOVA and Tukey HSD test to determine any statistical difference amongst groups.

Results Mtwo had the highest fatigue resistance compared to the other instruments (NCF 124 ± 25) (P < 0.001); there was no statistical difference between ProFile from the two different brands, although ProFile from Maillefer had the higher fatigue life (NCF 75 ± 10) compared to ProFile from Tulsa (NCF 66 ± 10). No difference was registered between FlexMaster (NCF 53 ± 5) and ProFile from Tulsa; ProTaper F2 had a significantly (P < 0.001) lower fatigue life compared to the other instruments tested (NCF 29 ± 5).

Conclusions Lifespan registered for the instruments tested in an apical abrupt curvature was Mtwo > ProFile from Maillefer > ProFile from Tulsa > FlexMaster > ProTaper.

Keywords: angle of curvature, cyclic fatigue, NiTi instruments, radius of curvature.

Introduction

The super-elasticity of nickel–titanium (NiTi) has led to the alloy having important practical applications in endodontics (Parashos & Messer 2006). NiTi properties occur as a result of the austenite to martensite transition, which in turn is because the alloy has an inherent ability to alter its type of atomic bonding (Thompson 2000). The martensitic transformation requires a reversible atomic process termed twinning that allows reduction in strain during the transformation (Thompson 2000).

The unexpected fracture of NiTi rotary instruments inside the root canal during root canal treatment is a matter of serious concern. Several factors contribute to instrument fracture (Cheung 2009), and the correct clinical use is important (McSpadden 2007):

- Practice is essential when learning new techniques and new instruments;
- Instrumentation time should not be rushed;
- Sharp and sudden movements should be avoided;
• A light touch and not pushing hard on the instrument;
• A touch-retract (i.e. pecking) action, with movements as large as allowed by the particular canal anatomy and instrument design characteristics should be used;
• Files must be regularly examined during use, preferably with magnification and discarded if distorted;
• Files should be replaced sooner after use in very narrow and very curved canals;
• Glide path and patency must always be obtained with small (at least #10) hand files;
• A pre-flaring minimum to the size of the tip of the first NiTi rotary instrument used should be established;
• The file should not be kept in one spot, particularly in curved canals, and with larger and greater taper instruments.

Fracture of instruments used in rotary motion occurs in two different ways: torsion and flexural fatigue (Serene et al. 1995, Sattapan et al. 2000). Torsional fracture occurs when an instrument tip or another part of the instrument is locked in a canal whilst the shank continues to rotate. When the torque exerted by the hand-piece exceeds the elastic limit of the metal, fracture of the tip becomes inevitable (Peters 2004, Parashos & Messer 2006). Instruments fractured because of torsional loads often carry specific signs such as plastic deformation (Sattapan et al. 2000).

Fracture because of 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 (Pruett et al. 1997, Haikel et al. 1999). If an instrument is held in a static position and continues to rotate, one-half of the instrument shaft on the outside of the curve is in tension, whilst the half of the shaft on the inside of the curve is in compression. 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 (Peters 2004, Parashos & Messer 2006).

Both cross-sectional area and file design (influencing stress distribution during load) may affect an instrument’s resistance to fracture when subjected to flexural and torsional load. Instruments with larger diameters have been found to succumb to flexural fatigue earlier than those with smaller diameters (Pruett et al. 1997, Haikel et al. 1999), and they appear to have greater internal stress accumulation (Ullmann & Peters 2005).

However, an increase in instrument diameter and corresponding increase in cross-sectional area may contribute to increased resistance to torsional failure (Parashos & Messer 2006). Mathematical modelling to evaluate the effect of the design of rotary NiTi instruments has concluded that instruments with a U-flute design and smaller cross-sectional area were more flexible than the triangular triple-helix design, but weaker when subjected to torsional stress (Turpin et al. 2000, Berutti et al. 2003).

Resistance of rotary instruments to cyclic fatigue is affected during laboratory tests by the angle and radius of the simulated curvature. Increased severity in the angle and radius of the curves around which the instrument rotates decreases instrument lifespan (Pruett et al. 1997, Haikel et al. 1999, Grande et al. 2006). Instruments have been tested in canals having radii of 2, 5 and 10 mm, with the conclusion that the smaller the radius, the shorter the life of the instrument when rotating (Pruett et al. 1997, Haikel et al. 1999, Grande et al. 2006). Cyclic fatigue studies have used 30°, 45°, 60° and 90° angles of curvature demonstrating that the higher the angle of curvature, the more severe is the curvature and the less is the resistance of the instruments to cyclic fatigue (Pruett et al. 1997).

Similarly, several studies have shown that an increased diameter of the instrument at the point of maximum curvature, which is determined by tip size and taper, reduces the time to fracture (Pruett et al. 1997, Haikel et al. 1999, Gambarini 2001, Grande et al. 2006, Plotino et al. 2006, 2007). Ruddle (2002) has asserted that the position of the curvature of a canal is a factor in instrument safety, a point that was demonstrated in an earlier study (Malagnino et al. 1999). When the curvature is located in a coronal portion of the root canal, the instrument is subjected to the maximum stress at a point at which its diameter is larger.

The point of maximum curvature chosen for most cyclic fatigue studies was between 5 and 7 mm from the tip of the instrument. Clinically, this may be classified as a curvature in the middle-third of the root canal. Frequently, abrupt apical curvatures may be encountered clinically, and they may not be visible on the radiograph. NiTi rotary instruments must be so flexible to permit the clinician to use them safely even in those unexpected apical abrupt curvatures. Consequently, the aim of the present study was to evaluate the cyclic fatigue resistance of one instrument size (tip size 25) of five NiTi rotary systems in an abrupt apical curvature.
Materials and methods

Five groups of instruments of tip size 25 with different design were tested: group 1: ProTaper Universal F2 (Dentsply Maillefer, Ballaigues, Switzerland); group 2: FlexMaster tip size 25, 0.06 taper (VDW, Munich, Germany); group 3: Mtwo tip size 25, 0.06 taper (Sweden & Martina, Padova, Italy); group 4: ProFile tip size 25, 0.06 taper (Dentsply Maillefer, Ballaigues, Switzerland); group 5: ProFile tip size 25, 0.06 taper (Dentsply Tulsa, Tulsa, OK, USA).

Ten instruments for each group were tested within a tapered artificial canal with an angle of curvature of $90^\circ$ and radius of curvature of 2 mm. The centre of the curvature was approximately 2.5 mm from the tip of the instrument (Fig. 1). The artificial canal was milled in stainless-steel blocks with a tapered shape corresponding to the dimensions of the instruments tested, thus providing the instruments with a suitable trajectory (Fig. 2). A separate artificial canal was constructed on the dimensions of the ProTaper F2, but it was not used because the instrument fitted in the canal constructed for the tip size 25, 0.06 taper instruments.

The artificial canal was mounted on a stainless-steel block that was connected to a main frame to which a mobile plastic support for the hand-piece was also connected. The dental hand-piece was mounted upon a mobile device that allowed for precise and simple placement of each instrument inside the artificial canal, ensuring three-dimensional alignment and positioning of the instruments to the same depth. The artificial canal was then covered with tempered glass to prevent the instruments from slipping out and to allow for observation of the instrument.

The instruments were rotated at a constant speed of 300 rpm using a 6:1 reduction hand-piece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled motor (Silver; VDW GmbH, Munich, Germany). To reduce the friction of the file as it contacted the artificial canal walls, high-flow synthetic oil designed for lubrication (Super Oil; Singer, Elizabethport, New Jersey, USA) was applied.

All instruments were rotated until fracture occurred. Fracture was easily detectable because the instruments were visible through the glass window. The time to fracture for each file was visually recorded with a chronometer to the nearest whole second, and the

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure1.png}
\caption{The artificial canal used to test fatigue resistance of NiTi rotary instruments.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.45\textwidth]{figure2.png}
\caption{A ProFile instrument inserted in the curvature chosen for this study. Note the correspondence between the shape of the instrument and the shape of the artificial canal: the instrument follows precisely the trajectory established by the artificial canal.}
\end{figure}
number of rotations was calculated to the nearest whole number. The time to fracture in seconds was multiplied by the number of rotations per minute (RPM)/60 (number of rotations per seconds) to obtain the number of cycles to failure (NCF) for each instrument. Mean values were then calculated. The length of the fractured tip was also recorded for each instrument, and the mean values were then calculated for each instrument type in each group.

Data were analysed by one-way anova and Tukey HSD test to determine any statistical difference amongst groups; the significance was determined at the 95% confidence level.

Results

Mean values ± standard deviation expressed as NCF and mean length of the fractured fragments are displayed in Table 1. The one-way anova test revealed statistically significant differences between groups ($P < 0.001$). ProTaper Universal F2 instruments had significantly lower mean number of cycles to failure when compared with size 25 and 0.06 taper files ($P < 0.001$). Mtwo instruments had a significantly higher mean number of cycles to failure when compared with the other size 25 and 0.06 taper files and ProTaper Universal F2 ($P < 0.001$). ProFile (Tulsa instruments) were not significantly different from FlexMaster and ProFile (Maillefer), whilst a significant difference was found between FlexMaster and ProFile (Maillefer) ($P = 0.005$).

The mean length of the fractured segment was also recorded to evaluate the correct positioning of the tested instrument inside the canal curvature and whether similar stresses were being induced. No statistically significant difference in the mean length of the fractured fragments was evident for any of the instruments tested. Instrument tips were always free after fracturing, demonstrating that instruments were rotated freely inside the artificial root canal, thus minimizing the influence of torsional stress.

Discussion

Apical abrupt curvatures of root canals represent difficult areas for instrumentation and filling. Little information on the mechanical performance of NiTi rotary instruments in apical abrupt curvatures is available. Furthermore, no evidence has been presented that proves how safe is the use of rotary instruments in such cases.

The results of the present study revealed that Mtwo instruments resisted fatigue fracture for a longer time demonstrating more flexural strength than the other instruments. On the contrary, ProTaper Universal F2 resisted significantly less time than the other instruments. These results may be explained by the fact that ProTaper F2 has a larger diameter than instruments tip size 25 and constant 0.06 taper at 2.5 mm from the tip, corresponding to the point of maximum stress during the test.

Previous studies showed that the diameter of the instrument at the point of maximum curvature influenced fatigue life. That is, NCF decreased as the diameter of the instrument increased (Pruett et al. 1997, Haikel et al. 1999, Gambarini 2001, Plotino et al. 2006, 2007). The same happens with an increased mass (Grande et al. 2006). As ProTaper instruments have a bigger metal mass and slightly increased diameters than Mtwo at 2.5 mm from the tip, ProTaper instruments had a lower lifespan in the present study. The influence of the abrupt curvature on fatigue can be shown by comparing the present results with similar studies. The same instruments (ProTaper F2 and Mtwo 25, 0.06) tested with the same methodology but using less severe curvatures resisted longer before fracture (Grande et al. 2006).

According to previous studies (Pruett et al. 1997, Haikel et al. 1999), fatigue life of NiTi rotary instruments is significantly influenced by the angle and the radius of curvature. That is, NCF significantly decreases as the radius of curvature decreases and the angle of curvature increases.

Table 1 Mean number of cycles to failure (NCF) ± standard deviation and mean fragment length ± standard deviation of the instruments tested

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProTaper F2</td>
<td>FlexMaster 25/0.06</td>
<td>Mtwo 25/0.06</td>
<td>ProFile – Maillefer 25/0.06</td>
<td>ProFile – Tulsa 25/0.06</td>
</tr>
<tr>
<td>NCF</td>
<td>29 ± 5\textsuperscript{a}</td>
<td>53 ± 5\textsuperscript{a}</td>
<td>124 ± 25\textsuperscript{c}</td>
<td>75 ± 10\textsuperscript{d}</td>
</tr>
<tr>
<td>Fragment length</td>
<td>2.6 ± 0.3</td>
<td>2.4 ± 0.1</td>
<td>2.5 ± 0.2</td>
<td>2.4 ± 0.1</td>
</tr>
</tbody>
</table>

Different superscript letters represent statistically significant results.
It should be noted that the results of the present study do not have a direct clinical relevance, as this experimental design of cyclic fatigue tests are usually not meant to reproduce clinical conditions, rather only to serve as a means to compare differences between the files. The dissimilarity to the clinical situation where instruments are never left to continue to rotate in one position for an extended period of time should be pointed. Severe apical curvatures are obviously a stressful and dangerous anatomy of NiTi rotary instruments, with an increased risk of intracanal failure. However, apical abrupt curvatures are not always visible radiographically and can be encountered frequently, especially when two canals join. If clinicians become aware of the problem whilst scouting canals, they can take into consideration the use of a manual instrument. If not, it would probably be an advantage to select rotary instruments that resist fracture longer in such complex curvatures.

Analysis of the data regarding the length of the fractured segment revealed no statistically significant difference in the mean size of all the instruments tested. The maximum overall difference amongst the groups was <1 mm (Table 1). This confirmed that instruments subjected to cyclic fatigue fractured at the centre of the curvature or just below this point, as previously reported (Pruett et al. 1997, Fife et al. 2004). SEM evaluation of the fractured fragments was not performed in the present study because in a previous study (Grande et al. 2006), using the same methodology, SEM analysis of the surface of the instruments revealed that in all the cases the instruments fractured because of pure metal fatigue, thus excluding the influence of torsional stresses on the fracture.

Conclusions

Under the experimental condition of the present study, Mtwo had significantly higher fatigue resistance when compared to the other tested instruments in an abrupt curvature.

References


