Influence of file motion on cyclic fatigue of new nickel titanium instruments

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Summary
Aim. **The aim of the present study was to compare the resistance to cyclic fatigue of Hyflex® (Coltene-Whaledent, Allstatten, Switzerland) size 40 taper.04 nickel titanium instruments used in continuous rotation versus the use with a reciprocating motion. The null hypothesis was that different file motions had no influence on the lifetime of instruments subjected to a cyclic fatigue test.**
Methodology. **24 Hyflex® size 40 taper.04 nickel titanium instruments were randomly divided in two groups (n=12 each), and submitted to a cyclic fatigue test. The first group (CR group) were used with a continuous rotation, while the second one (RCP group) with a reciprocating motion. The cyclic fatigue tests were performed by using a stainless steel block containing an artificial canal shaped with a 135° angle. All instruments were rotated or reciprocated until fracture occurred. The time to fracture was recorded visually with a 1/100 second chronometer. Data were recorded and statistically analysed.**
Results. **Results indicated that instruments used with a reciprocating motion showed a significant increase in the meantime to failure when compared to those used in continuous rotation.**
Conclusions. **The null hypothesis was rejected. Results of the present study showed that reciprocating motion extended resistance to cyclic fatigue of the tested nickel titanium instruments, when compared to continuous rotation.**

Key words: cyclic fatigue, nickel titanium, instruments.

Introduction

The introduction of Nickel-Titanium (NiTi) alloy in endodontics was a significant improvement, allowing excellent result in terms of cleaning and shaping of root canals, while reducing operative time and minimizing iatrogenic errors. Thanks to the superior mechanical properties of the NiTi alloy (1) it was possible to use endodontic instruments in continuous rotation, increasing the effectiveness and rapidity of the cutting. However, several studies reported an increased tendency to intracanal separation of NiTi Rotary instruments when compared to stainless steel manual instruments (2-4).
This increased risk of intracanal separation is due to the continuous rotation movement inside a curved canal, which submits NiTi instruments to greater flexural stress and consequently to increased metal fatigue, when compared to stainless steel file used manually (5).
Despite the improvements in instrument design over the last 20 years, intracanal separation of NiTi rotary instruments remains a quite common (from 2% to 9% of cases) procedural error, which can dramatically affect the outcome of the endodontic treatment (6).
Instrument fracture can occur because due to excessive torsion or fatigue, or, more often, due to a combination of the two factors. Torsional fracture occurs when the torsional torque applied to the instrument exceed torsional elastic limit of instrument itself. Clinically it could be happen when an instrument is locked into the canal while the motor continues to apply a moment of force.
Fatigue fracture occurs when instrument undergoes to a cyclic stress. A material submitted to cycle of stress lower than fracture force limit get a fracture without any previous sign of plastic deformation.
Intracanal failure is not clinically predictable; because it is not possible to evaluate how much fatigue an instrument accumulates during its work inside the canal. Research has shown that intracanal cyclic fatigue which an instrument accumulates during canal shaping of curved canals depends on anatomy (7), rotation speed (8). Instrument design and manufacturing (9, 10).
Recently, a new manufacturing technique has been developed and commercialized: the Hyflex® nickel titanium instruments (Coltene-Whaledent, Allstatten, Switzerland). These NiTi files have been manufactured utilizing a process that controls the material's memory, making the files extremely flexible, while significantly reducing the restoring force. This gives the file the ability to precisely follow and respect the original root canals trajectories, reducing the risk of ledging and transportation or perforation. Moreover the thermally treated alloy (CM wire technology) used for the manufacturing of Hyflex instruments has been shown to improve cyclic fatigue resistance (11).

In order to minimize these risks, Yared proposed the use of nickel titanium instruments of increased tapers in a reciprocating motion (12). In the proposed technique, canal is negotiated with a stainless steel size 08 hand file and than an F2ProTaper NiTi rotary instrument is used for the canal preparation in a clockwise (CW) and counter clock wise (CCW) movement. The CW and the CCW rotations used by Yared were four-tenth and two-tenth of a circle respectively and the rotational speed was 400 rpm (12). The concept of using a single NiTi instrument to prepare the entire root canal is interesting, and it is possible due to the fact that reciprocating motion reduced instrumentation stress. However, such a drastic change in the movement kinematics needs to be assessed in terms of *in vitro* testing of facture resistance. Recent literature seems to show that reciprocating movements can provide mechanical advantages compared to continuous rotation (13, 14). These preliminary positive results need further studies, also because many different reciprocating movement and many different instrument designs can be used in clinical practice, thus affecting the overall results.
The aim of the present study is to valuate if reciprocating motion can increase Hyflex instrument lifetime in a cyclic fatigue test compared to continuous rotation. The null hypothesis is that there is no difference in fatigue resistance related to the different operative mode.

Materials and methods

24 Hyflex® size 40 taper.04 nickel titanium instruments were randomly divided in two groups (n=12 each). All instruments had been previously inspected by using an optical stereomicroscope with 20 magnification for morphologic analysis and for any signs of visible deformation. If defective instruments were found, they were discarded. All instruments were then submitted to a cyclic fatigue test. The first group (CR group) were used with a continuous rotation, while the second one (RCP group) with a reciprocating motion. A specific endodontic motor (Acteon dual endoSatelec, France), that allows both movements, was used. The selected reciprocation motion was the following one: 150 degree of counter clock wise (CCW) rotation followed by a 30 degree of clock wise (CW) rotation. In both movements speed was set at 300 rpm.
The cyclic fatigue tests were performed by using a stainless steel block containing an artificial canal shaped to form a 135° angle (Fig. 1). Instruments were placed into the artificial canal at the same depth, and rotated or reciprocated until fracture occurred. The time to fracture was recorded visually with a 1/100 second chronometer. The same operator performed all tests.
Means and standard deviations of time to fracture were calculated, and statistical analysis were performed by using univariate analysis or post-hoc analysis in software (SPSS for Windows 11.0) and the level of significance was set to $p<0.05$.

Results

Results indicated that reciprocating motion showed a significant increase ($p<0,05$) in the time to failure when compared to continuous rotation. In continuous rotation (CR group) instruments mean time to failure was 8,75 sec (SD 1,34) while for the reciprocating motion (RCP group) mean time to failure was 14,55 sec (SD 1,56).

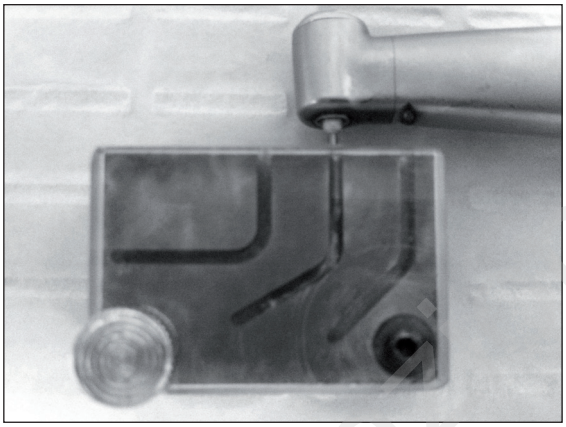

Figure 1. The testing apparatus.

Discussion

The results of the present study showed that reciprocating motion could extend cyclic fatigue life of Hyflex NiTi instruments compared with continuous rotation. The null hypothesis was rejected, since the different movements affected the lifespan of the NiTi instruments. These results are in accordance with another recent research article, which demonstrated that movement kinematics, had a significant influence on cyclic fatigue life (13).
Fatigue failure usually occurs by the formation of micro crack at the surface of the file that starts from surface irregularities. During each loading cycle micro cracks develop, getting deeper in material, until complete separation of the file (15). All endodontic file shows some irregularities on the surface, and inner defect, as a consequence of the manufacturing process, and distribution of these defects influence fracture strength of the endodontic instruments (16, 17). Consequently instrument fatigue life can be regarded as a function of the load, irregularities and size of crack on the surface (15).
Endodontic rotary file are subjected to a bending stress during their clinical use in a curved canal. A bending force applied to an instrument result in a tensile stress, that tends to open micro cracks, on the convex side, and in a compression stress, that tend to close micro cracks, on the concave side. When an instrument is in continuous rotation in a curve, tensile stresses follow a sinusoid trend. In fact there is an alternation of tensile and compression stresses when a certain portion of the instrument translate from convex side to concave side.
Each 360° rotation identify one loading cycle in which each point of instrument surface go through maximum tensile stress and maximum compressive stress.
In other words during one cycle the crack open and close once. On the opposite, the Reciprocating motion used in the present study consisted in 150° of rotation CCW and 30° of CW rotation.

Therefore, the instrument approximately turned 5/12 of the cycle (150 degrees) and returned 1/12 of the cycle (30 degrees), which meant that only after three complete reciprocating movements the instrument completed one entire rotation. Therefore, in the same amount of time (overall rotational speed, which is calculated by number of rotations per minute) the risk of opening and closing cracks is lower, when compared to the continuous rotation.

Therefore the improvement in cyclic fatigue resistance showed by the reciprocating movement should be related to two main factors. First, the rotation cycles are slightly reduced and consequently the overall number of rotation is reduced. Secondly, during reciprocation, tensile stress in a point of the material surface have a sinusoid trend, being interrupted by the counter rotation, in which tensile stress invert his trend. In other words there is a different distribution of the same tensile values during time, and this can reduce the overall accumulation of fatigue.

There are no previous reports on the effect of reciprocating motion on the cyclic fatigue life of Hyflex instruments. According to the manufacture (18) the innovative manufacturing technique (CM wire technology) used in the production of the Hyflex® instruments allowed a significant improvement versus traditional NiTi rotary instruments. It is interesting to note that, besides this increase in fatigue resistance related to the innovative CM wire technology, there was still room for improvement related to the movement kinematics. Further studies are needed to confirm these experimental results and to evaluate their clinical relevance.

Conclusions

We may conclude that reciprocating motion extended resistance to cyclic fatigue of the tested nickel titanium instruments, when compared to continuous rotation. The null hypothesis (different file motions had no influence on the lifetime of instruments subjected to a cyclic fatigue test) was rejected.

References

1. Walia H, Branteley WA, Gerstein H. An Initial Investigation of the Bending and Torsional Properties of Nitinol Root Canal Files. J Endod 1988; 14:346-351.
2. Wolcott S, Wolcott J, Ishley D, Kennedy W, Johnson S, Minnich S, Meyers J. Separation incidence of protaper rotary instruments: a large cohort clinical evaluation. J Endod 2006; 32:1139-41.
3. Parashos P, Messer HH. Rotary NiTi instrument fracture and its consequences. J Endod 2006; 32:1031-43.
4. Iqbal MK, Kohli MR, Kim JS. A retrospective clinical study of incidence of root canal instrument separation in an endodontics graduate program: a PennEndo database study. J Endod 2006; 32:1048-52.
5. Peters OA. Accessing root canal systems: requirements and techniques. PractProcedAesthet Dent 2006 Jun; 18(5):277-9.
6. Gambarini G. Cyclic fatigue of nickel-titanium rotary instruments after clinical use with low-and high-torque endodontic motors. J Endod 2001; 27:772-4.
7. Pruett JP, Clement DJ, Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod 1997 Feb; 23(2):77-85.
8. Zelada G, Varela P, Martın B, Bahı´llo JG, Magan F, Ahn S. The effect of rotational speed and the curvature of root canals on the breakage of rotary endodontic instruments. Journal of Endodontics 2002; 28:540–2.
9. Xu X, Zheng Y. Comparative study of torsional and bending properties for six models of nickel-titanium root canal instruments with different cross-sections. J of Endod 2006; 32:372-5.
10. Gambarini G, Pompa G, Di Carlo S, De Luca M, Testarelli L. An initial investigation on torsional properties of nickel-titanium instruments produced with a new manufacturing method. Aust Endod J 2009; 35(2):70-2.
11. Grande NM, Plotino G, Vincenzi V, Testarelli L, Gambarini G. Valutazione sperimentale di strumenti endodontici in NiTi a memoria di forma “self-restoring”. G Ital Endod 2011; 25/1:XII-XIX.
12. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. International Endodontic Journal 2008; 41:339-44.
13. De-Deus G, Moreira EJL, Lopes HP, Elias CN. Extended cyclic fatigue life of F2 Pro Taper instruments used in reciprocating movement. Int Endod J. 2010 Dec; 43(12):1063-8.
14. You SY, Bae KS, Baek SH, Kum KY, Shon WJ, Lee W. Lifespan of One Nickel-Titanium Rotary File with Reciprocating Motion in Curved Root Canals. J Endod. 2010 Dec; 36(12):1991-4.
15. Christ HJ. Fundamental mechanisms of fatigue and fracture. Student Health Technology Information 2008; 133:56-67.
16. Anderson ME, Price JW, Parashos P. Fracture resistance of electropolished rotary nickel-titanium endodontic instruments. J of Endod 2007; 33:1212-26.
17. Wei X, Ling J, Jiang J, Huang X, Liu L. Modes of failure of ProTaper nickel-titanium rotary instruments after clinical use. Journal of Endodontics 2007; 33:276-9.
18. Testarelli L, Plotino G, Al-Sudani D, Vincenzi V, Giansiracusa A, Grande NM, Gambarini G. Bending properties of a new nickel-titanium alloy with a lower percent by weight of nickel. J Endod 2011 Sep; 37 (9): 1293-5. HYFLEX.