Evaluation of selected mechanical properties of NiTi rotary glide path files manufactured from controlled memory wires

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This study aimed to investigate mechanical properties related to flexibility and fracture resistance of controlled memory wire-manufactured nickel-titanium rotary glide path files [HyFlex EDM Glide Path File (EDM) and HyFlex GPF (GPF)], Scout RaCe (RaCe) served as control. Bending loads, torsional/cyclic fatigue resistance, and screw-in forces were measured. EDM showed a significantly larger torque at fracture, a longer time to cyclic fracture in reciprocation and a larger angular deflection compared with GPF and RaCe. EDM showed significantly lower bending loads and lower angular deflection values than GPF and RaCe, and a significantly larger time to cyclic fracture than RaCe. The time to cyclic fracture was significantly longer in reciprocation compared with continuous rotation in EDM and GPF. It can be concluded that EDM and/or GPF showed higher flexibility and cyclic/torsional fatigue resistance compared with RaCe; and that reciprocation conferred better cyclic fatigue resistance to EDM and GPF.

Keywords: Controlled memory wire, Flexibility, Fracture resistance, Nickel-titanium rotary glide path file, Screw-in force

INTRODUCTION

Glide path preparation is critical in nickel-titanium (NiTi) rotary root canal preparation since it allows for the safe advancement of the instrument tip, thereby decreasing the risk of instrument fracture1 and contributing to the prevention of procedural errors such as canal deviation2. Studies have shown that NiTi rotary glide path preparation is advantageous compared with manual preparation since it is faster and better maintains the canal anatomy3,4. Various small-sized NiTi files designed for glide path preparation have been developed5.

Thermal processing of NiTi alloys is known to improve mechanical performance and metallurgical characteristics by changing transition temperatures6. Thus, several brands of thermally-processed NiTi instruments have been marketed with the claim of increased fracture resistance and flexibility7. Among these, HyFlex CM (Coltene-Whaledent, Allstetten, Switzerland) is made from controlled memory (CM) wire, which is manufactured with proprietary thermomechanical processing and is reported to show higher cyclic fatigue resistance8. HyFlex EDM (Coltene-Whaledent), which is also made from CM wire and processed by electrical discharge machining, is reported to show improved cyclic fatigue resistance7,8 and exhibit peculiar structural properties such as elevated phase transformation temperatures and hardness9. As glide path files corresponding to these brands, HyFlex GPF (Coltene-Whaledent) and HyFlex EDM Glide Path File (Coltene-Whaledent) have been developed.

NiTi rotary instruments may fracture due to torsional stresses or/and cyclic fatigue10. Apically directed forces generated when a file is screwed into the root canal, termed screw-in forces, are regarded as a cause of torsional breakage due to increased engagement of the file in the canal wall11,12. Glide path files may have a high risk of fracture, particularly when applied to narrow and curved canals, and thus should possess high torsional and cyclic fatigue resistance and generate lower screw-in forces. Reciprocating movement, originally introduced in NiTi rotary preparation for single-file instrumentation13, is reported to increase the resistance to failure14 and decrease screw-in forces15 compared with continuous rotation. However, the effects of reciprocation in glide path preparation have not yet been investigated.

The primary purpose of this study was to investigate CM wire-manufactured glide path files with regard to their mechanical properties related to flexibility and fracture resistance. Thus, the bending property, torsional resistance, cyclic fatigue resistance, and screw-in force generation were examined. The secondary purpose was to examine the effect of reciprocating motion on the cyclic fatigue resistance and screw-in force generation of these files. The null hypotheses were; (i) there are no differences in the tested mechanical properties among glide path files investigated; and (ii) the cyclic fatigue resistance and screw-in force generation of these files do not differ between reciprocation and continuous rotation.

MATERIALS AND METHODS

HyFlex EDM Glide Path File (tip diameter 0.10 mm, 5% taper; EDM), HyFlex GPF (tip diameter 0.15 mm, 2% taper; GPF), and Scout RaCe (manufactured from...
conventional NiTi alloy; tip diameter 0.15 mm, 2% taper; FKG, La Chaux-de-Fonds, Switzerland; RaCe) were tested in this study. All files were 25 mm in length. EDM has 3 different horizontal cross-sections varying throughout the shaft: quadratic at the tip, trapezoidal in the middle, and triangular towards the shaft. GPF and RaCe has a square cross-section. Additionally, RaCe has alternating twisted and untwisted segments along the file length.

**Bending test**
A custom-made cantilever bending test apparatus was used (Fig. 1). Briefly, specimens (n=10 in each instrument) were clamped to the apparatus 7 mm from the tip, loaded to a point 2 mm from the tip (deflecting speed 1.0 mm/min) until the deflection reached 3.0 mm, and then unloaded. The bending load was measured at 0.5 and 2.0 mm deflection, which corresponded to the elastic and super-elastic range, respectively. The temperature of the files and apparatus was kept at 37°C.

**Torsional test**
The torsional test was performed according to ISO3630-1 (International Organization for Standardization 1992; n=10 in each instrument). Each file was placed on a torsional testing apparatus (Orientec, Tokyo, Japan), clamped at 3 mm from the tip using a chuck, and rotated in clockwise direction at 2 rpm. The torque load and angular rotation were monitored, and the maximum torque and angular deflection at fracture were recorded.

**Cyclic fatigue test**
A stainless steel 3-pins device was used (Fig. 2). Briefly, each file was constrained to a curvature (60°, radius 5 mm) by 3 stainless steel pins, and rotated with either reciprocation (300 rpm; 180° clockwise and 90° counterclockwise) or continuous rotation (300 rpm), using a prototype automated root canal preparation system (J. MORITA, Kyoto, Japan). The deflection load imposed by the file was recorded by a load cell (LUR-A-50NSA1, Kyowa Electronic Instruments, Tokyo, Japan) fixed to the middle pin. Silicone oil was used to reduce friction and heat generation during the test. All files (n=20, each) were rotated at 37°C until fracture, which was identified by a sudden change in the deflection load, and the time to fracture was recorded.

**Screw-in force measurement**
A custom-made automated root canal preparation and torque/force analyzing device was used (Fig. 3).
A total of 60 J-shaped simulated root canal blocks (Endo Training Bloc, Dentsply Maillefer, Ballaigues, Switzerland), filled with a lubricant (RC-Prep, Premier, Plymouth Meeting, PA, USA), were mounted on the stage of the device. Test files were rotated with the prototype motor using either reciprocation or continuous rotation, as described above. The hand piece was moved in a simulated pecking motion (downward for 2 s and upward for 1 s at 10 mm/min). Vertical forces were measured with a load cell (LUX-B-ID, Kyowa Electronic Instruments) connected to the stage and forces in an upward direction were defined as the screw-in force. Data were registered until the file reached the working length and the maximum value was computed.

**Data analysis**
The data from the bending and torsional tests were analyzed by one-way analysis of variance (ANOVA) and the Games-Howell test. The data from the cyclic fatigue test and screw-in force measurements were analyzed by two-way factorial ANOVA, followed by a post-hoc simple main effect test with a Bonferroni correction. Significance was set at $p<0.05$.

**RESULTS**

**Bending test**
At 0.5-mm deflection, bending load values (N±SD) were 0.19±0.06, 0.12±0.02 and 0.15±0.02 in EDM, GPF, and RaCe, respectively. There were significant differences among the three groups ($p<0.004$), and post-hoc comparisons indicated that GPF showed significantly lower bending load values compared with EDM and RaCe ($p<0.05$). At 2-mm deflection, there were significant differences among the three groups ($p<0.001$), with significant differences revealed by post-hoc comparisons ($p<0.05$) among the three groups; EDM (1.13±0.15)>RaCe (0.43±0.03)>GPF (0.21±0.03).

**Torsional test**
There were significant differences in the maximum torque among the three groups ($p<0.004$). Post-hoc tests indicated that the maximum torque in EDM was significantly higher than those in GPF and RaCe ($p<0.05$; Fig. 4A). There were also significant differences in angular deflection among the three groups ($p<0.001$). Post-hoc tests indicated that GPF showed significantly higher angular deflection values compared with EDM and RaCe ($p<0.05$; Fig. 4B).

**Cyclic fatigue test**
Figure 5 shows the results of the cyclic fatigue test. There were significant main effects of instrument and motion, and a significant interaction between instrument and motion ($p<0.001$). Under reciprocation, post-hoc multiple comparisons indicated that there were significant differences in the time to fracture among the three groups (EDM>GPF>RaCe; $p<0.05$). Under continuous rotation, EDM and GPF showed significantly longer time than RaCe ($p<0.05$). Reciprocation showed a significantly longer time to fracture than continuous rotation in EDM and GPF ($p<0.001$).

**Screw-in force**
The maximum screw-in force values are shown in Fig. 6. There was a significant main effect of instrument ($p<0.001$), but no significant main effect of motion ($p>0.05$) and no significant interaction between instrument and motion ($p>0.05$). Post-hoc tests indicated that maximum...
screw-in force values in EDM were significantly greater than those in GPF and RaCe (p<0.001).

**DISCUSSION**

This study compared selected mechanical properties of three brands of glide path files that differ in terms of alloy processing and manufacturing procedures. The data obtained do not solely reflect the difference in the alloy processing and manufacturing, but may have been influenced by the different design and geometry (taper, diameter, cross sectional shape, etc.) of each instrument. Nevertheless, the data may provide useful information in understanding the behavior of each brand of files during glide path preparation.

The results can be summarized as; (i) EDM showed a significantly larger torque at fracture, a longer time to cyclic fracture in reciprocation and a larger screw-in force compared with GPF and RaCe; and (ii) GPF showed significantly lower bending loads and higher angular deflection values than EDM and RaCe, and a significantly longer time to cyclic fracture than RaCe. Thus, the first null hypothesis was rejected. Moreover, the time to cyclic fracture was significantly longer in reciprocation compared with continuous rotation in EDM and GPF, whereas screw-in force levels were not affected by the difference in the motion. Thus, the second null hypothesis was partly rejected.

Bending loads depend on the elastic moduli of the files, which vary according to several factors including different crystalline structures of NiTi alloy19), and the cross-sectional area22) and taper20) of the instruments. At body temperature, CM wire is composed of a mixture of martensite, R-phase, and a small amount of austenite23). The martensitic phase deforms with a smaller load compared with the austensitic phase. Moreover, the martensitic transformation stress decreases along with the increase in the austenite transformation finishing temperature (Af)19,21). In this regard, one study has reported that row CM wires exhibit higher Af (54.3±4.2°C) compared with conventional NiTi wires (23.6±2.3°C)20). It has also been reported that HyFlex EDM and HyFlex CM have Af of over 52°C and around 32–37°C, respectively9), and that RaCe exhibits Af of 24.7±2.5°C24). Thus, lower load values for GPF may be attributed to the higher Af of the CM wire. EDM showed the largest load at 2.0 mm deflection, although the Af of HyFlex EDM is higher than that of HyFlex CM9). This is likely because EDM has a larger taper compared with CM and RaCe.

Torsional fracture occurs as a result of plastic deformation caused by force exceeding the elastic limit of the metal19). In the present study, EDM, which has larger diameter at 3 mm from the tip, showed the largest maximum torque among the three instruments (Fig. 4A). This was consistent with a previous study that showed that the maximum torque increases proportionally to the diameter of instruments22). GPF exhibited significantly higher angular deflection compared with RaCe (Fig. 4B), which may be associated with the superior flexibility of CM wire compared with conventional NiTi wire23). However, GPF and RaCe showed similar maximum torque values (Fig. 4A), which is consistent with a previous study showing that torque values are similar in 2 types of Typhoon files (CM wire and conventional NiTi wire)20).
The findings of the cyclic fatigue test demonstrated that the cyclic fatigue resistance of EDM and GPF was better than that of RaCe, particularly under reciprocation (Fig. 5), which is consistent with a previous study showing that instruments manufactured from CM wire show a remarkable increase in cyclic fatigue resistance compared with those from conventional NiTi wire. This is associated with the fact that CM wire has a higher Af compared with conventional NiTi wire, indicating that CM wire has a hybrid (austenite-martensite) structure at body temperature. Thus, CM wire contains a certain proportion of martensite, which has remarkable fatigue resistance. EDM showed a higher fatigue resistance than GPF under reciprocation, which is in accordance with a previous study, and may be associated with the finding that HyFlex EDM is mainly composed of martensite and R-phase. It is known that R-phase, which is an intermediate phase formed during the transformation of the martensite phase and austenite phase, exhibits superior resistance to cyclic fatigue. However, the time to fracture of EDM and GPF under continuous rotation was not significantly different (Fig. 5). This is likely associated with the larger taper of EDM compared with GPF, since increasing the taper of NiTi instruments decreases the resistance to cyclic fatigue fracture.

This study evaluated the cyclic fatigue life under reciprocal motion by the time to fracture, as in previous studies. This is because assessment of the number of cycles to failure, used in other studies, may not be accurate for reciprocation, since the rotation speed is not constant. The findings demonstrated that reciprocation showed a longer time to fracture than continuous rotation in EDM and GPF (Fig. 5). This is consistent with previous studies showing that reciprocation induces slower crack propagation than continuous rotation, and that cyclic fatigue resistance of CM wire instruments increases with reciprocation.

In this study, EDM showed greater screw-in force levels than GPF and RaCe (Fig. 6), which may be ascribed to the larger taper of EDM compared with the other instruments. There was no difference in the maximum value of the screw-in force between GPF and RaCe, which have the same square cross-sectional shape, tip size, and taper. However, the maximum values of the screw-in force were similar between reciprocation and continuous rotation. These results may be associated with the size of the simulated root canal block (#15, 0.02 taper), which was close to the size of the instruments tested and thus the screw-in force may be readily released by the upward movement of the files. This assumption is supported by the fact that the torque and force generated by rotary instruments are dependent on the amount of contact between the instrument and the canal wall. It seems reasonable to suppose that when the contact area between a small-sized file and the canal wall is small the effect of different kinematic motions and file designs on the screw-in force generation is negligible.

The present findings may support the notion that CM wire-manufactured instruments offer clinical advantages over conventional NiTi instruments in preparing curved canals, particularly with regard to the improved torsional and cyclic fatigue fracture resistance. EDM has a greater taper (5%), which may confer some clinical advantages to this instrument; the greater taper may increase torsional fracture resistance, and the greater-tapered glide path may facilitate the use of subsequent instruments. The lower flexibility of EDM, most likely due to the greater taper, may be minimally influence on its shaping ability, since it has been reported that flexibility of glide path files does not affect the degree of apical transportation. However, larger screw-in force generation of EDM should be taken into consideration during its clinical usage, since the force could be associated with torsional fatigue and overinstrumentation.

Under the present experimental conditions, it can be concluded that (i) EDM and/or GPF showed lower bending loads and higher cyclic fatigue and torsional resistance compared with RaCe, whereas EDM generated higher screw-in forces than GPF and RaCe; and (ii) reciprocation conferred better cyclic fatigue resistance to EDM and GPF than did continuous rotation.

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