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Influence of different motions on the cyclic fatigue resistance of Reciproc and Reciproc Blue endodontic instruments

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Abstract

Aim: The aim of this study was to evaluate the cyclic fatigue resistance of Reciproc (RCP) and RPC Blue (RCPB) instruments used in continuous rotation, “RECIPROC” mode, and “WAVEONE” mode. **Materials and Methods:** Sixty RCP and 60 RCPB R25 files were used. For each file type, three groups (n = 20) were defined depending on the used kinematics: continuous rotation, “RECIPROC” mode, and “WAVEONE” mode. A stainless-steel artificial canal with 60° angle and 5-mm radius of curvature was milled reproducing the size and taper of the used files. The test device was electrically heated to 35°C to simulate the clinical environment. All files were reciprocated or rotated until fracture. The time to failure and the length of the fractured fragments were measured. A fractographic examination was performed by scanning the electron microscopy to confirm the cause of fracture. Collected data underwent a two-way analysis of variance (α = 0.05). **Results:** RCPB files exhibited better cyclic fatigue resistance than RCP. The “RECIPROC” motion yielded greater cyclic fatigue resistance than the “WAVEONE” movement; the least resistance was observed in the continuous rotation groups. No significant differences were found among groups in terms of length of the fractured fragment. The fractographic analysis confirmed that all scanned samples separated due to cyclic fatigue. **Conclusions:** Within the limitation of the present study, the “RECIPROC” mode increased the cyclic fatigue resistance of the tested instruments compared to “WAVEONE” mode and continuous rotation. To prevent RCP and RCPB file separation, motion kinematics other than the native “RECIPROC” movement should be discouraged in the clinical setting.

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Full Text

Introduction

Stainless steel files are universally used in endodontics and still indispensable in the clinical practice. However, the most modern endodontic files are manufactured with different types of nickel-titanium (NiTi) alloys, and their vast majority is designed to be engine driven. NiTi endodontic files are more flexible but, on the other hand, they seem to be exposed to increased risk of separation in the clinical setting.[1] A mechanical NiTi instrument may fracture as a result of an excess of torsional or cyclic fatigue;[2] the former occurs when the tip of the file is locked while the shank continues to rotate,[3] the latter is the consequence of alternating tensile and compressive mechanical loads caused by the rotation of the endodontic instrument inside a curved canal.[4] Resistance to torsional fatigue cannot be easily improved as it substantially depends on the technique and the operator; conversely, the resistance to cyclic stress can be more easily enhanced during the manufacturing process of endodontic files.[5] Indeed, file manufacturers have developed innovative instrument designs, NiTi alloy treatments, production processes, and kinematics to reduce fracture occurrence.[6]

It has been shown that kinematics is important for the cyclic fatigue life of NiTi files; the reciprocating motion was especially shown to increase the cyclic lifespan of NiTi files.[7] In 2008, a new approach using a NiTi single file in a reciprocating movement was introduced.[8] The risk of cyclic fatigue fracture is reduced because the counter rotation of reciprocating motion diminishes the stress exerted on the file during canal shaping.[9] The findings of a recent review suggest that reciprocating motion improves the cyclic fatigue resistance of the mechanical instruments, compared to continuous rotation, independently of other variables such as rotation speed, canal curvature, and instrument design.[10] Consequently, endodontic brands have started to launch alternative movement kinematics into the dental market.

In 2011, Reciproc (RCP) instruments (RCP; WDV GmbH, Munich, Germany), a single-file reciprocating system, were launched to simplify the root canal preparation. Only one shaping file is required to provide the canal with adequate size and taper.[11] RCP instruments are made of a heat-treated NiTi alloy called M-Wire.[12] M-Wire alloy is composed of 508 Nitinol that has undergone a proprietary method of treatment resulting in a phase shift characterized by portions of martensite and R-phase.[13] The benefit of the M-Wire alloys is an improved fatigue resistance.[14]

RCP instruments have been recently upgraded to RCP Blue (RCPB; VDW GmbH) by using an innovative heat treatment that transforms the molecular structure of the alloy and gives the instrument a visible blue color due to a titanium oxide layer, in addition to greater flexibility and cyclic fatigue resistance.[15] This postmachining treatment reduces the shape memory of the NiTi alloy and induces the occurrence of martensitic transformation in two phases just below the body temperature.[3] RCP and RCPB instruments share the same S-shaped cross-section, 2 cutting edges, and a noncutting tip.[7] The specific movement suggested is the same left-cutting “RECIPROC” mode used for RCP files.

To date and to our knowledge, cyclic fatigue resistance of RCPB endodontic instruments has not been tested under different reciprocating motions. Thus, the aim of the present in vitro study was to evaluate if different movement kinematics can influence the cyclic fatigue resistance of the new RCPB files and their predecessor RCP. The null hypotheses are that there is no difference in fatigue resistance between the two considered motions and between RCP and RCPB instruments.

Materials and Methods

Sample size was calculated referring to preliminary data (power = 0.80; alpha = 0.05; number of groups = 6; δ = 40.0; σ = 43.0). Afterward, 60 25-mm long RCP R25 (25/0.08) and 60 RCPB R25 (25/0.08) instruments were inspected at ×25 magnification under a stereomicroscope (Leica MZ10 F, Wetzlar, Germany) to exclude the presence of defects. The files were randomly divided into three groups (n = 20) on the basis of the tested motion: continuous rotation in "REV" mode at 300 rpm (Group 1), reciprocating movement with "RECIPROC" mode (Group 2), and reciprocating movement with "WAVEONE" mode (Group 3). The X-Smart IQ (Dentsply Sirona, York, PA, USA) endodontic motor with 6:1 hand piece was used.

The static cyclic fatigue test was carried out using a custom-made device that provided a reproducible simulation of an instrument confined in an artificial curved canal [Figure 1]. A stainless-steel canal was designed and constructed with a tapered shape corresponding to the dimensions of the instruments tested, thus providing the instruments with a suitable trajectory. The artificial canal was manufactured with a 60° angle and a 5-mm radius of curvature from the tip of the instrument, having a total working length of 16 mm. Special synthetic oil (WD-40 Company, Milton Keynes, United Kingdom) was applied for lubrication to reduce the friction of the file against the artificial canal walls and thus avoid temperature rise. The endodontic hand piece was mounted on an adjustable device to reproduce the position of each instrument inside the canal simulator. To standardize and monitor the environmental conditions of the experimental setup, a thermometer was mounted on the steel block to control the temperature provided by a hotplate set at 35°C. All the instruments were subjected to cyclic fatigue testing and rotated or reciprocated until fracture. For each instrument, the time to failure (TtF) was recorded in seconds with a digital chronometer (HS-3V-1R, Casio, Tokyo, Japan). The fragment length (FL) was also measured for each instrument with a digital microcaliper (Series 500, Mitutoyo, Kawasaki, Japan).{Figure 1}

Five fractured files for each subgroup were blindly selected and ultrasonically cleaned in absolute alcohol for electron microscope scanning (scanning electron microscope [SEM]; Quanta 250, Fei Company, Hillsboro, NE, USA). The SEM analysis was aimed at examining the topographic features and confirming that the files fractured because of cyclic fatigue.

The collected data were subjected to the statistical analysis with dedicated software (Statistical Package for the Social Sciences software version 15, SPSS Inc., Chicago, IL, USA). A first part of the analysis assessed the required assumptions for the use of parametric tests: the normality of the distribution and equality of variances were tested with a Shapiro–Wilk and Levene test, respectively. Finally, the differences among the considered subgroups in terms of were assessed by means of a two-way analysis of variance with a post hoc Duncan's test (α = 0.05).

Results

The results obtained in the cyclic fatigue tests are reported in [Table 1]. Irrespective of the instrument type being tested, the inferential statistical analysis showed that the "RECIPROC" groups allowed for significantly increased cyclic fatigue resistance compared to "WAVEONE" and continuous rotation groups ($P < 0.05$) with no significant differences between the two latter groups ($P > 0.05$). RCPB instruments showed greater cyclic fatigue resistance compared to RCPB, regardless of the motion kinematics used ($P < 0.05$).{Table 1}

There was no significant difference ($P > 0.05$) in the mean length of the fractured fragments for all the instruments tested. The scanning electron microphotographs of the fracture surfaces revealed similar overload areas and fracture initiation zones on analyzed instruments. The crack initiation origin and the surface pattern with dimples and cones were observed in the same fracture plane [Figure 2].{Figure 2}

Discussion

The results of the present in vitro study showed that different motions can influence the cyclic fatigue life of the tested NiTi instruments. The null hypotheses were rejected, since the different kinematics affected the lifespan of RCP and RCPB files and the two instrument types had different resistance to cyclic fatigue. More specifically, the statistical analysis demonstrated that the reciprocating movement has the potential to increase the cyclic fatigue resistance compared to the continuous rotation; furthermore, the new blue NiTi alloy showed improved the mechanical properties compared to M-Wire.

The undesired separation of rotary NiTi files has been attributed to torsional or cyclic fatigue. Mechanical NiTi files are subjected to cyclic fatigue when they rotate in a curved space and the repeated mechanical cycles alter their structure up to file separation.[16] Reciprocating NiTi instruments have been developed as a means of increasing performance and safety following the principle that they can work below the elastic limit of the NiTi alloy.[17] The reciprocating working motions consist of a series of rotations and counterrotations in which the cutting angle is greater than the release angle, while the instrument continuously progresses towards the apex of the canal.[18] Only two commercial reciprocal motions exist to date; in the present study, the preset "RECIPROC" mode (150° CCW angle and 30° CW angle; total angle: 180°; angle of progression for each reciprocation cycle: 120°; speed: 300 rpm) and the preset "WAVEONE" mode (170° CCW angle, and 50° CW angle; total angle: 220°; angle of progression for each reciprocating cycle: 120°; speed: 350 rpm) were used.[19] Cyclic fatigue could be influenced by reciprocation angles but speed could also play a role in cyclic behavior.[20] A previous study compared these two reciprocal movements on various NiTi files, but it showed that there were no statistically significant differences because the diversities in stress resistance have been related to design and alloy characteristics of the instruments used.[21] Unfortunately, the exactly angles, speed, acceleration, and deceleration of the instruments are unknown, because they are protected by the manufacturers' patents, so the calculation of the number of cycles to failure (NCF) could not be made; in fact, it is not possible to precisely establish the NCF in reciprocation doing forward and backward angles. The authors agree with a recent study stating that NCF is not the best parameter to compare different kinematics.[22] Nonetheless, the use of TtF permits a rapid comparison between mechanical stress resistance of rotated or reciprocated endodontic files. It can be postulated that TtF is more clinically relevant, reflecting how the instruments are used clinically, while NCF is more related to the metallurgical property of the file itself, being indicative without considering the speed variable.[23] In the present study, the reciprocating movements exhibited greater fatigue resistance than continuous rotation, but only the native "RECIPROC" motion showed statistical significance compared to the others motions tested on RCP and RCPB instruments. A speculative explanation is that this finding could be ascribed to a smaller total angle (cutting and release angles jointly) of "RECIPROC" motion and lower rotational speed compared to "WAVEONE" one.

RCP properties have been amply studied, but also some studies about the cyclic fatigue resistance of RCPB files are available,[3],[7],[15],[22],[24],[25],[26],[27],[28],[29] despite their recent introduction into dental market. Unfortunately, it is not possible to directly compare all their data with the results obtained in the present study because of a lack of standardization of the environmental conditions. Most in vitro studies have been carried out at the room temperature, whereas NiTi instruments are called upon to work at the body temperature (~37°C). Body temperature has a significant effect on the cyclic fatigue resistance.[25],[29] The temperature at which the instruments are tested could influence the results of cyclic fatigue resistance on NiTi files with a different behavior depending on the previous heat treatment of the alloy.[30] Martensitic transformation of heat-treated NiTi alloy, superelastic behavior, and cyclic fatigue resistance can be affected by the environmental temperature, reducing the fatigue life of the instrument exposed to body temperature.[31] This agrees with a preceding study in which a temperature increase negatively affected the cyclic fatigue resistance of RCP and RCPB files.[28] In addition, a recent differential scanning calorimetry study on the metallurgical properties of RCPB instruments confirmed their two-stage martensitic transformation below the body temperature, which leads to a softer and more ductile NiTi alloy in the clinical use.[25] In the present in vitro study, the simulation of the environmental conditions (i.e., simulation of body temperature) was followed to obtain actual results about cyclic fatigue.

Fractographic analysis was performed on RCP and RCPB files subjected to cyclic fatigue to identify the causes of failure. The SEM analysis showed the images of typical fractographic appearances of cyclic failure that were similar in continuous and reciprocating groups. Finally, in the present study, there was no significant difference in the length of fractured fragments indicating the correct position of the instruments inside the canal simulator.

Conclusions

Within the limitation of the present in vitro study, which confirmed the superiority of RCPB in terms of cyclic fatigue resistance over their predecessors, the reciprocal motion "RECIPROC" mode improved the cyclic fatigue resistance of the tested files compared to "WAVEONE" mode and continuous rotation. In the clinical settings, the observance of the native motion could be a strategy to prevent file separation and increase cyclic fatigue resistance of RCP and RCPB.

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Conflicts of interest

There are no conflicts of interest.

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