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Fatigue resistance of rotary endodontic files submitted to axial motion in multiplanar canals manufactured by 3D printing

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Abstract

The objective of the research herein presented was to assess the time to fracture of *Hyflex CM* files subjected to rotational bending tests, with or without back and forth motion, in an apical canal similar to those existent in a real tooth with multiplanar curvatures.
Therefore, a lower first molar was modelled and manufactured in an AISI 316L stainless steel using selective laser melting technology, featuring the required multiplanar curvatures, which were confirmed by radiography. Thereafter, endodontic files were submitted to either rotational bending tests without back and forth motion (Group A) or rotational bending tests with back and forth motion (Group B) inside an artificial root canal with primary, secondary and tertiary curvatures. Time to fracture was recorded and fragments of the endodontic files tested were observed by optical microscopy.
Instruments of Group A showed an average time to fracture of 119 seconds and an average fractured tip length of 4.9 mm, while instruments of group B displayed an average time to fracture of 194.1 seconds (+63%) and an average fractured tip length equal to 4.13 mm. All instruments fractured due to fatigue crack propagation.
Hence, it was possible to conclude that back and forth motion extended the fatigue lifetime of the files tested once allowed diminishing the number of cycles with higher stress range applied, and spread the induced stresses by an enlarged area of the instrument. Additionally, almost plane surfaces were observed at fractured cross sections of the instruments tested, allowing to infer a very low influence of torsional loading when compared with bending.

Keywords: Lower first molar (LFM); Multiplanar curvatures; Rotary endodontic files; Back and forth motion; Fatigue resistance; Selective laser melting.

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1. Introduction

Root canal morphology is commonly accepted as an important factor to consider when performing endodontic treatments. In fact, multiple curved root canals usually increase the difficulty of clinical procedures [1] and the success of a root canal debridement and shaping using rotary instrumentation is dependent on the instrument's ability to follow the original centred path of the tooth canal. Hence, flexibility is regarded as one crucial characteristic that allows the instrument to adapt to highly curved canals [2].

Current instrumentation made of Nickel-Titanium alloys (Ni-Ti) and displaying control memory effect (CM) show high flexibility, although file's fracture can still occur due to steady torsion, cyclic bending or torsional fatigue, especially when highly curved root canals are involved [3]. The lower first molars (LFM) are the type of tooth most commonly subjected to endodontic therapy [4] and conventional radiographic images show the severity of the mesiobuccal (MB) canal primary curvature; in addition, the canal is a 3D geometry with secondary and tertiary curvatures, also known as multiplanar curvatures, which are clinical challenging as they can cause file's fracture due to torsional failure and to the ever-present possibility of failure due by cyclic fatigue [1].

Several studies were made in the past years regarding the effect of root canal curvature on the fatigue life of Ni-Ti rotary instrumentation. As an example, Li et al. [5] evaluated the fatigue life of Ni-Ti files subjected to different rotation speeds for different angles of a single planar curvature. More recently, the fatigue resistance of Ni-Ti rotary instruments submitted to single and double planar curvature canals, without axial motion, was determined [5], and the experimental results confirmed that double curvature anatomies of root canal were much more stressful for Ni-Ti files than single planar curvatures. Additionally, the effect of axial motion, also known as back and forth motion, allows varying the travel distance of the endodontic file inside teeth's root canal [6].

Therefore, the objective of this study was to assess the fatigue life of Ni-Ti rotary files subjected to in-vitro rotational bending tests, with or without axial motion, in an apical canal with multiplanar curvature of a 3D stainless steel tooth model created by laser additive manufacturing technology.

2. Materials and methods

A lower first molar was manufactured through an additive technology from a CAD 3D tooth model (Fig.1), which was designed using *SolidWorks*®. For the manufacturing process, it was used the selective laser melting technology available on a SLM250 machine and the material used for fabrication was an AISI 316L stainless steel. According to the molar shape and to obtain the best surface quality, a 30 µm layer thickness manufacturing strategy with specific parameters for thin walls parts was adopted. Two X-ray images, namely bucolingual and mesiodistal views from a maxillary molar morphology study [1] were used to accurately model the artificial tooth (Figs. 1 a, b). On the bucolingual view, the canal shows a primary curvature, while a double curvature can be seen on the mesiodistal view with an upper secondary curvature and a tertiary curvature on the apical region. It's important to mention that the smallest radius of curvature, $r = 2.81$ mm, was localized in the tertiary curvature (Fig. 1c). Additionally, based on the adapted Schneider's method [7], main dimensions of the curvatures were measured from the X-ray images of the original tooth and of the modelled tooth (Table 1) (Fig. 1a, b, c), which allowed to calculate relative errors that were comprehended between 9.3 and 10.1% (Table 1). In addition, two X-ray images of the lower first molar model produced on stainless steel were taken with an industrial ANDREX Constant Potential X-Ray set (100 KV, 4,0 mA, 6 min), (Fig. 1d), respectively, allowing to confirm the similitude between the original and the tooth model fabricated just before the experimental tests had begun, in which rotational motion provided by a *WaveOne* rotary handpiece (*Dentsply*) was superimposed to axial motion allowing to simulate back and forth motion (Fig. 2a).

Therefore, as-fabricated *HyFlex CM* ref. .04/20 rotary endodontic files with tip size (diameter) equal 0.20 mm and taper equal to 0.04 were tested (Fig. 2b). All instruments were submitted to a rotational speed of 500 rpm and an input torque of 4 N.cm. Besides rotational bending loading, instruments belonging to group B were also submitted to an axial speed of 3 mm/s along a distance of 3 mm. Each test was initiated by placing the endodontic file in position (Fig.2 c) and fatigue tests were carried out until fracture occurred.