Dynamic Torsional and Cyclic Fracture Behavior of ProFile Rotary Instruments at Continuous or Reciprocating Rotation as Visualized with High-speed Digital Video Imaging

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Abstract

Introduction: This study examined the dynamic fracture behavior of nickel-titanium rotary instruments in torsional or cyclic loading at continuous or reciprocating rotation by means of high-speed digital video imaging. **Methods:** The ProFile instruments (size 30, 0.06 taper; Dentsply Maillefer, Ballaigues, Switzerland) were categorized into 4 groups ($n = 7$ in each group) as follows: torsional/continuous (TC), torsional/reciprocating (TR), cyclic/continuous (CC), and cyclic/reciprocating (CR). Torsional loading was performed by rotating the instruments by holding the tip with a vise. For cyclic loading, a custom-made device with a 38° curvature was used. Dynamic fracture behavior was observed with a high-speed camera. The time to fracture was recorded, and the fractured surface was examined with scanning electron microscopy. **Results:** The TC group initially exhibited necking of the file followed by the development of an initial crack line. The TR group demonstrated opening and closing of a crack according to its rotation in the cutting and noncutting directions, respectively. The CC group separated without any detectable signs of deformation. In the CR group, initial crack formation was recognized in 5 of 7 samples. The reciprocating rotation exhibited a longer time to fracture in both torsional and cyclic fatigue testing ($P < .05$). The scanning electron microscopic images showed a severely deformed surface in the TR group. **Conclusions:** The dynamic fracture behavior of NiTi rotary instruments, as visualized with high-speed digital video imaging, varied between the different modes of rotation and different fatigue testing. Reciprocating rotation induced a slower crack propagation and conferred higher fatigue resistance than continuous rotation in both torsional and cyclic loads. *(J Endod 2017;■:1–6)*

Key Words

Cyclic fatigue, fracture, high-speed camera, nickel-titanium rotary instrument, reciprocating, scanning electron microscope, torsional fatigue

> **Significance**
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> The dynamic fracture behavior of NiTi rotary instruments, as visualized with high-speed digital video imaging, varied between different modes of rotation (continuous and reciprocal) and different types of fatigue testing (torsional and cyclic).

The unexpected fracture of rotating nickel-titanium (NiTi) instruments inside root canals remains a matter of great concern (1). The instrument fracture is known to occur in 2 different forms (ie, torsional fatigue fracture and cyclic fatigue fracture) (2). Torsional fatigue fracture is induced when an instrument is locked into a canal during rotation and the resulting torque exceeds the elastic limit of the NiTi alloy (3). Cyclic fatigue fracture is caused by repeated compressive/tensile stresses that accumulate around the curved point of rotating instruments (2, 4). Various efforts have been made to increase the fracture resistance of NiTi rotary instruments, such as modification of the file design (5), use of heat-treated alloys (6), and improvement of the surface treatment (7) and manufacturing process (8, 9). Moreover, reciprocating rotation is advocated to reduce the risk of instrument fracture because the values of the rotation angle to the cutting direction are below the angle at ultimate torsional stress; thus, separation of the reciprocating instruments can be prevented (3, 10).

In previous studies, mechanisms of the fracture of NiTi instruments have been investigated with fractographic examination under scanning electron microscopy. The surface of instruments fractured by cyclic fatigue loading exhibits specific features in the scanning electron microscopic images, including the presence of crack initiation areas and the formation of dimples indicating ductile rupture. In contrast, the morphological features of torsional fatigue fractures are characterized by the presence of concentric abrasion marks and fibrous dimples at the center of rotation (11–13). Moreover, finite element analysis has revealed that torsional fatigue stress increases radially outward from the center of the model where the neutral stress axis lies (14, 15). However, the dynamic fracture behavior of crack initiation and propagation in NiTi rotary instruments has not been examined.

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0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2017.03.024

High-speed videography enables visualization of fast-moving objects as still images and has been used to investigate various high-speed phenomena such as intracanal irrigant flow and cavitation during erbium-doped: yttrium-aluminum-garnet laser–assisted irrigation (16) and the kinematics of reciprocating endodontic motors (17). Thus, herein we applied a high-speed digital video imaging technique to investigate fracture initiation and propagation in and the ultimate failure of rotating NiTi instruments. The purpose of this study was to analyze the dynamic fracture behavior of NiTi rotary instruments in torsional or cyclic loading at continuous or reciprocal rotation via high-speed video imaging. The hypotheses raised were as follows:

1. Different modes of rotation (continuous and reciprocal) and different types of fatigue testing (torsional and cyclic) induce different dynamic fracture behaviors of NiTi rotary instruments
2. Reciprocating rotation confers higher fatigue resistance than continuous rotation in both torsional and cyclic loads

Material and Methods

Twenty-eight new ProFile NiTi rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) with a tip size of 30 and a 0.06 taper were used. The instruments were divided into the following 4 groups (n = 7 in each group) according to the type of fracture loading/mode of rotation used in the experiment: torsional/continuous (TC), torsional/reciprocating (TR), cyclic/continuous (CC), and CR (cyclic/reciprocating).

High-speed Digital Video Recording

A high-speed camera (Phantom V12; Vision Research Inc, Wayne, NJ) was used to record the rotation of the instrument at 100 frames per second. The rotating instrument was sufficiently lit using a metal halide lamp (LS-M350; Sumita Optical Glass Inc, Saitama, Japan). The camera was focused on the predicted site of instrument fracture, which was determined by preliminary experiments. The resulting movies were analyzed with video editing software; VisualDubMod 1.5.10.2 (http://www.virtualdub.org/) was used to extract individual frames, and Vegas Movie Studio HD Platinum Ver. 11.0 (Sony Creative Software, Middleton, WI) was used to edit the images and adjust the contrast.

Rotation Device and Rotation Mode

A custom-made endodontic motor (modified from Root ZX II OTR Module; J Morita Corp, Kyoto, Japan, by adding a “reciprocating rotation without torque control” function) was used to rotate the instruments. Continuous rotation was made at 300 rpm without torque

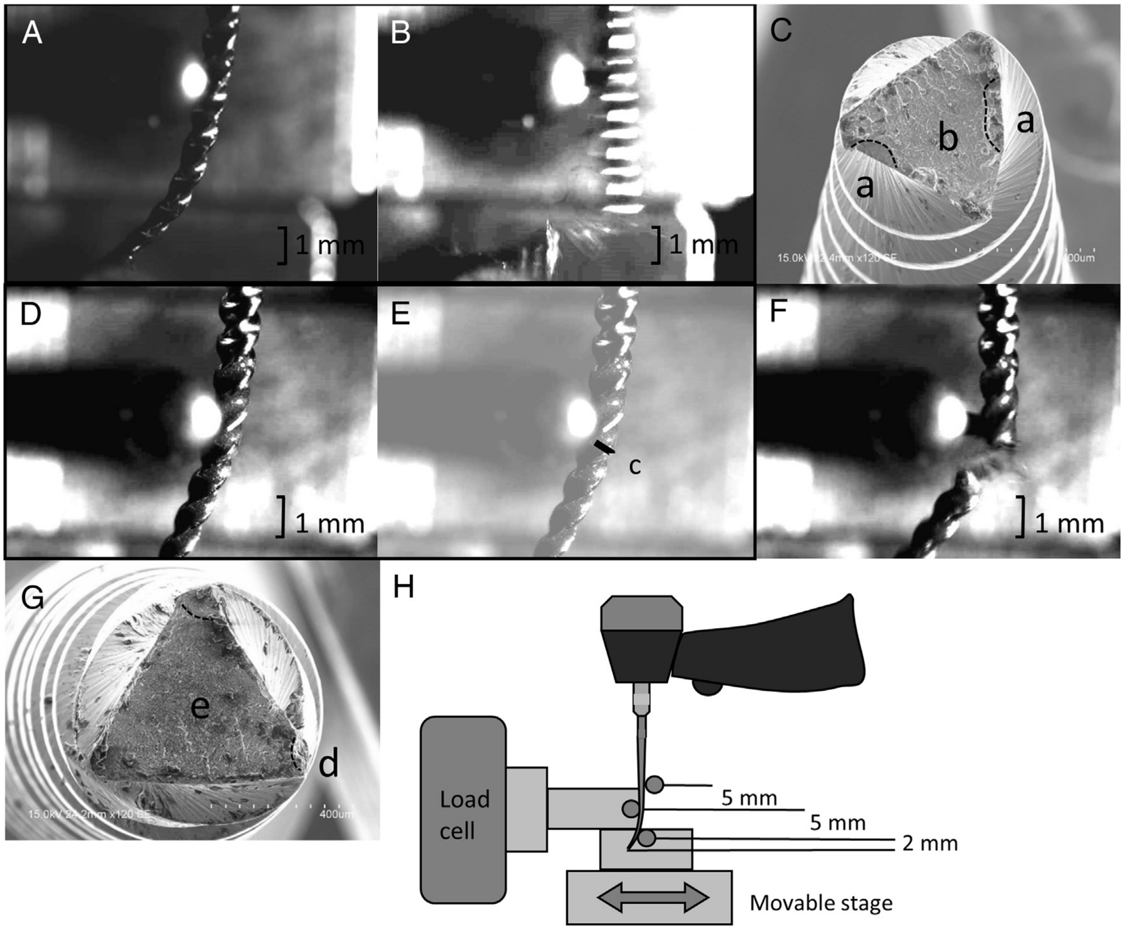

Figure 1. Representative high-speed photographic images and scanning electron microscopic images of separated ProFile instruments obtained from (*A–C*) groups CC and (*D–G*) CR and (*F*) the cyclic fatigue test device. *H* shows a schematic drawing of the cyclic fatigue test device. (*A*) Crack formation of the file is not recognized in the 830th frame (8.30 seconds after starting video recording), and (*B*) separation of the file is observed in the next frame (831st frame). (*C*) The fracture surface shows crack initiation areas (a) and a fast fracture zone (b). The *dotted lines* show the border of the crack initiation areas. (*D*) An initial crack line (c) is recognized in the 3738th frame (*E* is an explanatory image of *D*), and (*F*) separation of the file is observed in the next frame (3739th frame). (*G*) The fracture surface shows crack initiation areas (d) and a fast fracture zone (e). The *dotted lines* show the border of the crack initiation.