ARTICLE IN PRESS
+ MODEL
Journal of the Formosan Medical Association (2016) xx, 1–7

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.jfma-online.com

ORIGINAL ARTICLE

Fracture resistance of dental nickel–titanium rotary instruments with novel surface treatment: Thin film metallic glass coating

Chih-Wen Chi [a,b], Yu-Lun Deng [c], Jyh-Wei Lee [c,d,e,*], Chun-Pin Lin [a,f,g,*]

[a] Graduate Institute of Clinical Dentistry, School of Dentistry, National Taiwan University, Taipei City, Taiwan
[b] National Taiwan University Hospital Hsin-Chu Branch, College of Medicine, National Taiwan University, Hsin-Chu, Taiwan
[c] Department of Materials Engineering, Ming Chi University of Technology, New Taipei City, Taiwan
[d] Center for Thin Films Technologies and Applications, Ming Chi University of Technology, New Taipei, Taiwan
[e] College of Engineering, Chang Gung University, Taoyuan, Taiwan
[f] National Taiwan University Hospital, College of Medicine, National Taiwan University, Taipei, Taiwan
[g] School of Dentistry, China Medical University and China Medical University Hospital, Taichung, Taiwan

Received 19 June 2016; accepted 5 July 2016

KEYWORDS
cyclic fatigue life;
NiTi endodontic instrument;
surface treatment;
thin film metallic glass

Background/Purpose: Dental nickel–titanium (NiTi) rotary instruments are widely used in endodontic therapy because they are efficient with a higher success rate. However, an unpredictable fracture of instruments may happen due to the surface characteristics of imperfection (or irregularity). This study assessed whether a novel surface treatment could increase fatigue fracture resistance of dental NiTi rotary instruments.
Methods: A 200- or 500-nm thick Ti–zirconium–boron (Ti-Zr-B) thin film metallic glass was deposited on ProTaper Universal F2 files using a physical vapor deposition process. The characteristics of coating were analyzed by scanning electron microscopy, transmission electron microscopy, and X-ray diffractometry. In cyclic fatigue tests, the files were performed in a simulated root canal (radius = 5 mm, angulation = 60°) under a rotating speed of 300 rpm.

Conflicts of interest: The authors have no conflicts of interest relevant to this article.

* Corresponding authors. Jyh-Wei Lee, Department of Materials Engineering, Ming Chi University of Technology, 84 Gungjuan Road, Taishan, New Taipei City 24301, Taiwan; Chun-Pin Lin, School of Dentistry, National Taiwan University, Number 1, Changde Street, Taipei 10048, Taiwan.
E-mail addresses: jefflee@mail.mcut.edu.tw (J.-W. Lee), chunpinlin@gmail.com (C.-P. Lin).

http://dx.doi.org/10.1016/j.jfma.2016.07.003

The fatigue fractured cross sections of the files were analyzed with their fractographic performances through scanning electron microscopy images.
Results: The amorphous structure of the Ti-Zr-B coating was confirmed by transmission electron microscopy and X-ray diffractometry. The surface of treated files presented smooth morphologies without grinding irregularity. For the 200- and 500-nm surface treatment groups, the coated files exhibited higher resistance of cyclic fatigue than untreated files. In fractographic analysis, treated files showed significantly larger crack-initiation zone; however, no significant differences in the areas of fatigue propagation and catastrophic fracture were found compared to untreated files.
Conclusion: The novel surface treatment of Ti-Zr-B thin film metallic glass on dental NiTi rotary files can effectively improve the fatigue fracture resistance by offering a smooth coated surface with amorphous microstructure.

Introduction

Nickel–titanium (NiTi) rotary instruments have been popularly used in endodontic treatment for more than two decades. Compared with conventional stainless steel files, NiTi instruments present superior flexibility and shape-memory ability.[1,2] NiTi rotary instruments can shape the canal more efficiently and prevent canal aberrations including ledge, perforation, and transportation in curved root canals.[3–5] Therefore, the original shape of the canal can be maintained and the following clinical procedure can be simplified.[6,7] The process of endodontic treatment thus becomes more efficient with a higher success rate.[8] Despite the advantages of NiTi instruments, instrument fracture in the root canal remains the main issue in clinical applications.

NiTi instrument failure can be divided into two main mechanisms: torsional fracture and cyclic fatigue.[9,10] Torsional fracture is due to the extensive resistance from the root canal wall. Cyclic fatigue results from the alternation of tension and compression of the rotary instrument in the curved canal.[11] Indeed, a rotary instrument receives various loading as the combination of the cyclic and torsional stress which may lead to its fracture during clinic root canal treatment.[12] The instrument fracture or crack is usually attributed to the defects on its edge or surface.[13] Therefore, surface treatments such as electropolishing and ion implantation are applied to enhance the fatigue life by removing surface irregularities, cracks, and residual stresses.[14,15] However, previous studies reported that electrochemical polishing treatments are not able to increase the mechanical resistance of the instrument, and unpredictable fracture may happen at times in clinical practice.[16]

Recently, metallic glass (MG) materials have attracted lots of attention due to their amorphous structure and unique mechanical properties.[17,18] A good corrosion resistance of the MG material is clearly revealed since no grain boundaries, dislocations, and crystalline defects as corrosion initiation sites are found on its surface. Furthermore, the development of thin film metallic glass (TFMG) through physical vapor deposition process becomes more and more popular because of the unique properties of MG in the thin film form.[19–23] A recent study showed that zirconium (Zr)-based TFMG is capable of smoothening the substrate surface and improving the fatigue life of a 316L stainless steel substrate.[19] Besides, the hardness of the 316L stainless steel substrate is also increased by the Zr-based TFMG coating.[24] Despite the advantages of TFMG coating, it has not yet been applied to dental instruments.

In this study, the new surface treatment with a unique material, Ti-Zr-boron (Ti-Zr-B) based TFMG coating, was applied to the surface of the ProTaper Universal F2 (Dentsply Maillefer, Ballaigues, Switzerland) by a physical vapor deposition process. The mechanical behavior of the TFMG-coated files was evaluated using the cyclic fatigue test. The fracture mechanism of the treated files was also investigated with fractographic analysis.

Methods

Surface treatment

The Ti-Zr-B TFMG was deposited on the ProTaper Universal F2 files using a carousel-type radio frequency and pulsed direct current reactive magnetron sputtering system in an argon ambient under room temperature. The p-type (100) silicon wafer was also deposited for the physical characterization measurement of the Ti-Zr-B TFMG coating. This sputtering system consisted of three rectangular targets and a 360° rotating sample holder in the center of the chamber.[23] Three pure element targets of Ti, Zr, and B with purity of 99.99% were used and the dimension of each target was 127 mm $\times$ 305 mm $\times$ 6 mm. The distance between the sample holder and targets was set at 250 mm. No substrate bias was applied during sputtering. The coated files with 200- and 500-nm thickness of Ti-Zr-B thin films were prepared by adjusting the deposition time.

Observation of the thin film on silicon substrate and files

The 200-nm thick TFMG on silicon (Si) substrate was analyzed under a transmission electron microscope (TEM;