Environmental Temperature Drastically Affects Flexural Fatigue Resistance of Nickel-titanium Rotary Files

Nicola Maria Grande, DDS, PhD, [*] *Gianluca Plotino, DDS, PhD,* [†] *Enrico Silla, DDS,* [*] *Eugenio Pedullà, DDS, PhD,* [‡] *Gustavo DeDeus, DDS, MsC, PhD,* [§] *Gianluca Gambarini, MD, DDS,* [†] *and Francesco Somma, MD, DDS* [*]

Abstract

Introduction: The aim of the present study was to analyze how a low environmental temperature can affect the fatigue life of instruments made by different types of heat-treated nickel-titanium alloys. **Methods:** The flexural cyclic fatigue of 40 new specimens for each of the following systems was tested for cyclic fatigue resistance: ProTaper Universal F2 (Dentsply Maillefer, Ballaigues, Switzerland), ProTaper Gold F2 (Dentsply Tulsa Dental Specialties, Tulsa, OK), Twisted Files SM2 (SybronEndo, Orange, CA), Mtwo #25.06 (VDW, Munich, Germany), and Vortex Blue #30.04 and #40.06 (Dentsply Tulsa Dental Specialties). Instruments were tested at 2 different environmental temperatures: 20°C (±2°C) for room temperature (RT) group and −20°C (±2°C) for the cooled environment (CE) group (n = 20). The number of cycles to failure (NCF) and the length of the fractured fragment (FL) were recorded. The means and standard deviations of NCF and FL were then calculated; NCF data were statistically analyzed using a paired t test between groups RT and CE for each instrument tested (P < .05), whereas FL data were analyzed using analysis of variance (P < .05). **Results:** The mean NCF values measured were significantly higher for the CE groups than the RT groups in all the systems tested (P < .05). The increase in cyclic fatigue resistance varied from 274%–854%. No differences in FL were registered among the different groups (P < .05). **Conclusions:** A low environmental temperature determines a drastic increase in the flexural fatigue resistance of NiTi endodontic instruments manufactured with traditional alloy and different heat treatments. (*J Endod 2017;■:1–4*)

Key Words

Cyclic Fatigue, NiTi, root canal preparation

Significance

Improving the fatigue resistance of NiTi rotary instruments is still needed for clinicians and researchers. Many different efforts have been made to try to change the behavior of the metal introducing heat-treated alloys. This article investigates the possibility of changing the environment by reducing the temperature during the use of NiTi files to improve their fatigue resistance.

The introduction of rotary nickel-titanium (NiTi) instruments in clinical practice has deeply changed the procedures related with endodontic treatments, and in the last 20 years they became widely used to perform mechanical debridement and shaping of root canals (1, 2). Since the first report on the use of NiTi alloy for the manufacturing of endodontic instruments (3), many different engine-driven rotary systems were made available commercially using NiTi files of varying designs and dimensions. Basically, the evolution of these systems has been focused on changes in the geometry and design of the files together with the simplification of the operative sequences; nevertheless, the basic properties of the alloy remained almost unchanged (1, 4). In recent years, however, the alloy itself has evolved with the introduction of heat treatments and new manufacturing procedures (4, 5). Heat treatment, or aging, is 1 of the simplest and most economic methods for manipulating the transformation properties of shape-memory alloys (6). The heat treatment effect is dependent on time, temperature (T°), processing history, and the amount of prior cold work (7). These treatments aim to change the transitional T° of the alloy (4, 8) (ie, the T° at which the crystalline disposition of the nickel and titanium atoms has the main shift from a cubic [austenitic phase] to a tetragonal molecular arrangement [martensitic phase]) (Fig. 1*A–C*) (9). A high percentage of the martensitic phase at room T° increases the flexibility of the files and improves the performances in terms of cyclic fatigue resistance (10). The traditional NiTi alloy shifts to the stress-induced martensitic phase thanks to the mechanical stress that files undergo during shaping procedures. This is caused by the root canal curvature and the friction of the blades on root canal dentin (9). This feature is what is commonly referred to as the *superelastic behavior* of the traditional NiTi alloy. The improved flexibility and mechanical properties of NiTi files may be obtained differently with a thermal treatment that permanently modifies the thermomechanical history of the alloy at room T° (11, 12). Another feature of the NiTi alloy that is not used in the endodontic field is the transitory martensitic transformation that the metal undergoes when subjected to low T°. By cooling the metal to a T° lower than the transitional T°, the percentage of the martensitic phase could reach the maximum range possible for the alloy itself (12), whatever the heat

From the *Catholic University of Sacred Heart; †Sapienza University of Rome, Rome; ‡University of Catania, Catania, Italy; and §Department of Endodontics, Fluminense Federal University, Rio de Janeiro, Brazil.

Address requests for reprints to Dr Nicola Maria Grande, Via Calabria 25, 00187 Rome, Italy. E-mail address: nmgrande@gmail.com

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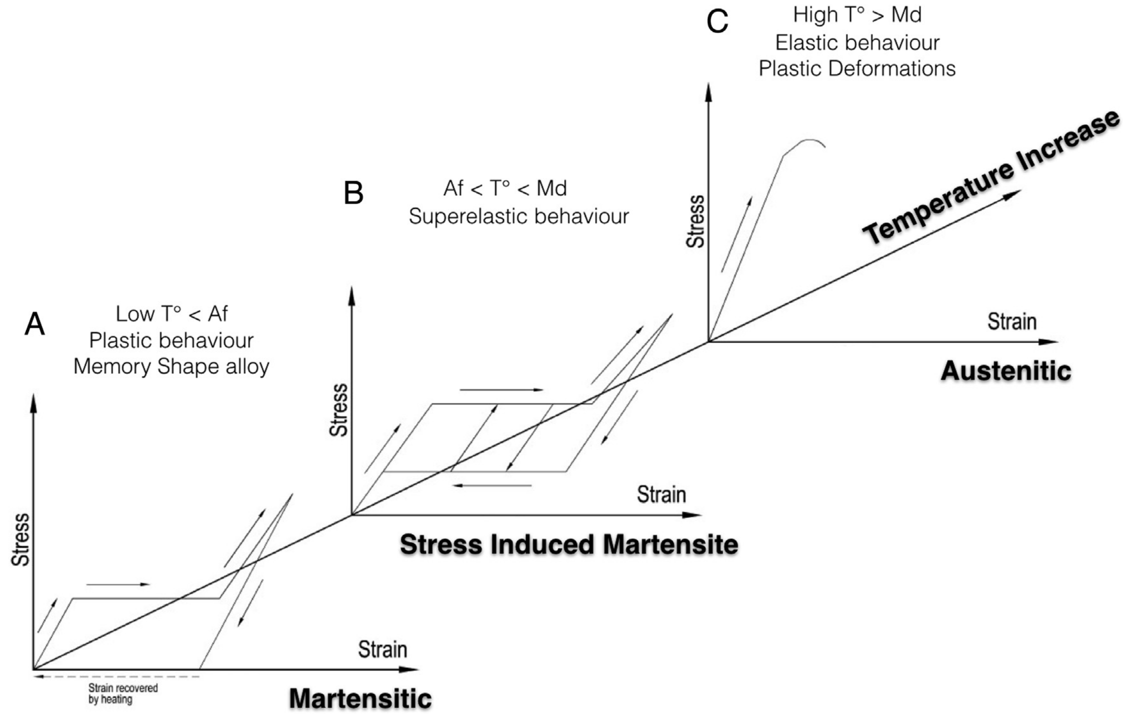

Figure 1. A schematic of the variation of the stress-strain curve for an NiTi alloy increasing the environmental temperature (T°) from left to right. (*A*) The martensitic behavior at a T° lower than the austenitic finish (Af) T°; in this state, NiTi has a shape-memory martensitic behavior, and it has its lowest elastic modulus. (*B*) The superelastic behavior of NiTi at a T° higher than Af and lower than the martensite deformation limit T° (Md); in this T° range, there is the possibility to have stress-induced martensite.(*C*) The NiTi stress-strain curve above the Md T°, which is always greater than the Af T°. In this range, stressed-induced martensite will not form, and NiTi will show plastic deformation responses without the typical plateau observed in the other crystalline phases.

treatment and the thermomechanical history are (Fig. 1). These modifications are widely used in the orthodontic field where the wires in NiTi shift from one phase to another thanks to the temperature increase that is present in the oral cavity.

The aim of the present study was to evaluate the impact of an environmental temperature lower than common clinical use and room T° (low environmental T°) on the flexural cyclic fatigue resistance of different NiTi alloys used for the manufacturing of endodontic rotary instruments. The null hypothesis tested in this study was that there is no difference in the cyclic fatigue resistance of instruments tested at room T° and in a low T° environment.

Materials and Method

The flexural cyclic fatigue of the following NiTi instruments was tested: ProTaper Universal F2 (Dentsply Maillefer, Ballaigues, Switzerland), ProTaper Gold F2 (Dentsply Tulsa Dental Specialties, Tulsa, OK), Twisted Files SM2 (SybronEndo, Orange, CA), Mtwo #25.06 (VDW, Munich, Germany), and Vortex Blue #30.04 and #40.06 (Dentsply Tulsa Dental Specialties). Forty samples from the same production batch for each type of instrument tested were randomly divided in 2 groups (n = 20): the room temperature (RT) group was tested at 20°C (±2°C), and the cooled environment (CE) group was tested at a temperature of −20°C (±2°C). The instruments were inspected under a stereomicroscope (Leica M205 C; Leica, Wetzlar, Germany) for defects or deformities, and they were discarded and replaced with a new one if defective. The cyclic fatigue testing device used in this study has been used for previously published studies on flexural cyclic fatigue (5, 13). The device consists of a mainframe connected with a mobile plastic support that firmly holds the electric handpiece and that allows precise 3-dimensional alignment and reproducible placement of each instrument inside the artificial canal and with a stainless steel block containing the artificial canals itself. The artificial canal is manufactured by reproducing the exact size and taper of the instruments to be tested, thus providing the instrument with a suitable trajectory that follows exactly the parameters of the curvature chosen for the experiment. An artificial root canal with a 60° angle of curvature and 5-mm radius of curvature was used for each size of the instruments tested. The center of the curvature was 6 mm from the tip of the instrument. The artificial root canal was covered with a tempered glass that permits the direct observation of the moment of fracture. A small circular hole (5 mm in diameter) in the center of the curved trajectory of the simulated canal was drilled in the glass to permit cooling of the instrument and the measurement of T° reached during testing. The instruments were rotated at 300 rpm using a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany), powered by a torque-controlled electric motor (VDW Silver; VDW GmBH, Munich, Germany). Before and during the cyclic fatigue test, a tetrafluoroethane-based cooling spray (Cold Spray; Kumapan, San Damiano D'Asti, Italy) was applied directly on the instrument surface from a fixed distance of 10 cm. A digital laser infrared T° sensor (LaserGrip 1080; Etekcity, Anaheim, CA) was fixed to the device for constantly monitoring the T° of the instrument during testing. The rotation was started when a T° of −20°C ± 2°C was reached on the instrument surface and this T° was maintained constant for all the duration of the test. In case the T° exceeded the established range values, the test was not considered valid and was repeated with a new specimen.

The instruments were rotated until fracture occurred, and the time to fracture was registered in seconds. The number of cycles to failure (NCF) was then calculated combining the number of seconds in rotation

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