The Effect of Electropolishing on Torque and Force During Simulated Root Canal Preparation with ProTaper Shaping Files

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Abstract

Surface modifications of nickel-titanium instruments such as electropolishing may reduce fracture incidence but could potentially alter the instruments' mechanical properties. We studied the impact of two surface types, machined and electropolished, of ProTaper shaping files on torque and force during simulated root canal preparation. Pilot holes of 0.5-mm diameter were drilled perpendicularly through 3-mm thick human dentin discs and served as standardized simulated root canals (SSRCs). A total of 300 SSRCs were prepared with ProTaper Sx, S1, and S2 instruments using an automated testing platform. Maximum torque (in Ncm) and maximum force values (in N) were measured. In three experimental groups (Sx, S1, and S2) preparation of SSRCs was performed using electropolished versus machined instruments in the same dentin disc. For all three tested instruments, peak torque was higher for electropolished files; apically exerted forces were similar, except for Sx, in which machined instruments developed higher forces. We conclude that surface treatment by electropolishing alters the cutting ability of nickel-titanium rotary instruments. *(J Endod 2009;35:102–106)*

Key Words

Electropolishing, rotary instrumentaion, surface treatment

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Nickel-titanium (NiTi) endodontic instruments were introduced to facilitate instrumentation of curved canals with few or no procedural errors. Despite numerous advantages, there is concern about the incidence of instrument fractures during root canal preparation (1). Cyclic fatigue and torsional overload have been identified as the main reasons for rotary nickel-titanium instrument fracture (2, 3). Different studies have suggested that cyclic fatigue (flexural and torsional) caused by repeated tensile-compressive stress plays an important role in the fracture of NiTi instruments (2, 4). Flexural fatigue is believed to occur without any visible sign of deformation of the instrument, and the clinician is not alerted that the instrument might be prone to fracture (2).

Although fractured instruments may not compromise the outcome if treatment is performed to a high technical standard (1), retained file fragments may impede microbial control beyond the obstruction. Moreover, excessive removal of tooth structure in an attempt to retrieve the instrument fragment may be associated with root perforation and reduced root strength (5). Therefore, it is important to be aware of the factors that may lead to instrument fracture. These include the following: anatomy (4), technical aspects like speed and torque (6), clinical skills (7), frequency of instrument reusage (8, 9), sterilization (10), instrument size (3), and design (11). In addition, surface properties may play a role in the fatigue resistance of NiTi-rotary instruments (12, 13).

It has been shown that both new and used NiTi instruments show surface defects like microfissures, cracks, and machining grooves, which were left on the surface after manufacturing. Because of the alloy's pseudoelastic properties, NiTi instruments are typically machined and not twisted. Machining of rotary NiTi instruments often results in a surface that is irregular; stressed; plastically deformed; and showing cracks, milling groves, pits, and fissures and regions of metal rollover (14, 15).

These surface irregularities may act as areas of stress concentration and crack initiation during clinical use (16). Failure is then largely a process of crack propagation. Considering that crack initiation may comprise a major proportion of fatigue life, resistance to fatigue can be enhanced by a smooth, defect-free surface (16). Various surface treatment techniques have been tried to create smooth surfaces and thus to enhance wear resistance of rotary NiTi instruments.

Electropolishing involves the removal of a very thin surface layer by immersing the material in a highly ionic solution with an electric current (17). This process has a leveling effect, producing a smooth surface with an increased reflectivity (Fig. 1). The amorphous outer layer is removed, leaving a passive surface free of imbedded contaminants and work-induced residual stresses (18). Such surface modifications may reduce fracture incidence but could potentially alter the instruments' mechanical properties. In fact, previous reports indicated that electropolishing may increase the resistance to cyclic fatigue (12, 13). However, little is known about the effect this surface treatment has on the cutting of dentin by rotary files.

Hence, the aim of the present study was to determine the impact of two different surface types (conventionally machined vs electropolished) of ProTaper shaping files (Dentsply Mailleter, Ballaigues, Switzerland) on torque and force during simulated root canal preparation.

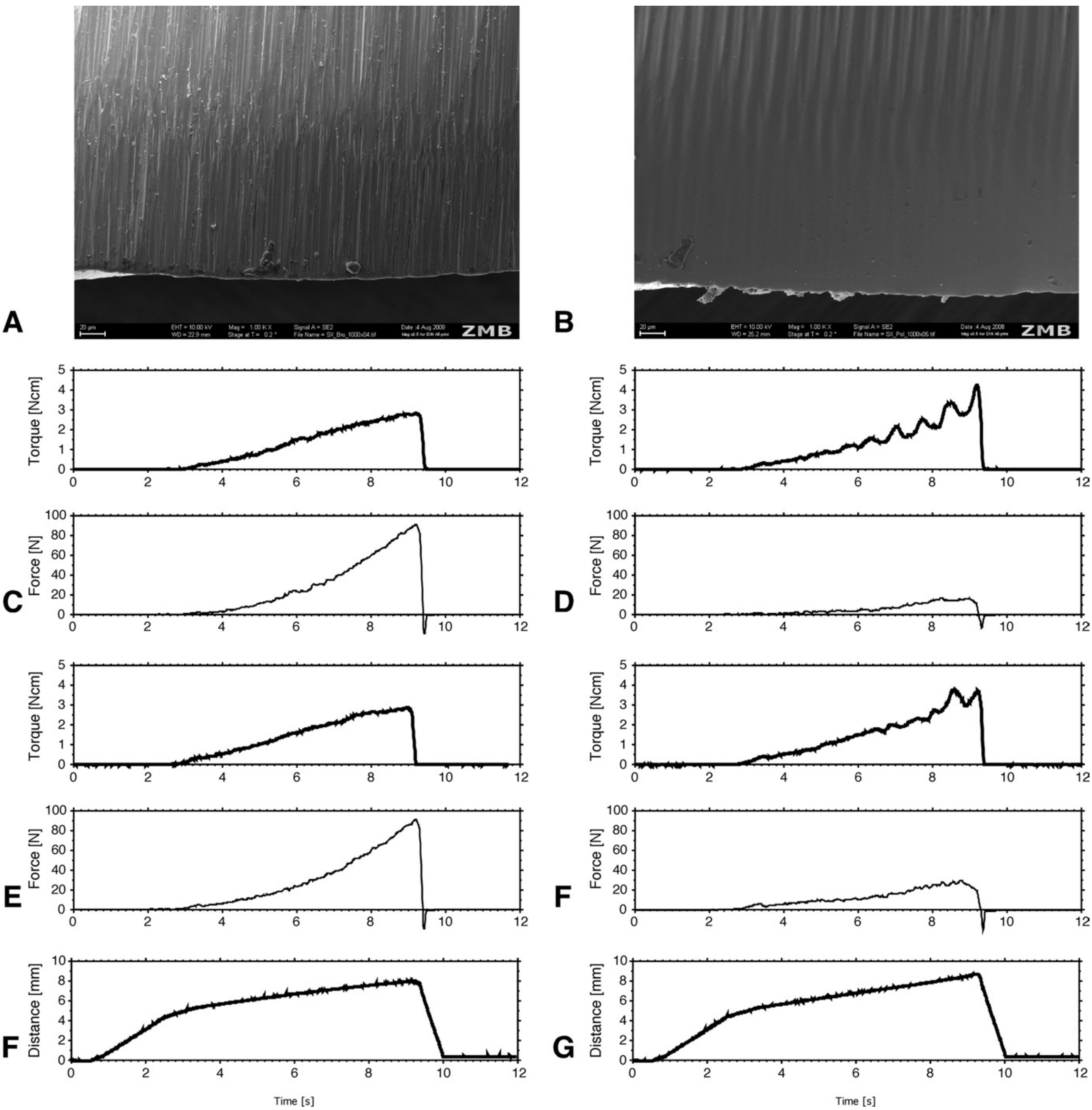

Figure 1. Comparison of differently finished ProTaper Sx instruments. Scanning electron micrographs of both instruments show specific surface textures in the (*A*) machined and (*B*) electropolished condition. Original magnification ×1,000. The torque and force during preparation of the first simulated canal (*C* and *D*) can be compared with the same parameters recorded for simulated canal 5 (*E* and *F*). All simulated canals were prepared automatically with preset insertion depth (*F* and *G*). Data are averaged over 10 instruments each.

Materials and Methods

Preparation of Standardized Simulated Root Canals

Human third molars free of decay and restorations were selected from a collection of extracted teeth. Teeth had been collected from patients with their approval for subsequent *in vitro* studies and stored in 0.1% thymol solution at 5°C until use. Dentin disks of 3 mm thickness were prepared as previously described (19) using a diamond-coated saw (SP 1600; Leica, Nussloch, Germany). All discs were inspected under a stereomicroscope (Leica Wild M3Z; Wild, Heerbrugg, Switzerland) equipped with an internal light source (Intralux 4000; SOWO-DENT, Birmensdorf, Switzerland) for possible enamel remnants; specimens showing such remnants were discarded. Spaced out as far as possible, six pilot holes 0.5 mm in diameter were drilled perpendicularly through the dentin discs with a stationary drill under water cooling. The drill diameter was the smallest one sufficient for a precise and circular hole; these holes served as standardized simulated root canals (SSRCs) for subsequent testing.

Tested Instruments and Torque Platform

SSRCs were prepared using conventionally machined or electropolished ProTaper Sx, S1, and S2 shaping instruments (Fig. 1). Each group consisted of 10 previously unused instruments; five SSRCs were instrumented with each individual rotary. Machined Sx, S1, and S2 instruments were tested in the same disc (six SSRCs) together with the electropolished counterparts. Thus, a total of 300 SSRCs in 50 discs were prepared. ProTaper finishing files are not electropolished by the manufacturer and were thus not tested in this study.

A computer-controlled testing platform described in detail elsewhere (20) was used to record values for torque and apically directed force. Using data from pilot experiments with manual feed, optimized feed parameters were programmed for instrument insertion speed and depth, and rotational speed was preset at 250 rpm using the proprietary Endotest software (Department of Preventive Dentistry, Periodontology and Cariology, University of Zurich, Switzerland) (19). No lubricant was used to ensure that the tested mechanical parameters were not affected (21).

Specimens were then mounted on a specially designed holder attached to a strain gauge, which was connected to a preamplifier (A&D 30; Orientec, Tokyo, Japan). A torque sensor (MTTRA 2, with amplifier Microtest; Microtec Systems, Villingen, Germany) and a motor (Type ZSS; Phytron, Gröbenzell, Germany) were mounted on a stable metal platform, which moved along a low-friction guide rail. The movements of the instruments into the SSRCs were executed by a linear drive (P01-2380; LinMot, Zürich, Switzerland), which was controlled by Endotest running on a Macintosh PowerPC computer (Apple, Cupertino, CA). The programmed run time for the preparation of a single SSRC was 12 seconds; the actual times of canal wall contact were 8 to 10 seconds (Fig. 1).

Data for torque, force, and insertion depth were acquired from the sensors via three analog channels at a sampling rate of 100 Hz using a 12-bit interface (PCI-MIO-16CE; National Instruments, Austin TX). In preliminary experiments, measurement accuracy was determined to be 0.01 Ncm and 0.1 N. Variables recorded during each measurement were stored in a proprietary format for subsequent offline analyses.

Data Analysis

Maximum values for torque and force were calculated offline. Data analysis revealed normal distribution, and, hence, paired *t* tests were used to compare group means; analysis of variance was used to compare time points (SSRC 1-5) for individual instruments regarding changes in torque and force.

Results

Over the course of this study, single rotaries were subjected to a total canal preparation time of 40 to 50 seconds in five SSRCs. During this time, neither torque nor apically directed force changed significantly (analysis of variance, $p > 0.05$). Therefore, data for all 50 SSRC prepared by each rotary type were pooled.

Overall, higher maximum torque values were recorded for electropolished instruments compared with machined counterparts (Fig. 2), with significant differences between corresponding instrument types (paired *t* test Sx, S1: $p < 0.0001$; S2: $p < 0.01$). Highest maximum torque values of 4.89 ± 1.31 Ncm were measured using electropolished Sx instruments, whereas the lowest maximum torque scores of 1.60 ± 0.24 Ncm were recorded when testing machined S2 instruments (Fig. 2).

Maximum apical forces ranged from 9.27 ± 7.74 N to 32.76 ± 14.89 N using electropolished and 9.53 ± 6.07 N to 90.59 ± 16.78 N using machined instruments, respectively (Fig. 2). Although a paired *t* test revealed no difference between surface types in the S1 and S2 group ($p = 0.87$, $p = 0.82$), machined Sx instruments showed significantly higher maximum apical forces than electropolished ones ($p < 0.0001$, Fig. 1).

Discussion

The aim of this *in vitro* study was to assess the impact of two different surface types, machined and electropolished, of ProTaper shaping instruments on their mechanical behavior (maximum torque and apically directed force).

Under the conditions of the current study, electropolished ProTaper shaping files generated higher mean maximum torque values compared with their conventionally machined counterparts. When maximum apical force was assessed, differences were found only using Sx instruments; machined Sx instruments displayed higher values than their electropolished counterparts.

These results suggest that electropolishing NiTi surfaces altered mechanical properties during simulated root canal instrumentation, resulting in significantly higher mean maximum torque values. Unexpectedly, we found that the machined Sx instrument generated significantly higher values for apical-directed force.

The current study attempted to simulate mechanical conditions during root canal preparation in a standardized environment. This model (19) allowed the study of the mechanical performance of ProTaper instruments identical in construction but different in surface treatments. To control the possible biologic variability of the human dentin material (22) used in this study, the two different instrument types were tested in the same disc. Hence, direct comparison of the obtained data for torque and force was possible. On the other hand, this study does not completely mirror a clinical situation because the shape and curvature of a root canal and real canal length could neither be standardized nor reproduced by these simulations.

The amount of torque generated depends on the size of the contact areas between the instrument and the canal walls (23). Contact areas between instruments and the simulated canal walls were standardized by positioning and introducing each instrument into the canal in exactly the same manner; the computer then controlled canal preparation to a preselected depth. Clinically, however, the size of the contact area is unknown and can vary after various instrumentation sequences; therefore, the absolute torque values measured in this experiment will vary from those seen preparing any given root canal.

Because surface defects of new instruments have been identified to contribute to instrument fracture (13, 24), electropolishing was recently introduced by some manufacturers to improve the fatigue life of rotary NiTi instruments. As stated before, electropolishing is a controlled electrochemical removal of surface roughness and is performed by immersing the instrument in a specially formulated, usually acidic, electrolyte solution and passing a direct electric current to facilitate a selective dissolution of the material (17). Thus, electropolishing eliminates or reduces the number and extent of surface defects. Experimental data suggest that the removal of machining grooves, resulting in a smoother surface, can improve the fracture-related fatigue resistance (12, 13). However, others did not find an extension of instrument life spans, specifically low-cycle fatigue life, by electropolishing (25–27).

The leveling effect of electropolishing may dull the formerly sharp edges of the instrument, which, in turn, may lead to higher torque values during root canal preparation because of greater contact areas. This is in agreement with the findings of the current study. Our results indicate that electropolished surfaces did alter mechanical properties during simulated root canal instrumentation, resulting in significantly higher mean maximum torque values.

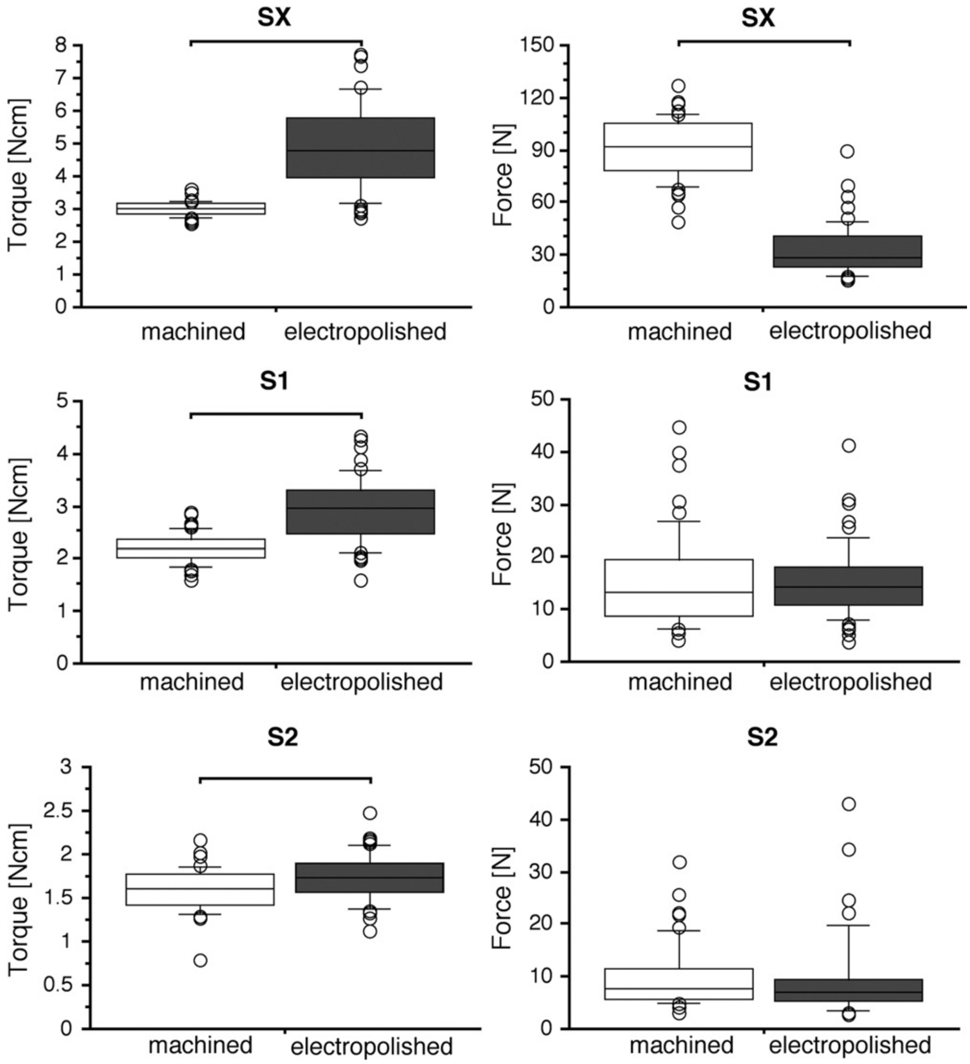

Figure 2. The maximum mean torque and forces of machined and electropolished ProTaper instruments. Data are pooled from all five simulated canals and 10 instruments each so that $n = 50$; significant differences ($p < 0.05$) indicated by bars.

An additional unexpected finding was that machined Sx instruments showed significantly higher values for apical-directed force than electropolished ones. Apical force develops according to the insertion speed and instrument cutting efficiency; because the insertion speed was preselected in this experiment, one possible reason could be reduced cutting efficacy. On the other hand, it was noted that the SSRSs appeared to be larger after preparation with machined Sx compared with electropolished ones. This corresponded with oscillations in the torque record compared with a more uniform torque increase in the electropolished Sx instruments.

One reason for this effect may be that threading in occurs differently in files with different surface textures (28). This appears to be the first study evaluating the effects of different surface treatments on the torque and force values obtained during standardized canal preparation with ProTaper shaping files. Anderson et al. (13) investigated the behavior of electropolished and machined size #30 .04 Endowave (J Morita, Tokyo, Japan; in the United States, it is sold as EndoSequence; BrasselerUSA, Savannah, GA), Race (FKG, La Chaux-De-Fonds, Switzerland), and Profile (Denstply Tulsa Dental, Tulsa, OK) instruments subjected to flexural and torsional stress. Under the conditions of their experiments, electropolishing prolonged fatigue life of NiTi instruments, whereas comparatively little effect on torsional strength was recorded (13).

In contrast, Bui et al. (25) showed that electropolishing of size #25.04 ProFile instruments significantly reduced their resistance to cyclic fatigue but did not affect torsional resistance or cutting efficiency. In those experiments, penetration of the instruments in simulated canals in plastic blocks was used to determine cutting efficacy.

Herold et al. (26), in an *ex vivo* experiment, studied the effect of electropolishing on the development of microfractures in EndoSequence instruments and compared it with untreated ProFile instruments. Their results indicate that electropolishing did not prevent the development of microfractures in EndoSequence instruments, whereas no such fractures could be detected in ProFile instruments.

In fact, EndoSequence fractures were recorded significantly more often using both 600 rpm (as recommended by the manufacturer) as well as 300 rpm compared with ProFile used at 300 rpm. However, this model may introduce more variables because of anatomic variations of the extracted teeth that were prepared. In the present study, it was attempted to remove the variability associated with the preparation of extracted teeth while using dentin as a substrate as compared with plastic blocks (25).

The observed difference in the effect of electropolishing specifically on fatigue resistance may be explained by differences in the processes used by different manufacturers and instrument cross-sections (ie, a stiffer and inherently less fatigue-resistant instrument with a simple cross-section may not benefit as much from electropolishing compared with a flexible one with a difficult to manufacture cross-section).

During manufacture of NiTi rotaries, electropolishing is a technique-sensitive process, and some variation in published data (13, 25, 27) could be explained by that fact. Based on the mechanism of action, it is very likely that electropolishing alters the shape of the NiTi instrument cutting flutes. One way to avoid possible instrument dulling and any subsequent loss of cutting ability or cutting efficiency could be changes in cross-sectional design before electropolishing is applied. In the present experiment, there was no observable change in cutting parameters during the five simulated canal preparations. Therefore, we conclude that, although there were differences in torque and force introduced among the tested instruments, no effect on instrument longevity was recorded. Moreover, within the limitation of the present *in vitro* setting, it appears that electropolishing of ProTaper Shaping instruments leads to increased torque during preparation of simulated root canals.

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