EVANDRO PIRES VIEIRA

“INFLUÊNCIA DO MOVIMENTO DE PRESSÃO LATERAL NA RESISTÊNCIA À TORÇÃO E À FADIGA DE INSTRUMENTOS *PROTAPER UNIVERSAL*”

Faculdade de Odontologia
Universidade Federal de Minas Gerais
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Tese apresentada ao Programa de Pós-Graduação em Odontologia da Universidade Federal de Minas Gerais, como requisito parcial à obtenção do grau de Doutor em Odontologia - área de concentração: Endodontia

Orientação: Profa. Dra. Maria Guiomar de A Bahia
Prof. Dr. Vicente Tadeu Lopes Buono

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"... cada um de nós compõe sua história, cada ser em si carrega o dom de ser capaz,

e ser feliz..."

Sumário

RESUMO

O objetivo deste estudo foi avaliar a influência do movimento de pressão lateral, durante o uso clínico múltiplo, na resistência à torção e à fadiga de instrumentos rotatórios de NiTi *ProTaper Universal*. Vinte jogos de instrumentos novos foram ensaiados até a ruptura em máquina de torção (n = 10) e em dispositivo de fadiga (n = 10), para determinar os valores médios de torque máximo e de número de ciclos até a fratura (NCF), respectivamente. Quarenta jogos de instrumentos novos foram usados no trabalho. Cada jogo foi empregado na formatação de 5 molares, sendo que em vinte jogos foi utilizado movimento de pressão lateral (CPL) com os instrumentos S1, S2 e SX e, nos outros jogos, esses instrumentos foram utilizados sem movimento de pressão lateral (SPL). Posteriormente, os instrumentos utilizados na clínica foram ensaiados até a ruptura em máquina de torção, para avaliação do consumo da resistência torcional, ou em bancada de fadiga, para avaliação de sua vida restante. Três jogos de cada grupo foram observados por microscopia eletrônica de varredura antes e após o uso. Os dados foram analisados por ANOVA (95% de confiança). Os testes de torção mostraram redução da resistência torcional nos instrumentos após uso clínico, sendo esta redução significativa para os instrumentos S2, F1 e F2 do grupo CPL e F1 e F2 do grupo SPL. Houve também redução significativa na resistência em fadiga para todos os instrumentos após o uso clínico. O movimento de pressão lateral apresentou a tendência de reduzir tanto o torque máximo como o NCF nos instrumentos S1 e S2, como de aumentá-los nos instrumentos F1 e F2, embora sem diferença estatisticamente significativa nesses parâmetros. Análise qualitativa das imagens obtidas por microscopia eletrônica de varredura mostrou maior incidência de trincas transversais nos instrumentos submetidos à pressão lateral e de trincas longitudinais nos instrumentos do grupo SPL. Apesar de o uso clínico ter reduzido a resistência torcional e flexural, os instrumentos *ProTaper Universal* mostraram-se seguros na formatação de 5 molares.

"INFLUENCE OF LATERAL PRESSURE MOTION ON THE TORSION AND FATIGUE RESISTANCE OF ROTARY PROTAPER UNIVERSAL INSTRUMENTS"

ABSTRACT

The aim of this work was to assess the influence of lateral pressure motion during multiple clinical uses on the torsional and fatigue resistance of NiTi rotary ProTaper Universal endodontic instruments. Twenty sets of new instruments were tested until rupture in a torsion test machine (n = 10) and in a fatigue test device (n = 10), in order to determine the mean values of maximum torque and of number of cycles to failure (NCF), respectively. Forty sets of new instruments were used in the work. Each set was employed to clean and shape 5 molars, twenty sets using lateral pressure (LP) motion with the S1, S2 and SX instruments, while in the other sets no lateral pressure motion (NLP) was applied to these instruments. After that, the clinically used instruments were torsion tested until rupture, to evaluate the consumption of torsional resistance, or fatigue tested to assess their remaining fatigue life. Three sets of each group were observed by scanning electron microscopy before and after being used. Data were analyzed using ANOVA (95% confidence). Torsion tests showed a decrease in the instruments' torsional resistance after clinical use, this decrease being statistically significant for the instruments S2, F1 and F2 of the LP group, and F1 and F2 of the NLP group. There was also a significant reduction in the fatigue resistance of all instruments after clinical use. The lateral pressure motion produced a tendency to decrease both the maximum torque and the NCF of S1 and S2 instruments, as well as to increase them in F1 and F2, although without a significant difference in these parameters. Qualitative analysis of the images obtained by scanning electron microscopy showed predominance of transverse cracks in the instruments submitted to lateral pressure motion and of longitudinal cracks in the instruments of the NLP group. Despite the reduction in torsional and fatigue resistance caused by the clinical use, ProTaper Universal instruments proved to be safe in cleaning and shaping 5 molars.

1. INTRODUÇÃO

O processo de limpeza e formatação do sistema de canais radiculares (SCR) é considerado uma etapa decisiva na terapia endodôntica, porque determina a eficácia das etapas subseqüentes. Este inclui o desbridamento mecânico e a otimização da geometria do canal para uma adequada obturação tridimensional. A manutenção do canal patente até o forame apical e a preparação cuidadosa através do desgaste das paredes do canal radicular são essenciais para o domínio da formatação (COHEN e BURNS 2000; PETERS, 2004).

Em canais radiculares relativamente retilíneos, a etapa de limpeza e formatação costuma ocorrer sem maiores problemas ou dificuldades. Porém, quando um instrumento penetra em um canal radicular curvo, ele apresenta uma tendência natural em retornar à sua forma natural reta, o que se acentua pelo emprego de instrumentos rígidos, causando erros como transporte, degraus, *zips* e perfurações do canal radicular (ROANE *et al*., 1985; WILDEY *et al*., 1992).

Os instrumentos rotatórios, fabricados a partir de liga níquel-titânio (NiTi) foram introduzidos na prática endodôntica com o intuito de aumentar a segurança durante a formatação de canais radiculares curvos, minimizando erros de procedimento. Os instrumentos endodônticos de NiTi acionados a motor, com diferentes conicidades e geometrias de seção transversal, têm apresentado bons resultados na formatação de canais curvos, mantendo a trajetória original do canal (SHAFER e VLASSIS 2004).

As ligas NiTi possuem uma habilidade inerente de alterar sua estrutura cristalina, levando a mudanças significativas em suas propriedades mecânicas. Estas mudanças ocorrem em função de variação da temperatura e/ou da aplicação de tensão. De um modo geral, as ligas NiTi são utilizadas devido às suas propriedades especiais: efeito memória de forma (EMF) e superelasticidade (SE). Tanto o EMF quanto a SE estão associados a mudanças de fase no estado sólido, a transformação martensítica (TM). No caso dos instrumentos endodônticos, a TM ocorre em função da tensão gerada no interior do canal radicular. Assim que a tensão cessa a transformação reversa ocorre, restaurando a forma original dos instrumentos (THOMPSON 2000).

Apesar da maior flexibilidade dos instrumentos confeccionados em NiTi, sua fratura ainda é uma preocupação, porque estes instrumentos podem se romper abaixo do seu limite de elasticidade e sem qualquer sinal visível de deformação plástica. Logo, a inspeção visual não é um método confiável para avaliação dos instrumentos de NiTi após o uso clínico (PRUETT *et al*., 1997; PATIÑO *et al*., 2005).

A fratura dos instrumentos rotatórios acontece de diferentes maneiras: por sobrecarga de torção, por fadiga flexural e/ou torcional ou por uma combinação de ambas (SATAPAN *et al*., 2000; BAHIA et *al*., 2008). A geometria do canal radicular, descrita através do raio e ângulo de curvatura, associada ao diâmetro do instrumento no ponto de curvatura máxima, determinado pela distância da curvatura à sua ponta, definirão o estado de tensão sobre a haste flexionada e o processo de fadiga deste instrumento (PRUETT *et al*., 1997; BAHIA e BUONO 2005). Quando o instrumento gira no interior de um canal curvo, tensões alternadas de tração e compressão são geradas no mesmo, em adição às tensões torcionais advindas da resistência ao corte. O torque a que é submetido o instrumento é um entre muitos parâmetros que podem influenciar a incidência de travamento, deformação e fratura por torção. Se o nível de torque aplicado ao instrumento é igual ou maior que seu torque máximo, o instrumento poderá se deformar e romper (YARED 2004; BAHIA *et al*., 2006).

Diversos autores avaliaram a resistência à fadiga de instrumentos de NiTi após uso clínico, tanto em pacientes como em canais simulados, e concluíram que a fadiga por flexão parece ter um efeito cumulativo nos instrumentos, tornando-os menos resistentes após cada uso (HAIKEL *et al*., 1999; BAHIA *e* BUONO, 2005). Trabalhos anteriores sobre instrumentos *ProTaper* e *ProTaper Universal* mostraram que o uso clínico, não só diminui a resistência à torção (ULMANN et al., 2005; VIEIRA *et al*., 2009), mas também influencia a deterioração da resistência à fadiga flexural nestes instrumentos (VIEIRA *et al*., 2008; FIFE *et al.* 2004; OUNSI *et al*., 2007).

O alto índice de curvaturas encontradas no terço médio dos canais radiculares (MARTINS *et al.,* 2003) pode comprometer o acesso direto ao forame apical, promovendo tensões desnecessárias ao longo do instrumento, aumentando o risco de fratura dos mesmos. As interferências coronárias devem ser eliminadas para que os instrumentos possam progredir no sentido apical durante a formatação dos canais radiculares. Assim, o pré-alargamento dos terços coronário e médio permite a progressão do instrumento em direção apical através da eliminação destas interferências (SCHILDER 1974; BLUM *et al.,* 1999).

O sistema *ProTaper Universal*, objeto deste estudo, possui uma característica singular que é o fato dos instrumentos de formatação e acabamento serem usados com movimentos diferentes. Ruddle (2005) propôs que os instrumentos de formatação S1, S2 e SX deveriam ser utilizados com movimento de pressão lateral para otimizar a eficácia da preparação. Este movimento corta lateral e seletivamente a dentina na parte externa da curvatura criando um espaço lateral, que facilita aos instrumentos subseqüentes e mais calibrosos se moverem progressivamente e com segurança em direção apical.

O efeito da utilização do movimento de pressão lateral sobre o comportamento em torção dos instrumentos de NiTi não foi ainda investigado. Além disso, alguns estudos sobre o movimento de pressão lateral lançaram dúvidas sobre a eficácia desta técnica na remoção de dentina ao nível coronário (PLOTINO *et al*., 2007a) e sua influência sobre a resistência à fadiga dos instrumentos (PLOTINO *et al*., 2007b). PLOTINO *et al*. (2007a) não encontraram nenhuma diferença na quantidade de dentina removida por instrumentos *ProTaper* e *Mtwo* utilizados com pressão lateral ou de forma passiva, enquanto os instrumentos *Mtwo* 25/06 tiveram suas vida em fadiga reduzidas quando utilizados com movimento de pressão lateral (PLOTINO *et al*., 2007b).

Baseado nestas considerações, o objetivo deste estudo foi avaliar a influência do movimento de pressão lateral, durante o uso clínico múltiplo de instrumentos rotatórios *ProTaper Universal,* na resistência à torção e à fadiga dos mesmos.

2. OBJETIVOS

2.1 Objetivo Geral

Avaliar a influência do movimento de pressão lateral, durante o uso clínico múltiplo de instrumentos rotatórios *ProTaper Universal,* na resistência à torção e à fadiga destes instrumentos.

2.2 Objetivos Específicos

- Avaliar a resistência à fadiga de instrumentos de NiTi *ProTaper Universal* novos, através do número de ciclos até a fratura (NCF);
- Avaliar o comportamento em torção de instrumentos de NiTi *ProTaper Universal* novos, através dos parâmetros torque máximo e deflexão até a fratura;
- Observar e comparar os danos superficiais dos instrumentos *ProTaper Universal* associados à fadiga estrutural, após a formatação dos canais radiculares de cinco molares com e sem movimento de pressão lateral;
- Avaliar a influência do movimento de pressão lateral durante o uso clínico múltiplo, no consumo da resistência em torção dos instrumentos *ProTaper Universal;*
- Avaliar a influência do movimento de pressão lateral durante o uso clínico múltiplo, no consumo da resistência em fadiga dos instrumentos *ProTaper Universal.*

3. ARTIGO 1

TORSIONAL BEHAVIOUR OF ROTARY NITI PROTAPER UNIVERSAL INSTRUMENTS AFTER MULTIPLE CLINICAL USE

E. P. Vieira1, R. K. L. Nakagawa1, V. T. L. Buono2 & M. G. A. Bahia1

1Department of Restoration Dentistry, Faculty of Dentistry, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil; and 2Department of Metallurgical and Materials Engineering, Engineering School, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil

Key words: clinical use, endodontic instruments, nickel–titanium, ProTaper Universal, torsional resistance.

Running title: **Torsional behaviour of rotary NiTi ProTaper Universal instruments**

Correspondence: Professor Vicente T. L. Buono. Department of Metallurgical and Materials Engineering, Engineering School, Universidade Federal de Minas Gerais, Av. Antonio Carlos, 6.627 – Building 2, room 2640 - Campus Pampulha 31270-901, Belo Horizonte, MG - Brazil.

Tel: +55 31 3238-1859, Fax: +55 31 3238-1815,

E-mail: vbuono@demet.ufmg.br

ARTIGO 2

THE EFFECT OF LATERAL PRESSURE MOTION ON TORSIONAL BEHAVIOR OF ROTARY PROTAPER UNIVERSAL INSTRUMENTS AFTER MULTIPLE CLINICAL USES

E. P. Vieira[1], V. T. L. Buono[2], M. G. A. Bahia[1]

[1]Department of Restoration Dentistry, Faculty of Dentistry, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil; [2]Department of Metallurgical and Materials Engineering; Engineering School, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil.

Key words: clinical use, endodontic instruments, torsional resistance, nickel-titanium

Running title: **Lateral pressure motion of ProTaper Universal instruments**

Correspondence: Professor Vicente T. L. Buono. Department of Metallurgical and Materials Engineering, Engineering School, Universidade Federal de Minas Gerais, Av. Antonio Carlos, 6.627 – Building 2, room 2640 - Campus Pampulha 31270-901, Belo Horizonte, MG - Brazil.

Tel: +55 31 3238-1859, Fax: +55 31 3238-1815,

E-mail: vbuono@demet.ufmg.br

ARTIGO 3

FATIGUE RESISTANCE OF ROTARY PROTAPER UNIVERSAL INSTRUMENTS AFTER USE WITH AND WITHOUT LATERAL PRESSURE MOTION

E. P. Vieira[1], V. T. L. Buono[2], M. G. A. Bahia[1]

[1]Department of Restoration Dentistry, Faculty of Dentistry, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil; [2]Department of Metallurgical and Materials Engineering; Engineering School, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil.

Key words: clinical use, endodontic instruments, fatigue resistance, nickel-titanium

Running title: **Lateral pressure motion and fatigue of ProTaper Universal**

Correspondence: Professor Vicente T. L. Buono. Department of Metallurgical and Materials Engineering, Engineering School, Universidade Federal de Minas Gerais, Av. Antonio Carlos, 6.627 – Building 2, room 2640 - Campus Pampulha 31270-901, Belo Horizonte, MG - Brazil.

Tel: +55 31 3238-1859, Fax: +55 31 3238-1815,

E-mail: vbuono@demet.ufmg.br

Fatigue resistance of rotary ProTaper Universal instruments after use with and without lateral pressure motion

Evandro Pires Vieira, DDS, MS,* Vicente Tadeu Lopes Buono, BS, MS, PhD,† Maria Guiomar de Azevedo Bahia, DDS, MS, PhD,*

*Department of Restorative Dentistry, Faculty of Dentistry, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil, †Department of Metallurgical and Materials Engineering, School of Engineering, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil.

Correspondence:

Professor Vicente T. L. Buono

Department of Metallurgical and Materials Engineering

Federal University of Minas Gerais

Av. Antonio Carlos, 6.627 – Campus Pampulha

Escola de Engenharia – Bloco 2 – sala 2640

31270-901, Belo Horizonte, MG - Brazil.

Tel: +55 31 3409-1859, Fax: +55 31 3409-1815

E-mail: vbuono@demet.ufmg.br

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Abstract

Introduction: The purpose of this study was to evaluate the fatigue resistance of rotary ProTaper Universal instruments after multiple clinical uses with and without lateral pressure motion. **Methods:** Thirty sets of ProTaper Universal (PTU) instruments (Dentsply-Maillefer, Ballaigues, Switzerland), type S1, S2, F1 and F2, totaling 120 files, were analyzed and divided into three groups, as follows: Control Group (CG), with 10 sets of new instruments, which were fatigue tested until rupture to determine their fatigue resistance; Lateral pressure (LP), with 10 sets of instruments, each set used clinically in five mandibular and maxillary molars (15 to 20 canals), using the shaping instruments with lateral pressure motion; and No-Lateral Pressure (NLP), with 10 sets of instruments, each set used clinically in five mandibular and maxillary molars (15 to 20 canals), using the shaping instruments without lateral pressure motion. The instruments in the LP and NLP groups were subsequently fatigue tested. Data were analyzed using analysis of variance ($\alpha = 0.05$). **Results:** Multiple clinical uses caused a reduction in the fatigue life of the analyzed instruments. When the effect of employing lateral pressure motion with the shaping instruments was assessed, a tendency for the consumed fatigue life to be higher for S1 and S2 instruments in LP and for F1 and F2 instruments in NLP was observed. **Conclusion:** The use of lateral pressure motion can decrease the consuption of fatigue life for the F1 and F2 instruments.

Key words: NiTi rotary instruments, ProTaper Universal, lateral pressure motion, flexural fatigue.

Introduction

During root canal shaping, rotary NiTi instruments undergo flexural and torsional cyclic loads simultaneously, thus the fracture of endodontic rotary instruments can be results from the processes of torsional overload or flexural and torsional fatigue (1, 2). Torsional fracture occurs when the elastic limit of the nickel-titanium alloy is exceeded during binding of the rotary instrument to root canal walls. This is usually accompanied by visibly discernible evidence of plastic deformation of the instrument (1).

Conversely, flexural fatigue is caused by the continuous rotation of an instrument in a curved canal space in the absence of binding, wherein the opposing sides of the instrument are subjected to alternating cycles of tensile and compressive stresses. Fatigue fracture occurs by means of the initiation and propagation of cracks at stress levels that are below the ultimate strength of the material under a static load. The magnitude of the tensile and compressive stress imposed on the flexed area of the instrument depends on the curvature radius and the diameter of the instrument (3, 4). The smaller curvature radius and larger the instrument's diameter, the greater is the maximum tensile strain amplitude induced upon the instrument's surface and consequently the number of cycles the instrument can resist is reduced (3, 5).

Previous work on instruments ProTaper and ProTaper Universal showed that the clinical use not only decreases the torsional resistance (6), but also influences the deterioration of flexural fatigue resistance in these instruments (7-10).

Cyclic torsional loading occur each time the continually rotating NiTi instrument meets resistance, it undergoes torsional loading, depending of the dentine hardness and the canal diameter. In addiction, has been observed that torsional fatigue can play an important role in the failure of rotary endodontic instruments, decreasing their resistance to flexural fatigue because they can act as nucleation sites for flexural fatigue cracks (2).

The ProTaper Universal instruments have a variable taper over the length of their cutting blades, allowing each instrument to prepare a specific area of the canal to reduce torsional loads, instrument fatigue, and the potential for breakage (11). Contrary to the majority of rotary NiTi instruments, which are usually used with a slight in-and-out movement until the working length is reached, ProTaper Universal instruments should be used like a ”brush”, that is, with a lateral pressure motion (11). This would selectively remove interferences and create lateral spaces that facilitate larger instruments to safely and progressively move deeper into canals (11).

However, some reports about the lateral pressure motion have cast doubts on the effectiveness of this technique in removing dentine at the coronal level (12) and on its influence on the instrument’s fatigue life (13). In addition, Plotino et al (12) found no difference in the amount of dentine removed by ProTaper and Mtwo instruments used with and without lateral pressure, while Mtwo instruments of larger size had their lifespan reduced by using them with a lateral brushing movement (13).

In recent study, the use of lateral pressure motion with S1 and S2 PTU instruments during the shaping of curved root canals tended to produce smaller decreases in the torsional resistance of the finishing instruments F1 and F2 (14). In the present study, the remaining fatigue life of rotary NiTi ProTaper Universal instruments was evaluated after multiple clinical uses, both with and without lateral pressure motion during root canal cleaning and shaping. The aim was to assess the influence of lateral pressure motion on fatigue resistance of these instruments.

Material and methods

Thirty sets of ProTaper Universal (PTU) instruments (Dentsply-Maillefer, Ballaigues, Switzerland), type S1, S2, F1 and F2, totaling 120 files, were analyzed and divided into three groups, as follows: Control Group (CG), with 10 sets of new instruments, which were fatigue tested until rupture to determine their fatigue resistance; Lateral pressure (LP), with 10 sets of instruments, each set used clinically in five mandibular and maxillary molars (15 to 20 canals), using the shaping instruments with lateral pressure motion; and No-Lateral Pressure (NLP), with 10 sets of instruments, each set used clinically in five mandibular and maxillary molars (15 to 20 canals), using the shaping instruments without lateral pressure motion.

There was no previous selection of tooth for the two experimental groups, the instruments were employed without pre-evaluating canal geometry. The instruments of the experimental groups were tested subsequently in fatigue until fracture. The SX and F3 instruments used in the clinical procedures were not included in the study, since these instruments work only in the straight portion of the canals (SX) or in preparation of straight canals (F3).

Both direct and angled radiographs were obtained to determine the canal radius and angle of curvature, as defined by Pruett (3). The measurement of these parameters was performed by projecting the radiographic images using a profile projector (Mitutoyo, Tokyo, Japan) at 10 x magnification.

Root canals were explored with sizes 10 and 15 stainless steel K-files (Dentsply-Maillefer, Ballaigues, Switzerland). Cleaning and shaping of the canals were completed in accordance with a crown down technique (10). The PTU shaping instruments in the LP group were used with lateral pressure motion to laterally and selectively cut dentine on the outstroke, while in the group NLP no lateral pressure motion was employed. In both experimental groups the preparation was finished using the PTU finishing instruments F1 and F2 in a ‘no brushing’ manner until the working length, established at 0.5 mm of the canal patency length. A 5.25% sodium hypochlorite solution was used for irrigation and Rc-prep (Premier Dental Products, Norristown, PA, USA) was used as a lubricant. The rotational speed was 300 rpm, applied by an endodontic electric motor (Endo Plus, VK Driller, São Paulo, SP, Brazil), operating at a torque of 5 N.cm.

After use in each patient, the instruments were washed, ultrasonically cleaned for 5 min in ethanol and steam autoclave sterilized. The S1, S2, F1 and F2 instruments of LP and NLP were observed by optical microscopy (Mitutoyo TM, Tokyo, Japan) to determine the presence of distortion, unwinding defects and macroscopic deformation. Before being tested to fatigue failure, 9 sets of these instruments, three sets of each group (CG, LP and NLP), were randomly selected and examined by scanning electron microscopy (SEM) (Jeol JSM 6360, Tokyo, Japan) to assess their surface characteristics.

Fatigue tests were carried out in a test device with an artificial canal made of quenched AISI H13 tool steel. This canal consisted of an arch, whose angle of curvature was 45 degrees with a radius of 5mm, and a guide cylinder of 10mm in diameter made of the same material. The chosen geometry placed the area of maximum canal curvature at about 3mm from the tip of the instruments. The instruments were allowed to rotate freely inside the artificial canal and the number of cycles to failure (NCF) was obtained by multiplying the rotation speed used in the fatigue test device, 300rpm, by the test time registered with a digital chronometer. The point of fracture in relation to the tip of the instrument was determined by measuring the fractured file with an endodontic rule.

To determine the statistical significance of the differences in the measured parameters amongst the different groups, data from fatigue tests, which showed normal distribution, were subjected to one-way analysis of variance (ANOVA). The nonparametric Mann-Whitney test was employed to compare the values of radii and angles of curvature of the root canals, which had asymmetric distribution. Significance was determined at the 95% confidence level for both types of tests.

Results

The mean values (and standard deviations) of the radii and angles of curvature of the curved root canals were 4.3 (1.6) mm and 39.9 (15.2) degrees in the instrumented teeth of LP Group and 3.8 (3.8) mm and 35.3 (15.6) degrees in the NLP Group. Statistical analysis using the Mann-Whitney test showed significant difference ($p = 0.017$) regarding the angles, though no statistically significant difference ($p = 0.169$) was found in the radii of the curvatures in the canals of LP and NLP groups.

The results of the fatigue tests are summarized in Fig. 1. The fatigue resistance of ProTaper Universal rotary instruments, measured by the NCF values, showed a tendency to decrease with clinical use for all instruments analyzed. Comparative statistical analyses between the remaining NCF values and those of new instruments (CG) showed statistically significant differences ($p < 0.05$) amongst the same size instruments used in LP and NLP. However, no statistically significant differences in NCF were found between similar instruments used with (LP) and without lateral pressure motion (NLP). The fatigue results are better visualized in terms of the "consumed fatigue life", given by the ratio between the average values of NCF for each type of instrument after clinical use by the corresponding average value for new instruments. This consumption of fatigue life is shown in Fig 2, which reveals the tendency for this consumption to be higher for S1 and S2 instruments in LP and for F1 and F2 instruments in NLP.

Although none of the instruments fractured or deformed permanently during root canal shaping, microcracks were observed by SEM in all clinically used instruments. Subjectively, there seemed to be a higher frequency of transverse cracks in the instruments submitted to lateral pressure motion, whereas instruments that did not undergo lateral pressure motion were characterized by a predominance of longitudinal cracks. The position of the fracture points relative to the instrument tips was 3.0 mm in average, for all instruments tested. The fracture surfaces of fatigue tested instruments observed by SEM were all similar and exhibited the typical features of this fracture mode, a region of crack nucleation and propagation and a large central area, associated with the final ductile failure.

Discussion

Prior studies on NiTi rotary instruments have confirmed that the diameter of the instrument and the geometry of the root canal determine their fatigue life during clinical use, given that the maximum tensile strain amplitude to which these instruments are submitted depends on the curvature radius of the root canal, as well as on the diameter of the instrument at its maximum bending point (3-5, 10). In the present study, the values of the curvature radius of the teeth from the LP and NLP groups presented no statistically significant difference. Therefore, it is reasonable to affirm that the amplitude of the deformation to which the instruments of the same dimensions had been submitted proved to be similar.

In this study, the F1 instrument, as compared to the other instruments, presented the greatest consumption of fatigue life, 30% and 34% in the LP and NLP groups, respectively. This finding may well be due to the higher variations in diameter among the S2 and F1 instruments in the region closest to the maximum bending point, thus resulting in higher torsional stresses on the F1 instruments in the dilation of the root canals. This cyclical torsional stress of higher amplitude tends to generate longitudinal cracks that reduce the NiTi instruments' resistance to flexional fatigue (2). A similar result was found by Ounsi et al (9), who justified such a tendency as being due to the abrupt change in the dimensions of the S2 and F1 instruments. Although the manufacturer reports that the change in the diameter of the PTU S2 instrument would allow for a more gradual transition between instruments, in the present study, these modifications do not represent an improvement in the resistance to the fatigue of the F1 instruments. However, when one compares the fatigue behavior of the ProTaper instruments (10) used with lateral pressure by the same operator, a much greater consumption of fatigue life can be observed for the S1, S2, F1, and F2 instruments of the ProTaper system, as compared to the other results from this study. Another important observation is that, in the work of Vieira et al (10), the ProTaper S2 instrument presented a greater consumption of fatigue life when compared to the other instruments of the same system. The comparison among the dimensions of the S2 instrument in the two systems (15) illustrates a tendency toward a reduction in the diameter of the S2 PTU instrument near its tip, which may well have led to a better fatigue behavior of this instrument in the present study (29% versus 52% of fatigue life consumption). By contrast, the reduction in the diameter of the S2 PTU instrument may have caused a lesser widening of the canals, in turn submitting the F1 PTU instrument to a more severe torsional fatigue with a greater consumption of its fatigue life. As reported by Bahia et al (2), the cyclic straining in torsion produces a significant reduction in the NiTi rotary instruments flexural fatigue resistance.

Overall, the reduction observed here in the remaining fatigue life of the clinically used instruments (Fig. 1) is a common characteristic of the NiTi rotary instruments, as has already been reported by many authors concerning a variety of instrument types (5, 8-10). Specifically in the case of PTU instruments, the results presented herein show a statistically significant reduction in the resistance to fatigue with clinical use for all of the analyzed instruments.

As regards the consequences of the use of the lateral pressure movement, a tendency toward an increase in the consumption of fatigue life for the S1 and S2 instruments, as well as a reduction in the F1 and F2 instruments, could also be observed (Fig. 2), although this comparison did not prove to be statistically significant. This study complements findings obtained in the study of the influence of the lateral pressure motion on the torsional resistance of PTU instruments (14), in which smaller reductions in the resistance to torsion from F1 and F2 instruments, due to the premature and accentuated dilation of the root canal with this type of preparation technique, could be observed. Similar to that observed in the present work, the S1 and S2 instruments were flexed in the coronal, medium, and apical thirds of the root canal, reducing their torsional resistance and consuming their fatigue life. As observed before (2, 6, 14), the SEM images obtained in the present study showed the predominance of transverse cracks generated by flexural stresses in the instruments submitted to lateral pressure motion. By contrast, the instruments that were not used with lateral pressure were characterized by a predominance of longitudinal cracks stemming from cyclic stresses caused by torsion.

Nevertheless, it is important to highlight that although the flexural fatigue does have a cumulative effect on the endodontic instruments, this study demonstrated the possibility of reusing ProTaper Universal instruments in the preparation of up to five molars without causing fractures.

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Figure Legends

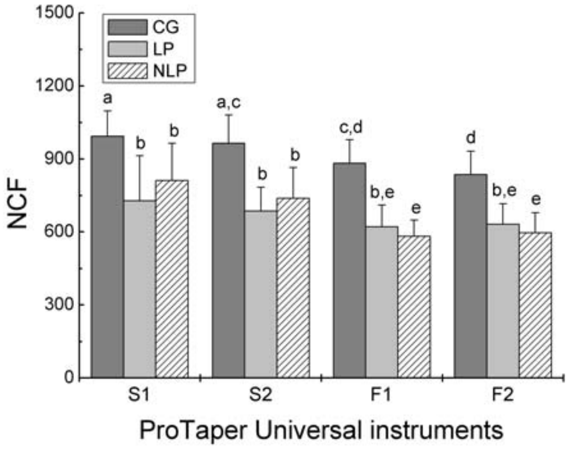

Figure 1 Mean values of NCF in fatigue tested new and used instruments (standard deviations shown as error bars).

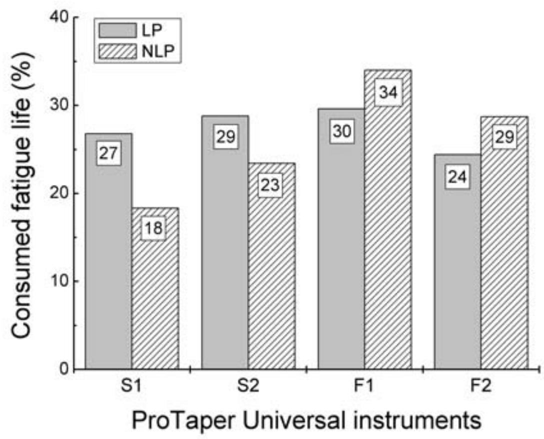

Figure 2 Mean values of consumed fatigue life in fatigue tested used instruments

4. CONSIDERAÇÕES FINAIS

Os resultados obtidos neste trabalho dão suporte às seguintes considerações sobre o uso clínico dos instrumentos rotatórios de NiTi *ProTaper Universal*:

A resistência torcional e resistência à fadiga flexural são as propriedades mecânicas do instrumento que determinam seu emprego clínico seguro. Os ensaios de torção realizados neste trabalho revelaram que os valores de torque máximo até a fratura tiveram uma relação direta com o diâmetro (calibre e *taper*) do instrumento. Por outro lado, os resultados dos ensaios de fadiga dos instrumentos novos demonstraram que a vida em fadiga dos instrumentos foi inversamente proporcional ao calibre dos mesmos: a medida que o diâmetro aumentou, o número de ciclos até a fratura diminuiu.

Em relação ao uso clínico, foi observado que os instrumentos PTU tiveram suas resistências em torção e em fadiga flexural reduzidas, quando comparadas aos instrumentos novos. Os resultados dos ensaios de torção e de fadiga deste estudo demonstraram que os efeitos cumulativos do uso clínico múltiplo em instrumentos *ProTaper Universal* têm uma influência mais intensa sobre o comportamento em fadiga flexural do que em sua resistência torcional.

Os instrumentos rotatórios de NiTi apresentam excelente resistência à fadiga em situações que envolvem deformações cíclicas severas no sistema de canais radiculares curvos. A ocorrência dos danos superficiais, devido à fadiga estrutural, em todos os instrumentos *ProTaper Universal* analisados após a instrumentação dos canais radiculares de cinco molares sugere que, no processo de fadiga destes instrumentos, as trincas são nucleadas precocemente, mas a sua propagação é lenta e ocupa a maior parte da vida útil dos mesmos, permitindo, assim, a sua reutilização na prática clínica.

O aparecimento de trincas longitudinais em adição às trincas transversais nas superfícies dos instrumentos utilizados clinicamente está associado à fadiga torcional, evidenciando que, durante a formatação dos canais radiculares, os instrumentos foram submetidos tanto a tensões cíclicas flexurais como torcionais. A fratura final, entretanto, pode ocorrer por fadiga ou sobrecarga em torção, em um material deteriorado anteriormente pelos dois modos de fadiga, flexural e torcional.

O movimento de pressão lateral teve como consequência uma tendência à redução do torque máximo e do número de ciclos até a fratura nos instrumentos S1 e S2, bem como de aumentá-los nos instrumentos F1 e F2. Estes resultados podem ser explicados pelo fato de que o uso dos instrumentos de formatação S1, S2 e SX com movimento de pressão lateral remove seletivamente a dentina na parte externa da curvatura, criando espaço para facilitar a penetração progressiva e segura dos instrumentos de acabamento F1 e F2. Contudo, durante o movimento de pressão lateral, os instrumentos de formatação são flexionados nos terços coronário, médio e apical do canal, acentuando a fadiga flexural dos mesmos.

Finalmente, embora a fadiga estrutural tenha um efeito cumulativo nos instrumentos endodônticos, consumindo sua resistência torcional e sua vida em fadiga, e considerando ainda que a fratura de instrumentos rotatórios de NiTi resulta da concomitância de vários fatores, este estudo demonstrou a possibilidade da reutilização dos instrumentos *ProTaper Universal* no preparo de até cinco molares, sem nenhuma fratura.

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Torsional behaviour of rotary NiTi ProTaper Universal instruments after multiple clinical use

E. P. Vieira[1], R. K. L. Nakagawa[1], V. T. L. Buono[2] & M. G. A. Bahia[1]

[1]Department of Restoration Dentistry, Faculty of Dentistry, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil; and [2]Department of Metallurgical and Materials Engineering, Engineering School, Federal University of Minas Gerais, Belo Horizonte-MG, Brazil

Abstract

Vieira EP, Nakagawa RKL, Buono VTL, Bahia MGA. Torsional behaviour of rotary NiTi ProTaper Universal instruments after multiple clinical use. *International Endodontic Journal*, **42**, 947–953, 2009.

Aim To assess the influence of multiple clinical uses on the torsional behaviour of ProTaper Universal rotary NiTi instruments.

Methodology Root canal treatments were performed on patients using the ProTaper Universal rotary system to prepare canals. Ten sets of instruments were used by an experienced endodontist, each set being used in five molar teeth. After clinical use, S1, S2, F1 and F2 instruments were analysed for damage by optical and scanning electron microscopy. The used sets, along with a control group of 10 sets of new instruments, were then torsion tested based on the ISO 3630-1 specification. Data obtained were subjected to a one-way analysis of variance (ANOVA) with $\alpha = 0.05$.

Results The use of the ProTaper Universal rotary instruments by an experienced endodontist allowed for the cleaning and shaping of the root canal system of five molar teeth without fracture. The maximum torque for instruments S2, F1 and F2, and the angular deflection at fracture for instruments S2 and F1 were significantly lower following clinical use. The largest decrease in maximum torque was 18.6% ($P = 0.014$) for S2 instruments. The same maximum percent decrease was found for angular deflection at fracture for F1 instruments ($P = 0.009$).

Conclusions Torsional resistance and angular deflection of used instruments, as compared to that of new instruments, were reduced following clinical use.

Keywords: clinical use, endodontic instruments, nickel–titanium, ProTaper Universal, torsional resistance.

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Introduction

Reasons for the fracture of rotary NiTi instruments include variations in canal anatomy, such as merging, curving, re-curving, dilacerating or dividing canals (Ruddle 2002). In addition, other factors can affect the fracture resistance of endodontic instruments, such as size, taper, alloy composition, manufacturing methods, flexibility and rigidity, instrument shape and direction of rotation (Hilt *et al.* 2000). The cross-sectional profile also has a significant influence on the mechanical behaviour of NiTi instruments (Schäfer *et al.* 2003, Melo *et al.* 2008). The factors affecting the performance include the depth of the flute, the area of the inner core, the radial land and the peripheral ground surface (Gambarini 2005, Xu & Zheng 2006).

The fatigue life of a rotary endodontic instrument is related to the degree to which it is flexed when placed in a curved root canal, with greater flexures leading to a shorter fatigue life expectation (Pruett *et al.* 1997, Melo *et al.* 2002, Bahia & Buono 2005). Torsional failure occurs when the tip or another part of the instrument is locked in the canal, whilst the shaft continues to rotate. If the elastic limit of the metal is

Correspondence: Vicente T. L. Buono, Professor, Department of Metallurgical and Materials Engineering, Federal University of Minas Gerais, Rua Espírito Santo 35 room 206, 30160-030, Belo Horizonte, MG, Brazil (Tel.: +55 31 3409 1859; fax: +55 31 3409 1815; e-mail: vbuono@demet.ufmg.br).

exceeded, the instrument undergoes plastic deformation, which can be followed by fracture if the load is high enough (Blum *et al.* 1999, Gambarini 2000).

Peters *et al.* (2003) established that torque is correlated not only with apically exerted force, but also with preoperative canal volume. Hence, the preparation of narrow and constricted canals can subject rotary NiTi instruments to higher torsional loads and high-apically directed forces. The problem of fracture by torsional overload has been dealt with by determining the maximum torque at separation for each type of instrument and then using low-torque endodontic motors, which can be programmed in such a way as to avoid the application of torque values higher than that of each instrument can support without failing. Nevertheless, this approach does not take into account the fact that fatigue loads developed during curved root canal shaping may decrease the torsional resistance of endodontic instruments. This effect was studied by various authors (Yared *et al.* 2003, Ullmann & Peters 2005, Bahia *et al.* 2006), who reported a reduction in the maximum torque to failure for all instruments evaluated.

The reuse of rotary instruments of NiTi is a constant concern. The cumulative effects of multiple clinical uses on the incidence of fatigue, deformation and instrument separation have been analysed (Yared *et al.* 2000, Gambarini 2001, Fife *et al.* 2004, Bahia & Buono 2005), with the conclusion that their clinical reuse progressively reduced their resistance to fatigue. During canal preparation, especially in curved root canals in molar teeth, these instruments are submitted to a high degree of cyclic deformation that may consume a considerable amount of their fatigue life (Bahia & Buono 2005).

In a recent study, Vieira *et al.* (2008) observed that the flexural fatigue resistance of ProTaper instruments, used clinically by an experienced endodontist for the cleaning and shaping of five molars, was reduced up to 52% when compared with that of new instruments. The present work was undertaken to assess the influence of multiple clinical uses on the torsional behaviour of ProTaper Universal rotary NiTi instruments.

Material and methods

Twenty sets of ProTaper Universal instruments (Dentsply Maillefer, Ballaigues, Switzerland), type S1, S2, F1 and F2, totalling 88 files, were analysed. They were divided into two groups: (i) control group (CG), with 10 sets of new instruments tested in torsion until fracture to establish the mean values of maximum torque and angular deflection at fracture for each type of instrument and (ii) experimental group (EG), with 10 sets of instruments, each set used clinically by an endodontist with experience using the ProTaper Universal system in five molar teeth to shape between 15 and 20 root canals. The instruments of the EG were tested subsequently in torsion until fracture. The SX and F3 instruments used in the clinical procedures were not included in the study, since these instruments work only in the straight portion of the canals (SX) or in preparation of straight canals (F3).

Direct and angled radiographs of each tooth were obtained using a paralleling technique to evaluate anatomy, as well as to determine the canal radius and angle of curvature, as defined by Pruett *et al.* (1997), and its approximate length. The measurement of these parameters was performed by projecting the radiographic images using a profile projector (Mitutoyo, Tokyo, Japan) at 10 × magnification. The canal radius of curvature was measured along the outer canal wall.

After the orifices were located and the canal explored with sizes 10 and 15 stainless steel K-files (Dentsply Maillefer), cleaning and shaping of the canals were completed in accordance with a crowndown technique recommended by Ruddle (2005). Once a glide path had been created, the ProTaper Universal shaping instruments were used like a ‘brush’ to laterally and selectively cut dentine on the outstroke. The preparation was finished using the ProTaper Universal finishing instruments F1 and F2 in a ‘nonbrushing’ manner. The clinical protocol was followed with recapitulations until the working length, established at 0.5 mm of the canal patency length, could be reached by at least an F2 instrument, at which point shaping was considered complete.

A 5.25% sodium hypochlorite solution was used for irrigation and Rc-prep (Premier Dental Products, Norristown, PA, USA) was used as a lubricant. The rotational speed was 300 rpm, applied by an endodontic electric motor (Endo Plus, VK Driller, São Paulo, SP, Brazil), operating at a torque of 5 N·cm together with a hand piece of 16 : 1 reduction (W&H 975, Dentalwerk, Bürmoos, Austria).

After use in each patient, the instruments were washed, ultrasonically cleaned for 5 min in ethanol and steam autoclave sterilized. The S1, S2, F1 and F2 instruments of the EG were observed by optical microscopy (Mitutoyo TM, Tokyo, Japan), at 30 × magnification, to determine the presence of distortion, unwinding defects and macroscopic deformation. Before torsion testing, three sets of instruments were randomly selected and examined by scanning electron microscopy (SEM) (Jeol JSM 6360, Tokyo, Japan) to assess their surface characteristics.

Torsion testing was based on ISO 3630-1 specification, and using a torsion machine (Analógica, Belo Horizonte, MG, Brazil) was described in Bahia *et al.* (2006). The rotation speed was set clockwise to 2 rpm. The end of the shaft was clamped into a chuck connected to a reversible geared motor. Three millimetres of the instrument's tip was clamped in another chuck with brass jaws to prevent sliding. Continuous recording of torque and angular deflection, as well as measurements of the maximum torque and angular deflection to failure, was provided by a specifically designed computer program.

To determine the statistical significance of differences in the measured parameters amongst different groups, data obtained were subjected to a one-way analysis of variance (ANOVA). Significance was determined at the 95% confidence level.

Results

During the clinical part of the study, none of the instruments fractured or deformed permanently. The mean values (and standard deviations) of radius and angle of curvature characterizing the geometry of the root canals of the 50 molars instrumented with the 10 sets of files (five molars for each set) were 4.0 mm (1.7 mm) and 33.1° (11.1°), respectively.

The results of the torsion tests are summarized in Fig. 1, which shows mean values of the maximum torque and angular deflection at fracture of new instruments (CG) and of those previously used in the clinical practice (EG). As is common, torsional resistance increased as the diameter of the instruments increased, with the mean values of maximum torque appearing statistically different when instruments in the CG were compared one to another: S1–S2, S2–F1 and F1–F2. A similar tendency was observed for angular deflection at fracture in the CG, and statistically significant differences were found when comparing instruments S1 with S2, and F1 with F2, but not when comparing S2 with F2 instruments.

The mean values in Fig. 1 indicated that multiple clinical uses caused a reduction in maximum torque and angular deflection at fracture of ProTaper Universal instruments. Comparison between the values of maximum torque, measured for the same type of

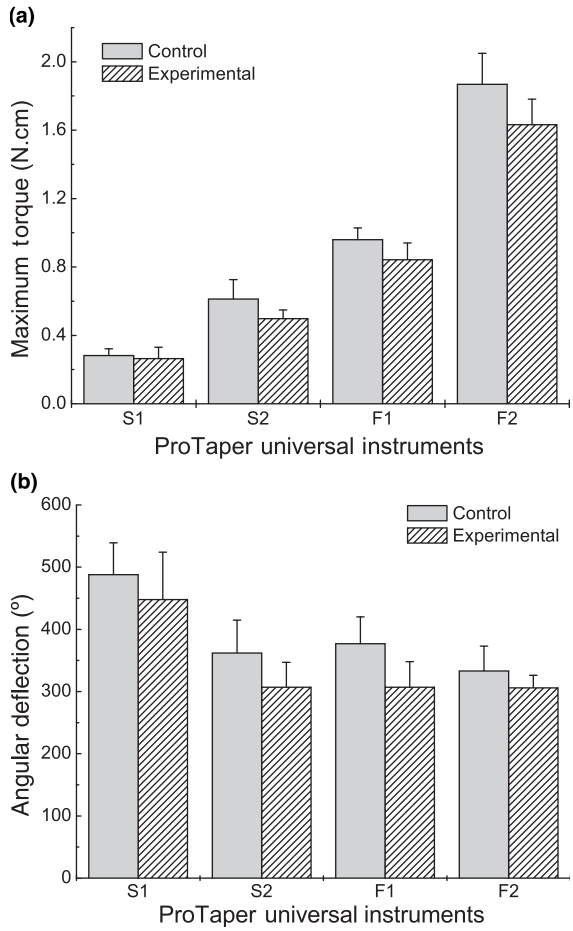

Figure 1 Mean values of maximum torque (a) and angular deflection at fracture (b) of ProTaper Universal instruments from the control and experimental groups. Error bars represent the standard deviations.

instruments from the Control and EGs, showed that this tendency was significant for instruments S2 ($P = 0.014$), F1 ($P = 0.007$) and F2 ($P = 0.006$), but not for S1 ($P = 0.475$). When a similar analysis was performed for angular deflection at fracture, statistically significant reduction in this parameter was found for S2 ($P = 0.003$) and F1 ($P = 0.009$) instruments, but not for S1 ($P = 0.546$) and F2 ($P = 0.097$).

After canal shaping, all instruments examined by SEM had microcracks and widening of machine grooves, as well as wear and blunting of the cutting edges. These surface characteristics were qualitatively similar in all three sets of randomly selected instruments of the EG. The SEM images shown in Fig. 2 illustrate typical microcracks found in used S2 instruments. The majority of the cracks were transverse to

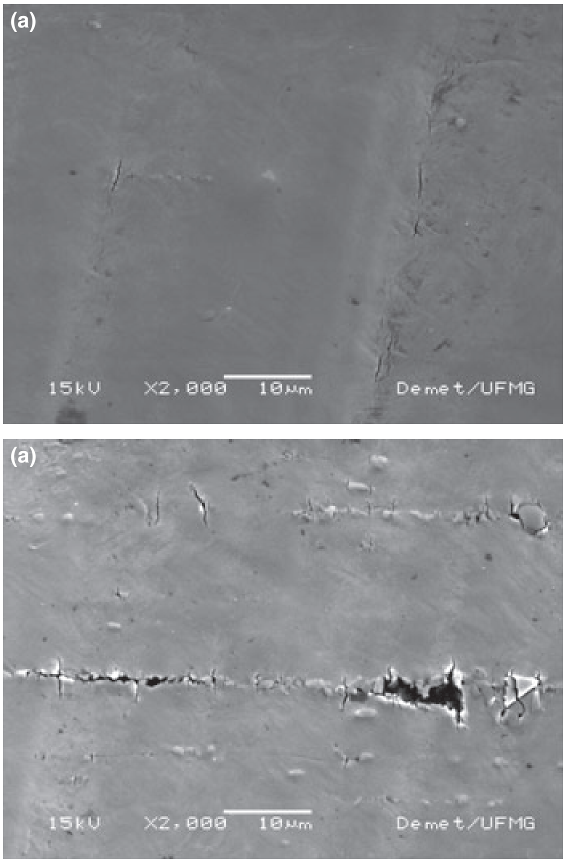

Figure 2 SEM images of the surface of an S2 ProTaper Universal instrument used for the cleaning and shaping of five molars showing (a) cracks transversal to the cutting edge and (b) longitudinal cracks.

the cutting edge (Fig. 2a), but longitudinal cracks, parallel to the long axis of the instrument, were also observed (Fig. 2b).

Discussion

The torsional behaviour of rotary NiTi endodontic instruments is affected by a variety of factors, such as size, taper, design, alloy chemical composition and thermomechanical processes applied during manufacturing (Kuhn & Jordan 2002, Bahia *et al.* 2005, Miyai *et al.* 2006). Nevertheless, there is a strong relationship between the maximum torque an instrument can withstand and its diameter (Peters & Barbakow 2002, Bahia & Buono 2005). It has also been suggested that the cross-sectional shape of instruments affects the stress distribution pattern as well as their torsional properties (Turpin *et al.* 2000, Berutti *et al.* 2003, Melo *et al.* 2008, Câmara *et al.* 2009, Kim *et al.* 2009). The results for the CG depicted in Fig. 1 are thus in agreement with the general observation that the maximum torque of endodontic instruments increases as instrument diameter becomes larger. On the other hand, measurements of angular deflection at fracture showed that this parameter does not correlate with instrument diameter in the same way (Gambarini 2001, Bahia *et al.* 2006). The results shown in Fig. 1 for new instruments confirm this observation.

In straight root canals, rotary endodontic instruments operate by cutting and removing organic tissue and debris, experiencing mostly frictional forces, which run in opposition to their torsional motion. However, when the instrument rotates inside a curved root canal, it is bent and thus submitted to tensile–compressive strain cycles in the region of the canal curvature, in addition to the torsional restraints. The strain levels attained by endodontic instruments during this cyclic loading depend on the root canal and instrument geometries, being concentrated at the portion of the instrument positioned in the maximum curvature region of the root canal (Bahia & Buono 2005, Cheung & Darvell 2007). These cyclic forms of stress cause flexural fatigue, involving crack nucleation and growth. The value of the tensile strain amplitude, ε_T, on the surface of an instrument of diameter D inserted into a canal of radius of curvature R can be estimated by the expression:

$$\varepsilon_T = \frac{D}{2R - D} \tag{1}$$

which is valid when the canal radius is measured at the outer canal wall (Bahia & Buono 2005), as was done in the present study. Alternatively, when R is measured at the canal central axis, this expression becomes (Cheung & Darvell 2007):

$$\varepsilon_T = \frac{D}{2R} \tag{2}$$

If the maximum amplitude is assumed to occur at 3 mm from the instrument tip, the region of the instrument subject to the maximum tensile strain amplitude is D_3. Table 1 shows the values of D_3 measured for ProTaper Universal instruments by Câmara *et al.* (2009) and the corresponding estimated values of ε_T, calculated using equation 1 for the average radius of curvature, 4.0 mm, of the root canals instrumented in the present study.

Cyclic flexural straining by the amounts shown in Table 1 would certainly cause damage to the

Table 1 Diameter of the ProTaper instruments at 3 mm from their tip, D_3, and corresponding maximum tensile amplitudes, ε_T, estimated for the average radius of curvature of 4.0 mm

Instrument	D_3 (mm)[a]	ε_T (%)
S1	0.29	3.8
S2	0.35	4.6
F1	0.42	5.5
F2	0.50	6.7

[a]Câmara *et al.* (2009).

instruments. The microcracks exemplified in Fig. 2 constitute evidence of this damage. The presence of longitudinal cracks, that is, cracks parallel to the long axis of the file, has previously been described (Peng *et al.* 2005, Tripi *et al.* 2006, Vieira *et al.* 2008), and is thought to reflect the direction of the stress on the surface of the instrument under torsional load. Similar cracking patterns have been observed on other rotary NiTi endodontic instruments subjected to cyclic torsional straining (Bahia *et al.* 2008). During this type of cyclic deformation, planes with a maximum shear stress are either perpendicular or parallel to the longitudinal axis, whilst the normal stress component on the slip plane is zero. Microscopic investigations have shown that microcracks nucleate in a slip band under cyclic torsion and then grow further in a direction perpendicular to the main stress. In a cylindrical bar, this direction makes an angle of 45° with the axis of the bar. Consequently, cracks in a round axle under cyclic torsion grow in the form of a spiral around its surface (Schijve 2001). The longitudinal appearance of the cracks observed in endodontic instruments is because of the fact that the instruments have helical shapes and that the cracks, being rather small in size, require large magnifications to be observed (Bahia *et al.* 2008).

When the torsional resistance of similar instruments belonging to CG and EG was compared, a tendency for this property to decrease with the clinical use in five molars was observed for all instruments analysed (Fig. 1). This tendency was statistically significant for S2, F1 and F2 instruments. Previous studies (Yared *et al.* 2003, Ullmann & Peters 2005, Bahia *et al.* 2006) reported that simulated clinical use lowered the mean values of maximum torque when compared with that of new instruments. Regarding the behaviour of angular deflection at fracture, Yared *et al.* (2003) and Ullmann & Peters (2005) found no statistically significant changes in this parameter between new instruments and those submitted to simulated clinical use. In the present study, angular deflection at fracture tended to decrease for the used instruments (Fig. 1b) and statistically significant decreases were found for S2 and F1 instruments. This result confirms previous findings on ProFile instruments submitted to simulated clinical use (Bahia *et al.* 2006). However, it is important to mention that angular deflection at fracture has little clinical significance, because at a typical rotational speed of 300 rpm, one complete revolution of a tip-locked instrument will occur in one-fifth of a second. Thus, differences in this parameter will not be perceived in clinical practice.

The reduction in maximum torque measured in the present study were, on average, 6%, 19%, 12% and 13% for S1, S2, F1 and F2 ProTaper Universal instruments, respectively. These results confirmed the role played by flexural fatigue in the torsional resistance of these instruments. However, in a previous work (Vieira *et al.* 2008) considerably higher values were found for the reduction of flexural fatigue life of ProTaper instruments clinically employed for the cleaning and shaping of five molars: 33%, 52%, 45% and 44% for S1, S2, F1 and F2 instruments, respectively. Taken together, these results indicated that the cumulative effects of multiple clinical uses on rotary NiTi endodontic instruments have a stronger influence on flexural fatigue behaviour than on their torsional resistance.

Although flexural fatigue appears to have a cumulative effect on rotary endodontic instruments, causing weakening over time, clinical studies have failed to demonstrate the extent of the cumulative effects of multiple clinical uses on the fatigue resistance of these instruments. For instance, Fife *et al.* (2004) did not observe statistically significant differences when the remaining fatigue life of ProTaper instruments used in two and four molars were compared, whilst Vieira *et al.* (2008) obtained a similar result after shaping of five and eight molars. Moreover, simulated clinical use of ProFile instruments up to one of two and three-fourth of their fatigue life (Bahia *et al.* 2006) and of ProTaper instruments up to 30%, 60% and 90% of their fatigue life (Ullmann & Peters 2005) did not significantly alter their torsional resistance when the pre-strained instruments were compared. These results were interpreted as indicating that crack nucleation occurs early during flexural fatigue of NiTi rotary instruments, low-crack growth occupying a large fraction of their low-cycle fatigue life (Bahia & Buono 2005).

Conclusions

Torsional resistance of used instruments was reduced by average amounts varying from 6% to 19%, when compared with that of new instruments. Structural fatigue took place during the clinical use of the instruments and, in addition to the usual transversal cracks generate by flexural fatigue, longitudinal cracks were also observed on the surface of the used instruments. Comparisons with data on ProTaper instruments indicate that the cumulative effects of multiple clinical uses on rotary NiTi endodontic instruments have a stronger influence on flexural fatigue behaviour than on their torsional resistance.

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Effect of Lateral Pressure Motion on the Torsional Behavior of Rotary ProTaper Universal Instruments

Evandro Pires Vieira, DDS, MS, Vicente Tadeu Lopes Buono, BS, MS, PhD,† and Maria Guiomar de Azevedo Bahia, DDS, MS, PhD**

Abstract

Introduction: The purpose of this study was to evaluate the torsional behavior of rotary ProTaper Universal instruments after multiple clinical uses with and without lateral pressure motion. **Methods:** Thirty sets of ProTaper Universal instruments were divided into 3 groups (n = 10): control group (CG) involving new instruments tested in torsion on the basis of ISO 3630-1, lateral pressure (LP) group involving instruments that were clinically used on 5 molars by using the shaping instruments S1 and S2 with lateral pressure motion, and no lateral pressure (NLP) group involving instruments that were clinically used on 5 molars without lateral pressure motion. The instruments in the LP and NLP groups were subsequently tested in torsion. Data were analyzed by using analysis of variance (α = 0.05). **Results:** Multiple clinical uses caused a reduction in the maximum torque in the analyzed instruments. When the effect of using lateral pressure motion with the shaping instruments was assessed, a tendency of reduction in the maximum torque for the S1 and S2 instruments and of increase for the F1 and F2 instruments was observed in the group with lateral pressure motion. **Conclusions:** The use of lateral pressure motion with the shaping instruments S1 and S2 tended to produce smaller decreases in the torsional resistance of the finishing instruments F1 and F2. *(J Endod 2011;■:1–4)*

Key Words

Lateral pressure motion, NiTi rotary instruments, ProTaper Universal, torsional resistance

The occasional fracture of an instrument in the root canals of teeth continues to be an inherent hazard in endodontic treatment. Torsional overload and flexural fatigue have been identified as the main reasons for rotary nickel-titanium (NiTi) instrument failure (1). The fatigue life of a rotary endodontic instrument is related to the degree to which it is flexed when placed in a curved root canal, with greater angles of curvature and smaller radii leading to a shorter life expectation (2–7). Failure by torsional overload can take place when the instrument is locked into the canal (8, 9). Furthermore, fatigue cracks that develop during the shaping of curved root canals might decrease the torsional resistance of endodontic instruments, causing a reduction in their maximum torque (7, 10, 11). Specifically regarding ProTaper Universal instruments (Dentsply-Maillefer, Ballaigues, Switzerland), it was shown that the torsional resistance of used instruments was reduced by an average of 6%–19%, when compared with new instruments (12).

The ProTaper Universal instruments were designed with a variable taper over the length of their cutting blades, allowing each instrument to prepare a specific area of the canal to reduce torsional loads, instrument fatigue, and the potential for breakage (13). Contrary to the majority of rotary NiTi instruments, which are usually used with a slight in-and-out movement until the working length is reached, ProTaper Universal instruments should be used like a brush, that is, with a lateral pressure motion (13). This would selectively remove interferences and create lateral spaces that facilitate larger instruments with stronger and more active cutting blades to safely and progressively move deeper into canals (13). However, some reports about the lateral pressure motion have cast doubts on the effectiveness of this technique in removing dentin at the coronal level (14) and on its influence on the instrument's fatigue life (15). Plotino et al (14) found no difference in the amount of dentin removed by ProTaper and Mtwo (VDW, Munich, Germany) instruments used with and without lateral pressure, whereas Mtwo instruments of larger size had their life span reduced by using them with a lateral brushing movement (15). In addition, as compared with other conventionally used NiTi rotary files, the use of ProTaper files following the manufacturer's directions apparently does not improve canal cleanliness (16).

To the best of our knowledge, the use of NiTi instruments with lateral pressure motion and its effect on torsional behavior have not yet been investigated. Thus, the aim of this study was to evaluate the torsional behavior of rotary NiTi ProTaper Universal instruments after multiple clinical uses, both with and without lateral pressure motion during root canal cleaning and shaping.

From the *Department of Restorative Dentistry, Faculty of Dentistry, and †Department of Metallurgical and Materials Engineering, School of Engineering, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, Minas Gerais, Brazil.

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Address requests for reprints to Professor Vicente Tadeu Lopes Buono, Department of Metallurgical and Materials Engineering, Federal University of Minas Gerais, Av. Antonio Carlos, 6.627, Campus Pampulha, Escola de Engenharia, Bloco 2, Sala 2640, 31270-901, Belo Horizonte, MG, Brazil. E-mail address: vbuono@demet.ufmg.br

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Materials and Methods

Thirty sets of ProTaper Universal (PTU) instruments of types S1, S2, F1, and F2, totaling 120 files, were analyzed and divided into 3 groups: control group (CG) involving 10 sets of new instruments tested in torsion until rupture; lateral pressure (LP) group involving 10 sets of instruments, with each set clinically used for the preparation of 5 mandibular and maxillary molars (totaling 132 canals), by using the shaping instruments with lateral pressure motion; and no lateral pressure (NLP) group involving 10 sets of instruments, with each set clinically used for the preparation of 5 mandibular and maxillary molars (totaling 126 canals), by using the shaping instruments S1 and S2 without lateral pressure motion. There was no previous selection of teeth for the 2 experimental groups; the instruments were used without pre-evaluating canal geometry.

Both direct and angled radiographs were obtained to determine the canal radius and the angle of curvature, as defined by Pruett et al (2). The measurement of these parameters was performed by projecting the radiographic images by using a profile projector (Mitutoyo, Tokyo, Japan) at 10× magnification.

Root canals were explored with size 10 and 15 stainless steel K-files (Dentsply-Maillefer). Cleaning and shaping of the canals were completed in accordance with a crown-down technique (13). The PTU shaping instruments S1 and S2 in the LP group were used with lateral pressure motion to cut the dentin laterally and selectively on the outstroke, whereas the finishing instruments F1 and F2 were passively allowed to move deeper into the canal in 1 or more paces. In the NLP group, no lateral pressure motion was used with S1 and S2; all instruments were used as F1 and F2 of the LP group. In both experimental groups the preparation was finished by using the PTU finishing instruments F1 and F2 in a non-brushing manner until working length, which was established at 0.5 mm of the canal patency length, was reached. A 5.25% sodium hypochlorite solution was used for irrigation, and Rc-prep (Premier Dental Products, Norristown, PA) was used as a lubricant. The rotational speed was set at 300 rpm with an endodontic electric motor (Endo Plus; VK Driller, São Paulo, SP, Brazil), which was operated at a torque of 5 N.cm.

After use, the instruments were washed, ultrasonically cleaned for 5 minutes in ethanol, and steam sterilized in an autoclave. The S1, S2, F1, and F2 instruments of LP and NLP were observed by optical microscopy (Mitutoyo TM) to determine the presence of distortion, unwinding defects, and macroscopic deformation. Before torsion testing, 3 sets of instruments were randomly selected and examined by scanning electron microscopy (SEM) (Jeol JSM 6360, Tokyo, Japan) to assess their surface characteristics.

Torsion testing was performed by using a torsion machine (Analógica, Belo Horizonte, MG, Brazil), on the basis of ISO 3630-1 specification. The rotation speed was set clockwise at 2 rpm. The end of the shaft was clamped into a chuck connected to a reversible geared motor. Three millimeters of the instrument's tip was clamped into another chuck with brass jaws to prevent sliding. Continuous recording of the torque was provided by a specifically designed computer program.

To determine the statistical significance of the differences in the measured parameters among the different groups, data from torsional tests, which showed normal distribution, were subjected to one-way analysis of variance (anova). The nonparametric Mann-Whitney test was used to compare the values of radii and angles of curvature of the root canals, which had asymmetric distribution. Significance was determined at the 95% confidence level for both types of tests.

Results

The mean values (and standard deviations) of the radii and angles of curvature of the instrumented curved root canals were 4.0 (1.6) mm and 34 (13) degrees in LP and 3.5 (1.7) mm and 37 (18) degrees in NLP. Statistical analysis with the Mann-Whitney test showed no significant difference (P = .168) regarding the angles, although a statistically significant difference (P = .035) was found in the radii of the curvatures in the canals of the LP and NLP groups.

The results of the torsion tests are summarized in Fig. 1. As expected, torsional resistance increased as the diameters of the instruments increased, and multiple clinical uses caused a reduction in the maximum torque of the PTU instruments. Comparative statistical analyses between the values of maximum torque for the same types of instruments in CG and LP showed that the decrease in maximum torque was significant for instruments S2 (P = .014), F1 (P = .007), and F2 (P = .006). In NLP, this decrease was statistically significant for F1 (P = .012) and F2 ($P \leq .001$) instruments. However, when similar instruments in the 2 experimental groups were compared, there was a tendency for reduction in the torque for S1 and S2 in LP and for F1 and F2 instruments in the NLP group, but no statistically significant differences were observed ($P > .05$).

Although none of the instruments fractured or deformed permanently, microcracks were observed by SEM in all of the clinically used instruments. Subjectively, there seemed to be a higher frequency of transverse cracks in the instruments submitted to lateral pressure motion (LP), whereas instruments that did not undergo lateral pressure motion (NLP) were characterized by a predominance of longitudinal cracks (Fig. 2).

Discussion

The ProTaper Universal system is an example of the effort of developers and manufacturers toward the achievement of optimal clinical results. However, the proposition of new techniques leads to new questions that should be addressed by researchers in the field. Thus, although the reason for using the shaping PTU instruments with lateral pressure motion is well-explained (13), the consequences of this motion in terms of the resulting shape of the root canal and on the instruments' life span remain uncovered. Recent studies have discussed the cleaning ability (16), apical root transportation (17), vertical root fracture (18), torsional and fatigue resistance of PTU (12, 19, 20), but the effect of lateral pressure motion on the torsional resistance of PTU instruments after multiple clinical uses has not yet been investigated.

It is generally accepted that the high degree of cyclic deformation to which NiTi rotary instruments are submitted during the preparation

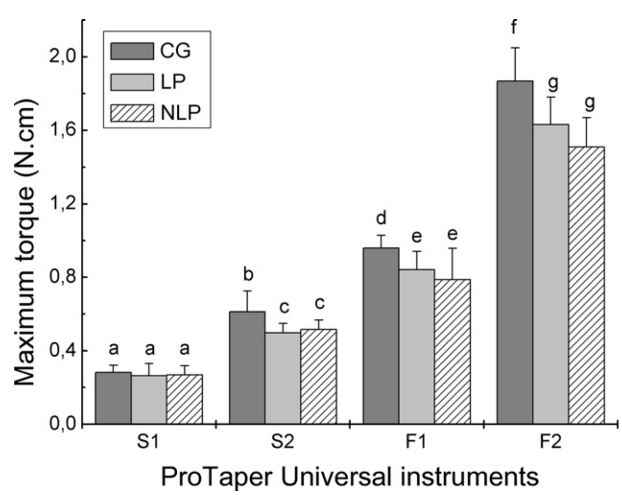

Figure 1. Mean values of maximum torque for instruments tested in torsion. Different labeled columns represent statistically significant differences (α = 0.05).

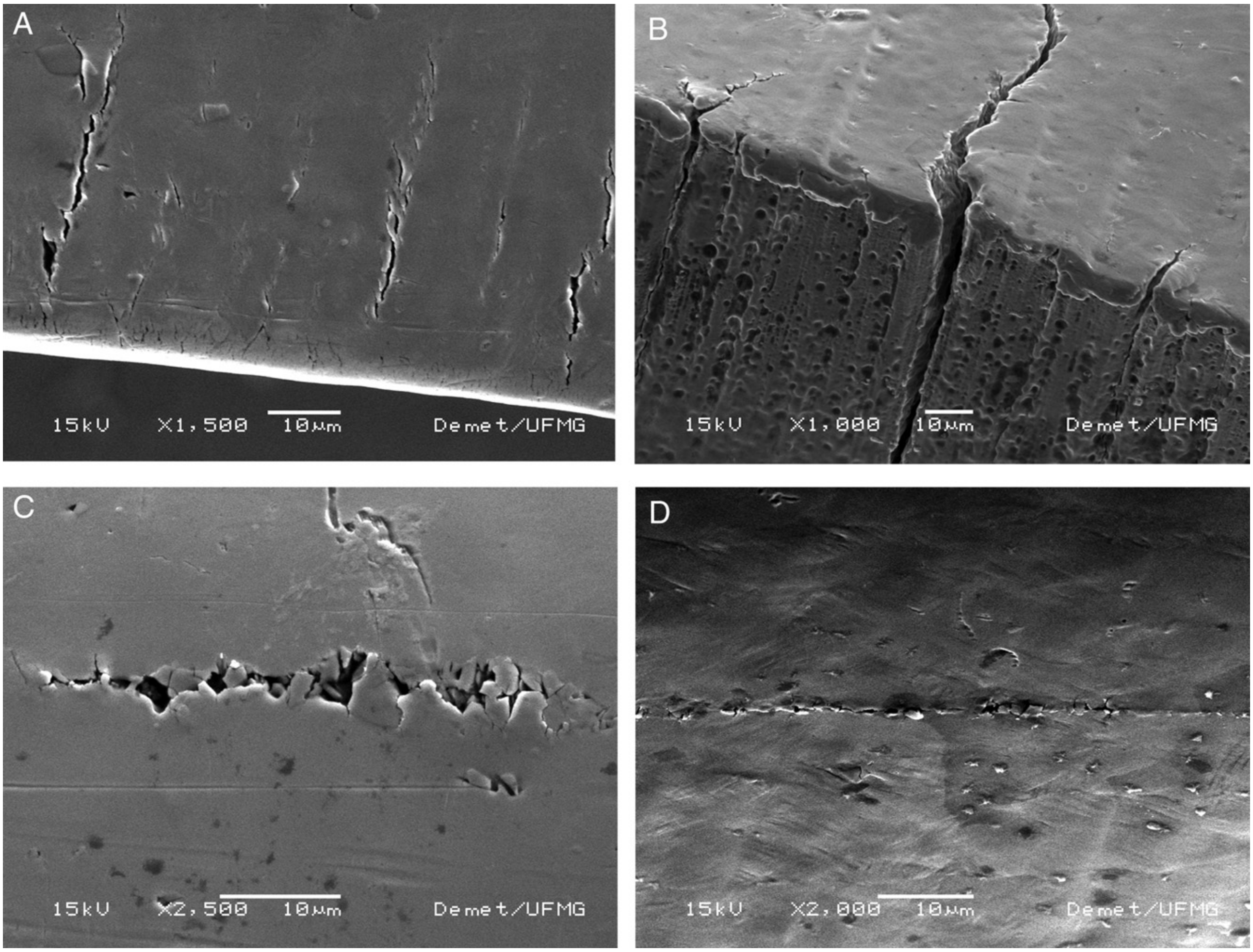

Figure 2. Transverse cracks in S2 instruments used with lateral pressure motion (LP) at (*A*) 1.5 mm and (*B*) 5.5 mm from the tip; longitudinal cracks in instruments that did not undergo lateral pressure motion (NLP) (*C*) S1 at 1.5 mm and (*D*) S2 at 3.0 mm from the tip.

of curved root canals can lead to mechanical fatigue (2–7), and that the instrument's fatigue resistance varies inversely with the amplitude of the maximum tensile strain, $\epsilon_t = D/(2R - D)$, to which an instrument of diameter D is submitted when it is bent into the root canal of radius R (6, 20, 21). It is also recognized that flexural fatigue reduces the fatigue life and the torsional resistance of NiTi rotary instruments in direct proportions (7, 10–12). Therefore, the higher the tensile strain amplitude is, the greater are the consumption of fatigue life and the reduction in torsional resistance, hence highlighting the importance of evaluating the geometric parameters of the curvatures of root canals.

In the present study, the average values of the curvature radii were 4.0 and 3.5 mm, respectively, for the teeth belonging to the LP and NLP groups. These values correspond to maximum tensile strains of 6.5% and 7.5%, respectively, for the F2 instrument, which has the largest diameter at 3 mm from the tip, where the maximum strain amplitude should be approximately located. In other words, the root canals in LP, on average, imposed smaller tensile strain amplitudes than those in NLP, although it should be observed that for the instruments with larger diameters, both strains are equally large as far as recoverable strains in superelastic NiTi are concerned (22). In addition, the number of canals prepared in LP, 132, was approximately 5% greater than in NLP, 126 canals. For analyzing the influence of clinical use in LP and NLP, it is thus reasonable to assume that the finishing instruments F1 and F2 underwent severe straining when used for the preparation of teeth and that this severe straining was similar in both groups. In fact, when the average values of the maximum torque of similar instruments from CG were compared with those from LP and NLP, clinical use reduced the torsional resistance of the instruments (Fig. 1), regardless of the differences in curvature of the root canals. These results are in agreement with findings from prior studies, in which simulated clinical use (10, 11) and multiple clinical uses (12) reduced the torsional resistance of NiTi rotary instruments.

When the effect of lateral pressure motion in the shaping of canals was assessed, a tendency of reduction in the maximum torque for the S1 and S2 instruments and of increasing this parameter for the F1 and F2 instruments could be observed in the LP group. Although not statistically significant, this tendency suggests that lateral pressure motion, because of a premature and accentuated dilation, caused an increase in the root canal's curvature radius and a consequent reduction in the maximum tensile strain amplitude. Accordingly, the finishing instruments F1 and F2 of LP were submitted to lower flexural and torsional stresses during apical instrumentation.

During the shaping of the root canals, instruments undergo both flexural and torsional cyclic stresses (8, 21, 23). Consequently, the ultimate causes for the failure of root canal treatments involve torsional overloads on materials that have deteriorated via the nucleation and propagation of the transversal and longitudinal cracks, which stem from flexural and torsional fatigue. One probable explanation for the tendency of the shaping instruments S1 and S2 to exhibit lower torsional resistance in LP than in NLP is that while applying lateral pressure, these instruments are flexed in the coronal, middle, and apical thirds of the root canal, thus accentuating their structural fatigue and reduction in torsional resistance.

In a similar manner, the results from the SEM analysis indicate a predominance of transversal cracks caused by flexural stress in the instruments submitted to lateral pressure motion, whereas the instruments used without lateral pressure motion were characterized by a predominance of longitudinal cracks stemming from torsional cyclic stresses.

On the basis of these results, it can be concluded that the use of lateral pressure motion with S1 and S2 PTU instruments during the shaping of curved root canals tended to produce smaller decreases in the torsional resistance of the finishing instruments F1 and F2.

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The authors deny any conflicts of interest related to this study.

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