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

Resistência à fadiga de instrumentos rotatórios ProTaper Universal após o uso com e sem movimento de pressão lateral

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ABSTRACT

Aim: 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), types 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 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 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 the S1 and S2 instruments in LP and for the F1 and F2 instruments in NLP was observed. **Conclusion:** The use of lateral pressure motion with the S1 and S2 PTU instruments during the shaping of curved root canals tended to decrease the consumption of the fatigue life of F1 and F2 instruments.

Uniterms: Endodontics. Root canal therapy. Dental instruments.

INTRODUCTION

During root canal shaping, rotary NiTi instruments simultaneously undergo flexural and torsional cyclic loads, and can fail by torsional overload or flexural and torsional fatigue[1-3]. Flexural fatigue is caused by the continuous rotation of an instrument in a curved canal space, wherein the opposing sides of the instrument are subjected to alternating cycles of tensile and compressive stress. The magnitude of the tensile stress imposed on the flexed area of the instrument depends on the canal's curvature radius and the instrument's diameter[4-6]. The smaller the curvature radius and the larger the diameter, the greater the maximum tensile strain amplitude induced upon the instrument's surface[1,6]. Previous works showed that clinical use not only decreased the torsional resistance[5], but also influenced the deterioration of flexural fatigue resistance in NiTi rotary instruments[7-10].

Cyclic torsional loading occurs each time the continually rotating NiTi instrument meets resistance, with the torsional load dependent on dentin hardness and canal diameter. In addition, it has been observed that torsional fatigue can play an important role in the failure of rotary endodontic instruments, decreasing their resistance to flexural fatigue[1].

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The ProTaper Universal (PTU) 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[3,6,11,12]. In a comparative analysis of fatigue resistence between ProTaper Universal (PTU; Dentsply Tulsa Dental, Tulsa, OK) and ProTaper Next (PTN, Dentsply Tulsa Dental, Tulsa, OK) instruments at different points of curvature, PTU S1 was significantly the most resistant instrument at 5 mm from the tip while PTN files were significantly more fatigue resistant at the other tested levels[13]. Contrary to the majority of rotary NiTi instruments, which are usually employed with a slight in-and-out movement until the working length is reached, PTU instruments should be used like a "brush", that is, with lateral pressure motion[3]. This would selectively remove interferences and create lateral spaces that facilitate larger instruments to safely and progressively move deeper into the canals[3].

However, some reports regarding lateral pressure motion have cast doubt on the effectiveness of this technique in removing dentin at the coronal level[14], as well as its influence on the instrument's fatigue life[15]. In addition, Plotino et al.[14], found no difference in the amount of dentin removed by ProTaper and Mtwo instruments used both with and without lateral pressure, while Mtwo instruments of larger sizes had their lifespans reduced when used with lateral brushing movement[15].

In a recent study, the use of lateral pressure motion with the 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 than when the shaping instruments were used without this type of motion[16]. 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 the fatigue resistance of these instruments, formulating a null hypothesis that lateral pressure motion has no influence on the instrument's fatigue life.

METHODS

Study groups

Thirty sets of PTU instruments (Dentsply-Maillefer, Ballaigues, Switzerland), types S1, S2, F1, and F2, totaling 120 files, were analyzed and divided into three groups:

(i) Control Group (CG), with 10 sets of new instruments, which were fatigue tested until rupture to determine their fatigue resistance;

(ii) Lateral Pressure (LP), with 10 sets of instruments, each set used clinically in five mandibular and maxillary molars (15 to 20 canals), totalling 50 molars. The shaping instruments were employed with lateral pressure motion;

(iii) No-Lateral Pressure (NLP), with 10 sets of instruments, each set used clinically in five mandibular and maxillary molars (15 to 20 canals), totalling 50 molars. The shaping instruments were employed without lateral pressure motion.

The sample size was based on a previous study[16], and the teeth were randomly selected so that each experimental group possessed the same number of upper and lower molars with aproximatelly the same number of root canals. Instruments were employed without pre-evaluating the canal geometry, which was posteriorly analyzed. The instruments of the experimental groups were subsequently tested for fatigue until fracture. The SX and F3 instruments used in the clinical procedures were not included in the study, as these instruments are used only in the straight portions of the canals (SX) or in the preparation of straight canals (F3).

Clinical trials

Both direct and angled radiographs were obtained to determine the canal radius of curvature, as defined by Pruett et al.[6]. The measurements were performed by projecting the radiographic images through a profile projector (Mitutoyo, Tokyo, Japan) at 10x magnification.

Root canals were explored with sizes 10 and 15 stainless steel K-files (Dentsply-Maillefer, Ballaigues, Switzerland) until reaching the canal patency length to create a smooth and reproducible glide path into this secured length of the canal. The cleaning and shaping of the canals were completed in accordance with a crown-down technique[3,10]. The shaping instruments in the LP group were used with lateral pressure motion to laterally and selectively cut dentin on the outstroke, while in the NLP group, no lateral pressure motion was employed. In both experimental groups, the preparation was finished, using F1 and F2 finishing instruments in a 'non brushing' manner until achieving the working length, which was 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. A rotational speed of 300 rpm was 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 sterilized in a steam autoclave. The used instruments were observed through optical microscopy, which contained a micrometer stage for measurements (Mitutoyo TM 500, Tokyo, Japan) in an attempt to detect the presence of distortion, unwinding defects or macroscopic deformation. Before their remaining fatigue life was tested, three sets of instruments in each group (CG, LP, and NLP) were randomly selected and examined by scanning electron microscopy (SEM) (Jeol JSM 6360, Tokyo, Japan).

Mechanical test – Fatigue

Fatigue tests were carried out on a test device (Figure 1) with an artificial canal made of quenched tool steel. This canal consisted of an arch with a curvature of 45 degrees, a radius of 5 mm, and a guide cylinder of 10 mm in diameter, which was also made of quenched tool steel. The chosen artificial canal geometry placed the area of the maximum canal curvature at about 3 mm from the instrument tip. The instruments were allowed to rotate freely inside the artificial canal, and the number of cycles to failure (NCF) was obtained by multiplying the constant rotation speed (300 rpm) by the test time registered with a digital chronometer.

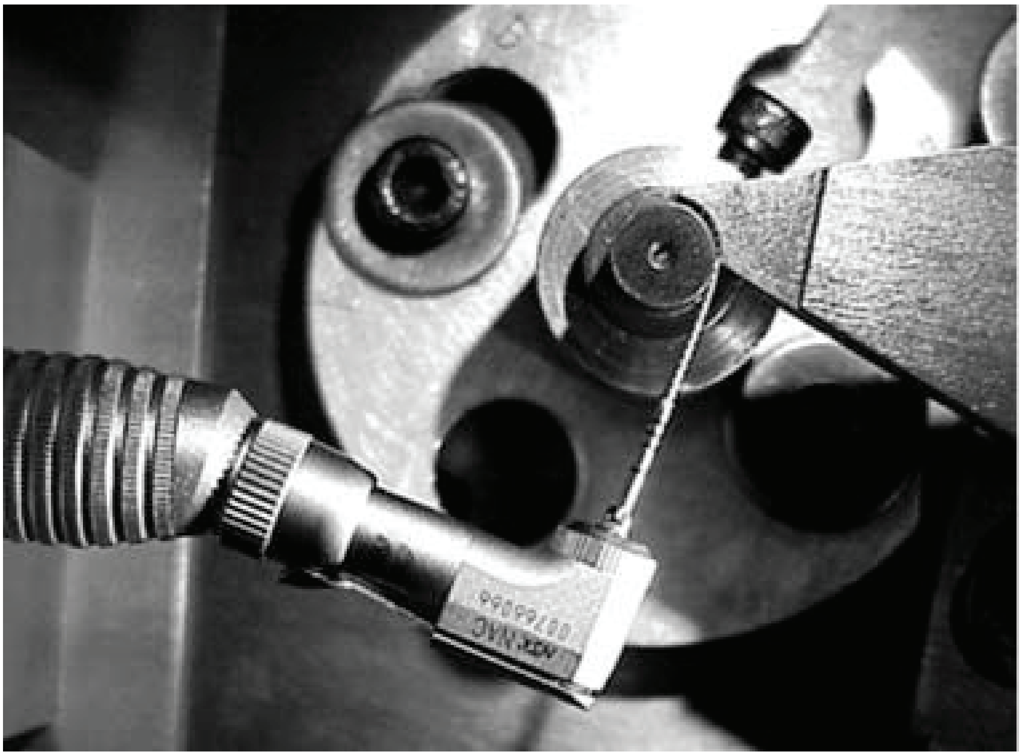

Figure 1 - Artificial canal with an instrument attached

Data analysis

Data from the fatigue tests, which showed a normal distribution, were subjected to one-way analysis of variance (ANOVA). The nonparametric Mann-Whitney test was employed to compare the radius of curvature of the root canals, which had an asymmetric distribution. Significance was determined at the 95% confidence level for both types of tests.

RESULTS

Curvature radius

The mean values of the curvature radius of the root canals were 4.3 mm for the instrumented teeth of the LP Group and 3.8 mm for the NLP Group. Statistical analysis using the Mann-Whitney test showed no significant difference ($p = 0.169$) for this parameter between the two groups.

Fatigue tests

The results of the fatigue tests are summarized in figure 2a. The NCF values showed a tendency to decrease with clinical use for all instruments that were analyzed. Comparative statistical analyses between the remaining NCF values and those of the new instruments (CG) showed statistically significant differences ($p < 0.05$) amongst the same-sized instruments used in LP and NLP. However, no statistically significant differences in NCF values were found between the same instruments used with (LP) and without lateral pressure motion (NLP). The fatigue results can be better viewed in terms of the "consumed fatigue life" expressed by the ratio between the average values of NCF for each type of instrument after clinical use and the corresponding average value for the unused instruments. The variations in this parameter are shown in figure 2b, which reveals the tendency of higher consumption for the S1 and S2 instruments in LP and for the F1 and F2 instruments in NLP.

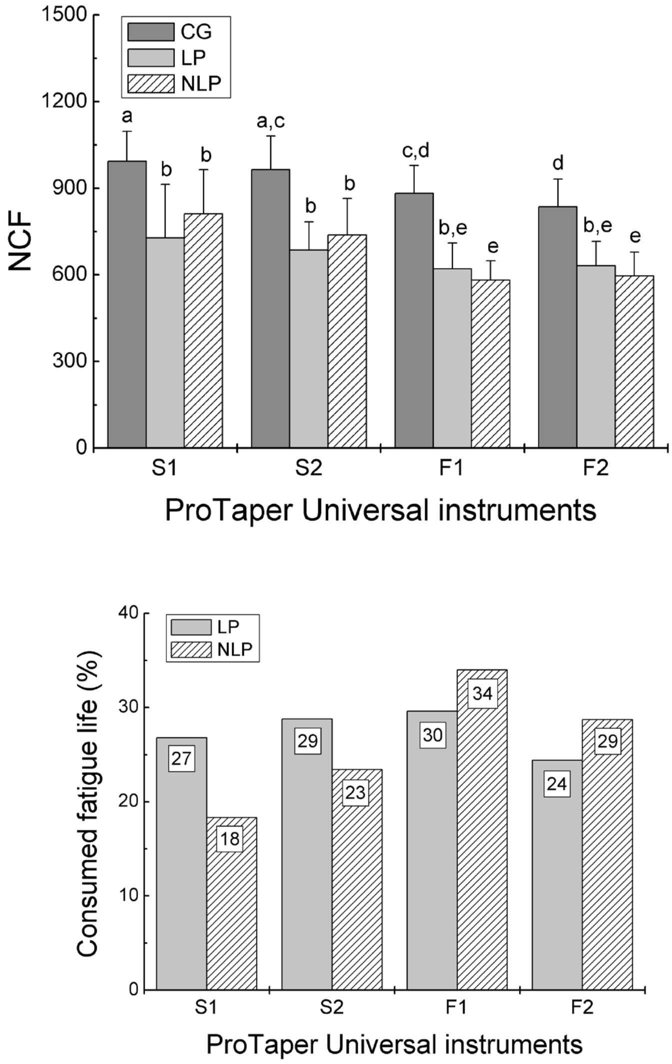

Figure 2 - (a) Mean values of the number of cycles to failure (NCF) in the fatigue-tested new and used instruments. Differently labeled columns represent statistically significant differences (p = 0.05); (b) Mean values of consumed fatigue life in the fatigue-tested used instruments.

SEM images

Although none of the instruments were permanently fractured or deformed during the root canal shaping, microcracks were observed by SEM in all the clinically used instruments examined in this study. Subjectively, there seemed to be a higher frequency of transverse cracks in the instruments when submitted to lateral pressure motion (Figure 3a), whereas the instruments that did not undergo lateral pressure motion were characterized by a predominance of longitudinal cracks (Figure 3b). The fracture surfaces of fatigue-tested instruments observed by SEM were all similar and exhibited the typical features of fatigue failure: a region of crack nucleation and propagation in the periphery and a large central area associated with the final ductile failure.

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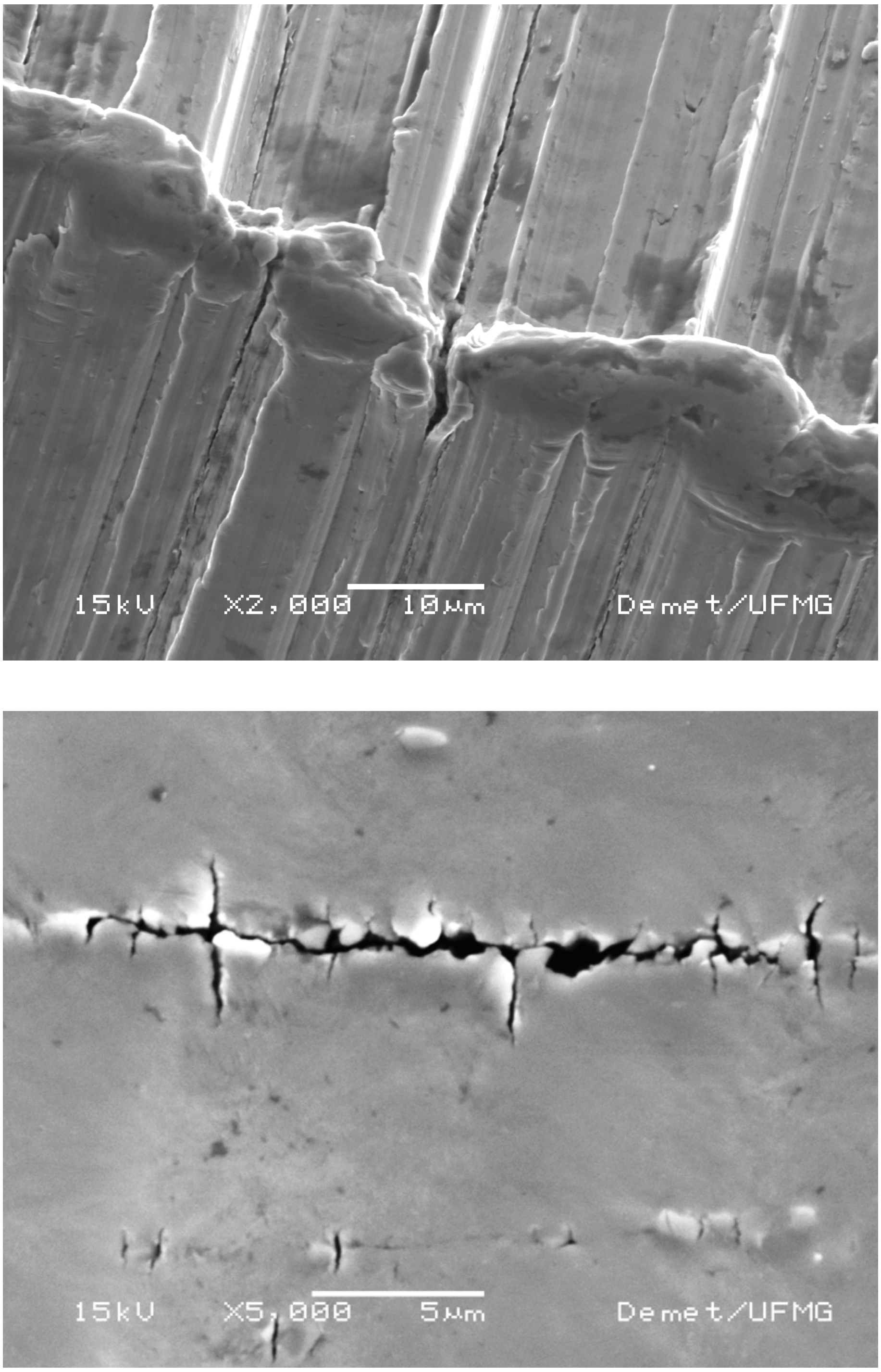

Figure 3 - Scanning electron microscopy images of (a) the surface of a F1 PTU instruments used for the shaping of 5 molars in the group with lateral pressure motion showing transversal cracks at 2.8 mm from the tip; (b) the surface of a F1 ProTaper Universal instrument (PTU) used for the shaping of 5 molars in the group without lateral pressure motion, showing a longitudinal crack at the same tip level.

DISCUSSION

Prior studies on NiTi rotary instruments have confirmed that the diameter of the instrument and the geometry of the root canal determine the fatigue life of the instrument 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 and the diameter of the instrument at its maximum bending point[1,5,6,16]. Although a clinical investigation has been carried out, and there are anatomical differences among the analyzed molars, curvature radius values did not differ between the groups. 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.

The F1 instrument, as compared to the other instruments, presented a tendency to show the greatest consumption of fatigue life, of about 30% and 34% in the LP and NLP groups, respectively. This finding may well have been due to the larger difference in diameter between 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 dilatation of the root canals. This cyclical torsional stress of higher amplitude tends to generate longitudinal cracks that reduce the resistance of the NiTi instruments to flexural fatigue[4]. A similar result was found by Ounsi et al.[8], who justified such a tendency as a result of the abrupt changes in the dimensions of the S2 and F1 instruments.

Overall, the reduction observed in the present study in the remaining fatigue life of the clinically used instruments (Figure 2b) is a common characteristic of NiTi rotary instruments, as has already been reported by many authors regarding a variety of instrument types[1,7,8,10]. Specifically in the case of PTU instruments, the results presented herein show a statistically significant reduction in fatigue resistance with clinical use for all of the analyzed instruments.

Regarding the consequences of the use of lateral pressure movement, our results point toward a reduction in the consumption of fatigue life for the F1 and F2 finishing instruments and an increase for the S1 and S2 shaping instruments. This study complements previous findings on the influence of lateral pressure motion on the torsional resistance of the PTU instruments[16], in which smaller reductions in the torsional resistance of the F1 and F2 instruments were observed due to the premature and accentuated dilatation of the root canal with this type of preparation technique. Similar to what was found in the present work, the S1 and S2 instruments were flexed in the coronal, medium, and apical thirds of the root canal, resulting in a reduction in their torsional resistance and a consumption of their fatigue life. This is in agreement with the observed predominance of transverse cracks generated by flexural stress in the instruments submitted to lateral pressure motion, as well as with the predominance of longitudinal cracks in those instruments not submitted to lateral pressure[16,17].

Another feature, which may have contributed to fracture did not occur, was the use of a high torque value (5 N.cm), preventing the instruments auto-reverse motion inside the canals. As observed by Berutti et al.[2], during shaping of acrylic blocks, a larger number of canals could be shaped before instrument fracture when high instead of low torque settings were used.

CONCLUSION

In summary, the use of lateral pressure motion with S1 and S2 PTU instruments during the shaping of curved root canals tended to increase the consumption of their fatigue life and to generate predominantly transverse cracks on them. On the other hand, the F1 and F2 PTU instruments that have been used after lateral pressure motion and that have been applied with S1 and S2 instruments showed a tendency to present a lower consumption of fatigue life than did the same instruments when no lateral pressure motion was used. The clinical implication of these findings is that when the S1 and S2 shaping instruments are used with lateral pressure, there will be an increase in the canal's curvature radius allowing F1 and F2 finishing instruments to work with less strain. Thus, these instruments present a higher fatigue life and greater resistance to fatigue fracturing during clinical use. Therefore, the null hypothesis that the lateral pressure motion would have no effect on the fatigue resistance of the instruments was rejected.

RESUMO

Objetivo: Avaliar a resistência à fadiga de instrumentos rotatórios ProTaper Universal após múltiplos usos clínicos com e sem movimento de pressão lateral. **Material e Métodos**: Trinta conjuntos de instrumentos ProTaper Universal (PTU) (Dentsply-Maillefer, Ballaigues, Suíça), calibres S1, S2, F1 e F2, em um total de 120 instrumentos, foram analisados e divididos em três grupos: Grupo com Pressão Lateral (PL), com 10 conjuntos de instrumentos, cada conjunto usado clinicamente em cinco molares inferiores e superiores (15 a 20 canais) utilizando os instrumentos de formatação com movimento de pressão lateral; e Grupo Sem Pressão Lateral (SPL), com 10 conjuntos de instrumentos, cada conjunto usado clinicamente em cinco molares inferiores e superiores (15 a 20 canais), utilizando os instrumentos de formatação sem movimento de pressão lateral. Os instrumentos dos grupos PL e SPL foram posteriormente testados em fadiga até a ruptura, juntamente com 10 conjuntos de instrumentos novos do Grupo Controle (GC). Os dados foram analisados por meio de análise de variância (α = 0,05). **Resultados**: Múltiplos usos clínicos causaram uma redução na vida em fadiga dos instrumentos analisados. Quando o efeito de se utilizar o movimento de pressão lateral com os instrumentos de formatação foi avaliado, houve uma tendência para o consumo da vida em fadiga ser maior para os instrumentos de S1 e S2 em PL e observou-se o mesmo para os instrumentos F1 e F2 no grupo SPL. **Conclusão**: O uso do movimento de pressão lateral com os instrumentos PTU S1 e S2 durante a formação de canais radiculares curvos tendeu a diminuir o consumo de vida em fadiga dos instrumentos F1 e F2.

Descritores: Endodontia. Tratamento do canal radicular. Instrumentos odontológicos.

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REFERENCES

1. Bahia MGA, Melo MCC, Buono VTL. Influence of cyclic torsional loading on the fatigue resistance of K3 instruments. Int. Endod. J. 2008; 41:883–91.
2. Berutti E, Negro AR, Lendini M, Pasqualini D. Influence of manual preflaring and torque on the failure rate of ProTaper rotary instruments. J. Endod. 2004; 30:228-30.
3. Ruddle CJ. The ProTaper technique. Endod. Topics. 2005; 10:187–90.
4. Bahia MGA, Buono VTL. Decrease in the fatigue resistance of nickel-titanium rotary instruments after clinical use in curved root canals. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 2005; 100:249–55.
5. Haïkel Y, Serfaty R, Bateman G, Senger B, Allemann C. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. J. Endod. 1999; 25:434–40.
6. Pruett JP, Clement DJ, Carnes DLJ. Cyclic fatigue testing of nickel-titanium endodontic instruments. J. Endod. 1997; 23:77–85.
7. Fife D, Gambarini G, Britto LR. Cyclic fatigue testing of ProTaper NiTi rotary instruments after clinical use. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 2004; 97:251–6.
8. Ounsi HF, Salameh Z, Al-Shalan T, Ferrari M, Grandini S, Pashley DH, Tay FR. Effect of clinical use on the cyclic fatigue resistance of ProTaper nickel-titanium rotary instruments. J. Endod. 2007; 33:737–41.
9. Ullmann CJ, Peters OA. Effect of cyclic fatigue on static fracture loads in ProTaper nickel–titanium rotary instruments. J. Endod. 2005; 31:183–6.
10. Vieira EP, França EC, Martins RC, Buono VTL, Bahia MGA. Influence of multiple clinical use on fatigue resistance of ProTaper rotary nickel-titanium instruments. Int. Endod. J. 2008; 41:163–72.
11. Aguiar CM, Mendes DA, Câmara AC, Figueiredo JAP. Assessment of canal walls after biomechanical preparation of root canals instrumented with ProTaper UniversalTM rotary system. J. Appl. Oral Sci. 2009; 17:590-5.
12. Câmara AS, Martins RC, Viana ACD, Leonardo RT, Buono VTL, Bahia MGA. Flexibility and torsional strength of ProTaper and ProTaper Universal rotary instruments assessed by mechanical tests. J. Endod. 2009; 35:113–6.
13. Pérez-Higueras JJ, Arias A, Macorra JC, Peters OA. Differences in cyclic fatigue resistance between ProTaper Next and ProTaper Universal instruments at different levels. J. Endod. 2014; 40:1477-81.
14. Plotino G, Grande NM, Falanga A, Di Giuseppe IL, Lamorgese V, Somma F. Dentine removal in the coronal portion of root canals following two preparation techniques. Int. Endod. J. 2007a; 40:852–8.
15. Plotino G, Grande NM, Sorci E, Malagnino VA, Somma F. Influence of a brushing working motion on the fatigue life of NiTi rotary instruments. Int. Endod. J. 2007b; 40:45–51.
16. Vieira EP, Buono VTL, Bahia MGA. Effect of lateral pressure motion on the torsional behavior of rotary ProTaper Universal instruments. J. Endod. 2011; 37:1124-7.
17. Vieira EP, Nakagawa RKL, Buono VTL, Bahia MGA. Torsional behaviour of rotary NiTi ProTaper Universal instruments after multiple clinical uses. Int. Endod. J. 2009; 42:947–53.