Abstract: This in vitro study assessed morphological changes and efficiency of reciprocating files after multiple uses. Sixty standardized Endo Training Blocks and 10 ReciprocR25 files were selected (six blocks for each file). Each file was its own control (before use vs. after each instrumentation). The instruments were used according to the manufacturer’s instructions, and scanning electron microscopy was used to observe fatigue cracks, metal strips/metal flash, pitting, fretting, debris, disruption of the cutting edge, and plastic deformations after each instrumentation. The presence of seven wear variables was scored semiquantitatively by viewing micrographs collected before and after use. The prepared areas in resin blocks were calculated and compared by using AutoCAD software. The control group had significantly lower values for all wear variables except fretting and plastic deformation. The presence of fatigue cracks and metal strips/metal flash significantly differed between unused instruments and instruments used four or five times, in all observed sections. The area of instrumented Endo Training Blocks significantly differed in relation to the number of instrument uses. The Reciproc files wore progressively, and repeated use affected their shaping efficiency in simulated canals.

Keywords: endodontics; microscopy; reciprocating files; shaping efficiency; surface wear.

Introduction

Root canal shaping is essential for successful endodontic therapy (1), as it determines the effectiveness of subsequent procedures, namely, mechanical debridement, rheological characteristics of irrigation delivery, and three-dimensional obturation (2). The introduction of single-file instrumentation techniques reduced working time and contamination risk in endodontic therapy. Most canal anatomies can be shaped with only one Reciproc instrument, without a glide path or initial instrumentation, and do not require the use of multiple hand and rotary instruments (3). De-Deus et al. (4) reported that Reciproc instruments could attain working length in most canals in which a size 10 K-file had previously been unable to penetrate. They attributed the effectiveness of the no-glide-path concept to the large rotating angles of reciprocating movement and the flexibility and cutting ability of the Reciproc instrument.

Reciprocating movement and use of a special thermomechanically processed NiTi alloy (M-Wire) increase the flexibility and fatigue resistance of files (5–8). However, the process of manufacturing NiTi instruments can create stress areas associated with crack initiation and propagation, thereby accelerating fatigue and leading to material failure (9,10). As a rule, more-flexible NiTi files are less resistant to torsional loading (11,12). Unlike stainless
steel files, NiTi instruments often fracture with no visible defects; thus, macroscopic inspection is of limited value (13). Canal anatomy and the angle and radius of curvature, as well as instrument size and taper, are important in resistance to wear and deterioration (14).

Root canal preparation can damage NiTi instruments, thus resulting in wear and deformation (15) and a consequent decrease in cutting efficiency (16). The manufacturer of the Reciproc instrument recommends its use in a maximum of four canals. However, studies (17,18) suggest that Reciproc files can be used in five, or even nine, root canals without causing anatomical deformities. Moreover, because some clinicians use these instruments in more than four canals, we elected to evaluate this behavior in vitro.

The surface characteristics and cutting efficiency of new and used M-wire NiTi instruments have been evaluated, but the findings are controversial. A 2014 study reported greater changes in Reciproc surfaces than in WaveOne files after use, which suggests that creating a glide path for the Reciproc instrument could reduce file wear (19). A more recent study reported less wear in Reciproc files than in other reciprocating instruments after multiple uses (20). However, both these studies evaluated Reciproc behavior after no more than three uses.

We used scanning electron microscopy (SEM) to assess morphological changes to the surface of ReciprocR25 (Dentsply-VDW, München, Germany) files after one to six uses and examined variations in shaping efficiency by comparing the prepared area in resin blocks after each instrumentation. The null hypothesis tested was that there would be no statistically significant differences in the surface topography or cutting efficiency of ReciprocR25 (Dentsply-VDW) files in vitro after multiple uses.

**Materials and Methods**

Sixty standardized Endo Training Blocks (1×1×3 cm; taper 0.02; canal length 16 mm) in resin (Dentsply-Maillefer, Ballaigues, Switzerland) were used in this study. Ten ReciprocR25 (Dentsply-VDW) files were used to prepare the artificial canals. Each file was its own control (before use vs. after each instrumentation), so the 10 unused instruments were the control group. The blocks were randomly divided into 10 groups (n = 6), and the 10 files were numbered R1 to R10, and the six Endo Blocks for each file were numbered C1 to C6 (e.g., R1C1, R1C2…R1C6; R2C1, R2C2…R2C6, etc.). All resin blocks were prepared by the same operator using the file to working length. The instruments were utilized
according to the instructions for use in a reciprocating motion with a VDW Silver endomotor (VDW, München, Germany) with the Reciproc All program setting. Irrigation was performed between instrumentations by using 2.5mL of NaOCl 5.25% for 20 s, which was delivered with a 0.3-mm-diameter NaviTip needle (Ultradent Products Inc., South Jordan, UT, USA). The same irrigation protocol was performed after the final instrumentation.

After each use, the instrument was cleaned in an ultrasonic sonicator bath (Athena Technology, Maharashtra, India) for 5 min (to remove surface residue), dried, and observed under SEM. Instruments were marked on their coronal section with a permanent marker to ensure they were always photographed in the same position. The instruments were not autoclaved. After removing the packaging, SEM was used to identify any manufacturing defects in the files, after which photomicrographs were obtained for all instruments after each use, to compare their characteristics with those of new instruments. Nine SEM photomicrographs were taken at 120×, 750×, and 1,500× magnification for each sample. All three magnifications were used for each third, i.e., three photomicrographs each for the coronal, middle, and apical third of each specimen. Thus, there were nine images for each new instrument and nine images per file use (n = 63 per specimen). All photomicrographs were obtained by the same operator, who used recognizable topographical landmarks to photograph the same areas of interest for all instruments. This procedure was done identically until six artificial canals had been prepared with each instrument, while separate instrument photomicrographs of the fracture surface were obtained at different magnifications and angles (Fig. 1).

The photomicrographs were evaluated by an external operator blinded to the purpose of the experiment, according to following modified criteria (21): disruption of the cutting edge, pitting, fretting, metal strips/metal flash, fatigue cracks/microfractures, plastic deformation, and smear debris. All SEM images were semiquantitatively evaluated (Fig. 2) for the presence/absence of defects by giving a score of 0 through 3, as follows:

0 (none): no defect;
1 (minor): defect less than 5 µm or covering less than 25% of surface;
2 (moderate): defect of 5-10 µm or covering 25-50% of surface;
3 (severe): defect greater than 10 µm or covering more than 50% of surface.

Defect size was measured by using reference segments present on the photomicrographs and measurement
options provided by the SEM software (JSM JEOL 6060LV, Jeol, Tokyo, Japan).

After the final irrigation, each canal lumen was dried by light air-blowing and paper points. All samples were marked on their lower section with a permanent marker, while ensuring that the code was clear and visible but did not cover the canal portion.

As contrast medium, black ink (Pelikan, Schindellegi, Germany) was injected into the simulated root canal space. Photographs of the resin blocks were obtained in the mesiodistal (MD) and buccolingual (BL) directions by using a copy stand and a digital camera (Nikon D60 with Medical Nikkor, Nikon Corp, Tokyo, Japan) mounted on a customized support at a standard distance from the samples, to obtain repeatable and overlapping images. Precise positioning of the blocks was ensured by using a silicone mold (22).

The 100 digitized images were processed with AutoCAD2014 (Autodesk Inc, San Rafael, CA, USA) and analyzed by an operator blinded to the purpose of the study. The images were first imported into the software scaled at their actual size, by using a known reference. All variables of the artificial canals were drawn by using a bidimensional polyline model, after which areas (in mm²) were automatically calculated (Fig. 3).

**Statistical analysis**

Normality of distribution was verified with the Kolmogorov-Smirnov test. Categorical variables are described as medians and interquartile range (IQR), and continuous variables are described as means and standard deviations (sd). The nonparametric Kruskal-Wallis test or one-way ANOVA was used to evaluate differences between more than two independent groups. When a significant difference was identified, the Dunn test for multiple comparisons or Bonferroni correction for multiple comparisons was used. Calculation of P-values for nonparametric tests was performed by using the exact method. All analyses were performed with SPSS software (version 22), and the level of significance set at 0.05.

**Results**

Five of 10 files separated during the final instrumentation in C6. To standardize the analysis, data related to the sixth instrumentation were excluded from the analysis. The Kruskal-Wallis nonparametric test was used to compare group medians, and the Dunn test was used for multiple comparisons with the control group. The test groups (number of uses) did not significantly differ from the control group (unused instruments) in relation to plastic deformation or fretting. The medians for all other variables were significantly lower for the control group than for the test groups.

In all sections analyzed, values for fatigue cracks/microfractures (Table 1) significantly differed between the controls and instruments used four or five times. In the middle section, controls and instruments used two or three times significantly differed. Values for metal strips/metal flash (Table 2) significantly differed between the controls and instruments used at least four times. In the middle section, controls and instruments used three times significantly differed. Values for pitting (Table 3) and disruption of the cutting edge (Table 4) significantly differed between the controls and instruments used five times in the middle third and apical/middle thirds, respectively. Although the coronal third of specimens had the highest debris values (Table 5), differences between controls and instruments used four or five times were significant only for the middle third.

The results of cutting efficiency analysis showed significant differences in instrumented areas between instruments used to treat one or two canals and those used to treat five canals, in all sections observed (Table 6, Fig. 4).

**Discussion**

To harmonize present and previous study methods, simulated canals were used in this experiment (23,24). Although the effects of preparation on instrument wear should ideally be studied in human teeth, it can be difficult to obtain a sufficient number of root canals of compa-
Table 1 *Fatigue cracks* score, by group (median,IQR)

|          | Control  | 1 canal | 2 canals | 3 canals | 4 canals | 5 canals | *P      |
|----------|----------|---------|----------|----------|----------|----------|---------|
|          | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) |         |
| Apical   | 0.00<sup>a</sup> | 0.00    | 0.00      | 0.00      | 1.00<sup>b</sup> | 1.00<sup>b</sup> | <0.001  |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-1.25) | (0.75-2.00) |         |
| Middle   | 0.00<sup>a,b</sup> | 1.00    | 2.00<sup>c</sup> | 2.00<sup>c</sup> | 3.00<sup>c</sup> | 3.00<sup>c</sup> | <0.001  |
|          | (0.00-0.00) | (0.75-1.00) | (1.00-2.00) | (1.75-2.25) | (2.00-3.00) | (2.75-3.00) |         |
| Coronal  | 0.00<sup>a</sup> | 0.00    | 0.00      | 1.00      | 1.00<sup>b</sup> | 1.00<sup>b</sup> | <0.001  |
|          | (0.00-0.00) | (0.00-0.00-25) | (0.00-1.00) | (0.75-1.00) | (1.00-2.00) |         |         |

<sup>a</sup><sup>-d</sup><sup>P</sup> <0.05, *Kruskal-Wallis test
Superscript a,b,c, and d indicate a significant difference versus control.

Table 2 *Metal strips/Metal flash* score, by group (median,IQR)

|          | Control  | 1 canal | 2 canals | 3 canals | 4 canals | 5 canals | *P      |
|----------|----------|---------|----------|----------|----------|----------|---------|
|          | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) |         |
| Apical   | 0.00<sup>a</sup> | 0.00    | 0.00      | 0.50      | 1.00<sup>c</sup> | 1.00<sup>c</sup> | <0.001  |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-1.00) | (0.00-1.00) | (0.75-2.00) | (1.00-2.00) |         |
| Middle   | 0.00<sup>a,b</sup> | 0.00    | 0.00      | 1.00<sup>c</sup> | 1.00<sup>c</sup> | 2.00<sup>c</sup> | 0.63    |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-1.00) | (1.00-1.00) | (1.00-2.00) | (1.00-2.00) |         |
| Coronal  | 0.00<sup>a</sup> | 0.00    | 0.00      | 0.00      | 1.00<sup>c</sup> | 0.50      | 0.63    |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (1.00-1.00) | (0.00-1.00) |         |

<sup>a</sup><sup>-c</sup><sup>P</sup> <0.05, Dunn test; *Kruskal-Wallis test
Superscript a, b, and c indicate statistically different values in the row (number of uses).

Table 3 *Pitting* score, by group (median,IQR)

|          | Control  | 1 canal | 2 canals | 3 canals | 4 canals | 5 canals | *P      |
|----------|----------|---------|----------|----------|----------|----------|---------|
|          | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) |         |
| Apical   | 0.00      | 0.00    | 0.00      | 0.50      | 1.00      | 0.01     |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-1.00) | (0.00-2.00) |         |         |
| Middle   | 0.00<sup>c</sup> | 0.00    | 0.50      | 0.50      | 1.00<sup>c</sup> | 1.50<sup>c</sup> | 0.006   |
|          | (0.00-0.00) | (0.00-0.25) | (0.00-1.00) | (0.00-1.25) | (0.00-2.00) | (0.00-2.25) |         |
| Coronal  | 0.00      | 0.00    | 0.00      | 0.00      | 0.00      | 1.00     |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) |         |         |

<sup>*P</sup> <0.05, *Kruskal-Wallis test
Superscript a indicates statistically different values in the row (number of uses).

Table 4 *Disruption of the cutting edge* score, by group (median,IQR)

|          | Control  | 1 canal | 2 canals | 3 canals | 4 canals | 5 canals | *P      |
|----------|----------|---------|----------|----------|----------|----------|---------|
|          | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) | (n = 10) |         |
| Apical   | 0.00<sup>c</sup> | 0.00    | 0.00      | 0.00      | 1.00<sup>c</sup> | <0.001   |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-2.00) |         |         |
| Middle   | 0.00<sup>c</sup> | 0.00    | 0.00      | 0.00      | 1.00<sup>c</sup> | <0.001   |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (1.00-1.25) |         |         |
| Coronal  | 0.00<sup>c</sup> | 0.00    | 0.00      | 0.00      | 0.00      | 1.00     |
|          | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) | (0.00-0.00) |         |         |

<sup>*P</sup> <0.05, *Kruskal-Wallis test
Superscript a indicates statistically different values in the row (number of uses).

Clear standards have not been established for testing cutting effectiveness or the sharpness of endodontic instruments (25). The use of special plastic samples guarantees a reproducible shape, size, and curvature for investigation. Clear as an ideal experimental model for qualitative and quantitative analysis of root canal preparation (27-29).

Analysis of fatigue cracks and metal strips/metal flash in the apical third showed that values were significantly lower in the control group than after four or five uses, as was the case for the coronal third. Additionally, the values for disruption of the cutting edge were significantly lower in the control group than after five uses.
The highest debris values were recorded for the coronal third. Debris were probably neither metallic nor due to shaping but instead were likely caused by repetitive positioning of the files on the SEM stub, which results in limited contact between the stub and coronal area of instruments and thus contamination. Differences in debris values for the controls and instruments used four or five times were significant only for the middle third. Although reduced cutting efficiency was observed, increased wear and tear in this section of the instruments resulted in greater debris retention.

In the middle section of instruments, signs of wear—namely, fatigue cracks and metal strips/metal flash—were significant only after the second and third instrumentations, respectively. In this section, wear increased in relation to number of uses. Differences were also significant for debris after four uses and for pitting and disruption of the cutting edge after five uses. The only variables with significant differences for all sections observed were fatigue cracks and metal strips/metal flash. When those differences were highlighted, the absolute minimum value was recorded for the middle third of instruments used two times; this value increased to four uses for the apical and coronal sections. The most frequent defects were associated with wear of the middle third, which was the section that most suffered solicitations.

Zelada et al. (30) reported that root canal curvature was positively associated with breakage risk in endodontic rotary instruments. In this study, 50% of samples separated, all at the sixth use during the final instrumentation. All samples separated near the point of maximum flexure in the curved canal. The fine crack lines observed in the middle third of Reciproc instruments immediately after the second use propagated in subsequent uses and caused fracture. Sattapan et al. (16) observed that files that broke because of excessive torsion showed signs of wear and tear above the point of fracture, whereas files that broke because of flexure did not exhibit defects associated with breakage. The fact that the broken files had deformations and that files broke at the point where flexure was greatest suggest that the present instruments fractured because of fatigue caused by flexural and torsional stress.

Previous studies using SEM analysis showed it was effective for evaluating surface wear of endodontic instruments (31-33). Immediately after removing the packaging, all files used in this study were analyzed under SEM for manufacturing defects. Debris was observed on about half the new instruments, and one exhibited pitting. Nevertheless, the new instruments had significantly lower values for all variables except fretting and plastic deformation. A 2008 study (34) examined the surface of endodontic instruments (ProFile, Protaper, Race, Hero, and K3 Endo) before use. No instrument was free of imperfections, which suggests that manufacturing and packaging of endodontic instruments are not ideal.

No instrument exhibited macroscopic defects, and no defect, except debris, was detected at the lowest magnification (120×). All microscopic defects were detectable at the higher magnifications (750×, 1,500×). The most frequently detected defect was fatigue cracks, and the value increased in relation to number of uses.

### Table 5 Debris score, by group (median, IQR)

| Area       | Control (n = 10) | 1 canal (n = 10) | 2 canals (n = 10) | 3 canals (n = 10) | 4 canals (n = 10) | 5 canals (n = 10) | *P  |
|------------|-----------------|-----------------|------------------|------------------|------------------|------------------|-----|
| Apical     | 0.50 (0.00-1.25)| 0.00 (0.00-0.25)| 0.00 (0.00-1.00) | 0.50 (0.00-1.25) | 0.00 (0.00-0.25) | 0.00 (0.00-2.25) | 0.59 |
| Middle     | 0.50 (0.00-0.25)| 0.00 (0.00-0.00) | 0.00 (0.00-0.10) | 0.50 (0.00-0.25) | 1.00 (0.75-1.00) | 0.00 (1.00-1.25) | 0.02 |
| Coronal    | 1.00 (0.00-1.25)| 2.00 (1.00-3.00) | 2.00 (1.00-2.25) | 2.00 (1.00-2.25) | 2.00 (1.75-2.25) | 0.00 (1.00-3.00) | 0.06 |

* *P < 0.05, *Kruskal-Wallis test

Superscript a indicates statistically different values in the row (number of uses).

### Table 6 Area, by group (mean, sd)

| Area       | 1 canal (n = 10) | 2 canals (n = 10) | 3 canals (n = 10) | 4 canals (n = 10) | 5 canals (n = 10) | *P  |
|------------|-----------------|-----------------|------------------|------------------|------------------|-----|
| Frontal    | 10.77a (0.50)   | 10.60a (0.79)   | 10.37 (0.81)     | 10.14 (0.56)     | 9.51a (0.50)     | 0.001 |
| Lateral    | 11.77a (0.69)   | 11.41a (0.94)   | 11.16 (0.91)     | 10.92 (0.81)     | 10.19a (0.72)    | 0.002 |

* *a,b P < 0.05, *ANOVA test

Superscript a and b indicate statistically different values in the row (number of uses).
the instruments did not undergo plastic deformation, SEM revealed changes to the cutting edge after five uses, namely, a slight flattening of the blade, in addition to small metal curls, depressions, and cracks. These findings show how friction forces generated by interaction of the file with root canal walls can damage this section of the instruments. These changes to the cutting edge could adversely affect the cutting efficiency of the files. Thus, the present null hypothesis was rejected.

Our results appear to suggest that, although the instruments shape the first and fifth canals differently, Reciproc files can be used safely for a maximum of five canals. In practice, however, root canals differ in size, taper, length, radius, and angle of curvature. Moreover, the properties of plastic are not identical to those of dentin. The difference between statistical and clinical significance should be considered when evaluating our results (35). Although we cannot recommend a maximum number of uses for Reciproc instruments, decreased cutting efficiency clearly increases working time inside the canal and the risk of separation (36). Further in vitro studies of extracted teeth and in vivo studies are required.

In conclusion, the present results indicate that Reciproc files progressively deteriorate, primarily because of fatigue microcracks, especially in the section working in the canal curvature, and that the root canal shape obtained in simulated canals is affected by repeated use of these instruments.

Conflict of interest
The authors have no conflict of interest to declare.

References
1. Schilder H (1974) Cleaning and shaping the root canal. Dent Clin North Am 18, 269-296.
2. Peters OA (2004) Current challenges and concepts in the preparation of root canal systems: a review. J Endod 30, 559-567.
3. Bartols A, Robra BP, Walther W (2017) The ability of Reciproc instruments to reach the full working length without glide path preparation: a clinical retrospective study. Peer J, doi: 10.7717/peerj.3583.
4. De-Deus G, Arruda TE, Souza EM, Neves A, Magalhães K, Thuanner E et al. (2013) The ability of the Reciproc R25 instrument to reach the full root canal working length without a glide path. Int Endod J 46, 993-998.
5. Kim HC, Kwak SW, Cheung GS, Ko DH, Chung SM, Lee W (2012) Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in reciprocation motion: Reciproc versus WaveOne. J Endod 38, 541-544.
6. Pereira ES, Peixoto IF, Viana AC, Oliveira II, Gonzalez BM, Buono VT et al. (2012) Physical and mechanical properties of a thermomechanically treated NiTi wire used in the manufacture of rotary endodontic instruments. Int Endod J 45, 469-474.
7. Castelló-Escrivá R, Alegre-Domingo T, Faus-Matoses V, Román-Richon S, Faus-Llacer VJ (2012) In vitro comparison of cyclic fatigue resistance of ProTaper, WaveOne, and Twisted Files. J Endod 38, 1521-1524.
8. Pirani C, Ruggeri O, Cirulli PP, Pelliccioni GA, Gandolfi MG, Prati C (2014) Metallurgical analysis and fatigue resistance of WaveOne and ProTaper nickel-titanium instruments. Odontology 102, 211-216.
9. Alapati SB, Brantley WA, Iijima M, Clark WA, Kovarik L, Buie C (2009) Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. J Endod 35, 1589-1593.
10. Scezla P, Harry D, Silva LE, Barbosa IB, Scezla MZ (2015) A comparison of two reciprocating instruments using bending stress and cyclic fatigue tests. Braz Oral Res 29, 1-7.
11. Peters OA, Paque F (2010) Current developments in rotary root canal instrument technology and clinical use: a review. Quintessence Int 41, 479-488.
12. Shen Y, Zhou HM, Zheng YF, Peng B, Haapasalo M (2013) Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. J Endod 39, 163-172.
13. Luzi A, Forner L, Almenar A, Llena C (2010) Microstructure alterations of rotary files after multiple simulated operative procedures. Med Oral Patol Oral Cir Bucal 15, e658-662.
14. Schrader C, Peters OA (2003) Analysis of torque and force with differently tapered rotary endodontic instruments in vitro. J Endod 31, 120-123.
15. Yamazaki- Arasaki A, Cabrales R, Santos M, Kleine B, Prokopowitsch I (2012) Topography of four different endodontic rotary systems, before and after being used for the 12th time. Microsc Res Tech 75, 97-102.
16. Sattapan B, Nervo GJ, Palamara JE, Messer HH (2000) Defects in nickel-titanium endodontic rotary files after clinical usage. J Endod 26, 161-165.
17. Park SK, Kim YJ, Shon WJ, You SY, Moon YM, Kim HC (2014) Clinical efficiency and reusability of the reciprocating nickel-titanium instruments according to the root canal anatomy. Scanning 36, 246-251.
18. Caballero H, Rivera F, Salas H (2015) Scanning electron microscopy of superficial defects in twisted files and Reciproc nickel-titanium files after use in extracted molars. IntEndod J 48, 229-235.
19. Pirani C, Paolucci A, Ruggeri O, Bossù M, Polimeni A, Gatto MR et al. (2014) Wear and metallographic analysis of WaveOne and reciproc NiTi instruments before and after three uses in root canals. Scanning 36, 517-525.
20. Hanan ARA, Meireles DA, Sponchiado Jr EC, Hanan S, Kuga MC, Bonetti-Filho I (2015) Surface characteristics of reciprocating instruments before and after use: a SEM analysis. Braz Dent J 26, 121-127.
21. Eggert C, Peters O, Barbakow F (1999) Wear of nickel titanium lightspeed instruments evaluated by scanning electron microscopy. J Endod 25, 494-497.

22. Ounsi HF, Franciosi G, Al-Hezaimi K, Salameh Z, Tay FR, Ferrari M et al. (2011) Comparison of two techniques for assessing the shaping efficacy of repeatedly-used NiTi rotary instruments. J Endod 37, 847-850.

23. Troian CH, Só MV, Figueiredo JA, Oliveira EP (2006) Deformation and fracture of RaCe and K3 endodontic instruments according to the number of uses. Int Endod J 39, 616-625.

24. Yang GB, Zhou XD, Zhang H, Wu HK (2006) Shaping ability of progressive versus constant taper instruments in simulated root canals. Int Endod J 39, 791-799.

25. Bergmans L, van Cleynenbreugel J, Wevers M, Lambrechts P (2001) Mechanical root canal preparation with NiTi rotary instruments: rationale, performance and safety-status report for the American Journal of Dentistry. Am J Dent 14, 324-333.

26. Schäfer E, Oitzinger M (2008) Cutting efficiency of five different types of rotary nickel-titanium instruments. J Endod 34, 198-200.

27. Ponti TM, McDonald N, Kuttler S, Strassler HE, Dumsha TC (2002) Canal-centering ability of two rotary file systems. J Endod 28, 283-286.

28. Schafer E, Erler M, Dammaschke T (2006) Comparative study on the shaping ability and cleaning efficiency of rotary Mtwo instruments. Part 1. Shaping ability in simulated curved canals. Int Endod J 39, 196-202.

29. Nikhil V, Srivastava N (2009) A new pre-clinical “endodontic model”: boon to learners. Endodontontology 21, 58-61.

30. Zelada G, Varela P, Martin B, Bahillo JG, Magán F, Ahn S (2002) The effect of rotational speed and the curvature of root canals on the breakage of rotary endodontic instruments. J Endod 28, 540-542.

31. Allen MJ, Glickman GN, Griggs JA (2007) Comparative analysis of endodontic path finders. J Endod 33, 723-726.

32. Kottoor J, Velmurugan N, Gopikrishna V, Krithikadatta J (2013) Effects of multiple root canal usage on the surface topography and fracture of two different Ni-Ti rotary file systems. Indian J Dent Res 24, 42-47.

33. Arantes WB, da Silva CM, Lage-Marques JL, Habitate SM, da Rosa LC, de Medeiros JM (2014) SEM analysis of defects and wear on Ni-Ti rotary instruments. Scanning 36, 411-418.

34. Chianello G, Specian VL, Hardt LC, Raldi DP, Lage-Marques JL, Habitate SM (2008) Surface finishing of unused rotary endodontic instruments: a SEM study. Braz Dent J 19, 109-113.

35. Barnett ML, Mathisen A (1997) Tyranny of the p-value: the conflict between statistical significance and common sense (editorial). J Dent Res 76, 534-536.

36. Bahia MGA, Buono VTL (2005) 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 100, 249-255.