Apical Transportation, Centering Ability, and Cleaning Effectiveness of Reciprocating Single-file System Associated with Different Glide Path Techniques

Guilherme Moreira de Carvalho, DDS, MSc, Emílio Carlos Sponchiado Junior, DDS, MSc, PhD,* Angela Delfina Bittencourt Garrido, DDS, MSc, PhD,* Raphael Carlos Comelli Lia, DDS, MSc, PhD,† Lucas da Fonseca Roberti Garcia, DDS, MSc, PhD,‡ and André Augusto Franco Marques, DDS, MSc, PhD§*

Abstract

Introduction: The aim of this study was to evaluate the apical transportation, the centering ability, and the cleaning effectiveness of a reciprocating single-file system associated to different glide path techniques. **Methods:** The mesial root canals of 52 mandibular molars were randomly distributed into 4 groups (n = 13) according to the different glide path techniques used before biomechanical preparation with Reciproc System (RS): KF/RS (sizes 10 and 15 K-files), NGP/RS (no glide path, only reciprocating system), PF/RS (sizes 13, 16, and 19 PathFile instruments), and NP (no preparation). Cone-beam computed tomography analysis was performed before and after instrumentation for apical third images acquisition. Apical transportation and its direction were evaluated by using the formula D = (X1 − X2) – (Y1 − Y2), and the centering ability was analyzed by the formula CC = (X1 − X2/Y1 − Y2 or Y1 − Y2/X1 − X2). The samples were submitted to histologic processing and analyzed under a digital microscope for debris quantification. The values were statistically analyzed (Kruskal-Wallis, the Dunn multiple comparisons test, $P < .05$). **Results:** All groups had similar apical transportation values, with no significant difference among them ($P > .05$). Groups had a tendency toward transportation in the mesial direction. No technique had perfect centering ability (=1.0), with no significant difference among them. KF/RS had larger amount of debris, with statistically significant difference in comparison with NGP/RS ($P > .05$). **Conclusions:** The different glide path techniques promoted minimal apical transportation, and the reciprocating single-file system tested remained relatively centralized within the root canal. Also, the different techniques interfered in the cleaning effectiveness of the reciprocating system. *(J Endod 2015;41:2045–2049)*

Key Words

Apical transportation, centering ability, cleaning effectiveness, glide path, reciprocating motion

Biomechanical preparation is the step responsible for root canal system cleaning and shaping, gradually increasing its diameter by action of several instruments (1). For years such preparation was performed with stainless steel hand instruments, which had a number of limitations mainly in curved and flat canals, leading to deviations, zip formations, and perforations (2).

Such limitations led to the development of nickel-titanium instruments with increased flexibility and cutting efficiency, favoring the treatment of curved canals and making the clinical procedure faster and safe (3). Constantly, new techniques and instruments have been proposed to reduce the difficulties in endodontic therapy (4, 5). Reciprocating systems, which are able to perform biomechanical preparation with only 1 instrument, are the latest innovations (4, 5).

Because of the reduced number of files used for root canal preparation, a glide path must be created before instrumentation to ensure the continuously free advancement of instruments throughout the entire working length (5–7).

Following the concept of reduced number of instruments for root canal preparation, glide path creation has also followed this trend of being performed with few instruments or a single file (8, 9). Thus, studies to better define the action of these instruments in the root canal's anatomy, when associated with reciprocating systems, are needed.

The aim of this study was to evaluate the apical transportation, the centering ability, and the cleaning effectiveness of a reciprocating single-file system associated to different glide path techniques. The null hypothesis tested was that the different glide path techniques would not interfere in the reciprocating single-file system performance.

Materials and Methods

Sample Selection

For this study, 52 freshly extracted mandibular molars, donated by the Bank of Teeth of the Amazonas State University, with prior approval from the Research Ethics Committee (Protocol. CAAE n° 23700713.7.0000.5020) were selected. The selected teeth had 16-mm length, completely formed roots, closed apex, and 2 mesial root

From the *Department of Endodontics, School of Dentistry, Federal University of Amazonas, Manaus, Amazonas; †Department of Physiology and Pathology, Araraquara School of Dentistry, São Paulo State University, Araraquara, São Paulo; ‡Department of Restorative Dentistry, Araçatuba School of Dentistry, São Paulo State University, Araçatuba, São Paulo; and §Department of Endodontics, School of Dentistry, State University of Amazonas, Manaus, Amazonas, Brazil.

Address requests for reprints to Dr Lucas da Fonseca Roberti Garcia, Rua Siró Kaku, n° 72, apto. 73, Bairro Jardim Botânico, CEP 14021-614 Ribeirão Preto, São Paulo, Brasil. E-mail address: drlucas.garcia@gmail.com

0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2015.09.005

canals with independent foramina. Moreover, only roots with angle of curvature ranging from 20° to 30° and radius of curvature ≤10 mm were selected for the study. The angle and radius of curvature were calculated according to the methods of Schneider (10) and Pruett et al (11), respectively.

After sample selection, the teeth were disinfected by immersing them in a 0.5% chloramine-T solution at a temperature of 4°C for 48 hours and then washed under running water for 24 hours. Next, the teeth were stored in receptacles containing distilled water at a temperature of 5°C until use.

Coronal opening was performed with spherical diamond-coated bur no. 1015 (KG Sorensen, Cotia, SP, Brazil) coupled to a high-speed handpiece (Extra Torque 605C; Kavo, Joinville, SC, Brazil) under constant water cooling. Afterwards, size 10 K-files (Dentsply Maillefer, Ballaigues, Switzerland) were introduced in the mesial canals in apical direction to determine the working length. The working length of mesial canals was standardized at 14 mm, and only mesial canals with an initial apical size correspondent to a size 10 K-file were selected for this study.

Biomechanical Preparation

To standardize the teeth position during biomechanical preparation, the distal portions of the teeth were embedded in colorless self-curing acrylic resin (Jet Classic; São Paulo, SP, Brazil) to form a resin block. After polymerization, the 52 blocks were randomly distributed into 4 groups (n = 13) according to the different glide path techniques performed before root canal preparation. In KF/RS group, glide path was created with sizes 10 and 15 K-files (KF) (Dentsply Maillefer) to the working length, followed by preparation with R25 instrument (size 25.08/21 mm) of Reciproc System (RS) (VDW GmbH, Munich, Germany) in reciprocating motion with a 6:1 contra-angle handpiece (VDW Silver Reciproc; Sirona Dental Systems GmbH, Bensheim, Germany) powered by an electric motor (VDW Silver Reciproc Motor; Sirona Dental Systems) in mode "RECIPROC ALL", according to the manufacturer's recommendations. The instrument was gradually inserted in a slow in-and-out pecking motion with a 3-mm amplitude limit for 3 pecking movements. Glyde File Prep (Dentsply Maillefer) was used as lubricant during root canal preparation. In NGP/RS group, glide path was not created. The root canals were prepared in the same manner as described in KF/RS group. In PF/RS group, glide path was created with PathFile (PF) rotary instruments (Dentsply Maillefer) sizes 13, 16, and 19. Next, the root canals were prepared in the same manner as described in KF/RS and NGP/RS groups. In NP group, no preparation was performed (negative control).

Each instrument was used to prepare only 1 root canal. After each insertion, the instruments were removed for cleaning with sterile gauze, and the root canals were irrigated with 2 mL 2.5% NaOCl solution (Rio Química, São José do Rio Preto, SP, Brazil) with a 30-gauge needle (NaviTip; Ultradent Products Inc, South Jordan, UT) 3 mm short of the working length. At the end of the biomechanical preparation, 1 mL 17% EDTA (Biodinâmica, Ibiporã, PR, Brazil) was applied for 3 minutes, and the canals were irrigated again with 2 mL 2.5% NaOCl (Rio Química). The resulting solution was aspirated (CapillaryTip; Ultradent Products Inc), and the teeth were stored in a humid environment at a temperature of 5°C. All procedures were performed by a single operator who is a specialist in endodontics.

Apical Transportation

To evaluate the apical transportation, an initial cone-beam computed tomography (CBCT) analysis was performed for image acquisition of mesial root canals. The resin blocks containing the teeth were coupled to a polystyrene platform (2.0 × 2.0 × 2.0 cm), with the mesial root canals parallel to the horizontal plane to standardize the teeth position before and after preparation. The platform/resin block set was adapted to the table of the CBCT scanner (i-CAT Cone Beam 3D; Dental Imaging System, Salt Lake City, UT) with the following specifications: x-ray source with valve voltage 120 kVp, valve current 3–7 mA, and focal point of 0.5 mm. The protocol Mand 6 cm, 40 sec, 0.2 voxel MaxRes was used for image acquisition.

For apical transportation analysis, the second and third millimeters of the apical third were selected, totaling 4 axial images of 1 mm for each mesial root canal. The apical transportation was calculated with the aid of the OsiriX software (OsiriX Imaging Software, http://dwww.osirix-viewer.com). The extension of the pre-preparation and post-preparation root canal diameters was measured in a blind manner by a calibrated examiner, according to the following formula:

$$D = (X1 - X2) - (Y1 - Y2)$$

X1 and X2 represented the measurement of the mesial external wall of the non-instrumented and instrumented root canals, respectively. Y1 and Y2 represented the measurement of the distal external wall of the non-instrumented and instrumented root canals, respectively (Fig. 1). Apical transportation equal to 0 means that no transportation occurred, a negative value means that transportation occurred in the distal direction, and a positive value indicates transportation in the mesial direction.

Centering Ability

The centering ability index was calculated for the second and third millimeters of the apical third by using the values obtained during apical transportation measurement, following the formula:

$$X1 - X2/Y1 - Y2 \text{ or } Y1 - Y2/X1 - X2$$

The formula adopted for the centering ability calculation depends on the value obtained by the enumerator, which should always be lower than the values obtained by the differences. Therefore, values equal to 1 indicated perfect centering ability of the instrument, and values closer to 0 indicated lower instrument's ability to maintain to the central axis of the root canal.

Cleaning Effectiveness

After CBCT analysis, the mesial root was separated from the whole structure of each tooth by using a double-faced diamond disk coupled to a low-speed handpiece (Dabi Atlante, Ribeirão Preto, SP, Brazil) and fixed in 4% formalin solution (Merck, Darmstadt, Germany) for 48 hours. Next, the mesial roots were washed in running water for 24 hours and immersed in Morse solution for 4 weeks for decalcification. Afterwards, the apical third of each mesial root was sectioned, washed in running water for 24 hours, and submitted to dehydration in alcohol (70%, 90%, 95%, and 100%), followed by diaphanization in xylene (Merck) for further paraffin embedding at 60°C. Semi-serial sections (10 semi-serial sections per specimen) of 5-μm thickness were cut and stained with hematoxylin-eosin (Merck).

The histologic sections were analyzed under a digital microscope (Dino-Lite Plus AM313 T; AnMo Electronics Corporation, New Taipei City, Taiwan) at ×60 and ×230 magnifications. With the aid of the Image Tool 3.0 software (San Antonio, TX), an integration grid (28 × 21) was superimposed over the histologic images to perform quantification of the points in the root canal that coincided with either clean areas or areas containing debris (Fig. 2). After quantification of the points present in the clean area and points in the areas containing debris, the

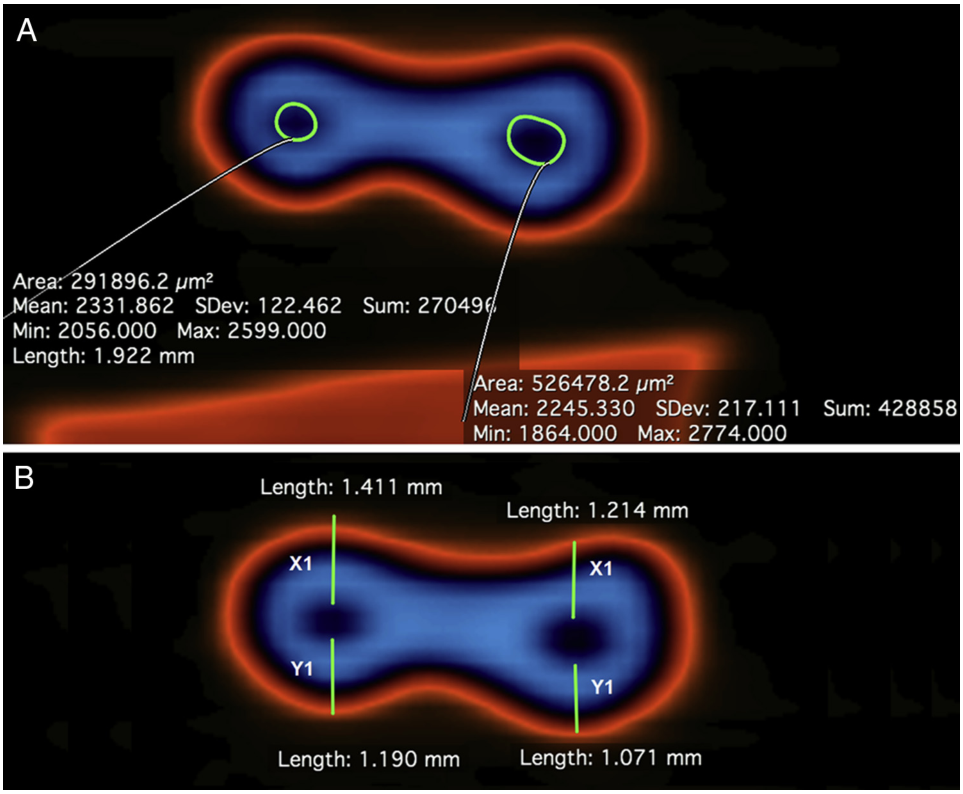

Figure 1. Representative CBCT images of pre-instrumented canals visualized in the Osirix MD software. (*A*) Root canal area outlined in green to determine its limit. (*B*) Measurement of apical transportation made before mesial root canal preparation to be applied in the formula D = (X1 − X2) × (Y1 − Y2).

cleaning effectiveness was calculated. The quantification was performed blindly by a single observer who was properly calibrated.

Statistical Analysis

The apical transportation, the centering ability, and the cleaning effectiveness were evaluated considering the mesial canals (buccal and lingual) of the same tooth as independent factors. The normal distribution of data was tested by the Kolmorov-Smirnov test, and the values obtained (Kruskal-Wallis, the Dunn multiple comparisons test, $P < .05$) were statistically analyzed by using the GraphPad InStat for Mac OS software (GraphPad Software, La Jolla, CA).

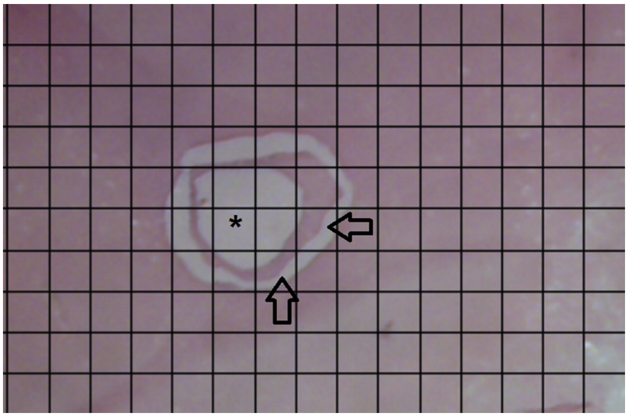

Figure 2. Representative image of histologic section at apical third with the integration grid superimposed showing the presence of pulp remnants in the NP group (*arrows*). Note the clean area (*). Hematoxylin-eosin stain; original magnification, ×230.

Results

Apical Transportation

The graphic representation (mm) for apical transportation is in Figure 3*A*. The different groups had similar apical transportation values, with no significant difference ($P > .05$) for any of the factors evaluated (apical distance, mesiobuccal and mesiolingual root canal, and glide path technique).

As regards the apical transportation direction, among the 156 root canals evaluated, only 1 root canal from the PF/RS group had no apical transportation. Most of root canals had a greater tendency toward transport to the mesial (outer) direction (n = 83) than toward the distal (inner) direction (n = 72), as can be seen in Figure 3*B*.

Centering Ability

None of the tested glide path techniques promoted perfect centering ability of the reciprocating system (=1.0). There was no significant difference among groups ($P > .05$) (Fig. 3*C*).

Cleaning Effectiveness (Histologic Analysis)

The mean values of debris (%) in the root canal lumen may be seen in Figure 3*D*. It was possible to observe the presence of debris in the root canals for all groups evaluated (Fig. 4). KF/RS had larger amount of debris, with statistically significant difference in comparison with NGP/RS ($P > .05$). Samples from the NP group (control), in which

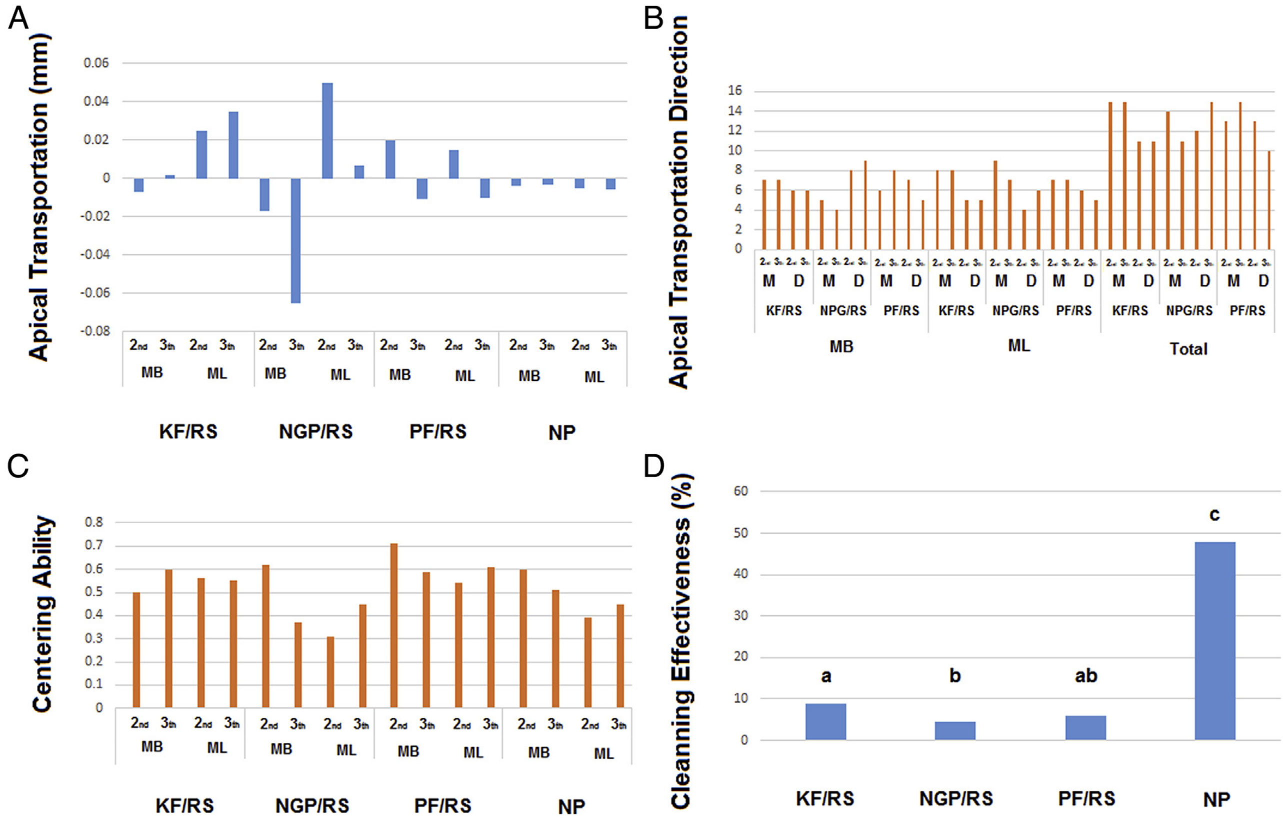

Figure 3. Mean values of apical transportation, centering ability, and cleaning effectiveness. (*A*) Graphic representation (mm) for apical transportation mean values. (*B*) Graphic representation of apical transportation direction. (*C*) Graphic representation of centering ability mean values. (*D*) Graphic representation of debris quantification (%) mean values in the root canal lumen. Different lowercase letters over bars indicate statistically significant difference (Kruskal-Wallis, the Dunn multiple comparisons test, $P < .05$). D, distal; M, mesial; MB, mesiobuccal; ML, mesiolingual.

no instrumentation was performed, had a significantly larger amount of debris than the other groups evaluated ($P < .05$).

Discussion

The present study evaluated the apical transportation, the centering ability, and the cleaning effectiveness of a single-file reciprocating system associated to different glide path techniques. On the basis of the results, it can be stated that the null hypothesis was partially accepted, because the different glide path techniques did not promote significant changes in apical transportation and centering ability of the reciprocating system evaluated; however, its cleaning effectiveness was affected.

With the advent of the single-file systems, the ability to create a proper glide path has increased considerably (5–7). The glide path

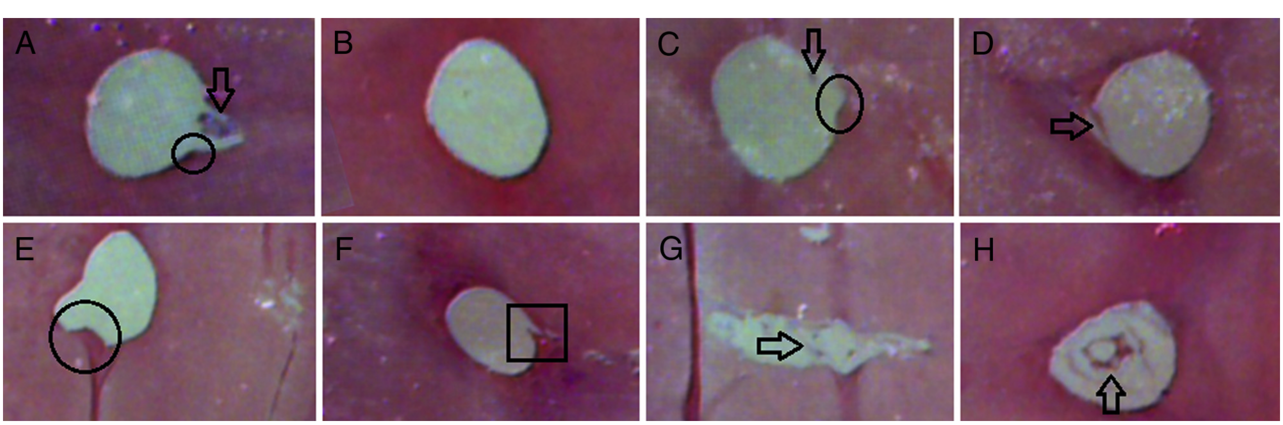

Figure 4. Representative images of histologic sections at the apical third. (*A*) KF/RS group. Root canal presenting a flattening area with debris (*arrow*). Note the limit of instrument action (*circle*). (*B*) Root canal with circular configuration and absence of debris. Hematoxylin-eosin stain; original magnification, ×230. (*C* and *D*) NGP/RS group. Root canals with circular configuration and presence of debris attached to the dentinal walls (*arrows*). Note the non-instrumented area (*circle*). Hematoxylin-eosin stain; original magnification, ×230. (*E*) PF/RS group. Root canal with irregular configuration and absence of debris. Non-instrumented area (*circle*). (*F*) Root canal showing evidence of debris in the isthmus area (*box*). Hematoxylin-eosin stain; original magnification, ×230. (*G* and *H*) NP group. Note the irregular walls of non-instrumented root canals, with great amounts of pulp remnants (*arrows*). Hematoxylin-eosin stain; original magnification, ×230.

reduces the frictional forces of the instrument against the root canal walls, preserving its original trajectory during instrumentation (12, 13).

Several studies have reported that single-file systems such as Reciproc are able to go through the entire working length before glide path creation in most cases (9, 14, 15). However, this fact is not corroborated by other authors (6, 7), who recommend glide path creation by using instruments with greater flexibility and smaller taper, especially in curved and atretic canals such as molars (16).

For this reason, mesial roots of lower molars with 2 canals and independent foramina, angle of curvature ranging from 20° to 30° (10), and radius of curvature ≤10 mm (11), were used in this study to simulate clinical conditions encountered by professionals in their routine (17).

When the results of apical transportation were analyzed, no significant difference among the glide path techniques was observed, corroborating the findings of other studies (17, 18). However, of all samples tested, only 1 root canal from the PF/RS group had no apical transportation. Nevertheless, the values obtained by the different glide path techniques were not higher than 0.300 mm. According to Fan et al (19), apical transportation is only clinically relevant when it is greater than 0.300 mm, compromising root canal filling.

When analyzing the apical transportation direction, there was a tendency toward transport to the mesial (outer) direction. Several studies have demonstrated a greater tendency toward transport to mesial direction (20, 21), because the distal wall acts in the anti-furcation direction, pushing the instrument, particularly those of larger taper, to the mesial wall, opposed to this curvature (17, 20, 22).

As regards the centering ability, none of the tested glide path techniques were able to maintain the reciprocating instrument perfectly centralized within the root canal. Although there was no significant difference among groups, it is worth emphasizing that the PF/RS had values closer to 1 than the other groups, which means better centering ability. Such results can be explained by the flexibility and smaller taper of the PathFile instruments, favoring an accurate definition of the root canal path, ensuring that the reciprocating instrument will follow this path to the apical foramen (23). Values closer to 0 were found in the NGP/RS group, demonstrating an instrument's tendency to not follow the original canal path when a glide path is not created, as reported by Berutti et al (5).

Regarding the cleaning effectiveness, the group in which the glide path was not created (NGP/RS) before root canal preparation with reciprocating instrument had the smallest amount of debris. This fact might be explained by the lower dentin removal, because only one single-instrument was used for root canal preparation (24, 25). However, the cleaning effectiveness of this group was statistically similar to the PF/RS group, where the largest number of instruments had been used, and a larger amount of dentin was removed, producing more debris. Such findings may be explained by the S-shaped cross section of the Reciproc instrument, which allows a constant output of dentin produced during root canal preparation (4, 26). In addition, the large taper of the 3 initial millimeters of the instrument may have influenced the results (4, 26). Despite the different glide path techniques performed before biomechanical preparation, the design of the reciprocating instrument was able to promote adequate cleaning of the root canal.

Despite the limitations of this *in vitro* study, it is valid to state that the reciprocating single-file system, irrespective of the glide path technique used, promoted minimal apical transportation and remained relatively centralized within the root canal. However, its cleaning effectiveness was compromised, because the results obtained by the KF/RS group were significantly different from those of the NGP/RS group.

Acknowledgments

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

References

1. Bürklein S, Tsotsis P, Schäfer E. Incidence of dentinal defects after root canal preparation: reciprocating versus rotary instrumentation. J Endod 2013;39:501–4.
2. Fornari VJ, Silva-Sousa YT, Vanni JR, et al. Histological evaluation of the effectiveness of increased apical enlargement for cleaning the apical third of curved canals. Int Endod J 2010;43:988–94.
3. da Frota MF, Filho IB, Berbert FL, et al. Cleaning capacity promoted by motor-driven or manual instrumentation using ProTaper Universal system: histological analysis. J Conserv Dent 2013;16:79–82.
4. Bürklein S, Hinschitza K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. Int Endod J 2012;45:449–61.
5. Berutti E, Paolino DS, Chiandussi G, et al. Root canal anatomy preservation of WaveOne reciprocating files with or without glide path. J Endod 2012;38:101–4.
6. Pasqualini D, Bianchi CC, Paolino DS, et al. Computed micro-tomographic evaluation of glide path with nickel-titanium rotary PathFile in maxillary first molars curved canals. J Endod 2012;38:389–93.
7. Elnaghy AM, Elsaka SE. Evaluation of root canal transportation, centering ratio, and remaining dentin thickness associated with ProTaper Next instruments with and without glide path. J Endod 2014;40:2053–6.
8. Yared G. Canal preparation with only one reciprocating instrument without prior hand file: a new concept. Available at: http://www.vdw-dental.com/fileadmin/redaktion/downloads/presse/yared_reciproc_concept_en.pdf. Accessed May 14, 2015.
9. De-Deus G, Arruda TE, Souza EM, et al. The ability of the Reciproc R25 instrument to reach the full root canal working length without a glide path. Int Endod J 2013;46:993–8.
10. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32:271–5.
11. Pruett JP, Clement DJ, Carnes DL Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod 1997;23:77–85.
12. 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.
13. Patino PV, Biedma BM, Liebana CR, et al. The influence of a manual glide path on the separation rate of NiTi rotary instruments. J Endod 2005;31:114–6.
14. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. Int Endod J 2008;41:339–44.
15. Lim YJ, Park SJ, Kim HC, Min KS. Comparison of the centering ability of Wave•One and Reciproc nickel-titanium instruments in simulated curved canals. Restor Dent Endod 2013;38:21–5.
16. D'Amario M, Baldi M, Petricca R, et al. Evaluation of a new nickel-titanium system to create the glide path in root canal preparation of curved canals. J Endod 2013;39:1581–4.
17. Gergi R, Osta N, Bourbouze G, et al. Effects of three nickel titanium instrument systems on root canal geometry assessed by micro-computed tomography. Int Endod J 2015;48:162–70.
18. Bürklein S, Poschmann T, Schäfer E. Shaping ability of different nickel-titanium systems in simulated S-shaped canals with and without glide path. J Endod 2014;40:1231–4.
19. Fan B, Wu MK, Wesselink PR. Leakage along warm gutta-percha fillings in the apical canals of curved roots. Endod Dent Traumatol 2000;16:29–33.
20. Junaid A, Freire LG, da Silveira Bueno CE, et al. Influence of single-file endodontics on apical transportation in curved root canals: an *ex vivo* micro-computed tomographic study. J Endod 2014;40:717–20.
21. Kim HC, Hwang YJ, Jung DW, et al. Micro-computed tomography and scanning electron microscopy comparisons of two nickel-titanium rotary root canal instruments used with reciprocating motion. Scanning 2013;35:112–8.
22. You SY, Kim HC, Bae KS, et al. Shaping ability of reciprocating motion in curved root canals: a comparative study with micro-computed tomography. J Endod 2011;37:1296–300.
23. Zanette F, Grazziotin-Soares R, Flores ME, et al. Apical root canal transportation and remaining dentin thickness associated with ProTaper Universal with and without PathFile. J Endod 2014;40:688–93.
24. Arya A, Bali D, Grewal MS. Histological analysis of cleaning efficacy of hand and rotary instruments in the apical third of the root canal: a comparative study. J Conserv Dent 2011;14:237–40.
25. Carvalho Mde S, Junior EC, Bitencourt Garrido AD, et al. Histological evaluation of the cleaning effectiveness of two reciprocating single-file systems in severely curved root canals: Reciproc versus WaveOne. Eur J Dent 2015;9:80–6.
26. Koçak S, Koçak MM, Sağlam BC, et al. Apical extrusion of debris using self-adjusting file, reciprocating single-file, and 2 rotary instrumentation systems. J Endod 2013;39:1278–80.