Micro-computed tomographic evaluation of two single rotary glide path systems

P.J. van der Vyver[1], F. Paleker[1], M. Vorster[1], F.A. de Wet[1]

[1]Department of Odontology, School of Dentistry, Faculty of Health Sciences, University of Pretoria, Pretoria, South Africa

Oral and Dental Hospital, Pretoria, South Africa

Running Title: **µCT of rotary glide path systems**

Keywords: Centring ability, glide path, K-Files, One-G, ProGlider, transportation

Corresponding author: Peet J van der Vyver

Postal address: PO Box 2609, Cresta, 2118, South Africa

Tel. no.: 2711 781 1020

Fax no.: 2711 781 1392

Email: peetv@iafrica.com

Abstract

Aim To compare (1) canal-centring ability and transportation of K-Flex files, ProGlider file, and One-G file after glide path preparation in curved root canals; (2) changes in canal volume after glide path preparation, using micro-computed tomography.

Methodology A total of 135 mesiobuccal root canals of maxillary molars were randomly divided into three glide path groups: (1) pre-curved sizes 10-15-20 K-Files (n = 45); (2) size 10 K-File followed by One-G (n = 45); and (3) size 10 K-File followed by ProGlider (n = 45). Micro-CT was used to scan teeth before and after glide path preparation. Centring ratio values and canal transportation values were compared between the three glide path preparation groups at the apical, midroot, and coronal levels. Changes in canal volume were compared for all glide path groups. The results were statistically analysed using a one-way ANOVA and Kruskal-Wallis H tests.

Results One-G and ProGlider displayed statistically significantly higher mean centring ratio values than K-Files at all levels examined ($P < 0.05$). Apical canal transportation values after glide path preparation were significantly higher for the K-Files ($P < 0.05$). At the midroot and coronal levels canal transportation results were statistically similar for all glide path groups ($P > 0.05$). Changes in canal volume were statistically similar for the three glide path groups ($P > 0.05$).

Conclusion One-G and ProGlider were significantly more centered at the apical, midroot, and coronal levels than K-Files. Apical canal transportation ratio values after glide path enlargement were significantly higher for K-Files than for One-G and ProGlider. All groups resulted in similar canal volume changes.

Introduction

Micro-computed tomography (μCT) enables researchers to evaluate root canal instrumentation techniques and generates information that can raise the standard of clinical root canal treatment (Rhodes *et al.* 1999, Pasqualini *et al*. 2012,.2015). Endodontic treatment failure can result when dentine removal is not equidistant from the canal centre, creating an uncentred preparation and/or canal transportation (Hülsmann *et al.* 2005, Cheung & Liu 2009). Canal transportation is a sustained deviation from the original axis of the canal that occurs during preparation. Rotary glide path files with a high root canal centring ability result in fewer modifications of the canal curvature (Pasqualini *et al*. 2012). Uncentered and transported preparations can result in procedural errors such as perforation, ledge formation, and bacterial extrusion (Berutti *et al.* 2004, 2009).

Stainless steel K-Files have been recommended for manual glide path enlargement (Berutti *et al*. 2004, Mounce 2005, West 2006). The endodontic glide path, a smooth, patent passage from the coronal orifice of the canal to the radiographic terminus or electronically determined portal of exit, can be achieved with both hand and rotary instruments (De Oliveira Alves *et al.* 2012). Many studies have illustrated the benefits of glide path formation, which include decreased subsequent shaping irregularities (Mounce 2005, Varela-Patiño *et al.* 2005, Paleker & Van der Vyver 2016). The use of NiTi rotary glide path instruments has been shown to produce more centred preparations with less transportation than stainless steel K-Files (Pasqualini *et al.* 2012).

The ProGlider (Dentsply Sirona, Ballaigues, Switzerland) is a single mechanical glide path file manufactured using M-Wire. It has a square cross-section with a diameter of 0.16 mm at D0 and is progressively tapered from 2% to 8% over its length. The One-G instrument (Micro-Mega, Besançon, France) is a single glide path file system with a 3% taper, a diameter of 0.14 mm at D0 and three cutting edges situated on three different radii relative to the canal axis.

The broad aim of this ex vivo study was to determine with the use of µCT scanning which of the glide path instruments is best suited for glide path preparation of curved mesiobuccal root canals of extracted human maxillary molars. The null hypothesis tested is that there are no differences in centring ability, canal transportation, and volume of dentine removed between the three instruments used in this study.

Materials and Methods

Specimen Preparation

One hundred and thirty-five extracted maxillary first molars with curved mesiobuccal root canals with one or two separate mesiobuccal canals were selected from a group of 160 pre-scanned teeth using a XTH 225 ST micro-focus X-ray CT system (Nikon Metrology, Leuven, Belgium). Only mesiobuccal root canals with curvatures between 25 and 35 degrees and radii of less than 10 mm were selected, as described by Pruett *et al.* (1997). VGStudioMax visualisation software (Volume Graphics GmbH, Heidelberg, Germany) was used to confirm these curvatures. After access, cavity preparation working length was determined by subtracting 0.5 mm from the length of the canal measured to the major apical terminus under 10 times magnification. The mesial canals were explored with a size 08 K-File (Dentsply Sirona) and canals were negotiated to patency. The specimens were coded and randomly divided into three equal experimental groups (n=45) for glide path preparation.

Glide Path Preparation

Glide path preparation was performed by a single operator in strict accordance with the manufacturer's recommendations for each system. All the rotary glide path files were operated by a 16:1 gear reduction hand piece powered by the X.Smart Plus endodontic motor (Dentsply Sirona). RC Prep (Premier, Plymouth Meeting, PA, USA) was used as a lubricating agent and 3% sodium hypochlorite (NaOCl) as canal irrigation.

Control group 1: An initial reproducible glide path was prepared using pre-curved size 10, 15 and 20 stainless steel K-Files (KF) (Dentsply Sirona) using a circumferential filing motion.

Test group 2: A pre-curved stainless steel size 10 K-File was negotiated to working length and One-G (OG) (Micro-Mega) was used to enlarge each canal utilising a brushing motion.

Test group 3: A pre-curved stainless steel size 10 K-File was negotiated to working length and the ProGlider (PG) (Dentsply Sirona) was then used to enlarge each canal utilising a brushing motion.

The teeth were scanned again to generate a glide path scan (Scan 2) for each specimen. VGStudioMax software (Volume Graphics GmbH) enabled merging of the pre-instrumentation 3D images and glide path preparation 3D images for each tooth. Canals from Scan 2 were superimposed on corresponding canals from Scan 1 to measure the changes following glide path preparation.

Image Analysis

The method described by Gambill *et al.* (1996) was used to measure canal transportation and centring ratio. Canal transportation and centring ratios were evaluated after glide path preparation (Figure 1).

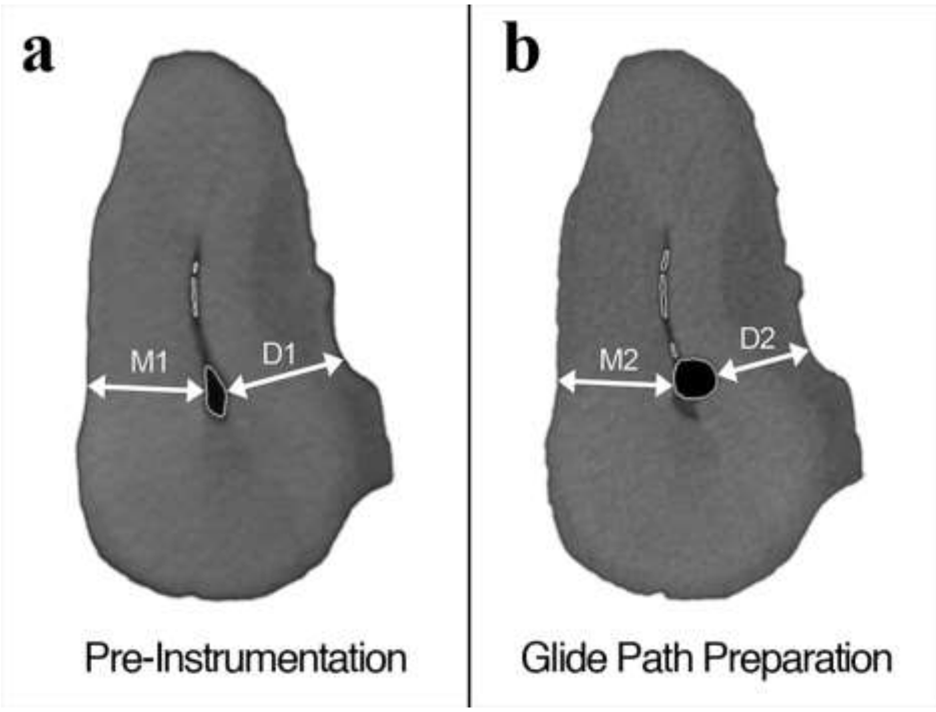

Figure 1 Pre-instrumentation and post-glide-path-preparation µCT images showing the effect of glide path preparation and points of measurement used to determine canal transportation and centring ratio.

The shortest distance from the prepared canal to the mesial or distal wall of the tooth at three different levels from the root apex was measured. Centring ratio and canal transportation values were measured at three different lengths from the anatomical apex of the mesiobuccal root canals. A cross-section at levels 2 mm (apical), 5 mm (midroot) and 9 mm (coronal) was evaluated according to the equations set out below.

Canal centring ability was determined by the following formula: CT = (M1-M2)/(D1-D2) where (D1-D2>M1-M2) or by (D1-D2)/(M1-M2) where (M1-M2)>(D1-D2). In the formula, M1 is the shortest distance from the mesial margin of tooth measured to the mesial margin of the uninstrumented canal. M2 is the shortest distance from the mesial margin of tooth measured to the mesial margin of the instrumented canal. Similarly, D1 is the shortest distance from the distal margin of tooth measured to the distal margin of the uninstrumented canal, and the D2 is the shortest distance from the distal margin of tooth measured to the distal margin of the instrumented canal. A value/ratio closest to 1 indicates perfect centring ability, while a result closer to zero indicates a poorer centring ability. Canal transportation was subsequently calculated by the following formula: T = (M1-M2) – (D1-D2). A value closest to 0 indicates no transportation, while a positive or a negative result indicates transportation. The further the value away from zero, the greater the transportation.

Canal transportation and centring ratios were evaluated after glide path preparation and after final preparation with the shaping instruments. All micro-CT measurements were calculated by a skilled third-party operator to avoid bias, but were validated by an experienced clinician. Data was recorded on a Microsoft Excel (Microsoft Corp., Redmond, Washington, USA) spreadsheet and verified.

Before glide path preparation and after glide path preparation the mesiobuccal canals of each specimen were traced from the canal orifice to the apical foramen and the total volume was measured, using VGStudioMax software (Volume Graphics GmbH). The changes in canal volume were determined in mm^3 for each root canal by subtracting the pre-instrumentation canal volume from the glide path volume (Hashem 2012).

Statistical Analysis

Canal transportation, centring ratio values, and volume of removed dentine values were compared in the experimental groups by using either one-way ANOVA (parametric distributions) or the Kruskal-Wallis H test (non-parametric distributions). Statistical significance was set at $P < 0.05$.

Results

Centring ratio

OG and PG were significantly more centered at the apical, midroot, and coronal levels than KF at each level examined and for the combined results of the three levels ($P < .05$). The combined results of the apical, middle, and coronal thirds for the mean centring ratio values for each group after glide path enlargement were also evaluated. The highest mean centring ratio value was observed with PG, followed by OG and then KF (0.35 ± 0.16). There was a significant difference between the mean centring ratio values of KF compared to OG and to PG, which were statistically similar ($P < 0.05$) (Table 1).

Canal transportation

Apical canal transportation ratio values after glide path enlargement were significantly higher for KF than for OG and PG ($P < 0.05$). At the midroot and coronal levels and for the combined results of the three levels, the canal transportation results were similar for all glide path groups ($P > 0.05$) (Table 1). The combined results of the apical, middle, and coronal thirds for the median transportation values for each group after glide path enlargement were examined. There were no significant differences between the median transportation values of the various groups ($P = 1336$). The highest median transportation value was obtained with KF, followed by PG and then OG (Table 1).

Table 1 Statistical analysis of mean centring ratio values and transportation (mm) for the tested groups (n=45)

File	Parameter	Apical		Midroot		Coronal		Combined	
		Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max
K-Files	Centring ratio	0.41 ± 0.17^{a}	0.107 - 0.752	0.32 ± 0.16^{a}	0.112-0.775	0.32 ± 0.14^{a}	0.145 – 0.702	0.35 ± 0.16^{a}	0.107-0.776
	Transportation	0.075 ± 0.03$^{\Delta}$	0.067 – 0.087	0.035 ± 0.02$^{\Delta}$	0.025 – 0.054	0.032 ± 0.02$^{\Delta}$	0.027 – 0.047	0.038 ± 0.03$^{\Delta}$	0.027 – 0.66
One-G	Centring ratio	0.61 ± 0.13^{a}	0.335 – 0.947	0.45 ± 0.18^{b}	0.211 – 0.846	0.39 ± 0.20^{a}	0.112 – 0.845	0.48 ± 0.20^{b}	0.112 – 0.947
	Transportation	0.063 ± 0.02$^{\varnothing}$	0.055 – 0.068	0.031 ± 0.01$^{\Delta}$	0.023 – 0.038	0.031 ± 0.01$^{\Delta}$	0.025 – 0.035	0.034 ± 0.02$^{\Delta}$	0.025 – 0.056
ProGlider	Centring ratio	0.66 ± 0.17^{a}	0.243 - 0.999	0.39 ± 0.15^{b}	0.176 – 0.901	0.43 ± 0.15^{a}	0.213 – 0.812	0.50 ± 0.20^{b}	0.176 – 0.999
	Transportation	0.067 ± 0.01$^{\varnothing}$	0.057 – 0.075	0.029 ± 0.02$^{\Delta}$	0.022 – 0.043	0.030 ± 0.02$^{\Delta}$	0.024 – 0.037	0.035 ± 0.02$^{\Delta}$	0.025 – 0.058

Different subscript letters (centring ratio) and symbols (transportation) in the same column indicate a significant difference at $P < 0.05$.

Figure 2 depicts representative samples from the different glide path preparation groups, illustrating the effect of glide path preparation at the apical third of the root canals.

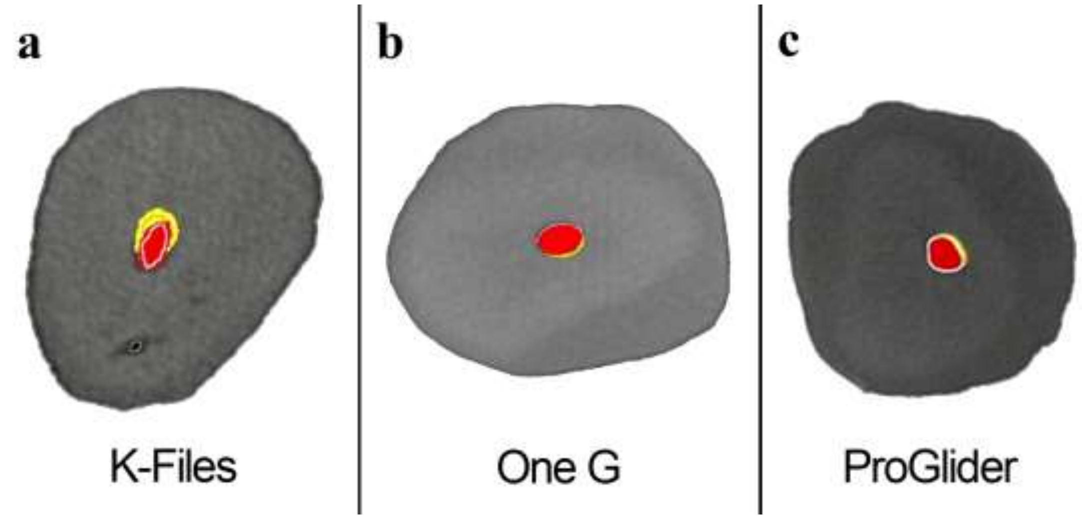

Figure 2 Representative axial µCT samples at the apical third of root canals from (A) KF showing a poor centring ratio and apical transportation; (B) OG showing a good centring ratio and minimal amount of transportation; (C) PG showing a good centring ratio and minimal amount of transportation (*Red* – pre-operative area; *Yellow* – effect of glide path preparation).

Volume of removed dentine

PG recorded the highest volume of removed dentine (0.57 $mm^3 \pm$ 0.39 $mm^{3)}$, followed by KF (0.53 $mm^3 \pm$ 0.34 mm^3) and then OG (0.39 $mm^3 \pm$ 0.28 mm^3) (Table 2). There were no significant differences between the groups regarding the volume of dentine removed ($P > 0.05$). Figure 3 depicts representative 3D reconstructions of mesiobuccal root canal volumes before instrumentation (red) and after glide path preparation (yellow) with the different glide path

Table 2 Descriptive statistics: Changes in canal volume (in mm^3) with glide path instruments (n=45)

Preparation Method	Median	Standard Deviation	Lower Quartile	Upper Quartile
K-Files	0.528 [a]	0.28	0.344	0.631
One-G	0.393 [a]	0.34	0.187	0.666
ProGlider	0.570 [a]	0.39	0.414	0.745

Mean values with the same superscript letters were not statistically significantly different at $P < 0.05$ using the Kruskal-Wallis H test.

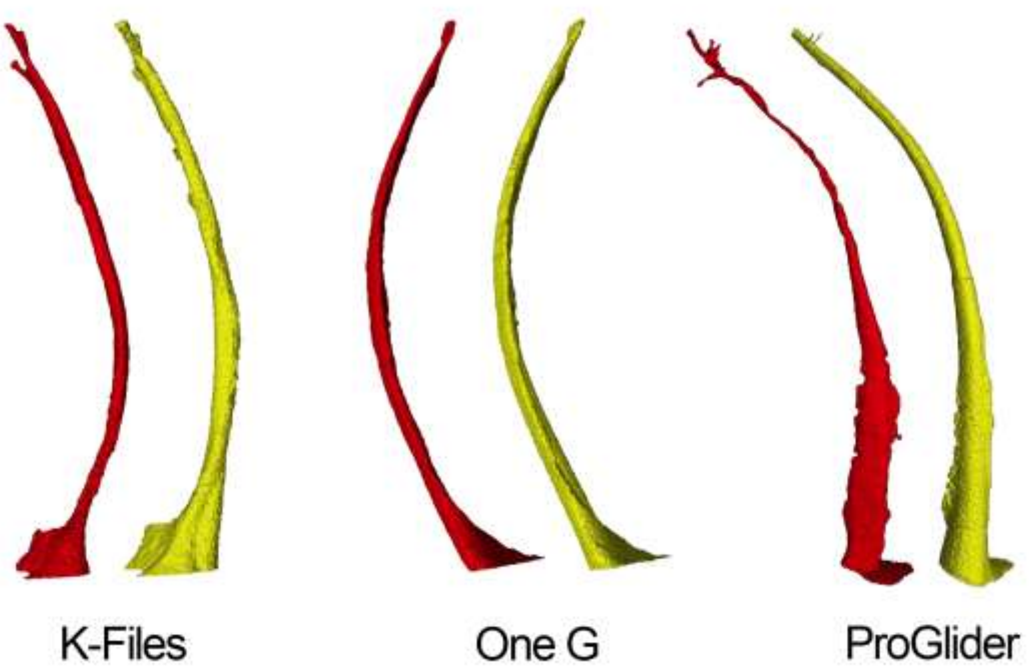

Figure 3 Representative 3D reconstructions of the buccolingual views of mesiobuccal root canal volumes, before instrumentation and after glide path preparation for the different groups (*Red* – pre-instrumentation volume; *Yellow* – volume after glide path preparation).

Discussion

The mean canal centring ability and transportation values of the glide path and shaping instruments in this study were compared at levels 2 mm (apical), 5 mm (midroot), and 9 mm (coronal) from the anatomical apex of the tooth. These areas were chosen because they are particularly vulnerable to iatrogenic mishaps, especially in canals that are curved (De Oliveira Alves *et al*. 2010).

At all levels examined, the mean centring ratios for KF were significantly larger than for the NiTi rotary glide path file groups. Statistically similar observations were made for the OG and PG groups at these levels. These results are similar to those of other studies that compared the effects of glide path enlargement after K-Files and NiTi rotary glide path file systems had been used (Berutti *et al.* 2009, Pasqualini *et al.* 2012). The results of this study revealed similar canal transportation mean values for the all three groups at the midroot and coronal levels. At the apical level, however, mean transportation values for stainless steel KF were significantly higher than those of both OG and PG. The two rotary glide path file groups exhibited similar apical canal transportation values. All endodontic instruments, regardless of the alloy used during manufacturing, tend to straighten inside the root canal (Tasdemir *et al*. 2005, Young *et al.* 2007). A number of studies have shown that NiTi rotary glide path file systems exhibit less apical canal transportation than stainless steel K-Files (Griffiths *et al.* 2001, Alovisi *et al.* 2017). The results for apical canal transportation in the present study confirm the findings of these studies.

In addition to the canal anatomy, the cross-sectional design, design of the instrument tip and stiffness of the file have been identified as factors potentially influencing preparation outcomes (Hülsmann *et al.* 2003, Iqbal *et al.* 2006). Griffiths *et al.* (2001) found a particularly high incidence of zips in acute apical curves associated with instruments with actively cutting tips. The differences in tip design between the NiTi rotary glide path files used here and stainless steel K-Files might be the main reason for the differences in the results presented in this study. Cross-sectional design influences various factors that will affect the stress distribution, polar moment of inertia, depth of the flute, area of the continuous inner core and radial land and peripheral surface ground (Iqbal *et al.* 2006).

The relative stiffness of stainless steel K-Files explains why these instruments exhibit a poor centring ability and higher apical canal transportation values in this study examining curved canals (Pasqualini *et al*. 2012). The high flexibility of NiTi rotary instruments is related to the low modulus of elasticity and to the super-elastic behaviour of this alloy (Walia *et al*. 1988). The performance of stainless steel K-Files might also be attributed to differences in the final apical preparation sizes among the three groups tested in this study. The final KF used for glide path enlargement was a size 20, while size 14 was used for OG and size 16 for PG. The centring and transportation changes created by glide path preparation instruments might be exacerbated during subsequent shaping. Through shaping, the long axis of a curved root canal will be displaced and in this way the angle of curvature will be decreased, which will result in the straightening of the original curvature of the canal.

In this study the highest volume of dentine removed was exhibited by PG. However, there were no significant volume differences between the three groups. The present findings are in keeping with those of a previous study that reported similar volume increases during glide path management with PathFiles and the ProGlider instrument (Kirchhoff *et al.* 2015). A CBCT study by Elnaghy & Elsaka (2014) compared the volume of removed dentine, transportation, and centring ability of ProTaper Next with and without glide path preparation. Elnaghy & Elsaka (2014) found that there were no significant differences among the tested groups with regard to the volume of removed dentine. However, ProTaper Next without a glide path showed a higher mean volume of removed dentine than the other tested groups (Elnaghy & Elsaka 2014). They concluded that a glide path preserving the original canal anatomy, with fewer canal aberrations and the lowest variation in canal geometry and centring, particularly at the apical level, might provide more favourable conditions for the subsequent shaping phase.

The benefits of mechanical glide path enlargement have been shown in various studies (Berutti *et al.* 2004, 2009). According to some authors, however, there are no demonstrable differences between manual and rotary glide path techniques (Roland *et al.* 2002). De Oliveira Alves *et al.* (2012) used the double digital radiograph technique to examine apical transportation after glide path preparation of curved root canals with K-Files, PathFiles, and Mtwo instruments. These findings are consistent with those of Bürklein & Schäfer (2013), who consider both techniques clinically reliable. Bürklein &

Schäfer (2013) reviewed various studies examining instrumentation techniques and concluded that the centring ratio and canal transportation effects of glide path preparation with K-Files are not significantly exacerbated by shaping. These authors suggest that preparing a manual glide path with stainless steel K-Files should still be considered a valid technique when compared with NiTi rotary glide path systems.

Conclusion

One-G and ProGlider displayed significantly higher mean centring ratios at the apical, midroot, and coronal levels than K-Files. Apical canal transportation ratio values after glide path enlargement were significantly higher for K-Files than for One-G and ProGlider. All glide path preparation groups resulted in similar changes in canal volume.

Conflict of interest

The authors state explicitly that there is no conflict of interest in connection with this article.

References

Alovisi M, Cemenasco A, Mancini L *et al.* (2017) Micro-CT evaluation of several glide path techniques and ProTaper Next shaping outcomes in maxillary first molar curved canals. *International Endodontic Journal* **50**, 387–97.

Berutti E, Negro AR, Lendini M, Pasqualini D (2004) Influence of manual preflaring and torque on the failure rate of ProTaper rotary instruments. *Journal of Endodontics* **30**, 228–30.

Berutti E, Cantatore G, Castellucci A *et al.* (2009) Use of nickel-titanium rotary PathFile to create the glide path: comparison with manual preflaring in simulated root canals. *Journal of Endodontics* **35**, 408–12.

Bürklein S, Schäfer E (2013) Critical evaluation of root canal transportation by instrumentation.

Endodontic Topics **29**, 110–24.

Cheung GS, Liu CS (2009) A retrospective study of endodontic treatment outcome between nickel-titanium rotary and stainless steel hand filing techniques. *Journal of Endodontics* **35**, 938–43.

De Oliveira Alves V, Da Silveira Bueno CE, Cunha RS, Pinheiro SL, Fontana CE, De Martin AS (2012) Comparison among manual instruments and pathfile and mtwo rotary instruments to create a glide path in the root canal preparation of curved canals. *Journal of Endodontics* **38**, 117–20.

Elnaghy AM, Elsaka SE (2014) Evaluation of root canal transportation, centering ratio, and remaining dentin thickness associated with Protaper NEXT instruments with and without glide path. *Journal of Endodontics* **40**, 2053–6.

Gambill JM, Alder M, del Rio CE (1996) Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *Journal of Endodontics* **22**, 369–375.

Griffiths IT, Chassot AL, Nascimento MF, Bryant ST, Dummer PMH (2001) Canal shapes produced sequentially during instrumentation with Quantec SC rotary nickel-titanium instruments: a study in simulated canals. *International Endodontic Journal* **34**, 107–12.

Hashem AAR, Ghoneim AG, Lutfy RA, Foda MY, Omar GAF (2012) Geometric analysis of root canals prepared by four rotary NiTi shaping systems. *Journal of Endodontics* **38**, 996–1000.

Hülsmann M, Herbst U, Schäfers F (2003) Comparative study of root-canal instruments using Lightspeed and Quantec SC rotary NiTi instruments. *International Endodontic Journal* **36**, 748–56.

Hülsmann M, Peters OA, Dummer PMH (2005) Mechanical preparation of root canals: shaping goals, techniques and means. *Endodontic Topics* **10**, 30–76.

Iqbal MK, Kohli MR, Kim JS (2006) A retrospective clinical study of incidence of root canal instrument separation in an endodontics graduate program: a PennEndo database study. *Journal of Endodontics* **32**, 1048–52.

Kirchhoff AL, Chu R, Mello I, Garzon ADP, Dos Santos M, Cunha RS (2015) Glide path management with single- and multiple-instrument rotary systems in curved canals: A micro-computed tomographic study. *Journal of Endodontics* **41**, 1880–3.

Mounce RE (2005) Endodontic K-files: invaluable endangered species or ready for the Smithsonian? *Dentistry Today* **24**, 102–4.

Paleker F, Van der Vyver PJ (2016) Comparison of canal transportation and centering ability of K-files, ProGlider File, and G-Files: A micro-computed tomography study of curved root canals. *Journal of Endodontics* **42**, 1105–9.

Pasqualini D, Bianchi CC, Paolino DS *et al* (2012) Computed micro-tomographic evaluation of glide path with nickel-titanium rotary PathFile in maxillary first molars curved canals. *Journal of Endodontics* **38**, 389–93.

Pasqualini D, Alovisi M, Cemenasco A *et al* (2015) Micro-computed tomography evaluation of ProTaper next and BioRace shaping outcomes in maxillary first molar curved canals. *Journal of Endodontics* **41**, 1706–10.

Pruett JP, Clement DJ, Carnes DL Jr (1997) Cyclic fatigue testing of nickeltitanium endodontic instruments. *Journal of Endodontics* **23**, 77–85.

Rhodes JS, Pitt Ford TR, Lynch PJ, Liepins PJ, Curtis RV (1999) Micro-computed tomograpy: a new tool for experimental endodontology. *International Endodontic Journal* **32**, 165–70.

Roland DD, Andelin WE, Browning DF, Hsu GHR, Torabinejad M (2002) The effect of preflaring on the rates of separation for 0.04 taper nickel titanium rotary instruments. *Journal of Endodontics* **28**, 543–5.

Tasdemir T, Aydemir H, Inan U, Ünal O (2005) Canal preparation with Hero 642 rotary Ni-Ti instruments compared with stainless steel hand K-file assessed using computed tomography. *International Endodontic Journal* **38**, 402–8.

Varela-Patiño P, Martin-Biedma B, Liébana CR, Cantatore G, Bahillo JG (2005) The influence of a manual glide path on the separation rate of NiTi rotary instruments. *Journal of Endodontics* **31**, 114–6.

Walia HM, Brantley WA, Gerstein H (1988) An initial investigation of the bending and torsional properties of Nitinol root canal files. *Journal of Endodontics* **14**, 346–51.

Alovisi M, Cemenasco A, Mancini L *et al* (2017) Micro-CT evaluation of several glide path techniques and ProTaper Next shaping outcomes in maxillary first molar curved canals. *International Endodontic Journal* **50**, 387–97.

Berutti E, Negro AR, Lendini M, Pasqualini D (2004) Influence of manual preflaring and torque on the failure rate of ProTaper rotary instruments. *Journal of Endodontics* **30**, 228–30.

Berutti E, Cantatore G, Castellucci A *et al* (2009) Use of nickel-titanium rotary PathFile to create the glide path: comparison with manual preflaring in simulated root canals. *Journal of Endodontics* **35**, 408–12.

Bürklein S, Schäfer E (2013) Critical evaluation of root canal transportation by instrumentation. *Endodontic Topics* **29**, 110–24.

Cheung GS, Liu CS (2009) A retrospective study of endodontic treatment outcome between nickel-titanium rotary and stainless steel hand filing techniques. *Journal of Endodontics* **35**, 938–43.

De Oliveira Alves V, Da Silveira Bueno CE, Cunha RS, Pinheiro SL, Fontana CE, De Martin AS (2012) Comparison among manual instruments and pathfile and mtwo rotary instruments to create a glide path in the root canal preparation of curved canals. *Journal of Endodontics* **38**, 117–20.

Elnaghy AM, Elsaka SE (2014) Evaluation of root canal transportation, centering ratio, and remaining dentin thickness associated with Protaper NEXT instruments with and without glide path. *Journal of Endodontics* **40**, 2053–6.

Gambill JM, Alder M, del Rio CE (1996) Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. *Journal of Endodontics* **22**, 369–75.

Griffiths IT, Chassot AL, Nascimento MF, Bryant ST, Dummer PMH (2001) Canal shapes produced sequentially during instrumentation with Quantec SC rotary nickel-titanium instruments: a study in simulated canals. *International Endodontic Journal* **34**, 107–12.

Hashem AAR, Ghoneim AG, Lutfy RA, Foda MY, Omar GAF (2012) Geometric analysis of root canals prepared by four rotary NiTi shaping systems. *Journal of Endodontics* **38**, 996–1000.

Hülsmann M, Herbst U, Schäfers F (2003) Comparative study of root-canal instruments using Lightspeed and Quantec SC rotary NiTi instruments. *International Endodontic Journal* **36**, 748–56.

Hülsmann M, Peters OA, Dummer PMH (2005) Mechanical preparation of root canals: shaping goals, techniques and means. *Endodontic Topics* **10**, 30–76.

Iqbal MK, Kohli MR, Kim JS (2006) A retrospective clinical study of incidence of root canal instrument separation in an endodontics graduate program: a PennEndo database study. *Journal of Endodontics* **32**, 1048–52.

Kirchhoff AL, Chu R, Mello I, Garzon ADP, Dos Santos M, Cunha RS (2015) Glide path management with single- and multiple-instrument rotary systems in curved canals: A micro-computed tomographic study. *Journal of Endodontics* **41**, 1880–3.

Mounce RE (2005) Endodontic K-files: invaluable endangered species or ready for the Smithsonian? *Dentistry Today* **24**, 102–4.

Paleker F, Van der Vyver PJ, (2016) Comparison of canal transportation and centering ability of K-files, ProGlider File, and G-Files: A micro-computed tomography study of curved root canals. *Journal of Endodontics* **42**, 1105–9.

Pasqualini D, Bianchi CC, Paolino DS *et al* (2012) Computed micro-tomographic evaluation of glide path with nickel-titanium rotary PathFile in maxillary first molars curved canals. *Journal of Endodontics* **38**, 389–93.

Pasqualini D, Alovisi M, Cemenasco A *et al* (2015) Micro-computed tomography evaluation of

ProTaper next and BioRace shaping outcomes in maxillary first molar curved canals. *Journal of Endodontics* **41**, 1706–10.

Rhodes JS, Pitt Ford TR, Lynch PJ, Liepins PJ, Curtis RV (1999) Micro-computed tomograpy: a new tool for experimental endodontology. *International Endodontic Journal* **32**, 165–70.

Roland DD, Andelin WE, Browning DF, Hsu GHR, Torabinejad M (2002) The effect of preflaring on the rates of separation for 0.04 taper nickel titanium rotary instruments. *Journal of Endodontics* **28**, 543–5.

Tasdemir T, Aydemir H, Inan U, Ünal O (2005) Canal preparation with Hero 642 rotary Ni-Ti instruments compared with stainless steel hand K-file assessed using computed tomography. *International Endodontic Journal* **38**,402–8.

Varela-Patiño P, Martin-Biedma B, Liébana CR, Cantatore G, Bahillo JG (2005) The influence of a manual glide path on the separation rate of NiTi rotary instruments. *Journal of Endodontics* **31**, 114–6.

Walia HM, Brantley WA, Gerstein H (1988) An initial investigation of the bending and torsional properties of Nitinol root canal files. *Journal of Endodontics* **14**, 346–51.

West J (2006) Endodontic update 2006. *Journal of Esthetic and Restorative Dentistry* **18**, 280–300.

Young GR, Parashos P, Messer HH (2007) The principles of techniques for cleaning root canals. *Australian Dental Journal* **52**, 52–63.