INTERNATIONAL ENDODONTIC JOURNAL

doi:10.1111/iej.12943

REVIEW

Association of manual or engine-driven glide path preparation with canal centring and apical transportation: a systematic review

R. C. Hartmann[1], O. A. Peters[2], J. A. P. de Figueiredo[1] & G. Rossi-Fedele[3]

[1]Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil; [2]Department of Endodontics, Arthur A. Dugoni School of Dentistry, University of the Pacific, San Francisco, CA, USA; and [3]Adelaide Dental School, The University of Adelaide, Adelaide, SA, Australia

Abstract

Hartmann RC, Peters OA, de Figueiredo JAP, Rossi-Fedele G. Association of manual or engine-driven glide path preparation with canal centring and apical transportation: a systematic review. *International Endodontic Journal*, **51**, 1239–1252, 2018.

The role and effect of glide path preparation in root canal treatment remain controversial. This systematic review aims to compare apical transportation and canal centring of different glide path preparation techniques, with or without subsequent engine-driven root canal preparation. A database search in PubMed, PubMed Central, Embase, Scopus, EBSCO Dentistry & Oral Sciences Source and Virtual Health Library was conducted, using appropriate key words to identify the effect of glide path preparation (or its absence) on apical transportation and canal centring. An assessment for the risk of bias in included studies was carried out. Amongst 2146 studies, 18 satisfied the inclusion criteria. Nine studies assessed glide path preparation *per se*, comparing apical transportation and canal centring of rotary systems and/or manual files; eleven further investigations examined the efficacy of the glide path prior to final canal preparation with different engine-driven systems. Risk of bias and other study design features with potential influence on study outcomes and clinical implications were assessed. Based on the available evidence, and within the limitation of the studies included, preparation of a glide path using rotary sequences performs similarly (in most of the component studies) or significantly better than manual preparation when assessing apical transportation or canal centring. When compared to the absence of a glide path, canal shaping following glide path preparation was of similar, or significantly better quality, in regard to apical transportation or canal centring.

Keywords: apical transportation, centralization, centring, glide path, root canal shaping, systematic review.

Received 25 January 2018; accepted 22 April 2018

Introduction

After canal preparation, the canal shape should ideally enclose the original main canal whilst avoiding preparation errors. Preparation errors are associated with difficulties in providing adequate cleaning, irrigation and filling of root canals, thus increasing the risk of failure (Gorni & Gagliani 2004, Lin *et al.* 2005). Moreover, a major shift from the original canal axis may result in perforation and/or weakening of tooth structure. Therefore, controlled intraradicular dentine removal is desirable (Gulabivala & Ng 2014).

Due to the tendency of files to return to their original shape and to cut along their entire length and surface area (Gulabivala & Ng 2014), there is a propensity to over prepare root canals towards the outer curvature in the apical portion and the inner

Correspondence: Rafael Chies Hartmann, School of Dentistry, Pontifical Catholic University of Rio Grande do Sul, Building 6, 6681 Ipiranga Avenue, Porto Alegre Zip Code: 90619-900, Rio Grande do Sul, Brazil. (Tel/Fax: +55 51 3320-3538; e-mail: rafaelhart@gmail.com).

curve in the more coronal parts in multi-rooted teeth (Peters 2004).

The preparation of a glide path after canal negotiation with small, flexible hand files aims to prevent breakage of engine-driven nickel-titanium instruments and reduce deviations of the canals axis, by allowing instruments to travel through the canals passively (Elnaghy & Elsaka 2014, Dhingra *et al.* 2015, Alovisi *et al.* 2017). There is no current consensus in the definition of glide path. A commonly quoted definition is 'a smooth radicular tunnel from canal orifice to physiologic terminus (foraminal constriction)' (West 2010). Further remarks from the same author include 'Its minimal size should be a "super loose No. 10" endodontic file', and 'The glide path must be discovered if already present in the endodontic anatomy or prepared if it is not present. The glide path can be short or long, narrow or wide, essentially straight or curved' (West 2010).

There appears to be no alternative definition of a glide path. Recently, several rotary nickel-titanium files have been proposed to achieve the so-called glide path (Berutti *et al.* 2009, Gergi *et al.* 2010, Pasqualini *et al.* 2015).

The role of a glide path prior to engine-driven canal instrumentation has been emphasized in endodontic literature; however, basic research studies offer mixed conclusions. Therefore, the purpose of this systematic review was twofold:

- To compare apical transportation and centring of different glide path preparation techniques, with or without final canal shaping.
- To compare apical transportation and centring following final shaping in the presence or absence of a glide path.

Materials and methods

Literature search strategy

A database search was conducted to find published articles related to the creation of a glide path during root canal preparation in the databases PubMed, PubMed Central (PMC), Embase, Scopus, EBSCO Dentistry & Oral Sciences Source (DOSS) and Virtual Health Library (VHL), using a combination of the following terms: [glide path] AND [root canal]. The search fields were 'Text word or all text' in PubMed, PMC and DOSS, whilst 'Title, Abstract and Keywords' in Scopus and VHL, and 'all fields' in Embase. No restrictions were made based on publication year. Final database search was completed on the 3rd of October 2017. The search results were imported into a computerized database, combined and duplicated publications were eliminated.

Inclusion criteria

The question under review was framed according to the PICO format (Population; Intervention; Comparison; Outcome): P unprepared root canals, I glide path preparation, C alternative glide path preparation or no glide path preparation, O apical transportation or deviation from the canal axis in the presence or absence of final preparation.

Studies were included in the systematic review if they met the following criteria:

- Publication in English or in other Latin alphabets
- Human teeth
- At least one group receiving glide path preparation
- Clinical or basic research presented
- Same nickel-titanium instrumentation used for root canal shaping following glide path preparation, if present
- Apical transportation and/or canal centring as outcome(s)

Articles were excluded when inclusion criteria were not met or when they were review articles or expert opinion. Case or clinical technique reports were also excluded.

The reference lists of those articles included were checked for additional articles of relevance, using the same criteria.

Evaluation of the selected studies

Titles and abstracts of the studies were read by two investigators (RCH, GRF) and if insufficiently clear, the full article was read for accuracy of data gathering. After initial screening of the title and abstract, full text evaluation of the relevant articles was performed to confirm eligibility against the inclusion criteria. Disagreements concerning inclusion of a study were discussed until decision was obtained by consensus. Two reviewers (RCH, GRF) performed data extraction.

The following information was extracted for each study and recorded on a data collection sheet: author (s), year of publication, journal, root used, root length, root canal curvature (assessment method and range), sample size, imaging method, protocol of root canal preparation, irrigation solutions and differences amongst the groups on transportation and centring of the root canal preparation. Authors of the included studies were contacted for clarification and/or requested to provide further information as needed.

Methodological quality assessment

The experimental quality of the included studies was evaluated by two independent reviewers (RCH, GRF) using a customized version of a previously published risk of bias assessment tool (Tsesis *et al.* 2015). The assessment included the following:

- Inclusion criteria strictness [Root canal curvature range (Adequate: less than 10°; Unclear: between 10° and 30°; Inadequate: more than 30°)]
- Allocation concealment [Random sequence generation (Adequate: yes; Unclear: not specified; Inadequate: no)]
- Manual glide path comparison group (Adequate: yes; Inadequate: no)
- *A priori* sample size calculation (Adequate: yes; Unclear: not specified; Inadequate: no)
- Canal preparation performed by the same operator or by calibrated operators (Adequate: yes; Unclear: not specified; Inadequate: no)
- Blinding of outcome assessment [Examiner(s) concealment of allocation (Adequate: yes; Unclear: not specified; Inadequate: no)]
- Observer(s) reliability assessment (Adequate: yes; Unclear: not specified; Inadequate: no)
- Attrition bias [Sample loss reported (Adequate: yes; Unclear: not specified; Inadequate: no)]

To summarize the validity of studies, they were grouped into the following categories:

- Low risk of bias (i.e. studies that met at least six of the quality criteria)
- Moderate risk of bias (i.e. studies that met between three and five of the quality criteria)
- High risk of bias (i.e. studies that met at less than three of the quality criteria)

Disagreements concerning study scores were discussed until a decision was obtained by consensus.

Results

After removal of duplicates, the database search strategy yielded a total of 2146 studies. Amongst the 2146 publications, 18 satisfied the inclusion criteria. The results of the search strategy are presented in Figure 1, as well as details and main characteristics of the included studies (Tables 1 and 2). Amongst these, nine compared different glide path preparation methods *per se* (Alves *et al.* 2012, Pasqualini *et al.* 2012a, D'Amario *et al.* 2013, Dhingra & Manchanda 2014, Kirchhoff *et al.* 2015, Turker & Uzunoglu 2015, Berástegui *et al.* 2016, Paleker & van der Vyver 2016, Alovisi *et al.* 2017), whilst 11 compared glide path preparation(s) or no glide path preparation prior to a common mechanical shaping protocol (Uroz-Torres *et al.* 2009, Meireles *et al.* 2012, Elnaghy & Elsaka 2014, Zanette *et al.* 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Ocampo *et al.* 2015, Turker & Uzunoglu 2015, Amaral *et al.* 2016, Coelho *et al.* 2016, Alovisi *et al.* 2017). The corresponding authors of seven studies were contacted for clarification (Alves *et al.* 2012, Pasqualini *et al.* 2012a, Dhingra & Manchanda 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Turker & Uzunoglu 2015, Alovisi *et al.* 2017), with only two providing the requested information (Carvalho *et al.* 2015, Alovisi *et al.* 2017).

The component studies included 981 canals in total. Of these, 471 canals were used to assess glide path preparation *per se* (i.e. prior to Ni-Ti mechanical instrumentation). The glide path was created using hand files [*K-files* 19.75% (n = 93) (Alves *et al.* 2012, Pasqualini *et al.* 2012a, D'Amario *et al.* 2013, Turker & Uzunoglu 2015, Paleker & van der Vyver 2016, Alovisi *et al.* 2017)] or one amongst six rotary systems [*PathFile* 32.48% (n = 153) (Alves *et al.* 2012, Pasqualini *et al.* 2012a, D'Amario *et al.* 2013, Dhingra & Manchanda 2014, Kirchhoff *et al.* 2015, Turker & Uzunoglu 2015, Berástegui *et al.* 2016, Alovisi *et al.* 2017); *ProGlider* 20.17% (n = 95) (Kirchhoff *et al.* 2015, Turker & Uzunoglu 2015, Berástegui *et al.* 2016, Paleker & van der Vyver 2016, Alovisi *et al.* 2017); *V GlidePath 2* 10.62% (n = 50) (Dhingra & Manchanda 2014); *G-File* 9.55% (n = 45) (D'Amario *et al.* 2013, Paleker & van der Vyver 2016); *Race ISO 10* 4.25% (n = 20) (Berástegui *et al.* 2016); *MTwo* 3.18% (n = 15) (Alves *et al.* 2012)].

A total of 585 canals were included in studies comparing the efficacy of glide path prior to the final preparation with different systems [*Path File* 32.14% (n = 188) (Meireles *et al.* 2012, Elnaghy & Elsaka 2014, Zanette *et al.* 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Ocampo *et al.* 2015, Turker & Uzunoglu 2015, Amaral *et al.* 2016, Alovisi *et al.*

2017); *K-file* 17.61% (*n* = 103) (Uroz-Torres *et al.* 2009, Meireles *et al.* 2012, Carvalho *et al.* 2015, Turker & Uzunoglu 2015, Alovisi *et al.* 2017); *ProGlider* 7.89% (*n* = 45) (Elnaghy & Elsaka 2014, Turker & Uzunoglu 2015, Alovisi *et al.* 2017)], with the remaining 42.56% (*n* = 249) (Uroz-Torres *et al.* 2009, Meireles *et al.* 2012, Elnaghy & Elsaka 2014, Zanette *et al.* 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Ocampo *et al.* 2015, Turker & Uzunoglu 2015, Amaral *et al.* 2016, Coelho *et al.* 2016) only used the shaping system in absence of glide path preparation. *ProTaper Next* was the most used system 36.24% of canals (*n* = 212) (Elnaghy & Elsaka 2014, Ocampo *et al.* 2015, Turker & Uzunoglu 2015, Alovisi *et al.* 2017); *WaveOne* in 28.38% of canals (*n* = 166) (Dhingra *et al.* 2015, Amaral *et al.* 2016, Coelho *et al.* 2016); *ProTaper Universal in* 14.53% (*n* = 85) (Meireles *et al.* 2012, Zanette *et al.* 2014); *Reciproc* in 11.79% (*n* = 69) (Carvalho *et al.* 2015, Coelho *et al.* 2016); *MTwo* in 6.84% (*n* = 40) (Uroz-Torres *et al.* 2009). Finally, 13 samples (2.22%) were not prepared and used as a negative control (Carvalho *et al.* 2015).

Preoperative root canal morphology assessment and characteristics of the samples included are reported in Table 1. The canal curvatures ranged between 10° and 76°, with the more common angles having values near to 25°. Half of the studies accepted variation of curvature angles of 10° (Alves *et al.* 2012, D'Amario *et al.* 2013, Elnaghy & Elsaka 2014, Zanette *et al.* 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Turker & Uzunoglu 2015, Amaral *et al.* 2016, Paleker & van der Vyver 2016), whereas only two measured the curvature ratios (Carvalho *et al.* 2015, Alovisi *et al.* 2017).

Evaluation methods and outcome measurement techniques are reported in Table 2. Due to the variety of methods and techniques used to measure the outcomes of the apical transportation and centring during the root canal preparations, and the limited access to mean and standard deviations data, it was not possible to standardize the research data and

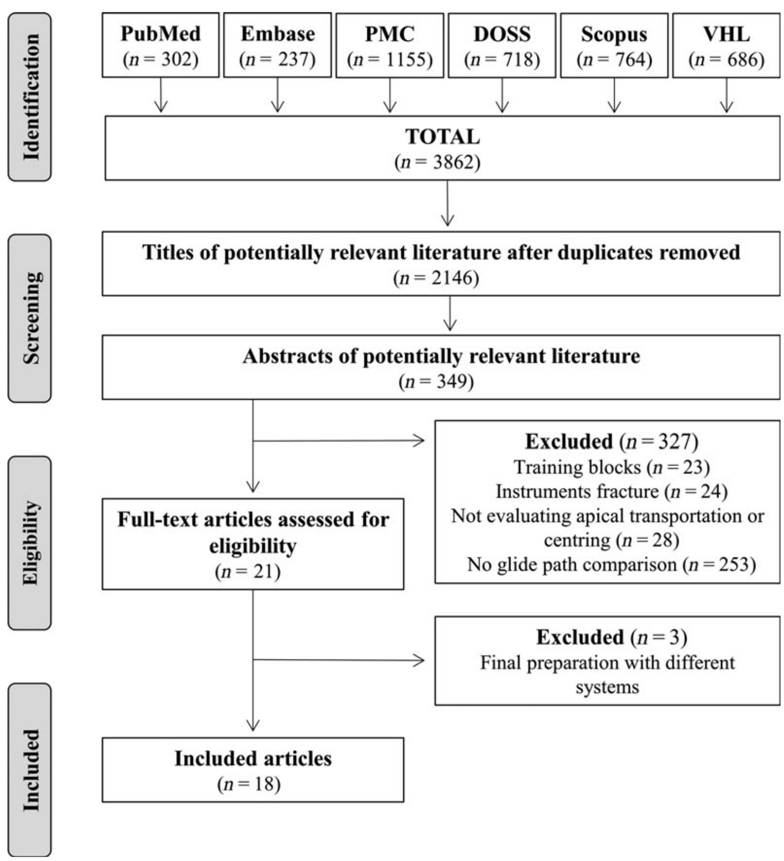

Figure 1 Flowchart of the methodology.

Table 1 Main characteristics of the included studies: sample characteristics

Study	Root type	Total number of teeth or canals	Assessment of curvature: Technique	Range	Radius	Root length	Sample size per group (canals)
Uroz-Torres *et al.* (2009)	Mesial root of mandibular molars	40	Pruett	25°–76°		12 mm	10 10 10 10
Alves *et al.* (2012)	Mesial root of mandibular molars	45	Pruett	25°–35°		>12 mm	15 15 15
Meireles *et al.* (2012)	Mesial root of mandibular molars	45	Schneider	20°–55°		20 mm	15 15 15
Pasqualini *et al.* (2012a,b)	Buccal roots of maxillary molars	8	Not specified	20°–55°			8 8
D'Amario *et al.* (2013)	Mesial root of mandibular molars	45	Pruett	25°–35°		12 mm	15 15 15
Dhingra & Manchanda (2014)	Mesial root of mandibular molars	100	Schneider	20°–40°			50 50
Elnaghy & Elsaka (2014)	Mesial root of mandibular molars	60	Schneider	25°–35°		13,16,20 & 21 mm	20 20 20
Zanette *et al.* (2014)	Mesio-buccal root of maxillary molars	40	Schafer	25°–35°			20 20
Carvalho *et al.* (2015)	Mesial root of mandibular molars	52	Schneider	20°–30°	<10 mm Pruett et al.	16 mm	13 13 13 13
Dhingra *et al.* (2015)	Mesial root of mandibular molars	100	Schneider	20°–30°			50 50
Kirchhoff *et al.* (2015)	Mesial root of mandibular molars	20	Schneider	≈34°		16 mm	20 20
Ocampo *et al.* (2015)	Buccal root of maxillary molars	67	Schneider	15°–20°			34 33
Turker & Uzunoglu (2015)	Mesial root of mandibular molars	40	Schafer	25°–35°		12 mm	10 10 10 10
Amaral *et al.* (2016)	Mesial root of mandibular molars	36	Schneider	10°–20°		21 mm	12 12 12
Berástegui *et al.* (2016)	Mesial root of mandibular molars	60	Schneider	25°–60°			20 20 20
Coelho *et al.* (2016)	Mesial root of mandibular molars	60	Schneider	25°–39°		12 mm	15 15 15 15
Paleker & van der Vyver (2016)	Mesial root of mandibular molars	90	Schneider	20°–30°			30 30 30
Alovisi *et al.* (2017)	Mesio-buccal root of maxillary molars	45	Schneider	25°–40°	>4 mm <8 mm Gu *et al.* (2010)	12 ± 2 mm	15 15 15

Table 2 Main characteristics of the included studies: methodology and results

Study	Groups	Instrumentation protocol	Imaging technique	Evaluation method	Reference	Formula Centring	Formula Transportation	Centring	Transportation
Uroz-Torres *et al.* (2009)	25-44GP: Manual+Mtwo 25-44:NGP:Mtwo 45-76GP: Manual+Mtwo 45-76:NGP:Mtwo	K-File #08, #10 & #15+ MT #30/05 MT #30/05 K-File #08, #10 & #15+ MT #30/05 MT #30/05	DR	Distance between pre and post instrumentation radiographs superimposed with #15 K-File and 30/05 Mtwo instrument on the canal	Iqbal *et al.* (2003)				Not statistically significant
Alves *et al.* (2012)	M:K-File MT:Mtwo PF:PathFile	K-File #10, #15 & #20 MT #10/04, #15/05 & #20/06 PF #13, #16 & #19	DR	Distance between pre and post instrumentation radiographs superimposed with #15 K-File			Personal opinion of 3 endodontists about of the presence of aberrations		Not statistically significant
Meireles *et al.* (2012)	G1-ProTaper G2-K-File+ ProTaper G3 - PathFile+ Protaper	K-File #15 & #20+ PTU #25 K-File #15, #20 & #25+ PTU #25 K-File #15 & #20+ PF #13, #16 & #19+ PTU #25	CR	Distance between pre and post instrumentation radiographs superimposed with #15 K-File					Not statistically significant
Pasqualini *et al.* (2012a,b)	PF:PathFile KF:K-File	PF #13, #16 & #19 K-File #08, #10, #12, #15, #17 & #20	Micro-CT	Axial images at 1 mm from the apical foramen, and at the maximum curvature were analyzed					Not statistically significant
D'Amario *et al.* (2013)	M:K-File GF:G-File PF:PathFile	K-File #10, #15 & #20 GF #12/03 & #17/03 PF #13, #16 & #19	DR	Distance between pre and post instrumentation radiographs superimposed with #15 K-File on the canal			A blinded endodontist measure the extent of the apical transportation		Not statistically significant
Dhingra & Manchanda (2014)	PF:PathFile VGP2: V GlidePath 2	PF #13, #16 & #19 VGP2 #13 & #17	CBCT	Thickness of Mesial and distal dentinal walls on selected axial images (0, 1, 2, 3, 5 and 7 mm)	Gambill *et al.* (1996)	$(m^1-m^2)/(d^1-d^2)$ or $(d^1-d^2)/(m^1-m^2)$ numerator was the smaller of the two numbers	$(m^1-m^2)-(d^1-d^2)$	Not statistically significant	PathFile presented less transportation
Elnaghy & Elsaka (2014)	PTN:ProTaper Next PG/PTN: ProGlider+PTN PF/PTN: PathFile+PTN	PTU SX+PTN #25 PG#16/02+ PTN #25 PF #13 & #16+ PTN #25	CBCT	3 cross-section levels that corresponded to 3, 5, and 7 mm distance from the apical end	Gambill *et al.* (1996)	$(m^1-m^2)/(d^1-d^2)$ or $(d^1-d^2)/(m^1-m^2)$ numerator was the smaller of the two numbers	$(m^1-m^2)-(d^1-d^2)$	Not statistically significant	PG not statistically significant different PF Without glide path presented more apical transportation

Table 2 Continued

Study	Groups	Instrumentation protocol	Imaging technique	Evaluation method	Reference	Formula Centring	Formula Transportation	Centring	Transportation
Zanette *et al.* (2014)	GA:PathFile+ ProTaper Universal	PF #13, #16 & #19+ PTU #40	DR	Distance between pre and post instrumentation radiographs superimposed with #15 K-File on the canal. 3 cross-section levels that corresponded to 1, 2 and distance from the apical end			The apical transportation was measured, in both vertical/height and horizontal/ width directions, and the thickness of buccal, palatal, mesial and distal walls at 3 l ocations		Not statistically significant
	GB:ProTaper Universal	K-File+PTU #40	CBCT						
Carvalho *et al.* (2015)	KF/RS-10/15K-File+Reciproc	K-File #10 & #15+ RP #25	CBCT	The extension of the pre- and post-preparation root canal were measured by a blind calibrated examiner		$(m^1-m^2)/(d^1-d^2)$ or $(d^1-d^2)/(m^1-m^2)$ numerator was the smaller of the two numbers	$(m^1-m^2)-(d^1-d^2)$	Not statistically significant	Not statistically significant
	NGP/RS-just Reciproc	RP #25							
	PF/RS-PathFile+ Reciproc	PF #13, #16 & #19+ RP #25							
	NP-no Preparation	No Preparation							
Dhingra *et al.* (2015)	WaveOne	WO #25	CBCT	Thickness of Mesial and distal dentinal walls on selected axial images (0, 1, 2, 3, 5 and 7 mm)	Gambill *et al.* (1996)	$(m^1-m^2)/(d^1-d^2)$ or $(d^1-d^2)/(m^1-m^2)$ numerator was the smaller of the two numbers	$(m^1-m^2)-(d^1-d^2)$	With PathFile presented better centring	PathFile presented less transportation
	PathFile+WaveOne	PF #13, #16 & #19+ WO #25							
Kirchhoff *et al.* (2015)	ProGlider	PG #16	Micro-CT	Mean measurement values of two calibrated blinded examiners on cross-sectional images	Gergi *et al.* (2010)		$(m^1-m^2)-(d^1-d^2)$		Not statistically significant
	PathFile	PF #13, #16 & #19							
Ocampo *et al.* (2015)	ProTaper Next	PTN #25	CBCT	The dentine thickness was measured both in Mesial and distal sides of roots pre-and post-instrumentation	Gergi *et al.* (2010)	$(m^1-m^2)/(d^1-d^2)$ or $(d^1-d^2)/(m^1-m^2)$ numerator was the bigger of the two numbers	$(m^1-m^2)-(d^1-d^2)$	Not statistically significant	Not statistically significant
	ProTaper Next+PathFile	PF #13, #16 & #19+ PTN #25							
Turker & Uzunoglu (2015)	M:Manual+PTN	K-File #10, #15 & #20+ PTN #25	DR	Distance between pre and post instrumentation radiographs superimposed with #15 K-File on the canal			A blinded endodontist measure the extent of the apical transportation		Not statistically significant
	PF:PathFile+PTN	PF #13, #16 & #19+ PTN #25							
	PG:ProGlider+PTN	PG #16/02+ PTN #25							
	PTN:ProTaper Next	PTN #25							

Table 2 Continued

Study	Groups	Instrumentation protocol	Imaging technique	Evaluation method	Reference	Formula Centring	Formula Transportation	Centring	Transportation
Amaral *et al.* (2016)	PFWO-PathFile+ WaveOne SXWO-SX+ WaveOne WO-WaveOne	PF #13, #16 & #19+ WO #25 PTU SX+WO #25 WO #25	Micro-CT	The mean measurement of 5 layers in each selected third generated a single thickness value of mesial and distal dentine for each canal before and after instrumentation	Gambill *et al.* (1996)	$(m^1-m^2)/(d^1-d^2)$ and $(d^1-d^2)/(m^1-m^2)$ use the smaller of the two numbers obtained	$(m^1-m^2)-(d^1-d^2)$	Not statistically significant	Not statistically significant
Berástegui *et al.* (2016)	PF-PathFile RI-Race ISO 10 PG-ProGlider	PF #13, #16 & #19 RI #10/02, #10/04 & #10/06 PG #16/02	CBCT	Superimposed the preoperative and postoperative sagittal slice images			One blinded examiner measure the extent of the apical transportation on sagittal slice images		Not statistically significant
Coelho *et al.* (2016)	WaveOne+GP WaveOne Reciproc+GP Reciproc	K-File #10, #15 & #20+ WO#25 WO #25 K-File #10, #15 & #20+ RP #25 RP #25	DR	The dentine thickness was measured both in mesial and distal sides of roots pre-and post-instrumentation	Gambill *et al.* (1996)	$(m^1-m^2)/(d^1-d^2)$ Closest to 1 was the most centered one		Not statistically significant	
Paleker & van der Vyver (2016)	KF:K-File GF:G-File PG:ProGlider	K-File # 1 0, #15 & #20 GF #17/03 PG #16/02	Micro-CT	Axial images of 1 and 7 mm from the apical foramen were analyzed by the software		$(x^1-x^2)/y$ Ratios closest to 0 indicated a superior centring ability	Distance between the walls of pre and post instrumentation canals in 8 points (45° each)	KF=GF GF=PG PG presented better centring compared to KF	
Alovisi *et al.* (2017)	PathFile+Pro Taper Next ProGlider+ ProTaper Next K-File+ ProTaper Next	PF #13 & #16+ PTN #25 PG #16/02+ PTN #25 K-File #12 & #15+ PTN #25	Micro-CT	The center of gravity for each scanning slice at the three levels of analysis (A, M and C) was traced, and coordinates on both axes of planar images were recorded	Peters *et al.* (2000)	The average of the x and y-coordinates of all pixels in the selection was automatically traced. Average canal transportation was calculated by the centroid shift before and after instrumentation		KF=PF PF=PG PG presented better centring compared to KF	PG not statistically significant different PF Glide path made with KF presented more transportation

CBCT, Cone beam computer tomography; CR, Conventional radiography; DR, Digital radiography; GF, G-File; KF, K-File; Micro-CT, Micro computed tomography; MT, Mtwo; PF, PathFile; PG, ProGlider; PTN, ProTaper Next; PTU, ProTaper Universal; RI, Race ISO 10; RP, Reciproc; VGP2, V GlidePath 2. The full sequence of PTU, PTN and MT was used, up to the instrument described; WO, WaveOne.

carry out a meta-analysis. Therefore, in the present systematic review, a narrative synthesis was carried out (Joanna Briggs Institute 2015), collating the data in Tables 1 and 2, presenting the relevant results from the component studies.

Of the 18 studies included, four presented a high risk of bias (Pasqualini *et al.* 2012a, Dhingra & Manchanda 2014, Elnaghy & Elsaka 2014, Dhingra *et al.* 2015), 10 showed a moderate risk of bias (Uroz-Torres *et al.* 2009, Meireles *et al.* 2012, Zanette *et al.* 2014, Carvalho *et al.* 2015, Kirchhoff *et al.* 2015, Ocampo *et al.* 2015, Amaral *et al.* 2016, Berástegui *et al.* 2016, Coelho *et al.* 2016, Paleker & van der Vyver 2016), and four had a low risk of bias (Alves *et al.* 2012, D'Amario *et al.* 2013, Turker & Uzunoglu 2015, Alovisi *et al.* 2017) (Figs 2 and 3).

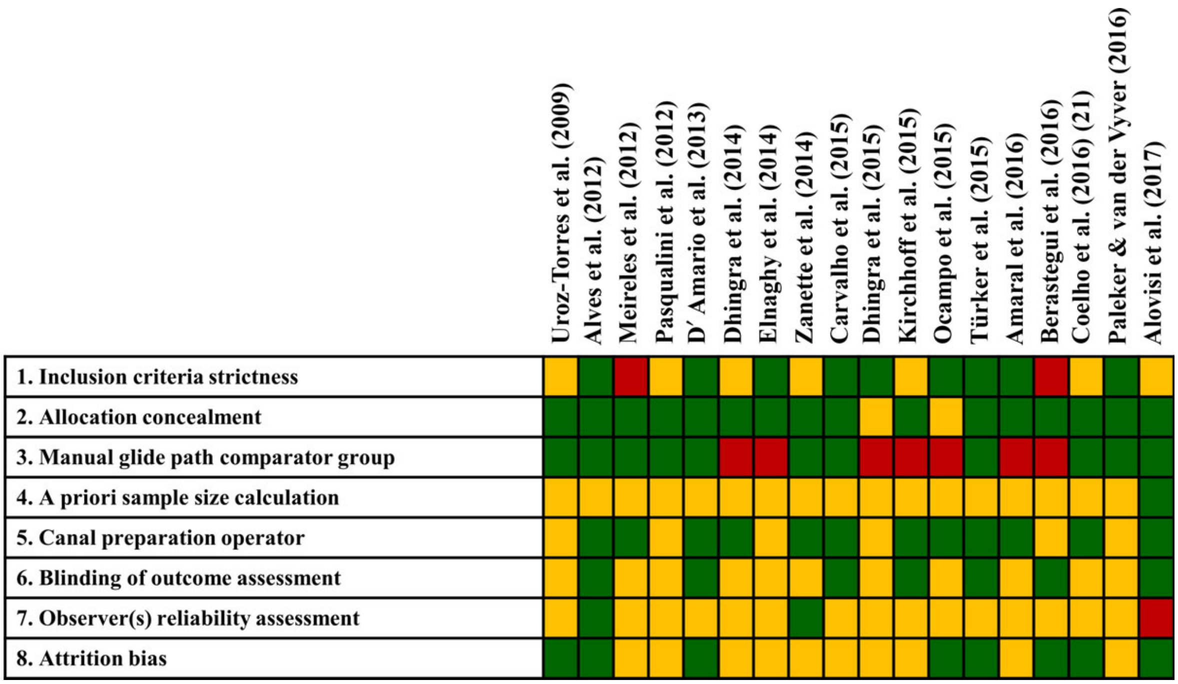

Figure 2 Risk of bias. Risk of bias summary: Reviewers' judgements about each risk of bias item for each included study.

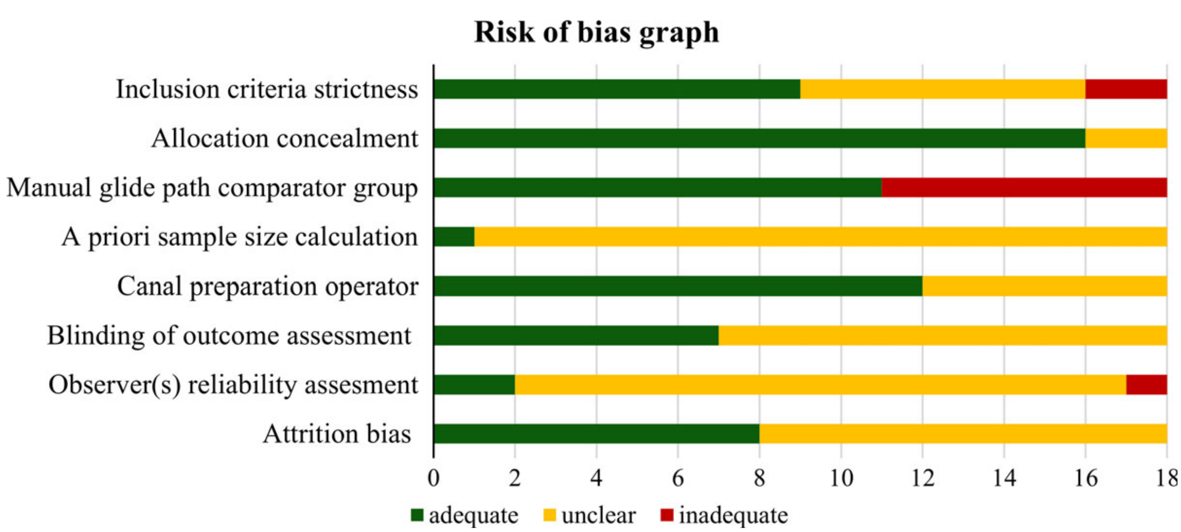

Figure 3 Risk of bias graph: Reviewers' judgements about each risk of bias item presented across all included studies.

Discussion

Preparation of a glide path using rotary sequences performs similarly (in most studies) or significantly better than manual preparation when assessing apical transportation or canal centring. When compared to the absence of a glide path, preparation of a glide path prior to final shaping performed similarly, or significantly better, with regard to apical transportation or canal centring.

All the canals assessed in the component studies received manual instrumentation at least to size 10 to achieve working length determination. In the absence of an established definition of glide path, this step was disregarded. However, it is worth mentioning that no canal was treated with engine-driven files solely in the component studies. Alternatively, preparation of a glide path mechanically in the absence of manual instrumentation has been suggested (Yared 2015).

Effect of final file tip size

The glide path preparation size never coincided with the apical size of the first engine-driven file reaching the same working length in the component studies. In fact, the final files used for glide path preparation were the following dimensions: at least 0.5 mm smaller (Elnaghy & Elsaka 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Amaral *et al.* 2016, Coelho *et al.* 2016), 0.1 or 0.2 mm smaller (Turker & Uzunoglu 2015, Alovisi *et al.* 2017), 0.2 mm larger (Zanette *et al.* 2014, Ocampo *et al.* 2015), 0.3 mm larger (Meireles *et al.* 2012, Turker & Uzunoglu 2015), 0.5 mm larger (Uroz-Torres *et al.* 2009) and 0.8 mm larger (Meireles *et al.* 2012). Thus, no association between the tip size of the final file used for glide path preparation and apical transportation and/or centring following engine-driven preparation was found.

Effect of glide path preparation per se

Nine studies evaluated the efficacy of the glide path preparation *per se* (Alves *et al.* 2012, Pasqualini *et al.* 2012a, D'Amario *et al.* 2013, Dhingra & Manchanda 2014, Kirchhoff *et al.* 2015, Turker & Uzunoglu 2015, Berástegui *et al.* 2016, Paleker & van der Vyver 2016, Alovisi *et al.* 2017). Seven of these compared manual K-files with engine-driven systems to achieve glide path preparation (i.e. PathFile, ProGlider, G-file). K-files performed worse with regard to canal centring ability in two studies (Paleker & van der Vyver 2016, Alovisi *et al.* 2017), and in one on apical transportation (Paleker & van der Vyver 2016). However, in five studies (Alves *et al.* 2012, Pasqualini *et al.* 2012a, D'Amario *et al.* 2013, Kirchhoff *et al.* 2015, Turker & Uzunoglu 2015), K-files were associated with similar results when comparing the apical transportation to the other systems. Therefore, rotary glide path preparation performed similarly to or better than manual preparation.

Two investigations (Dhingra & Manchanda 2014, Berástegui *et al.* 2016) assessed the ability of several engine-driven glide path systems (i.e. PathFile, ProGlider, Race ISO 10, V Glide Path 2). In one study, there were no significant differences on apical transportation when PathFile, Race ISO 10 and ProGlider were compared (Berástegui *et al.* 2016). Similarly, the second study compared PathFile with V Glide Path 2 and revealed no differences on the centring of the preparation, although the PathFile system exhibited less apical transportation (Dhingra & Manchanda 2014). Thus, the different rotary glide path preparation systems performed similarly.

Glide path prior to the final preparation with different systems

Eleven studies (Uroz-Torres *et al.* 2009, Meireles *et al.* 2012, Elnaghy & Elsaka 2014, Zanette *et al.* 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Ocampo *et al.* 2015, Turker & Uzunoglu 2015, Amaral *et al.* 2016, Coelho *et al.* 2016, Alovisi *et al.* 2017) assessed the effect of glide path preparation using various techniques on subsequent root canal shaping with different preparation systems (i.e. ProTaper Next, ProTaper Universal, MTwo, WaveOne, Reciproc). Amongst these, seven studies used manual K-files for comparison (Uroz-Torres *et al.* 2009, Meireles *et al.* 2012, Zanette *et al.* 2014, Carvalho *et al.* 2015, Turker & Uzunoglu 2015, Coelho *et al.* 2016, Alovisi *et al.* 2017). In six of these, no differences were observed in regard to centring ability and apical transportation during subsequent shaping (Uroz-Torres *et al.* 2009, Meireles *et al.* 2012, Zanette *et al.* 2014, Carvalho *et al.* 2015, Turker & Uzunoglu 2015, Coelho *et al.* 2016). However, in one study, the glide path prepared using K-files had the largest effect on centring ability (Alovisi *et al.* 2017). In summary, no differences regarding apical transportation and canal centring were found, even if glide path preparation up to size 15 or 20 was completed by manual instrumentation.

Four studies had a control group without glide path preparation before final root canal shaping (Elnaghy & Elsaka 2014, Dhingra *et al.* 2015, Ocampo *et al.* 2015, Amaral *et al.* 2016). Amongst these, two demonstrated that the absence of glide path increased apical transportation following final shaping with ProTaper Next or WaveOne (Elnaghy & Elsaka 2014, Dhingra *et al.* 2015); conversely, no differences were found in two investigations using the same sequences (Ocampo *et al.* 2015, Amaral *et al.* 2016). When assessing centring ability, no differences were found in three studies (Elnaghy & Elsaka 2014, Ocampo *et al.* 2015, Amaral *et al.* 2016). Therefore, a glide path may be helpful to reduce apical transportation; however, inconsistent results were present amongst the included studies.

Methodological aspects

All the component studies used custom-made jigs or similar to standardize imaging. Periapical radiographs were commonly used to assess root curvature prior to the assays, with one exception which used μCT scanning (Pasqualini *et al.* 2012a). Only two investigations assessed the radius of the curvatures (Carvalho *et al.* 2015, Alovisi *et al.* 2017). It is worth noting that this factor, together with curvature degree, length and location, has an influence on the preparation outcomes (Hülsmann *et al.* 2005).

The imaging technique used may also have affected the results of the component studies. Periapical radiographs were used as a method of evaluation of apical transportation in seven investigations (Uroz-Torres *et al.* 2009, Alves *et al.* 2012, Meireles *et al.* 2012, D'Amario *et al.* 2013, Zanette *et al.* 2014, Turker & Uzunoglu 2015, Coelho *et al.* 2016). Interestingly, these studies found no significant differences amongst the experimental groups. The lack of significant differences can be partly explained by the limited sensitivity of two-dimensional imaging to assess three-dimensional structures. Conversely, when using three-dimensional imaging, some significant differences were found. CBCT was used to assess apical transportation and shaping centring in seven investigations (Dhingra & Manchanda 2014, Elnaghy & Elsaka 2014, Zanette *et al.* 2014, Carvalho *et al.* 2015, Dhingra *et al.* 2015, Turker & Uzunoglu 2015, Berástegui *et al.* 2016), and two studies revealed significant results in regard to final root canal shaping achieved with WaveOne and ProTaper Next and showing better performance when a glide path was prepared (Elnaghy & Elsaka 2014, Dhingra *et al.* 2015). Finally, μCT was employed in five studies (Pasqualini *et al.* 2012a, Kirchhoff *et al.* 2015, Amaral *et al.* 2016, Paleker & van der Vyver 2016, Alovisi *et al.* 2017), of these, four (Pasqualini *et al.* 2012a, Kirchhoff *et al.* 2015, Amaral *et al.* 2016, Paleker & van der Vyver 2016) evaluated apical transportation. Only one study (Paleker & van der Vyver 2016) reported significant differences, with G-file and ProGlider showing better results when compared to K-File glide path preparations. Canal centring ability was analysed in three investigations with μCT (Amaral *et al.* 2016, Paleker & van der Vyver 2016, Alovisi *et al.* 2017), with one not detecting differences when comparing final shaping using WaveOne with or without the previous use of PathFile (Amaral *et al.* 2016). In a second study, preparation of a glide path with K-files was associated with less centred preparations compared to preparation with ProGlider (Alovisi *et al.* 2017). Similarly, a third study reported better centring for PathFile, when compared with K-files (Paleker & van der Vyver 2016).

Two lines of statistical reasoning may help to explain the limited amount of significantly different results and assess the study heterogeneity. First, some data sets had large standard deviations in relation to the mean values of the results. Second, a sizeable coefficient of variation was noted, which is another measure that improves the characterization of the data dispersion (data not shown). The latter measure is the ratio of the standard deviation to the mean, stated as a percentage. Low values are considered better, as this value indicates that the variability in measurements is small relative to their mean. In all the studies where this data was available, large values of the coefficient of variation were observed. Therefore, it appeared that heterogeneous samples were present in several component studies (Winner 2009).

In addition to heterogeneity of samples, there was a frequent absence of an *a priori* power size calculation, occurring in 17 out of 18 component studies. Therefore, their results should be interpreted with caution because inadequate power size cannot be ruled out.

In the present review, the methodological quality of the included studies was appraised and categorized according to their risk of bias. Bias is defined a systematic errors that may lead a false estimation of the intervention. Thus, it is crucial to assess the risk of bias of all studies included in a systematic review (Higgins *et al.* 2011). When synthesizing the results of the component studies based on their risk of bias, only one of the four studies with a low risk of bias revealed significant differences (Alovisi *et al.* 2017). However, of five other studies that had significant differences (Dhingra & Manchanda 2014, Elnaghy & Elsaka 2014, Dhingra *et al.* 2015, Paleker & van der Vyver 2016), three were described as having a high risk of bias (Dhingra & Manchanda 2014, Elnaghy & Elsaka 2014, Dhingra *et al.* 2015). This observation highlights the difficulties in providing robust recommendations in the presence of bias, which can lead to inconsistencies amongst the relevant evidence.

Clinical implications

A preliminary canal negotiation using a hand file of at least size 10 is currently recommended in routine clinical practice to prevent deviations from the main canal (Hargreaves *et al.* 2011). None of the component studies assessed apical transportation or centring without this step.

Engine-driven glide path preparation performed at least similarly to manual instrumentation, and no significant differences were found when comparing the different rotary systems. The preparation of a manual glide path may still be important to prevent instrument breakage. Interestingly, the component studies indicated this specific complication as associated solely with engine-driven glide path preparation (Uroz-Torres *et al.* 2009, Alves *et al.* 2012, Turker & Uzunoglu 2015, Berástegui *et al.* 2016). However, a different systematic review is necessary to summarize this aspect. Finally, glide path preparation with rotary files is associated with less postoperative pain and faster symptom resolution, when compared to the use of hand files (Pasqualini *et al.* 2012b).

The clinical relevance of the apical transportation magnitude needs further understanding. The highest values reported was 0.32 mm (Uroz-Torres *et al.* 2009), which should be considered an outlier, taking into account that the remaining mean apical transportation values were less than 0.19 mm. This outlier value can be explained by the fact that their mean value of canal curvature degree was higher than the remaining component studies. Although a systematic review with meta-analysis was unable to draw definitive conclusions for the effect on outcomes of technical errors during shaping, significantly lower success rates were often reported in their component studies if these occurred (Ng *et al.* 2008). Furthermore, adequate root canal filling, which depends on previous root canal shaping, improves outcomes significantly (Ng *et al.* 2008).

Conclusions

Based on the available evidence, and within the limitation of the studies included, preparation of a glide path using engine-driven sequences is associated with similar (in the majority of the included studies) or reduced apical transportation and/or loss of canal centring ability when compared to manual preparation. Preparation of a glide path prior to final shaping was also associated with similar or reduced apical transportation and/or loss of centring, when compared with the absence of a glide path. However, it is worth noting that these deviations from the main canal occurred regardless.

Acknowledgement

We thank CAPES Foundation (Ministry of Education of Brazil, Brasılia/DF, Brazil) for granting a scholarship to Rafael Chies Hartmann.

Conflict of interest

Dr. Peters reports Grants and Personal fees from Dentsply Sirona, outside the submitted work. The other authors have stated explicitly that there are no conflict of interests 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.

Alves O, 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.

Amaral ROJF, Leonardi DP, Gabardo MCL, Coelho BS, Oliveira KVD, Baratto Filho F (2016) Influence of cervical and apical enlargement associated with the wave one system on the transportation and centralization of endodontic preparations. *Journal of Endodontics* **42**, 626–31.

Berástegui E, Ballester-Palacios ML, Rivas-Frau X, Mercade M, Canalda C (2016) Evaluación de la lima Proglider para crear una vía de deslizamiento en conductos curvos usando tomografía computerizada de haz cónico. *Endodoncia* **34**, 193–203.

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.

Carvalho GM, Sponchiado Junior EC, Garrido AD, Lia RC, Garcia Lda F, Marques AA (2015) Apical transportation, centering ability, and cleaning effectiveness of reciprocating single-file system associated with different glide path techniques. *Journal of Endodontics* **41**, 2045–9.

Coelho MS, Fontana CE, Kato AS, de Martin AS, da Silveira Bueno CE (2016) Effects of glide path on the centering ability and preparation time of two reciprocating instruments. *Iranian Endodontic Journal* **11**, 33–7.

D'Amario M, Baldi M, Petricca R, *et al.* (2013) Evaluation of a new nickel-titanium system to create the glide path in root canal preparation of curved canals. *Journal of Endodontics* **39**, 1581–4.

Dhingra A, Manchanda N (2014) Modifications in canal anatomy of curved canals of mandibular first molars by two glide path instruments using CBCT. *Journal of Clinical and Diagnostic Research* **8**, Zc13–7.

Dhingra A, Nagar N, Sapra V (2015) Influence of the glide path on various parameters of root canal prepared with WaveOne reciprocating file using cone beam computed tomography. *Dental Research Journal* **12**, 534–40.

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.

Gergi R, Rjeily JA, Sader J, Naaman A (2010) Comparison of canal transportation and centering ability of Twisted files, Pathfile-Protaper system, and stainless steel hand K-files by using computed tomography. *Journal of Endodontics* **36**, 904–7.

Gorni FG, Gagliani MM (2004) The outcome of endodontic retreatment: a 2-yr follow-up. *Journal of Endodontics* **30**, 1–4.

Gu Y, Lu Q, Wang P, Ni L (2010) Root canal morphology of permanent three-rooted mandibular first molars: part II–measurement of root canal curvatures. *Journal of Endodontics* **36**, 1341–6.

Gulabivala K, Ng YL (2014) Non-surgical root-canal treatment. In: Gulabivala K, Ng Y-L eds. *Endodontics*, 4th edn. London: Mosby, pp. 174–236

Hargreaves KM, Cohen S, Berman LH (2011) *Cohen's Pathways of the Pulp*. St. Louis, MO: Mosby Elsevier.

Higgins JPT, Altman DG, Gøtzsche PC, *et al.* (2011) The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *British Medical Journal* **343**, d5928.

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

Iqbal MK, Maggiore F, Suh B, Edwards KR, Kang J, Kim S (2003) Comparison of apical transportation in four Ni-Ti rotary instrumentation techniques. *Journal of Endodontics* **29**, 587–91.

Joanna Briggs Institute (2015) *Joanna Briggs Institute reviewers' manual: 2015 edition*. Adelaide: Joanna Briggs Institute.

Kirchhoff AL, Chu R, Mello I, Garzon AD, 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.

Lin LM, Rosenberg PA, Lin J (2005) Do procedural errors cause endodontic treatment failure? *Journal of the American Dental Association* **136**, 187–93. quiz 231.

Meireles DA, Marques AAF, Garcia LFR, Garrido ADB, Sponchiado EC (2012) Assessment of apical deviation of root canals after debridement with the Hybrid, ProTaper and PathFile systems. *Journal of Interdisciplinary Dentistry* **2**, 20–4.

Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K (2008) Outcome of primary root canal treatment: systematic review of the literature – Part 2. Influence of clinical factors. *International Endodontic Journal* **41**, 6–31.

Ocampo A, Henao Bedoya A, Saavedra Amaya J, Fernanda Serpa M, Gutiérrez Barreto J (2015) Transportación y centricidad en conductos curvos con ProTaper Next y PathFile. *Universitas Odontologica* **34**, 37–46.

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.* (2012a) 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, Mollo L, Scotti N, *et al.* (2012b) Postoperative pain after manual and mechanical glide path: a randomized clinical trial. *Journal of Endodontics* **38**, 32–6.

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.

Peters OA (2004) Current challenges and concepts in the preparation of root canal systems: a review. *Journal of Endodontics* **30**, 559–67.

Peters OA, Laib A, Ruegsegger P, Barbakow F (2000) Three-dimensional analysis of root canal geometry by high-resolution computed tomography. *Journal of Dental Research* **79**, 1405–9.

Tsesis I, Blazer T, Ben-Izhack G, *et al.* (2015) The precision of electronic apex locators in working length determination: a systematic review and meta-analysis of the literature. *Journal of Endodontics* **41**, 1818–23.

Turker SA, Uzunoglu E (2015) Apical root canal transportation of different pathfinding systems and their effects on shaping ability of ProTaper Next. *Journal of Clinical and Experimental Dentistry* **7**, e392–5.

Uroz-Torres D, González-Rodríguez MP, Ferrer-Luque CM (2009) Effectiveness of a manual glide path on the preparation of curved root canals by using Mtwo rotary instruments. *Journal of Endodontics* **35**, 699–702.

West JD (2010) The endodontic Glidepath: "Secret to rotary safety". *Dentistry Today* **29**, 8. 90-3.

Winner L (2009) *Applied Statistical Methods. 1st edn*. Gainesville, FL: Department of Statistics, University of Florida.

Yared G (2015) Canal preparation with nickel-titanium or stainless steel instruments without the risk of instrument fracture: preliminary observations. *Restorative Dentistry and Endodontics* **40**, 85–90.

Zanette F, Grazziotin-Soares R, Flores ME, Camargo Fontanella VR, Gavini G, Barletta FB (2014) Apical root canal transportation and remaining dentin thickness associated with Protaper Universal with and without Pathfile. *Journal of Endodontics* **40**, 688–93.