PUCRS

PONTIFÍCIA UNIVERSIDADE CATÓLICA DO RIO GRANDE DO SUL
PROGRAMA DE PÓS-GRADUAÇÃO EM ODONTOLOGIA
ÁREA DE CONCENTRAÇÃO ENDODONTIA
NÍVEL DOUTORADO

RAFAEL CHIES HARTMANN

MÉTODOS DE MENSURAÇÃO DE CURVATURAS RADICULARES E A INFLUÊNCIA DO *GLIDE PATH* NA MANUTENÇÃO DA CENTRALIZAÇÃO E NO TRANSPORTE APICAL PREPAROS ENDODÔNTICOS: REVISÕES SISTEMÁTICAS E ANÁLISE CRÍTICA

Porto Alegre
2018

PÓS-GRADUAÇÃO - *STRICTO SENSU*

Pontifícia Universidade Católica
do Rio Grande do Sul

PONTIFÍCIA UNIVERSIDADE CATÓLICA DO RIO GRANDE DO SUL
FACULDADE DE ODONTOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ODONTOLOGIA
ÁREA DE CONCENTRAÇÃO ENDODONTIA
NÍVEL DOUTORADO

RAFAEL CHIES HARTMANN

MÉTODOS DE MENSURAÇÃO DE CURVATURAS RADICULARES E A INFLUÊNCIA DO *GLIDE PATH* NA MANUTENÇÃO DA CENTRALIZAÇÃO E NO TRANSPORTE APICAL PREPAROS ENDODÔNTICOS: REVISÕES SISTEMÁTICAS E ANÁLISE CRÍTICA

Porto Alegre

2018

RAFAEL CHIES HARTMANN

MÉTODOS DE MENSURAÇÃO DE CURVATURAS RADICULARES E A INFLUÊNCIA DO *GLIDE PATH* NA MANUTENÇÃO DA CENTRALIZAÇÃO E NO TRANSPORTE APICAL PREPAROS ENDODÔNTICOS: REVISÕES SISTEMÁTICAS E ANÁLISE CRÍTICA

Tese apresentada ao Programa de Pós-Graduação em Odontologia da Faculdade de Odontologia da Pontifícia Universidade Católica do Rio Grande do Sul como requisito para obtenção do título de Doutor em Odontologia, na área de concentração de Endodontia.

Linha de Pesquisa: Etiopatogênese, Tratamento e Repercussões Sistêmicas das Doenças Periodontais, Pulpares e Periapicais.

Orientador: Prof. Dr. Maximiliano Schünke Gomes

Coorientadores: Prof. Dr. Giampiero Rossi-Fedele

Prof. Dr. José Antonio Poli de Figueiredo

Porto Alegre
2018

MÉTODOS DE MENSURAÇÃO DE CURVATURAS RADICULARES E A INFLUÊNCIA DO *GLIDE PATH* NA MANUTENÇÃO DA CENTRALIZAÇÃO E NO TRANSPORTE APICAL PREPAROS ENDODÔNTICOS: REVISÕES SISTEMÁTICAS E ANÁLISE CRÍTICA

Tese apresentada ao Programa de Pós-Graduação em Odontologia da Faculdade de Odontologia da Pontifícia Universidade Católica do Rio Grande do Sul como requisito para obtenção do título de Doutor em Odontologia, na área de concentração de Endodontia.

Aprovada em:_____de___________________de_________.

BANCA EXAMINADORA:

____
Prof. Dr. Maximiliano Schünke Gomes

____
Profª. Drª. Daiana Elisabeth Böttcher

____
Prof. Dr. Giampiero Rossi-Fedele

____
Prof. Dr. José Antonio Poli de Figueiredo

____
Profª. Drª. Silvana Beltrami Gonçalves Waltrick

Porto Alegre
2018

AGRADECIMENTOS

Agradeço primeiramente aos meus pais **Iliane Chies Hartmann** e **Martim Darlei Hartmann**, por terem me transmitidos os mais altos valores morais e por sempre abrirem mão de seus sonhos em detrimento dos meus, transformando minha caminhada menos penosa; espero um dia poder retribuir de alguma forma e ser motivo de orgulho.

À minha Avó **Ely Maria Hartmann**, que foi decisiva na decisão de viver odontologia. Foi ela que me ensinou que como cirurgiões-dentistas temos como missão ajudar todas as pessoas e que por isso, faz-se necessário o constante aprimoramento.

À minha irmã **Tatiana Hartmann Biasi** e meu cunhado **Edson Larry Biasi,** pelo companheirismo e por poder contar com vocês sempre que preciso. Obrigado por desde o início de minha vida profissional terem me ensinado que a odontologia é realmente aprendida no dia a dia com nossos pacientes.

À minha prima **Patrícia Chies da Fontoura** e seu marido **Paulo da Fontoura**, pelo apoio e compreensão durante toda essa caminhada. Valeu pela torcida e por acreditarem que eu seria capaz de chegar onde cheguei.

Ao meu Orientador dos três primeiros anos do doutorado e Coorientador **Prof. Dr. José Antonio Poli de Figueiredo** por todos os ensinamentos, desafios propostos, oportunidades oferecidas, amigos compartilhados e por ter acreditando no meu potencial mais do que eu mesmo. Sua dedicação ao ensino e a pesquisa são motivos inspiração. Sempre com tanta simplicidade transmitindo seus infinitos conhecimentos me enchem de admiração. Tenha certeza de que sempre poderás contar comigo para o que der e vier, foste uma das pessoas que mais fez diferença na minha vida. Se hoje sou professor, em grande parte foi me espelhando em ti. Valeu Fig.

Ao meu Coorientador **Prof. Dr. Giampiero Rossi-Fedele,** por ter me aceitado para o doutorado sanduiche do outro lado do mundo. Por ter compartilhado comigo seu inúmeros conhecimentos, sua amizade, sua universidade... Durante algum tempo, enquanto estava na Austrália, me senti sozinho e tu fostes o rosto amigo que me fez continuar. Como já havia lhe dito uma vez, mudaste a minha vida, meu modo de pensar, agir, de ver o mundo. Muito Obrigado Pierito.

Ao Meu Orientador **Prof. Dr. Maximiliano Schünke Gomes,** por ser um exemplo em todos os momentos, de dedicação à ciência e à docência. Apesar de inúmeras funções acumuladas e de ter assumido minha orientação na reta final, sempre conseguiu me orientar da melhor maneira possível. Muito obrigado pela calma e paciência que me orientou. Muito Obrigado Max.

A todos os professores da PUCRS, pelos ensinamentos, e em especial aos professores da endodontia: **Prof.ª Dr.ª Maristela Gutierrez de Borba e Prof. Dr. Alexandre Ghisi** por todos os conhecimentos compartilhados e por ampliar os meus na Endodontia. Muito Obrigado.

À **Prof.ª Dr.ª Silvana Beltrami Gonçalves Waltrick**, pela amizade, por todos ensinamentos, endodônticos e de vida, sendo constantemente um exemplo para mim de força de vontade, dedicação e amor ao que faz. Tê-la, hoje, como colega é motivo de muito orgulho para mim. Valeu Sil.

À **Prof.ª Dr.ª Maria Martha Campos,** por toda dedicação e empenho em tentar me tornar um bom aluno, seu amor à docência e a pesquisa sempre me inspiram a continuar. Muito obrigado Professora.

Ao **Prof. Dr. Geoffrey Sinclair Heithersay,** por todos os seus infinitos conhecimentos compartilhado, sua amizade e pela paciência que sempre me tratou. Sou seu grande fã. Thanks Prof.

Ao Amigo **MSc Miguel Fensterseifer,** pela amizade pelos conhecimentos compartilhados. Com certeza não seria possível termos escrito esse trabalho sem a tua ajuda. Valeu meu velho.

A todas as colegas do pós-graduação em Endodontia da PUCRS: **Prof.ª Dr.ª Daiana Elizabeth Böttcher, Thayana Souza Leão, Cynthia Jara Pintos, Barbara Koppe, Gabriela Bonacina, Isadora Souza Basso e Natália Pacheco,** obrigado pela parceria, pelas risadas, pelos cafés, pelos perrengues e pelos conhecimentos compartilhados, vocês são fundamentais para conclusão desta etapa.

A todos os professores do curso de especialização em endodontia da ABO/RS, por compartilharem seus vastos conhecimentos, sendo motivo de inspiração por sua dedicação e amor ao ensino da Endodontia.

Aos quase irmãos, **Letícia Manique**, **Liliana Agostini Stys**, **Lênio Togni, Maíra Cavalet e Thomaz Duarte** amigos desde a época da graduação. Obrigado pela parceria em todos os momentos bons e ruins, vocês sempre estiveram comigo, mesmo quando eu estava longe. Saibam que não conseguiria ter chegado aqui sem vocês. Valeu galera.

Aos Amigos da Austrália: **Abdo, Azadeh, Jessica, Leandro, Lívia, Mehbuba, Mohamed, Oscar e Wendel**. Só foi possível suportar a saudade de casa por causa de vocês. Thank you guys.

Aos demais amigos, por toda a ajuda e compreensão com minhas ausências devido a minha dedicação ao mestrado e doutorado. Muito obrigado por serem meus amigos, todos vocês são muito importantes para mim.

Aos secretários do PPGO, agradeço a simpatia, prontidão, organização e dedicação. Vocês são fundamentais.

À Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS) e à Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) pela oportunidade de realização deste Doutorado.

Obrigado a todos que de alguma forma contribuíram com o meu crescimento profissional e pessoal que me transformaram na pessoa que sou hoje.

Vida longa e próspera a todos **.**

SUMÁRIO

RESUMO

Introdução: A grande maioria dos condutos apresenta curvaturas e o conhecimento destas curvaturas permite ao clínico uma melhor escolha da terapêutica endodôntica. Para tanto, faz-se necessário o emprego de métodos que possam medir essas curvaturas com bons níveis de acurácia. A confecção de um glide path prévio à instrumentação dos canais radiculares é amplamente sugerida, pois pode evitar possíveis erros operatórios, tais como a perda de centralização do preparo e o transporte apical, especialmente em canais radiculares curvos. Como não há consenso quanto aos métodos que podem ser utilizados na medição das curvaturas radiculares, tampouco referente a eficácia do *glide path*, a presente investigação tem o objetivo de realizar duas revisões sistemáticas, a fim de responder às seguintes questões: 1- Quais são os métodos, descritos na literatura, empregados na mensuração dos ângulos e demais características das curvaturas dos canais radiculares? 2- O glide path é capaz de reduzir o transporte apical e a perda de centralização do preparo endodôntico? Além disso, qual a forma de confecção do glide path – manual ou motorizada – resulta em menores erros operatórios? **Métodos:** Utilizando os termos apropriados para cada revisão, foram realizadas buscas eletrônicas em seis bases de dados: PubMed, PubMed Central (PMC), Embase, Scopus, EBSCO Dentistry & Oral Sciences Source (DOSS) e Virtual Health Library (VHL). Foram utilizados estudos publicados em inglês ou em qualquer idioma com alfabeto latino não houve qualquer limite temporal para as publicações. Além disso, na segunda revisão, os estudos incluídos tiveram o risco de vieses analisado. **Resultados:** Na revisão 1, acerca dos métodos de mensuração das curvaturas, foram obtidos 6.346 estudos e destes, restaram 31 artigos que descreviam métodos inovadores. Onze estudos foram descritos a fim de mensurar apenas o ângulo das curvaturas radiculares, para isso utilizaram imagens em 2D. 13 estudos utilizaram também imagens em 2D, entretanto, além dos ângulos avaliaram outras características das curvaturas dos canais radiculares (posição, comprimento, direção, altura e forma). Além disso, sete estudos avaliaram as curvaturas através de métodos em 3D. Já na revisão 2, a respeito do glide path, obteve-se 2.146 artigos, sendo que 18 estudos preencheram os critérios de inclusão, compondo a análise final. 9 pesquisas avaliaram a confecção do glide path *per se* e 11 avaliaram a repercussão do glide path no preparo endodôntico motorizado final. **Conclusão:** a revisão 1 sugeriu que a maioria dos métodos de mensuração de curvaturas dos canais radiculares tem potenciais aplicações clínicas, no entanto, há uma falta de consenso sobre a técnica ideal. Além do ângulo, outros fatores, como raio e posição da curvatura, precisam ser mensurados e devem ser levados em consideração ao se avaliar a curvatura do canal radicular tanto em tratamentos clínicos como em ambientes de pesquisa. Já a revisão 2 revelou que a confecção motorizada, quando comparada com a confecção manual, do glide path apresenta resultados similares ou melhores de transporte apical e manutenção da centralização do canal radicular. Observou-se, também, que a confecção do glide path, previamente ao preparo endodôntico, está associada com resultados similares ou com a redução do transporte apical e a manutenção da centralização do preparo. Também foi observado que ocorrem desvios em todas as situações.

Palavras-chave: preparo endodôntico, ângulo de curvatura radicular, anatomia dos canais radiculares, glide path, transporte apical, centralização, revisão sistemática.

ABSTRACT

Introduction: The great majority of the roots present curvatures and the knowledge of these curves allows the clinician a better choice for endodontic therapy. Therefore, it is necessary to use methods that can measure these curvatures with good accuracy levels. The preparation of a glide path prior to root canal instrumentation is widely suggested because can avoid possible operative errors, such as loss of centralization and apical transportation, especially in curved root canals. There is no consensus concerning the methods that can be used to measure radicular curvatures, nor regarding the efficacy of glide path. The present investigation has the objective of performing two systematic reviews in order to answer the following questions: 1- What are the methods, described in the literature, used to measure the angles and other characteristics of the curvatures of the root canals? 2- The glide path is able to reduce the apical transportation and the loss of centralization of the endodontic preparation? Also, how does the glide path - manual or engine-driven - result in minor operative errors? **Methods:** Using the appropriate terms for each review, electronic searches were performed on six databases: PubMed, PubMed Central (PMC), Embase, Scopus, EBSCO Dentistry & Oral Sciences Source (DOSS) and Virtual Health Library (VHL). We used studies published in English or in any language with Latin alphabet. There was no time limit for publications. In addition, in the second review, the included studies, the risk of biases was analyzed. **Results:** In review 1, about the methods of measurement of curvatures, 6,336 studies were obtained and of these, 31 articles that described innovative methods. Eleven studies described the methods used to measure only the angle of the radicular curvatures, for which they used 2D images. 13 studies also used 2D images, however, in addition to the angles, evaluated other features of the root canal curvatures (position, length, direction, height and shape). In addition, seven studies evaluated curvatures using 3D methods. In review 2, regarding glide path, 2,146 articles were obtained, and 18 studies fulfilled the inclusion criteria, composing the final analysis. 9 studies evaluated the glide path per se and 11 evaluated the impact of glide path on final engine-driven endodontic preparation. **Conclusion:** Revision 1 suggested that most methods for root canal curvature measurement have potential clinical applications; however, there is a lack of consensus on the ideal technique. In addition to the angle, other features, such as radius and position of curvature, need to be measured and should be considered when evaluating root canal curvature in both clinical and research purposes. Revision 2 revealed that engine-driven confection of glide path, when compared to manual, presents similar or better results of apical transportation and maintenance of root canal centralization. It was also observed that the preparation of glide path, prior to endodontic preparation, is associated with similar results or with a reduction of the apical transportation and the maintenance of the preparation centralization. It was also observed that deviations occur in all situations.

Key Words: angle, curvature, measurement, radius, root canal anatomy, apical transportation, centralization, centring, glide path, root canal shaping, systematic review.

INTRODUÇÃO

A ciência endodôntica está baseada no conhecimento do complexo dentino-pulpar; na prevenção e tratamento de suas patologias e repercussões nas estruturas a ele relacionadas. De maneira resumida, o tratamento endodôntico pode ser definido como a combinação de instrumentação mecânica do sistema de canais radiculares, o seu saneamento químico, seguido do preenchimento em três dimensões, com a finalidade de manter ou restaurar a saúde dos tecidos perirradiculares[1, 2].

O sistema de canais radiculares (SCR) é um ambiente complexo que apresenta inúmeras reentrâncias, canais secundários e colaterais, zonas de istmo e deltas apicais, e que, quando contaminado, dificulta o tratamento endodôntico[3, 4]. Além de tudo, devemos considerar também, a prevalência de curvaturas[5], obliterações parciais ou totais dos canais radiculares[6], anomalias dentárias[7], reabsorções internas[8], que agregam maior complexidade ao tratamento.

A presença de curvatura ocorre na maioria dos canais radiculares, sendo referenciadas prevalências em torno de 84% dos canais[5, 9]. Este fato aumenta o desafio terapêutico, já que os instrumentos endodônticos são fabricados retos, e tendem a permanecer desta forma, distribuindo de maneira desigual as forças aplicadas sobre as paredes radiculares durante o preparo de canal curvos[10]. Consequentemente, nas porções mais apicais de canais curvos, a parede externa à curvatura tende a ser mais desgastada que a parede interna[11, 12, 9]. Este desequilíbrio durante o preparo endodôntico pode levar a deslocamentos do trajeto original do canal, desvios, degraus, perfurações e fraturas de instrumentos, reduzindo o índice de sucesso do tratamento[13, 14].

A instrumentação manual dos canais radiculares apresenta uma maior propensão a erros operatórios quando comparada as instrumentações guiadas a motor (movimento rotatório e/ou reciprocante). Este fato pode estar relacionado a experiência do operador e dificuldades na anatomia radicular. Entretanto, a liga de níquel-titânio, na qual os instrumentos motorizados são fabricados, parece ser o fator preponderante na redução de falhas durante o preparo [15-17].

A maior parte dos sistemas de instrumentação motorizada sugere que após a exploração do canal radicular, e previamente ao preparo, seja confeccionado o "*glide path*" [18-22]. Apesar de não haver um consenso a respeito da definição de *glide path*, o termo pode ser definido como "um canal radicular liso e livre, que se estende desde a cervical até a saída foraminal". Tem como finalidade evitar a fratura de instrumentos acionados pelo motor e reduzir os desvios nos canais radiculares, permitindo que os instrumentos percorram os canais passivamente até o limite apical [23]. Supostamente, a realização do *glide path* facilitaria a instrumentação de canais radiculares curvos. Entretanto, a repercussão do *glide path,* tanto no transporte apical quanto na centralização do preparo endodôntico, não é totalmente esclarecida e não há consenso a respeito de sua eficácia [24-43].

Curvaturas radiculares tem sido listadas como um fator de risco que pode afetar negativamente o resultado do tratamento [44]. Alguns *guidelines* recomendam que ao realizar a radiografia periapical inicial (prévia ao tratamento), deve ser medida a curvatura dos canais radiculares e que esse fator pode ser decisivo na seleção de cada tratamento endodôntico. Dependendo dos valores de ângulos e raios das curvaturas pode-se determinar a dificuldade de cada caso, determinar qual a melhor técnica de preparo e definir se o profissional possui habilidade e experiência suficiente para realizar o tratamento [44-46]. A medição da curvatura dos canais radiculares é uma etapa extremamente importante para o planejamento do tratamento, e inúmeros métodos vem sendo propostos na literatura [44-47]. Ainda assim, não há consenso a respeito de qual o método mais apropriado para a mensuração das curvaturas, tampouco existe consenso em relação a quais parâmetros – além do raio e do ângulo – sejam mais relevantes para o processo de medição (posição, comprimento, direção, altura e forma). Em conjunto, estes fatores relativos as curvaturas são importantes na determinação da complexidade de um tratamento de canal, e podem influenciar no sucesso da terapia endodôntica [48-81].

Devido à ausência de consenso na literatura, surge a proposta de investigar, através de uma revisão sistemática, se a confecção do *glide path* é capaz de reduzir o transporte apical e manter a centralização do preparo endodôntico. Ainda, qual a forma de confecção do *glide path* – manual ou motorizada – resulta em menores erros operatórios relacionados a centralização e transporte apical? Além disso, como a presença de curvaturas radiculares pode afetar sensivelmente estes fatores, há a necessidade de investigar criticamente, por meio de outra revisão sistemática, quais são os métodos empregados para a mensuração dos ângulos e demais características das curvaturas dos canais radiculares?

ARTIGO 1

Methods for measurement of root canal curvature: a systematic and critical review

Publicado no periódico *International Endodontic Journal*, *Epub Ahead of Print*.

Fator de impacto 3,015 e classificação A1 segundo a Capes.

INTERNATIONAL
ENDODONTIC JOURNAL

doi:10.1111/iej.12996

REVIEW

Methods for measurement of root canal curvature: a systematic and critical review

R. C. Hartmann[1], M. Fensterseifer[2], O. A. Peters[3,4], J. A. P. de Figueiredo[5], M. S. Gomes[1,6] & G. Rossi-Fedele[7]

[1]Postgraduate Program in Dentistry, Pontifical Catholic University of Rio Grande do Sul, Porto Alegre, Brazil; [2]Computer Vision Group, Universidad Politécnica de Madrid, Madrid, Spain; [3]Department of Endodontics, Arthur A. Dugoni School of Dentistry, University of the Pacific, San Francisco, CA, USA; [4]Oral Health Centre, University of Queensland, Herston, Qld, Australia; [5]Federal University of the Rio Grande do Sul, Porto Alegre, Brazil; [6]Medical and Dental Center of the Military Police of Rio Grande do Sul, Porto Alegre, Brazil; and [7]Adelaide Dental School, The University of Adelaide, Adelaide, SA, Australia

Abstract

Hartmann RC, Fensterseifer M, Peters OA, de Figueiredo JAP , Gomes MS, Rossi-Fedele G. Methods for measurement of root canal curvature: a systematic and critical review. *International Endodontic Journal.*

The assessment of root canal curvature is essential for clinical and research purposes. This systematic review presents an overview of the published techniques for the measurement of root canal curvature features using imaging and to provide a critique of their clinical application. 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 measurement methods for root canal curvatures. The search strategy retrieved 10594 records in total, and 31 records fulfilled the inclusion criteria. From 2D image acquisitions, eleven studies measured exclusively the angle of curvature, an additional thirteen measured other curvature features (level, height, radius, length and shape). Seven reports described methods from 3D imaging (CBCT, μCT). Root canal curvatures should be measured, for clinical proposes, to facilitate endodontic treatment planning, and in research, to reduce the risk of selection bias. This review has revealed that there are many methods described in the literature; however, no consensus exists on which method should be used. Some of the methodologies have potential clinical translation, whereas others are suitable for research purpose only, as they require a specific software or radiographic exposure in the mesiodistal direction.

Keywords: angle, curvature, measurement, radius, root canal anatomy, systematic review.

Received 4 May 2018; accepted 6 August 2018

Introduction

The assessment of root canal curvature (e.g. degree of curvature, radius, level, length, height and coefficient) is important for clinical and research purposes. Clinically, it is intuitive that extreme curvature can create procedural errors during root canal treatment, which can be associated with subsequent treatment failures (Lin *et al.* 2005).

In fact, excessive root canal curvature has been listed as a risk factor that may affect the outcome of treatment by the American Association of Endodontists (American Association of Endodontists 2010), the Canadian Academy of Endodontics (Canadian Academy of Endodontics 2017) and two research groups based in Europe (Falcon *et al.* 2001, Ree *et al.* 2003). Thus, an *a priori* assessment of root canal curvature based on pre-operative radiographs, amongst

Correspondence: Rafael Chies Hartmann, School of Dentistry, Pontifical Catholic University of Rio Grande do Sul, Building 6, 6681 Ipiranga Avenue, Porto Alegre, 90619-900 Rio Grande do Sul, Brazil (e-mail: rafaelhart@gmail.com).

other considerations, is recommended in order to assign a specific clinical level of potential difficulty and/or risk associated with root canal treatment (American Association of Endodontists 2010). Such an assessment is believed to aid in determining whether the clinician has appropriate competence or comfort level for the level of treatment complexity and whether referral to an endodontist should be considered (American Association of Endodontists 2010). In fact, several assessment forms and indices have been suggested for this purpose (Falcon *et al.* 2001, Ree *et al.* 2003, American Association of Endodontists 2010, Canadian Academy of Endodontics 2017). It is worth noting that the above-mentioned forms do not explicitly mention the method of curvature evaluation to be used. Finally, a recently proposed web-based endodontic case assessment tool, which also considers root canal curvature, has been evaluated for applications such as educational, primary/secondary care triage, record keeping, informed consent as well as medico-legal justification (Shah & Chong 2018).

Assessment of root canal curvature for basic research aims to remove selection bias by eliminating or limiting differences between baseline characteristics of the experimental groups that are compared (Shah & Chong 2018). In fact, when using different endodontic instruments in shaping root canals *ex vivo*, curvature characteristics have an effect on transportation (Nagy *et al.* 1997a,b, Dobo-Nagy *et al.* 2002, Uroz-Torres *et al.* 2009), as well as on the cycles to failure of nickel-titanium rotary files (Pruett *et al.* 1997) and subsequent fracture (Jardine & Gulabivala 2000).

Throughout the history of Endodontology, numerous techniques to assess root canal curvature have been proposed. Thus, the objective of the present review was to provide an overview of the published techniques for the assessment of root canal curvature using imaging and to provide a critique of their potential clinical and research applications.

Materials and methods

The current systematic review was conducted and reported in strict accordance with (PRISMA) guidelines for reporting systematic reviews and meta-analyses (Moher *et al.* 2009).

Data sources

An electronic database search was conducted to find published articles related to root canal curvatures measurement in the following 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: [Tooth root*] OR [Dental Pulp Cavit*] OR [Root Canal*] OR [Pulp canal*] AND [Curv*]. 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. A final database search was completed on 18 January 2018. The search results were imported into reference manager software (EndNote, Thompson Reuters, Toronto, Canada) and combined and duplicated publications were eliminated.

Resources selection and review

The question under review was not framed according to the PICO-PEO formats, as these did not apply as the present review aimed to summarize textual evidence (Joanna Briggs Institute 2015). Therefore, the question generated for this study to guide the systematic review was framed as follows: 'What are the imaging methods used to measure root canal curvatures features?'

Two independent reviewers (RCH and GRF) analysed the titles and abstracts of the articles that were identified, taking into consideration the inclusion and exclusion criteria established for this review. The inclusion criteria comprised studies that described previously unpublished imaging methods to measure root canal curvatures, published in English or other Latin alphabets. Articles were excluded when inclusion criteria were not met; reviews and clinical case reports were also excluded. Methods previously described for other imaging techniques were also excluded.

In case of disagreement, consensus was reached by discussing findings between the reviewers. The reference lists of all articles were checked for additional articles of relevance, using the same criteria.

The description of each method was retrieved and summarized from the included articles by two reviewers (RCH and GRF), and diagrammatic representations of the different methods were created. If deemed necessary, authors of the included studies were contacted for clarification and/or to request further information.

The three non-English studies retrieved [one in Spanish (Fuentes *et al.* 2015), and two in Portuguese (Berbert & Nishiyama 1994, Cabrales *et al.* 2006)], were independently translated into English by two authors (RCH and GRF), who are native speakers.

Results

The search strategy retrieved 10 594 records in total, of which 31 records fulfilled the inclusion criteria. The results of the search strategy are presented in Fig. 1. The main reason for excluding each of the 20 studies identified following full-text assessment is recorded in Table 1.

The methodologies used in the included studies were then grouped according to the number of dimensions used in imaging (2D or 3D) and then subdivided between those proposed to measure root curvature solely or if other factors were measured (Table 2). Main features of the component publications, as well as, strengths and limitations are described in Tables S1–S3. Diagrammatic representation of the methodologies used in the literature is presented in Figs 2–4.

Twenty-eight included publications were based on various radiographic techniques. Nineteen studies used periapical radiography (PR) to measure root canal curvature angle and other factors (Table 3). Amongst these, 13 investigations solely used bucco-lingual/palatine (i.e. clinical) view (Table 3). Nine of these methods assessed the angle of curvatures exclusively (Table 3), which differed in the position of the representative intersecting lines. In addition to curvature angle measurement, ten described its position, height, radius, length and shape considering clinical and proximal views (Table 3). Moreover, 11 of the radiography-based investigations placed K-files (sizes 08, 10, 15) or silver points with the purpose of facilitating root canal curvature visualisation (Southard *et al.* 1987, Backman *et al.* 1992, Luiten *et al.* 1995, Thompson *et al.* 1995, Hankins & ElDeeb 1996, Harlan *et al.* 1996, Lopes *et al.* 1998, Dobo-Nagy *et al.* 2000, Schäfer *et al.* 2002, Iqbal *et al.* 2003, Günday *et al.* 2005). Five studies used micro-computed tomography (µCT) (Peters *et al.* 2000, Bergmans *et al.* 2001, Lee *et al.* 2006, Eaton *et al.* 2015, Dannemann *et al.* 2017), two used cone-beam computed tomography (CBCT) (Estrela *et al.* 2008, Choi *et al.* 2015),

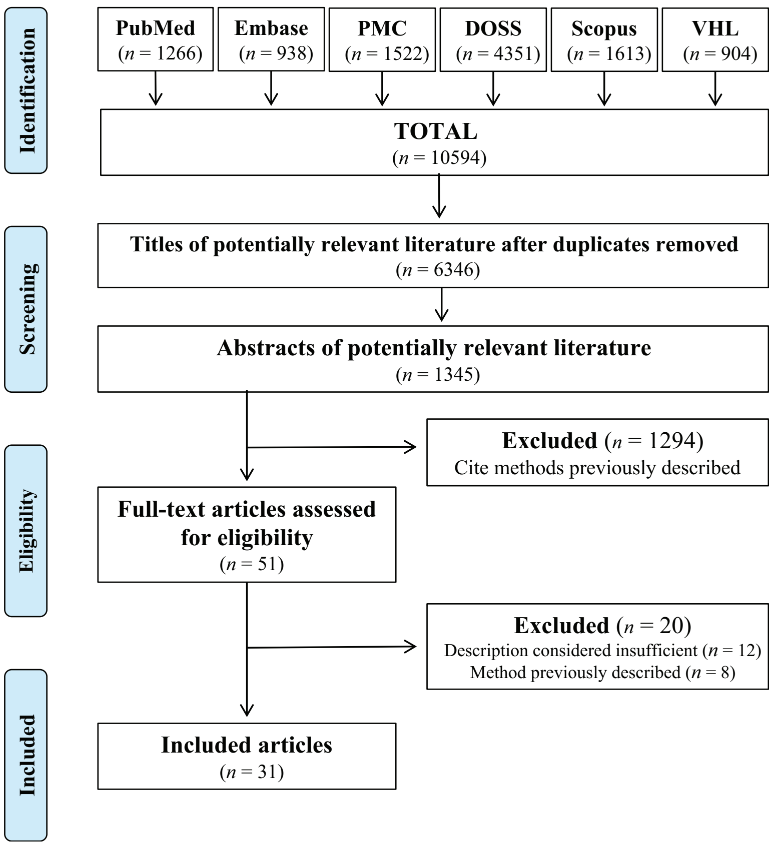

Figure 1 Flow chart of the search strategy.

Table 1 Characteristics of excluded studies

Year	Study	Characteristics of excluded studies
1985	Roane	Description considered insufficient
1989	Dummer *et al.*	Description considered insufficient
1990	Campos *et al.*	Description considered insufficient
1990	Gilles et al.	Description considered insufficient
1992	Cunnigham and Senia	Method previously described
1995	Nielsen *et al.*	Description considered insufficient
1997	Short	Description considered insufficient
1997	Goldberg *et al.*	Description considered insufficient
2000	Bramante *et al.*	Method previous described
2001	Kuttler *et al.*	Description considered insufficient
2009	Lopez *et al.*	Method previously described
2009	Sadeghi *et al.*	Method previously described
2010	Gergi *et al.*	Method previously described
2010	Gu *et al.*	Method previously described
2010	Michetti *et al.*	Description considered insufficient
2012	Benyo	Description considered insufficient
2012	Pasqualini *et al.*	Description considered insufficient
2012	Huerta *et al.*	Description considered insufficient
2013	Park *et al.*	Method previously described
2015	Lee *et al.*	Method previously described

and another two employed dental panoramic tomography (DPT) (Fuentes *et al.* 2015, 2018).

Three publications suggested an abstract, mathematically based method and presented diagrammatic representations for curvature and the measurement of other factors in the absence of any experimental component. Amongst these, one article describes a method of root canal curvature measurement to explain how to make curved stainless-steel guide tubes (CST) to test instruments fracture resistance (Pruett *et al.* 1997), another presented a mathematical curve description in simulated canals within acrylic blocks (AB) (Sonntag *et al.* 2006), and the third proposed a theoretical method (TM) to standardize curvature measurements (Zhang & Hu 2010).

Amongst the 24 studies that used 2D images (PR, DPT, CST, AB and TM) to describe their methods, five investigations reported that measurements were made on images of clinical and proximal views (Southard *et al.* 1987, Backman *et al.* 1992, Harlan *et al.* 1996, Dobo-Nagy *et al.* 2000, Iqbal *et al.* 2003), though amongst the latter only two combined the values obtained (Harlan *et al.* 1996, Dobo-Nagy *et al.* 2000).

Discussion

The present systematic review confirms the wide range of techniques available to measure root canal curvature and other factors based on imaging. Though there is an obvious lack of a consensus on the ideal technique to achieve this goal, it is reasonable to expect that some techniques are more suitable for clinical use and others are better restricted for research purposes. Factors such as the preference of the operator, practicality and ease of use, root canal morphology (e.g. presence of 'S-shaped' curves), as well as access to the various imaging techniques and imaging software, are likely to influence the choice of technique to measure root canal curvature.

In the absence of a validated reference method to measure root canal curvatures, an assessment of the reliability of the different methods included in the present systematic review is not possible. Furthermore, root canal curvature and other factors definitions varied amongst the different studies. Finally, it should be highlighted that the literature comparing the different methodologies is scarce, thus it is not possible to directly provide robust evidence-based clinical guidelines from this review of the literature.

In routine endodontics, most commonly used diagnostic and treatment planning tools are single or multiple periapical radiographs, which graphically represent in two dimensions what in fact is a three-dimensional structure. These images normally allow visualization of curvatures in the mesiodistal direction, but will not fully disclose features of the root canal system in the bucco-lingual direction, thus masking root canal complexities which cause root canal treatment to be less predictable (Choi *et al.* 2015, Sousa *et al.* 2017). This is a common limitation of various techniques proposed in the literature (Tables S1 and S2).

It is worth mentioning that around 84% of human teeth have clinically noticeable root canal curvatures (Schäfer *et al.* 2002, Zheng *et al.* 2009). Importantly, endodontic instruments have the tendency to conform to a straight canal, causing over preparation of the outer curvature in their apical portion and the inner curve of the root canal in the coronal parts of the curved roots (Peters 2004). Furthermore, canal preparation errors hinder adequate cleaning, irrigation and filling of root canals, and are thus likely to negatively affect treatment outcomes (Gorni & Gagliani 2004, Lin *et al.* 2005).

Several professional bodies and authorities suggest root canal curvature severity as one of the factors increasing the risk of preparation errors, with likely interference in the subsequent steps of root canal treatment (Falcon *et al.* 2001, Ree *et al.* 2003,

Table 2 Division and main contribution of the included studies

From 2D images		From 3D images		
Angles	Angles + other features	Angles + other features	Year	Main contribution
Schneider			1971	First method to measure the angle of curvatures
Weine			1982	Different lines to determine the curvature
Southard et al.			1987	Curvature measured in two vertices
	Backman et al.		1992	Radius of curvature and radius quotient
	Berbert & Nishiyama		1994	Level of the curvature
	Kyomen et al.		1994	Height of the curvature
Luiten et al.			1995	Different lines to determine the curvature
	Thompson et al.		1995	Distance of the beginning of the curvature
	Nagy et al.		1995	Mathematical description of the curvature
Hankins & Eldeeb			1996	Long-axis based curvature determination
Harlan et al.			1996	Single measurement from angles of both views
	Pruett et al.		1997	Radius of the curvature
	Lopes et al.		1998	Different lines to determine the radius
Pettiette et al.			1999	Different lines to determine the curvature
		Peters et al.	2000	Visualisation and determination of curvature in 3D
	Dobó-Nagy et al.		2000	Determination of curvature in 3D
		Bergmans et al.	2001	Determination of curvature and torsion
	Schäfer et al.		2002	Radius and length of curvature
	Iqbal et al.		2003	Determination of the maximum curvature view
	Günday et al.		2005	Canal access angle
Cabrales et al.			2006	Template to determinate the difficulty of the curvature
	Sonntag et al.		2006	Different mathematical description of the curvature
Willershausen et al.			2006	Different lines to measure curves with two vertices
		Lee et al.	2006	Different points to determinate the curvature
		Estrela et al.	2008	Measure of cervical and apical curvatures in 2 planes
	Zhang & Hu		2010	Theoretical interpretation of the curvatures
Fuentes et al.			2015	Different lines to determinate the curvature
		Eaton et al.	2015	Canal access angle in 3D
		Choi et al.	2015	Simplified determination of local curvature in 3D
		Dannemann et al.	2017	Determination of curvature and canal profile in 3D
Fuentes et al.			2018	Different lines to measure curves with two vertices

American Association of Endodontists 2010, Canadian Academy of Endodontics 2017). However, there is no apparent consensus on the numerical values of the degrees to be considered; the methods of curvature measurement are also often not explicitly reported in the proposed case difficulty assessment tools.

Angle is defined as the space between two lines or surfaces at the point at which they touch each other, measured in degrees or radian (Encyclopedia of Mathematics 2018). Two angles are called supplementary if they have their vertex and one side is common, whilst the other two sides form a straight line ($\alpha + \beta = 180°$) (Encyclopedia of Mathematics 2018). Sixteen of the component studies included in the present systematic review used the supplementary angle to determine root canal curvature, and not the angle formed by the lines on the root canal image but a projection of the coronal line. Interestingly, Berbert & Nishiyama (1994) did not explicitly mention which was the angle of curvature to be measured, however, based on subsequent studies using the methodology they proposed (Bramante & Betti 2000, Oget *et al.* 2017), it was deduced that the angle measured using their method was the supplementary one.

Several of the primary studies suggest that angle of curvature alone is insufficient to adequately describe root canal curvature (Table S1), with radius being a second parameter with an effect on the root canal treatment difficulty (Pruett *et al.* 1997, Schäfer *et al.* 2002). Furthermore, the position of the beginning of the curve, the level where they occur, the shape and the height are other important factors that ought to be considered to better understand root canal morphology (Dummer *et al.* 1989, Berbert & Nishiyama 1994, Kyomen *et al.* 1994, Nagy *et al.* 1995,

Table 3 Features proposed to measure root canal curvature described in the component studies

Reference	Plane	Angle	Position	Height	Radius	Length	Shape
Schneider 1971	**C**	**X**					
Weine 1982	**C**	**X**					
Southard *et al.* 1987	**CP**	**X**					
Backman *et al.* 1992	**CP**	**X**			**X**		
Berbert & Nishiyama 1994	**C**	**X**	**X**				
Kyomen *et al.* 1994	**C**			**X**			
Luiten *et al.* 1995	**C**	**X**					
Nagy *et al.* 1995	**C**	**X**				**X**	**X**
Thompson *et al.* 1995	**C**	**X**	**X**				
Hankins & ElDeeb 1996	**C**	**X**					
Harlan *et al.* 1996	**CP**	**X**					
Lopes *et al.* 1998	**C**	**X**			**X**		
Pettiette *et al.* 1999	**C**						
Dobo-Nagy *et al.* 2000	**CP**	**X**				**X**	**X**
Schäfer *et al.* 2002	**CP**	**X**			**X**	**X**	
Iqbal *et al.* 2003	**CP**	**X**			**X**		
Günday *et al.* 2005	**C**	**X**		**X**			
Cabrales *et al.* 2006	**C**	**X**					
Willerhausen *et al.* 2006	**C**	**X**					

C, Clinical view; CP, Clinical and proximal view.

Thompson *et al.* 1995, Dobo-Nagy *et al.* 2000). It should be noted that these differences in methodology may affect the interpretation of the different studies.

It must be noted that multiple investigations that were using K-files (08, 10, 15) or silver points (Southard *et al.* 1987, Backman *et al.* 1992, Luiten *et al.* 1995, Thompson *et al.* 1995, Hankins & ElDeeb 1996, Harlan *et al.* 1996, Lopes *et al.* 1998, Dobo-Nagy *et al.* 2000, Schäfer *et al.* 2002, Iqbal *et al.* 2003, Günday *et al.* 2005) placed into the root canal could present a confounding factor. Metal wires may not remain centred in the root canal, especially in wide canals; therefore, a file or silver point curvature may not be representative of the actual root canal curvature (Schäfer *et al.* 2002). Although this technique may be not suitable to measure the exact root canal curvature, it allows an appreciation of the challenge that a root canal instrument has to negotiate to reach the apical portion of the root canal (Cunningham & Senia 1992). One the other hand, from a clinical standpoint, the placement of files or silver points cannot be used for the assessment of root canal curvature before treatment, as this will require the preparation of an access cavity, thus root canal treatment will already have been initiated.

Three-dimensional imaging techniques are becoming increasingly popular in endodontics. Micro-computed tomography (μCT) provides high-resolution images, increasing the precision of qualitative evaluations and quantitative measurements of the root canal system. However, being time-consuming, associated with higher radiation exposure, and higher costs, it is unsuitable for patients (Peters *et al.* 2000, Lee *et al.* 2014, Ordinola-Zapata *et al.* 2017). Conversely, CBCT is a 3D alternative with clinical translation. When compared to two-dimensional imaging, CBCT presents greater accuracy regarding the determination of root canal morphology (Estrela *et al.* 2008, Sousa *et al.* 2017). Amongst the component studies, only two described using CBCT as an image resource (Estrela *et al.* 2008, Choi *et al.* 2015). Lastly, some studies used methods originally proposed for μCT to measure curvatures in CBCT, thus were not considered novel (Michetti *et al.* 2010, Park *et al.* 2013).

Visual estimation of root canal curvature is not reliable; thus, the use of a computer-based quantitative method is recommended (Faraj & Boutsioukis 2017). Although μCT and CBCT are more accurate in several aspects when compared to two-dimensional radiographic images, they normally require the use of specific software, which may not be readily available, thus this methodology may not be necessarily repeatable in other settings (Table S2). The potential for use of open source software for the measurement of root canal curvatures requires further assessment. The latter, in association with CBCT, may allow greater accuracy together with widespread clinical application

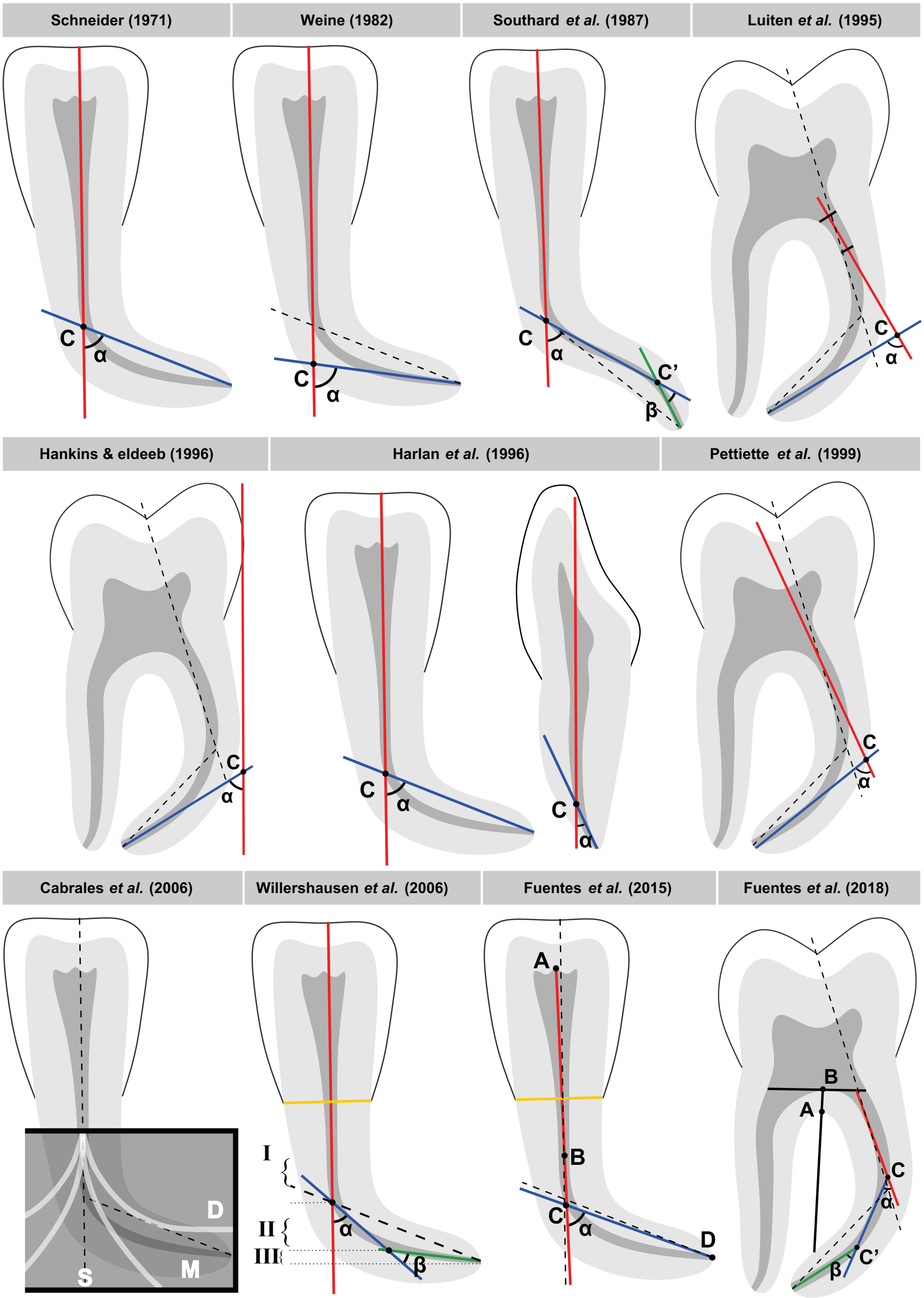

Figure 2 Diagrammatic representation of the methodologies proposed to measure angle of root canal curvature, from 2D imaging.

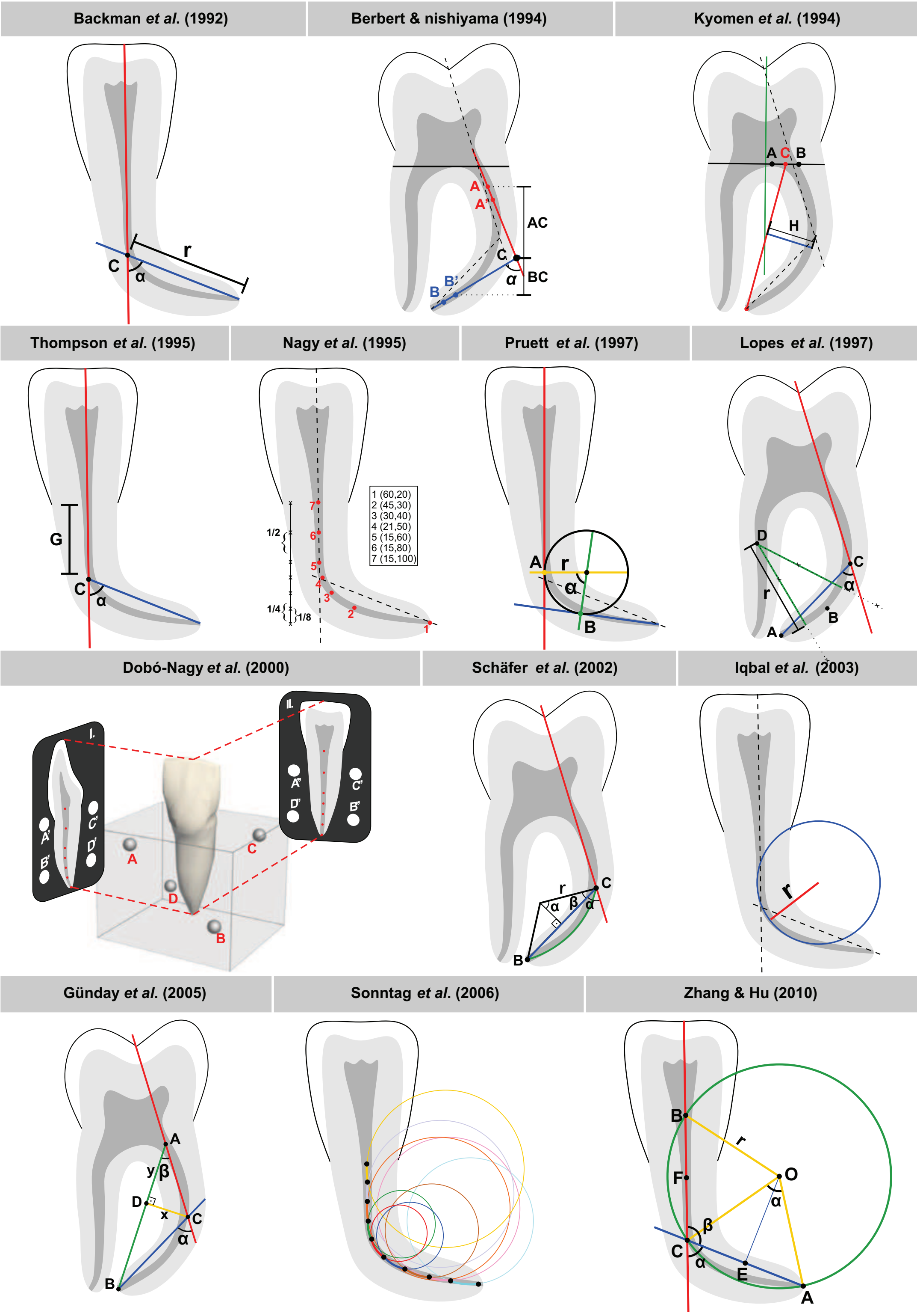

Figure 3 Diagrammatic representation of the methodologies proposed to measure angle of root canal curvature and other features, from 2D imaging.

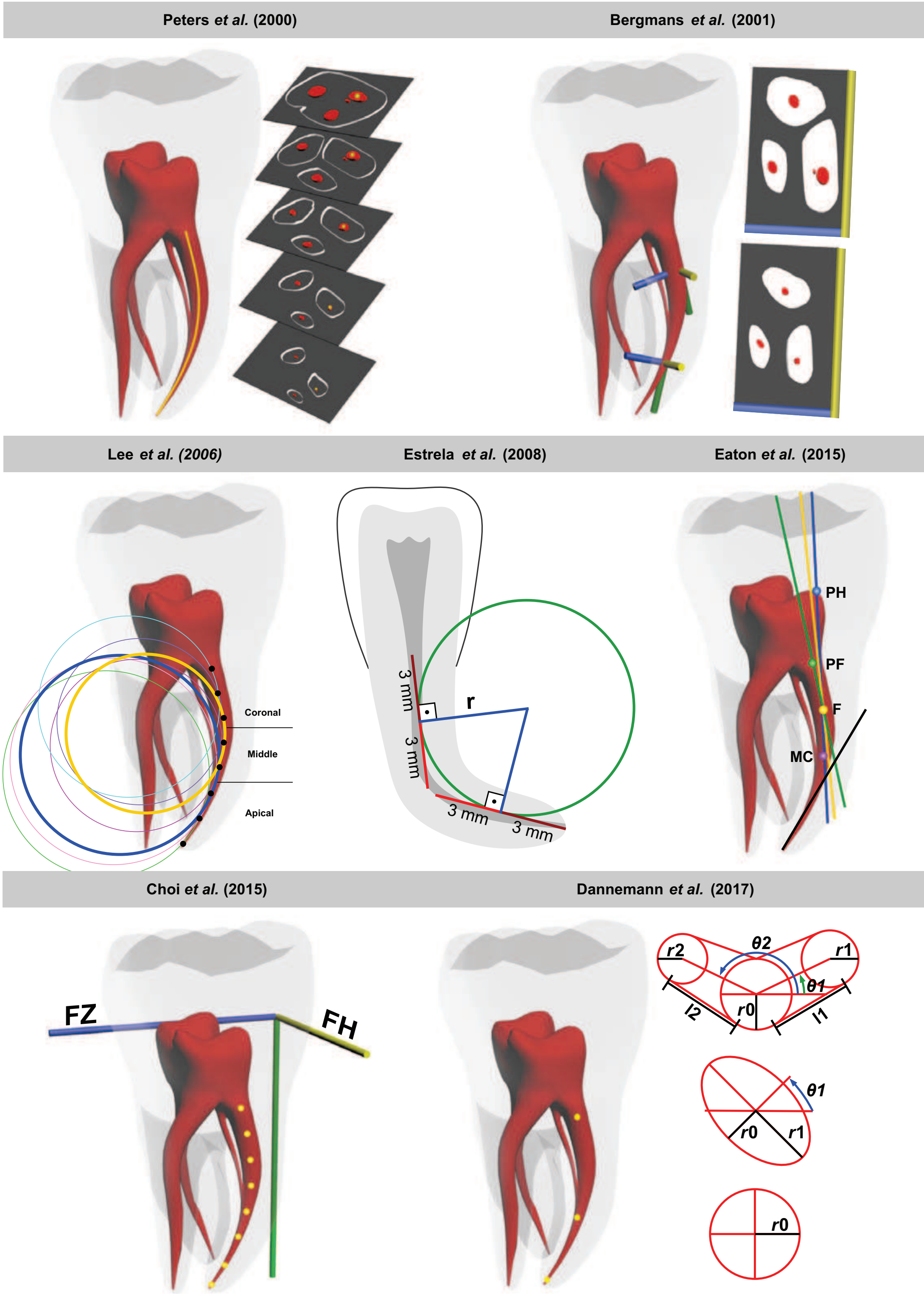

Figure 4 Diagrammatic representation of the methodologies proposed to measure angle of root canal curvature and other features, from 3D imaging.

of curvature measurement methodologies in the foreseeable future.

Conclusion

This systematic review includes publications with various methodologies for the measurement of root canal curvature angle and other factors. Most of the methods have potential clinical applications; however, there is a lack of consensus on the ideal technique to assess root canal curvature. In addition to angle, other factors, such as radius and position of the curvature, may need to be taken into consideration to evaluate root canal curvature in both clinical and research scenarios.

Conflict of interest

Dr. Peters reports personal fees and non-financial support 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

American Association of Endodontists (2010) Case difficulty assessment form and guidelines. https://www.aae.org/specialty/wp-content/uploads/sites/2/2017/06/2006casedifficultyassessmentformb_edited2010.pdf.

Backman CA, Oswald RJ, Pitts DL (1992) A radiographic comparison of two root canal instrumentation techniques. *Journal of Endodontics* **18**, 19–24.

Benyo B (2012) Identification of dental root canals and their medial line from micro-CT and cone-beam CT records. *Biomedical Engineering Online* **11**, 81.

Berbert A, Nishiyama CK (1994) Curvaturas radiculares: uma nova metologia para a mensuração e localização. *Revista Gaúcha de Odontologia* **42**, 356–8.

Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P (2001) A methodology for quantitative evaluation of root canal instrumentation using microcomputed tomography. *International Endodontic Journal* **34**, 390–8.

Bramante CM, Betti LV (2000) Comparative analysis of curved root canal preparation using nickel-titanium instruments with or without EDTA. *Journal of Endodontics* **26**, 278–80.

Cabrales RJS, Moura AAM, Yamazaki AK *et al.* (2006) Análise comparativa entre dois métodos para determinação do grau de curvatura de canais radiculares. *Journal of the Health Sciences Institute* **24**, 109–13.

Campos JM, del Rio C (1990) Comparison of mechanical and standard hand instrumentation techniques in curved root canals. *Journal of Endodontics* **16**, 230–4.

Canadian Academy of Endodontics (2017) CAE standards of practice. https://www.caendo.org/wp-content/uploads/2017/10/Standards-of-Practice-2017-.pdf.

Choi MR, Moon YM, Seo MS (2015) Prevalence and features of distolingual roots in mandibular molars analyzed by cone-beam computed tomography. *Imaging Science in Dentistry* **45**, 221–6.

Cunningham CJ, Senia ES (1992) A three-dimensional study of canal curvatures in the mesial roots of mandibular molars. *Journal of Endodontics* **18**, 294–300.

Dannemann M, Kucher M, Kirsch J *et al.* (2017) An approach for a mathematical description of human root canals by means of elementary parameters. *Journal of Endodontics* **43**, 536–43.

Dobo-Nagy C, Keszthelyi G, Szabo J, Sulyok P, Ledeczky G, Szabo J (2000) A computerized method for mathematical description of three-dimensional root canal axis. *Journal of Endodontics* **26**, 639–43.

Dobo-Nagy C, Serban T, Szabo J, Nagy G, Madlena M (2002) A comparison of the shaping characteristics of two nickel-titanium endodontic hand instruments. *International Endodontic Journal* **35**, 283–8.

Dummer PM, Alodeh MH, Doller R (1989) Shaping of simulated root canals in resin blocks using files activated by a sonic handpiece. *International Endodontic Journal* **22**, 211–5.

Eaton JA, Clement DJ, Lloyd A, Marchesan MA (2015) Micro-computed tomographic evaluation of the influence of root canal system landmarks on access outline forms and canal curvatures in mandibular molars. *Journal of Endodontics* **41**, 1888–91.

Encyclopedia of Mathematics (2018) Angle. *Encyclopedia of Mathematics*. http://www.encyclopediaofmath.org/index.php?title=Angle&oldid=13323.

Estrela C, Bueno MR, Sousa-Neto MD, Pecora JD (2008) Method for determination of root curvature radius using cone-beam computed tomography images. *Brazilian Dental Journal* **19**, 114–8.

Falcon HC, Richardson P, Shaw MJ, Bulman JS, Smith BG (2001) Developing an index of restorative dental treatment need. *British Dental Journal* **190**, 479–86.

Faraj S, Boutsioukis C (2017) Observer variation in the assessment of root canal curvature. *Internationa Endodontic Journal* **50**, 167–76.

Fuentes R, Arias A, Navarro P, Ottone N, Bucchi C (2015) Morphometric study of mandibular premolars in panoramic digital radiographs, analysis of root curvatures. *International Journal of Morphology* **33**, 476–82.

Fuentes R, Farfan C, Astete N, Navarro P, Arias A (2018) Distal root curvatures in mandibular molars: analysis using digital panoramic X-rays. *Folia Morphologica* **77**, 131–7.

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.

Gilles JA, del Rio CE (1990) Comparison of the Canal Master endodontic instrument and K-type files for enlargement of curved root canals. *Journal of Endodontics* **16**, 561–5.

Goldberg F, Araujo JA (1997) Comparison of three instruments in the preparation of curved root canals. *Endodontic Dental Traumatology* **13**, 265–8.

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.

Günday M, Sazak H, Garip Y (2005) A comparative study of three different root canal curvature measurement techniques and measuring the canal access angle in curved canals. *Journal of Endodontics* **31**, 796–8.

Hankins PJ, ElDeeb ME (1996) An evaluation of the Canal Master, balanced force, and step-back techniques. *Journal of Endodontics* **22**, 123–30.

Harlan AL, Nicholls JI, Steiner JC (1996) A comparison of curved canal instrumentation using nickel-titanium or stainless steel files with the balanced-force technique. *Journal of Endodontics* **22**, 410–3.

Huerta Ortiz ME, Del Olmo JL, Luna Lara CA, Parra RO (2012) Comparación de la capacidad de centrado de la instrumentación con conicidad constante contra progresiva en molares inferiores. *Oral* **13**, 862–4.

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.

Jardine SJ, Gulabivala K (2000) An in vitro comparison of canal preparation using two automated rotary nickel-titanium instrumentation techniques. *International Endodontic Journal* **33**, 381–91.

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

Kuttler S, Garala M, Perez R, Dorn SO (2001) The endodontic cube: a system designed for evaluation of root canal anatomy and canal preparation. *Journal of Endodontics* **27**, 533–6.

Kyomen SM, Caputo AA, White SN (1994) Critical analysis of the balanced force technique in endodontics. *Journal of Endodontics* **20**, 332–7.

Lee J-K, Ha B-H, Choi J-H, Heo S-M, Perinpanayagam H (2006) Quantitative three-dimensional analysis of root canal curvature in maxillary first molars using micro-computed tomography. *Journal of Endodontics* **32**, 941–5.

Lee KW, Kim Y, Perinpanayagam H *et al.* (2014) Comparison of alternative image reformatting techniques in micro-computed tomography and tooth clearing for detailed canal morphology. *Journal of Endodontics* **40**, 417–22.

Lee JK, Yoo YJ, Perinpanayagam H *et al.* (2015) Three-dimensional modelling and concurrent measurements of root anatomy in mandibular first molar mesial roots using micro-computed tomography. *International Endodontic Journal* **48**, 380–9.

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.

Lopes HP, Elias CN, Estrela C, Siqueira JF Jr (1998) Assessment of the apical transportation of root canals using the method of the curvature radius. *Brazilian Dental Journal* **9**, 39–45.

López FU, Travessas JAC, Fachin E, Fontanella V, Grecca F (2009) Apical transportation: two assessment methods. *Australian Endodontic Journal* **35**, 85–8.

Luiten DJ, Morgan LA, Baugartner JC, Marshall JG (1995) A comparison of four instrumentation techniques on apical canal transportation. *Journal of Endodontics* **21**, 26–32.

Michetti J, Maret D, Mallet JP, Diemer F (2010) Validation of cone beam computed tomography as a tool to explore root canal anatomy. *Journal of Endodontics* **36**, 1187–90.

Moher D, Liberati A, Tetzlaff J, Altman DG, Group P (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Journal of Clinical Epidemiology* **62**, 1006–12.

Nagy CD, Szabo J, Szabo J (1995) A mathematically based classification of root canal curvatures on natural human teeth. *Journal of Endodontics* **21**, 557–60.

Nagy CD, Bartha K, Bernath M, Verdes E, Szabo J (1997a) A comparative study of seven instruments in shaping the root canal in vitro. *International Endodontic Journal* **30**, 124–32.

Nagy CD, Bartha K, Bernath M, Verdes E, Szabo J (1997b) The effect of root canal morphology on canal shape following instrumentation using different techniques. *International Endodontic Journal* **30**, 133–40.

Nielsen RB, Alyassin AM, Peters DD, Carnes DL, Lancaster J (1995) Microcomputed tomography: an advanced system for detailed endodontic research. *Journal of Endodontics* **21**, 561–8.

Oget D, Braux J, Compas C, Guigand M (2017) Comparative analysis of root canal changes after preparation with three systems using Cone-Beam Computed Tomography. *Giornale Italiano di Endodonzia* **31**, 83–8.

Ordinola-Zapata R, Bramante CM, Versiani MA *et al.* (2017) Comparative accuracy of the Clearing Technique, CBCT and Micro-CT methods in studying the mesial root canal configuration of mandibular first molars. *International Endodontic Journal* **50**, 90–6.

Park PS, Kim KD, Perinpanayagam H *et al.* (2013) Three-dimensional analysis of root canal curvature and direction of maxillary lateral incisors by using cone-beam computed tomography. *Journal of Endodontics* **39**, 1124–9.

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.

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

Pettiette MT, Metzger Z, Phillips C, Trope M (1999) Endodontic complications of root canal therapy performed by dental students with stainless-steel K-files and nickel-titanium hand files. *Journal of Endodontics* **25**, 230–4.

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

Ree MH, Timmerman MF, Wesselink PR (2003) An evaluation of the usefulness of two endodontic case assessment forms by general dentists. *International Endodontic Journal* **36**, 545–55.

Roane JB, Sabala CL, Duncanson MG Jr (1985) The "balanced force" concept for instrumentation of curved canals. *Journal of Endodontics* **11**, 203–11.

Sadeghi S, Poryousef V (2009) A novel approach in assessment of root canal curvature. *Iranian Endodontic Journal* **4**, 131–4.

Schäfer E, Diez C, Hoppe W, Tepel J (2002) Roentgenographic investigation of frequency and degree of canal curvatures in human permanent teeth. *Journal of Endodontics* **28**, 211–6.

Schneider SW (1971) A comparison of canal preparations in straight and curved root canals. *Oral Surgery, Oral Medicine, and Oral Pathology* **32**, 271–5.

Shah PK, Chong BS (2018) A web-based endodontic case difficulty assessment tool. *Clinical Oral Investigations* **22**, 2381–8.

Short JA (1997) A comparison of canal centering ability of four instrumentation techniques. *Journal of Endodontics* **23**, 503–7.

Sonntag D, Stachniss-Carp S, Stachniss C, Stachniss V (2006) Determination of root canal curvatures before and after canal preparation (part II): a method based on numeric calculus. *Australian Endodontic Journal* **32**, 16–25.

Sousa TO, Haiter-Neto F, Nascimento EHL, Peroni LV, Freitas DQ, Hassan B (2017) Diagnostic accuracy of periapical radiography and cone-beam computed tomography in identifying root canal configuration of human premolars. *Journal of Endodontics* **43**, 1176–9.

Southard DW, Oswald RJ, Natkin E (1987) Instrumentation of curved molar root canals with the Roane technique. *Journal of Endodontics* **13**, 479–89.

Thompson SA, Al-Omari MAO, Dummer PMH (1995) Assessing the shape of root canals: an in vitro method using microradiography. *International Endodontic Journal* **28**, 61–7.

Uroz-Torres D, Gonzalez-Rodriguez 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.

Weine FS (1982) *Endodontic therapy / Franklin S. Weine, contributing authors, Marshall H. Smulson ... [et al.].* Saint Louis, MO: Mosby.

Willershausen B, Tekyatan H, Kasaj A, Marroquín BB (2006) Roentgenographic in vitro investigation of frequency and location of curvatures in human maxillary premolars. *Journal of Endodontics* **32**, 307–11.

Zhang R, Hu T (2010) Root canal curvature. *International Endodontic Journal* **43**, 616–8.

Zheng QH, Zhou XD, Jiang Y *et al.* (2009) Radiographic investigation of frequency and degree of canal curvatures in Chinese mandibular permanent incisors. *Journal of Endodontics* **35**, 175–8.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Methods used in the studies using 2D imaging, measuring only the angle of curvature.

Table S2 Methods used in studies that used 2D imaging, measuring angle and other features of canal curvature.

Table S3 Methods used in studies using 3D imaging, measuring angle and other features of canal curvature.

Table S1. Methods used in the studies using 2D imaging, measuring only the angle of curvature.

Study Year	T	Method Description	Strength	Limitations
Schneider 1971	PR	A line (red) was scribed on the radiograph parallel to the image of the canal long axis. A second line (blue) was drawn from the apical foramen to intersect with the first line at the point where the canal began to leave the long axis of the tooth (C). The acute angle thus formed was measured (α). [Straight (≤5°), moderate (10-20°) or severe (25-70°)].	Simple and clinically feasible, special software not required.	2D, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Weine 1982	PR	A line (red) from orifice through more the coronal portion of curve and another line (blue) from apex through the apical portion of the curve. The interior angle (α) formed by intersection of these lines (C) is the degree of curvature.	Simple and clinically feasible, special software not required.	2D, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Southard *et al.* 1987	PR	Teeth with only one curvature were measured by the Schneider's method. Teeth with S-type curve were measured as follows. A line (red) was drawn along the axis of the coronal portion of the root canal image. A second line (blue) was then drawn as a "best fit" line along the segment of canal from its initial point (C) of departure from the long axis line to the point (C') at which the second curve to the foramen occurred. A third line (green) was then drawn from the apical termination point of the instrument at the apical foramen to a point at which the outside edge of the instrument intersected the second line. [α: angle of the first curvature; β: angle of the second curvature].	Simple and partially clinically feasible, allows the measurement of different curvatures in the same root/canal; measures both angles (mesiodistal, buccal-lingual) of the curvature, special software not required.	2D, no correlation between the clinical and the proximal measurements, proximal view is impractical in the clinical scenario
Luiten *et al.* 1995	PR	A line (red) was drawn through the midpoint of a line drawn across the canal orifice and the midpoint of a line drawn across the canal 2 mm apical to the orifice. The apical line (blue) was drawn parallel to the apical 1 mm of the canal, intersecting (C) and the resulting angle measured (α).	Simple and clinically feasible, considers the centring of the coronal portion of the root canal, special software not required.	2D, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Hankins & EIdeeb 1996	PR	A line (red) was drawn representing the long axis of the tooth. Measurement of canal angulation involved drawing a line (blue) passing through the apical one-third of the file. The angle (α) formed by the intersection (C) of that line with the long axis of the tooth.	Clinically feasible, considers the long axis of the tooth, do not need special software	2D, only one angle of the curvature, do not considers the centring of the coronal portion of the root canal, measures only one angle of the curvature (mesiodistal).
Harlan *et al.* 1996	PR	Clinical and proximal angles were measured as described by Schneider. The true curvature of each sample root canal was then calculated using the formula: $T = atan [(tan (C))^2 + (tan (P))^2]1/2$, where C is the angle of the curvature in the clinical view and P in the proximal.	Simple and partially clinically feasible, measures and correlates both angles (mesiodistal, buccal-lingual) of the curvature, special software not required.	2D, proximal view is impractical in the clinical scenario, measures only one angle of the curvature in each view.

Pettiette *et al.* 1999	PR	A line (red) was drawn on the axis of the coronal third of the root canal and the second line (blue) was through the axis of the canal in its apical third. These lines met at an angle (C) that was defined as canal angulation (α).	Simple and clinically feasible, special software not required.	2D, restricted to the clinical view, do not considers the centring of the coronal portion of the root canal, measures only one angle of the curvature (mesiodistal).
Cabrales *et al.* 2006	PR	The curvatures were evaluated placing a scale in front of the radiographic image on the smaller radius. [>25mm simple, 25-11 medium; 8-11 difficult].	Simple and clinically feasible, special software not required.	2D, no specific measurement of the angle of the root canal curvature (classification according to curvature categories), measures only one angle of the curvature (mesiodistal), need a special template.
Willershausen *et al.* 2006	PR	A horizontal line (yellow) between the mesial and distal CEJ serves as coronal reference level. The middle of the root canal (red line) was used as a reference for the straight lines and tangents; distance I: distance from the CEJ to the first curvature; distance II: distance from the first curvature to the second curvature or radiological apex; distance III: distance from the second curvature to the radiological apex. [α: angle of the first curvature; β: angle of the second curvature].	Clinically feasible, allows the measurement of different curvatures in the same root/canal, considers the distance from the CEJ to the different curvatures, special software not required.	2D, restricted to the clinical view, all the measured angles are in the same view (mesiodistal).
Fuentes *et al.* 2015	DPT	Point A determined the pulp chambers roof (middle point of the crown). A line (yellow) was drawn connecting the mesial and distal CEJ. Then, point B was placed on the centre of the canal, 5 mm from the yellow line. A line (red) that passes through A and B determinates the coronal line. A line (blue) passing through point C (portion where the root canal leave the coronal line) and D (apical apex), determinates the apical line. The angle (α) was measured at the intersection of apical and coronal lines.	Simple and clinically feasible, special software not required.	2D, restricted to the clinical view, limited use to the dental panoramic tomography (susceptible to image distortions), measures only one angle of the curvature (mesiodistal).
Fuentes *et al.* 2018	DPT	The longitudinal axis of the tooth was determined through the projection of two points: one located in the furcation of the tooth (most concave point) (A) and the other located on the chamber floor above the furcation and at the midpoint of the mesiodistal distance in the chamber (B). A line tangent to the chamber floor was drawn, perpendicular to the long axis of the tooth. The lines of the angle were drawn to measure, establishing a midpoint in the distal root canal on the same plane as this line. A line (red) was drawn from this point following the direction of the root, in the centre of the canal, to the point at which the line left the canal (C). From the point at which this line left the canal, a second line (blue) was drawn, following the direction of the root, in the centre of the canal, to the point at which the line again left the canal (C').	Clinically feasible, measurement of different curvatures in the same root/canal, special software not required.	2D, restricted to the clinical view, limited use to the dental panoramic tomography (susceptible to image distortions), measures only angles of the curvature (mesiodistal).

T: Technique; PR: Periapical Radiograph; DPT: Dental Panoramic Tomography.

Table S2. Methods used in studies that used 2D imaging, measuring angle and other features of canal curvature.

Study Year	T	Method Description	Strength	Limitations
Backman *et al.* 1992	PR	The curvature angles were assessed using the Schneider or Southard methods. The radius measurement (r) for single curvatures was measured from the tip of the instrument at the apical foramen to where the canal deviated from the coronal axis (C). For double or S-type curvatures, two radius measurements were determined, the first from the point where the first curve began to the point at which the second curvature occurred. The second measurement was made from the tip of the instrument at the apical foramen to the point where the second curvature began. A value termed the "radius quotient" obtained by dividing the given angle by its "radius" measurement.	Clinically feasible, special software not required, includes the "radius quotient" measure, an additional information on the curvature description.	2D, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Berbert & Nishiyama 1994	PR	A line (black) was traced tangent to the chamber floor. On the cervical portion of the root canal image two dots were marked, one 2 mm (A) and other 3 mm (A') from the chamber floor line in the centre of the root canal. These two points determinate the cervical line (red). Two more points were determined, one 1 mm (B) and other 2 mm (B') from the apical foramen, defining the apical line (blue). The angle of the curvature (α) was measured at the intersection of these lines (C). The distance between B' and C (BC) and A to C (AC) were measured and by their division the quotient of curvature was obtained, determining the level where the curvature occurs [Cervical third (<0.5), middle (0.5-2) and apical (>2)].	Clinically feasible, special software not required, includes the measurement of the level of the curvature, an additional information on the curvature description.	2D, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Kyomen *et al.* 1994	PR	A line (green) representing the long axis of each tooth was drawn vertically through the tooth at the approximate mesiodistal midline, as judged at the level of the CEJ and continuing midway between the two roots. A line (black) was drawn perpendicular to this line, tangential to the most coronal extent of the floor of the pulp chamber. The distance from point A (point of contact of the line on the chamber floor) to point B (where the line intersects the mesial wall of the chamber) was halved, and this midpoint was labelled point C. A Line (red) was then drawn through points C and the apical foramen and this line segment was defined as root length. The maximum perpendicular linear distance from the red line to the mesial canal was recorded and defined as the maximum height of curvature (H).	Clinically feasible, special software not required, includes the measurement of the height of the curvature, an additional information on the curvature description.	2D, restricted to the clinical view, no measurement of the angle of the curvature.
Thompson *et al.* 1995	PR	The angle of the canal was measured using a modification of Schneider's method. The radius was measured using a drafting template and the distance of the beginning of the curve from the orifice (G) was measured to the nearest 0.5 mm.	Clinically feasible, special software not required, includes the measurement of the distance up to the beginning of the curvature, an additional information on the curvature description.	2D, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Nagy *et al.* 1995	PR	Seven points for each root canal axis were plotted using a halving technique. Coordinates of all the points were fed into a computer, and root canal axes were determined by fourth degree polynomial function approximation. Based on the results the root canal forms can be classified into the following groups:	Special software not required, includes a mathematical description of the curvature.	2D, complex and not clinically feasible, restricted to the clinical view

		straight or I form, apical curve or J form, curved canal along its entire length or C form, and multicurved or S form.		
Pruett *et al.* 1997	CST	A line (red) was drawn along the long axis of the coronal portion of the canal. A second line (blue) was drawn along the long axis of the apical portion of the canal. There is a point on each of these lines at which the canal deviates to begin (A) or end (B) the canal curvature. The curved portion of the canal is represented by a circle with tangents at points A and B. Angle of curvature can be defined by the angle (α) formed by perpendicular lines (yellow and green lines) drawn from the points of deviation (A and B) that intersect at the centre of the circle. The length of these lines is the radius of the circle and defines the radius of the canal curvature in millimetres.	Special software not required, includes the measurement of the radius of the curvature.	2D, complex and not clinically feasible, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Lopes *et al.* 1998	PR	The angle (α) of curvature of the canals was determined by Schneider's method. The apical foramen (A), the greatest curvature (B) and the intersection of the apical and coronal lines (C) were determined. The radius of curvature of the root canal was measured in the region of greatest curvature (B) using a geometric method. The centre of the curve (D) is determined by the meeting of the medians of two cords (green) in the region of the greatest curvature. [Mild (≥20mm), moderate (<20 and >10mm) or severe (≤10mm)].	Special software not required, includes the measurement of the radius of the curvature, an additional information on the curvature description..	2D, complex and not clinically feasible, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Dobó-Nagy *et al.* 2000	PR	Four metal spheres were placed into four different corners of each tooth block in a tetrahedral position for subsequent reconstruction. The blocks were radiographed in proximal (I) and clinical (II) views. On the radiograph images seven points of imaginary axis of the root canal were plotted, and the axis was calculated by fourth-degree polynomial function approximation as described by Nagy *et al.* 1995. Along the parallel order line one Monge image was translated to its turnaround image. Each well-ordered Monge image pair was put into a common coordinate system resulting in the 3D polynomial curve of the root canal axis.	Special software not required, measures and correlates both angles (mesiodistal, buccal-lingual) of the curvature, includes a mathematical description of the curvature in 3D.	2D, complex and not clinically feasible, requires a special apparatus.
Schäfer *et al.* 2002	PR	The angle of curvature was determined for both clinical and proximal view curvatures, according to the method described by Schneider. The line (green) between points B and C is the chord of the hypothetical circle that defines the curved part of the canal. The curved part of the root canal between points B and C is the circular arc of the hypothetical circle, which is specified by its radius (r). The radius of the curvature was calculated on the basis of the geometrical principals of an isosceles triangle.	Includes the measurement of the radius and the arc of the curvature, an additional information on the curvature description..	2D, complex and not clinically feasible, special software required, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).
Iqbal *et al.* 2003	PR	Series of radiographs were exposed, each time incrementally rotating the turntable until a file in the root canal appeared straight on the radiograph. The turntable was then rotated 90 degrees to reveal the maximum curvature of the root canal, and a preoperative radiograph of the tooth was obtained. The radius of the curvature was measured in a software drawing a circle well fitted on the image of the root canal.	Identify and includes the measurement of the maximum curvature, an additional information on the curvature description.	2D, not clinically feasible, special software required, needs a special apparatus.
Günday *et al.* 2005	PR	The canal orifice (A) and apex (B) points were connected with a line (green). The angle (β) formed by the intersection between the red line (parallel line described in the Schneider method) intercepting the green	Clinically feasible, special software not required,	2D, complex and not clinically feasible, restricted to

		one is defined as the canal access angle. At the point (C), where the red line leaves the root canal, a perpendicular line to AB was drawn (yellow). The point that the yellow line intersects the green is D. CD gives the curvature height (x), and the distance from A to point D is the curvature distance (y).	includes the measurement of the height of the curvature, an additional information on the curvature description.	the clinical view, measures only one angle of the curvature (mesiodistal).
Sonntag *et al.* 2006	AB	In mathematics, a curvature is described by means of hypothetical circles. The curvature at a specific point (x0) is described by selecting a circle that is optimally adapted to the configuration of the curve at that point. The smaller the curvature, the larger the hypothetical circle. The actual configuration of the canal wall is described by specifying x and y coordinates of selected measuring points. Using this point sequence, an equalising function describing the configuration in mathematical terms can be determined. The use of the equalising function adapted to the configuration of the long axis of the canal permits the exact determination of the curvature for each point x and for the point of maximum curvature, as well as the mean curvature of the measured canal section. The distance of the point of maximum curvature from the apical foramen can also be calculated by means of the arc length with x1 and x2, signifying the x-coordinates of apex and maximum curvature.	Includes a mathematical description of the curvature.	2D, complex and not clinically feasible, restricted to the clinical view, special software required.
Zhang & Hu 2010	TD	The angle of the curvature is defined according to Schneider. Point A denotes the apical foramen. The point where the canal begins the curvature is marked as point C. A line is then drawn parallel to the long axis of the canal through point C, and a point B is chosen on this line such that the distance between C and B is equal to that between A and C. The angle α formed by lines AC and CB is the angle of curvature. From E and F, the midpoints of AC and CB, respectively, two lines are drawn perpendicular to the lines AC and CB, which would meet at the circumcentre O. The distance between O and A, B or C is the radius (r) of the circumference, which determines the magnitude of the curve. The angle (α) can be transferred to an isosceles triangle, with the base on the line AC, then radius (r) length of the curvature can be determined.	Special software not required, includes the measurement of the radius of the curvature.	2D, complex and not clinically feasible, restricted to the clinical view, measures only one angle of the curvature (mesiodistal).

T: Technique; PR: Periapical Radiograph; CST: Curved Stainless-Steel Guide Tubes; AB: Acrylic Blocks; TD: Theoretical Discussion.

Table S3. Methods used in studies using 3D imaging, measuring angle and other features of canal curvature.

Study Year	T	Method Description	Strength	Limitations
Peters et al. 2000	µCT	Each slice was defined by a series of coordinated data for the x-, y-, and z-axes. The first two axes were parallel to the slice, while the z-axis was at right angles to each slice. The "centers of gravity" of the canals, calculated for each slice, were connected along the z-axis by a fitted line. The mean curvature of a canal was calculated from the geometric formula of the fitted line as the 2nd derivative. Volume and surface of the root canals were determined by means of the triangulated data and the Marching Cubes algorithm.	3D, comprehensive measurement of the angles and radius of the curvatures.	Not clinically feasible, special software required.
Bergmans et al. 2001	µCT	The root canal central axis is an important element for quantitative measurements in the 3D modelling. Such an axis was calculated by fitting a so-called spline curve through the geometric means of the contours that were obtained by intersecting the canal surface with each individual slice. In this way a 3D curve was obtained that reflected the anatomy of the root canal. Based on the principles of differential geometry, a local co-ordinate frame could be associated to each point along the curve (Frenet-Serret co-ordinate frame). It provides numerical values for the curvature (degree of bending) and the torsion (degree of twisting) of the curve at specific points, and hence fully describes its local 3D anatomy.	3D, comprehensive measurement of the angles, radius and torsion of the curvatures.	Not clinically feasible, special software required.
Lee et al. 2006	µCT	The central axis was defined as a cubic B-spline curve that passes through the point of intersection of the major and minor axes of ellipse of each image slice. The curvature (k) was defined as the rate of turning of the tangent vector at a given point. The radius of curvature of the tangential circle at each point along the central axis was measured and then and inverted it to provide a measure of the actual curvature. The following were calculated: firstly the mean curvature of each trisection (coronal, middle, and apical thirds); secondly the maximum curvature and its location (yellow circle); and thirdly the maximum curvature within the apical third and its location (blue circle).	3D, comprehensive measurement of the angles and radius of the curvatures in different thirds of the root.	Not clinically feasible, special software required.
Estrela et al. 2008	CBCT	The proposed method to determine the curvature radius of curved root canal uses two 6-mm semi straight lines (red) superimposed to the root canal, the primary line being the one that represents the longer continuity of the apical region and the secondary line being the one that represents the middle and cervical thirds. Regardless of the length of the secondary line, only the 6 mm closest to the primary line is used to measure. The midpoint of each semi straight line is determined. From this point, two lines perpendicular to the semi straight lines (blue) are drawn until they meet at a central point, which is named circumcentre. The length of the blue lines determinate the circumference radius, which defines the magnitude of the curve. [Small radius ($r \leq 4$ mm): severe curvature; intermediary radius ($4 < r \leq 8$mm): moderate curvature; and large radius ($r > 8$ mm): mild curvature].	Clinically feasible, multiplane measurement of the angles and radius of the curvatures in coronal and apical thirds of the root canal.	Special software required, not a real 3D measurement, since no correlation between the multiplanes analysis are carried out.
Eaton et al. 2015	µCT	The volume rendering for each sample was rotated until the maximum curvature view was evident for the canals and the image exported. Four points were determined: pulp horns (PH) (blue), centre of canal orifices at the pulp chamber floor (PF) (green), centre of canal at the furcation level (F) (yellow), and	Includes the measurement of different curvature angles, according to	Not clinically feasible, special software required, not a real 3D measurement,

		centre of primary curvature in the maximum view (MC) (purple). An apical line (black) was drawn and in the intersection with: minimally invasive line (PF), straight-line furcation (F) and straight-line radicular (PH), the angles were measured.	clinically relevant landmarks.	since the analysis is based on rendering images.
Choi et al. 2015	CBCT	The centre points of the canals were marked in the axial slice at the level of the CEJ. In order to measure the curvature, an imaginary centre of the root canal space was created in each image slice using all three planes. The software automatically displayed the location of the designated points as three-dimensional coordinates (x, y, and z). The x-axis (left/right axis) was parallel to what was described the "frontozygomatic" (FZ) line. The y-axis (posterior/anterior axis) was perpendicular to the FZ line and parallel to what was described as the "Frankfort horizontal" (FH) line. The z-axis (vertical axis) was perpendicular to both the FZ line and the FH line. The 3D coordinates (x, y, and z) of each landmark represented its 3D position relative to the origin. The centre of the root canal of every slice between the starting point (x0, y0, and z0) and the designation point (xn, yn, and zn) was plotted manually. The line connecting the individual points then formed the axis of the canal along the curve of the root canal.	3D, clinically feasible, comprehensive measurement of the angles and radius of the curvatures.	Lack of information regarding the process of calculation, special software required.
Dannemann et al. 2017	µCT	The 3-dimensional geometry of the root canals, calculated by a self-implemented image evaluation algorithm, was described by 3 different mathematical models: the elliptical model, the 1-circle model, and the 3-circle model. Root canals with a nearly elliptical cross section are reasonably approximated by the elliptical model, whereas the 3-circle model obtained a good agreement for curved shapes. The mathematical description was divided into 2 parts. First, the calculated centroids were described by 1, 2, or 3 implicit curves parallel to the XY plane, denoted as layers. Then, the centre (Xm, Ym, Zm) of the implicit curves was used to calculate the length and curvature of the root canal. The radius of curvature was denoted as $r = 1/k$	3D, highly comprehensive measurement of the angles and radius of the curvatures.	Very complex and not clinically feasible, special software required

T: Technique; µCT: Micro-Computed Tomography; CBCT: Cone-Beam Computed Tomography.

ARTIGO 2

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

Publicado no periódico *International Endodontic Journal*, 2018 Nov;51(11):1239-52.

Fator de impacto 3,015 e classificação A1 segundo a Capes.

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

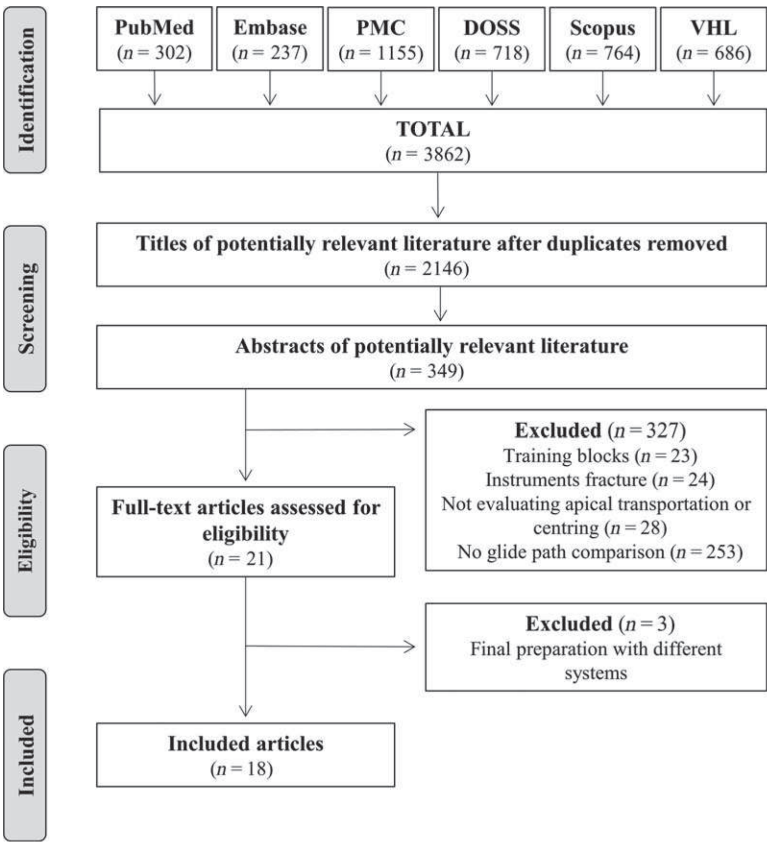

Figure 1 Flowchart of the methodology.

Table 1 Main characteristics of the included studies: sample characteristics

	Assessment of curvature						
Study	Root type	Total number of teeth or canals	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 GB:ProTaper Universal	PF #13, #16 & #19+ PTU #40 K-File+PTU #40	DR CBCT	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
Carvalho *et al.* (2015)	KF/RS-10/15K-File+Reciproc NGP/RS-just Reciproc PF/RS-PathFile+ Reciproc NP-no Preparation	K-File #10 & #15+ RP #25 RP #25 PF #13, #16 & #19+ RP #25 No Preparation	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
Dhingra *et al.* (2015)	WaveOne PathFile+WaveOne	WO #25 PF #13, #16 & #19+ 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
Kirchhoff *et al.* (2015)	ProGlider PathFile	PG #16 PF #13, #16 & #19	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
Ocampo *et al.* (2015)	ProTaper Next ProTaper Next+PathFile	PTN #25 PF #13, #16 & #19+ 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
Turker & Uzunoglu (2015)	M:Manual+PTN PF:PathFile+PTN PG:ProGlider+PTN PTN:ProTaper Next	K-File #10, #15 & #20+ PTN #25 PF #13, #16 & #19+ PTN #25 PG #16/02+ PTN #25 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

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).

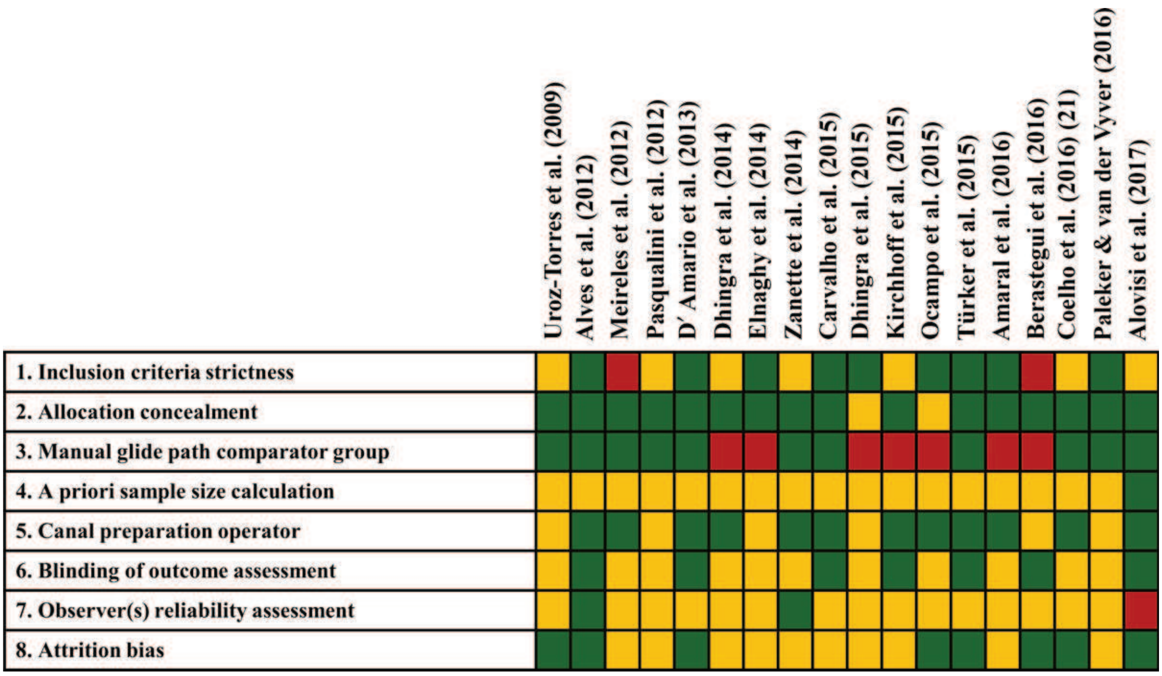

Figure 2 Risk of bias. Risk of bias summary: Reviewers' judgements about each risk of bias item for each included study.

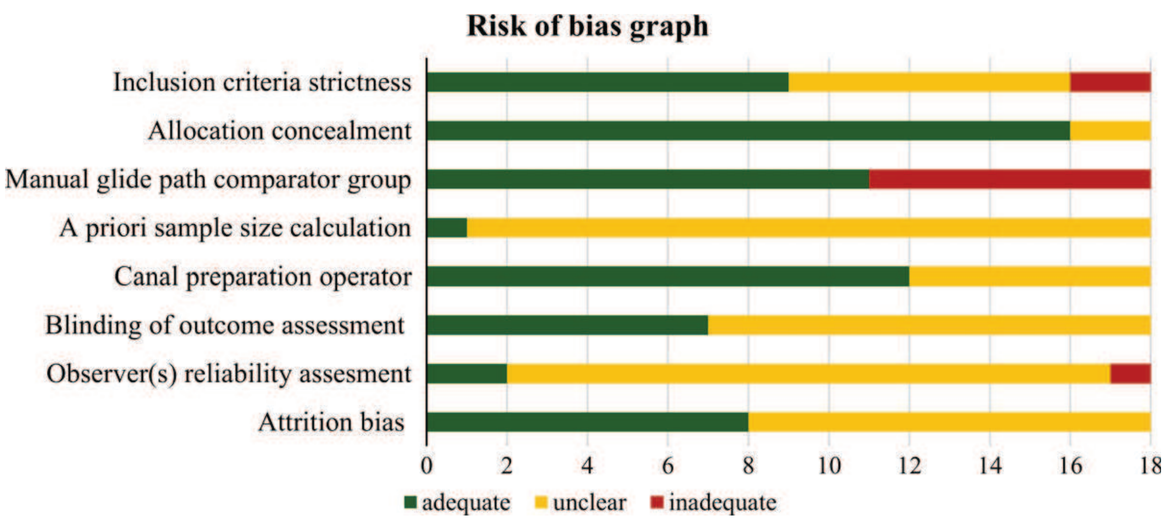

Figure 3 Risk of bias graph: Reviewers' judgements about each risk of bias item presented across all included studies.

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 post-operative 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.

CONSIDERAÇÕES FINAIS

O tratamento endodôntico tem como objetivo a manutenção e/ou o restabelecimento da saúde dos tecidos periapicais de suporte. Podemos citar os aspectos anatômicos e as questões microbiológicas como os principais desafios para se atingir o sucesso da terapêutica endodôntica[1, 2]. A anatomia dos canais radiculares é complexa e oferece dificuldades variadas durante o preparo e descontaminação endodôntica. Assim, durante a fase de modelagem dos canais radiculares, todas as medidas visando o respeito às características anatômicas originais dos condutos, preservando a qualidade dos preparos e a redução de erros operatórios, devem ser adotadas [82, 83].

Há a necessidade de que as decisões terapêuticas sejam tomadas baseadas em uma correta avaliação da complexidade anatômica dos canais radiculares [74, 4]. Para tanto, o conhecimento dos métodos disponíveis no que diz respeito a mensuração das curvaturas e suas caraterísticas passa a ter grande importância [84, 85], tanto sob o prisma clínico quanto em cenários ligados à pesquisa científica em Endodontia.

A primeira revisão crítica e sistemática, inclui publicações com várias metodologias para a medição dos ângulos de curvatura do canal radicular e outros fatores associados. A maioria dos métodos tem potenciais aplicações clínicas, no entanto, há uma falta de consenso sobre a técnica ideal para se mensurar curvaturas do canal radicular. Além do ângulo, outros fatores, como raio e posição da curvatura, precisam ser mensurados e devem ser levados em consideração para avaliar a curvatura do canal radicular tanto em tratamentos clínicos como em ambientes de pesquisa.

Chama a atenção que há um senso comum em se utilizar o ângulo suplementar nas medições de curvaturas. Entretanto, parece ser mais coerente, para futuros métodos, que sejam medidos os ângulos formados entre as retas cervicais e apicais nos métodos em 2D. Já nos métodos em 3D, uma dificuldade se deve ao grande volume de dados obtidos nas avaliações. Neste ponto, fazer a tradução e a interpretação dessas informações, para sua aplicação clínica, é o maior desafio.

O fato de que os métodos mais novos, realizados em imagens em 3D, são totalmente dependentes de softwares específicos, apresenta-se como ponto preocupante. Esse aspecto torna muito difícil a realização de estudos comparativos em múltiplos centros de pesquisa. Uma solução para esse empasse seria o desenvolvimento de um método independente que possa ser realizado através de softwares mais facilmente disponíveis ou até mesmo em softwares livres.

Com base nas evidências obtidas na segunda revisão sistemática, pode se observar uma ampla discussão e grande dificuldade em definir o termo *"glide path"*. Convém salientar que em todos os estudos houve a exploração dos canais radiculares com limas finas, previamente aos preparos; fato que, tecnicamente e dentro da definição vigente, já pode ser interpretado como um tipo de *glide path.* Sendo assim, a interpretação dos dados, no que diz respeito aos preparos que compararam a confecção de *glide path* manual e motorizado, deveriam ser revistos. Pois, apesar de serem considerados como tendo o *glide path* feito com o auxílio de motores, previamente, o *"glide path"* foi iniciado manualmente. Convém salientar que alguns estudos vem demonstrando que a exploração dos canais radiculares previamente a instrumentação motorizada não seja necessária [86, 87]. Todavia, como o foco desta revisão não foi a capacidade dos instrumentos de preparo atingirem o comprimento de trabalho, esse aspecto não foi discutido previamente.

Outro ponto interessante e passível de discussão é o fato de que os ângulos de curvatura radiculares utilizados durante a seleção das amostras são bastante variáveis.

Em 9 estudos houve uma variação de 10° ou menos, já em outros nove estudos essa variação foi maior. Este ponto pode repercutir negativamente nos resultados, já que pode haver uma heterogeneidade muito grande da amostra. Além disso, o fato de que a maior parte dos estudos utilizou raízes com curvaturas em torno de 25°, é possível que os resultados gerados não representem corretamente a repercussão do *glide path* no preparo endodôntico final. É compreensível que, segundo Schneider, ângulos maiores que 20° sejam considerados como curvaturas severas; entretanto, este nos parece um ângulo de curvatura radicular que não imprime grande desafio à instrumentação. Sendo assim, há a necessidade de avaliações, a respeito da eficácia do *glide path,* realizadas em amostras com ângulos de curvatura dos canais radiculares mais agudos.

Entretanto, com base nos dados coletados e agrupados nessa revisão, pode se concluir que a confecção motorizada do *glide path* apresenta resultados similares ou melhores de transporte apical e manutenção da centralização do canal radicular, quando comparada a preparação manual. Observou-se, também, que a confecção do *glide path,* anteriormente ao preparo endodôntico, está associada com resultados similares ou com a redução do transporte apical e a manutenção da centralização do preparo. Vale ressaltar que ocorreram desvios em todas as situações.

Houve a impossibilidade da realização de meta-análise dos dados, em função da grande heterogeneidade entre estudos. Isto ocorreu tanto nos métodos de avaliação de centralização do preparo e transporte apical, quanto nos métodos usados na mediação das curvaturas radiculares. É imprescindível, para a realização de meta-análises futuras, que haja uma padronização tanto dos métodos empregados quanto da forma de apresentação dos dados. Somente desta forma, agrupando os dados obtidos em diferentes estudos, será possível produzir, com consistência, evidência científica de maior relevância.

Com base nessas conclusões, constata-se a necessidade do desenvolvimento de novas pesquisas, que avaliem a repercussão do *glide path* nos preparos endodônticos. Além de estudos laboratoriais bem controlados e conduzidos, é imprescindível que se desenvolvam estudos observacionais longitudinais e/ou ensaios clínicos randomizados que avaliem as repercussões nos índices de sucesso quando da confecção, ou não do *glide path.*

Fica evidente que mais estudos relacionados a eficácia do *glide path* devem ser conduzidos pois são imprescindíveis, entretanto a padronização das amostras e da apresentação dos dados faz-se necessária. Uma forma de padronização na seleção das amostras começa pela correta medição das curvaturas radiculares, todavia não há consenso a respeito de qual método seria o mais indicado. Para tanto, é necessário que estudos futuros avaliem a precisão e reprodutibilidade dos métodos existentes a fim de, caso haja algum, possa ser determinado o método de referência nas medições de curvaturas radiculares. Caso não seja possível obter essa informação, um novo método deverá ser proposto.

Referências

1. Chandra A. Discuss the factors that affect the outcome of endodontic treatment. Australian endodontic journal : the journal of the Australian Society of Endodontology Inc. 2009;35:98-107.

2. Estrela C, Holland R, Estrela CR, Alencar AH, Sousa-Neto MD, Pecora JD. Characterization of successful root canal treatment. Brazilian dental journal. 2014;25:3-11.

3. Scarparo RK, Pereira L, Moro D, Grundling G, Gomes M, Grecca FS. Morphologic variations of maxillary molars palatal root and the importance of its knowledge for endodontic practice: a case series. The journal of contemporary dental practice. 2011;12:138-42.

4. Tian YY, Guo B, Zhang R, Yu X, Wang H, Hu T, et al. Root and canal morphology of maxillary first premolars in a Chinese subpopulation evaluated using cone-beam computed tomography. International endodontic journal. 2012;45:996-1003.

5. Schafer E, Diez C, Hoppe W, Tepel J. Roentgenographic investigation of frequency and degree of canal curvatures in human permanent teeth. Journal of endodontics. 2002;28:211-6.

6. Oginni AO, Adekoya-Sofowora CA, Kolawole KA. Evaluation of radiographs, clinical signs and symptoms associated with pulp canal obliteration: an aid to treatment decision. Dental traumatology : official publication of International Association for Dental Traumatology. 2009;25:620-5.

7. Vier-Pelisser FV, Pelisser A, Recuero LC, So MV, Borba MG, Figueiredo JA. Use of cone beam computed tomography in the diagnosis, planning and follow up of a type III dens invaginatus case. International endodontic journal. 2012;45:198-208.

8. Gunraj MN. Dental root resorption. Oral surgery, oral medicine, oral pathology, oral radiology, and endodontics. 1999;88:647-53.

9. Zheng QH, Zhou XD, Jiang Y, Sun TQ, Liu CX, Xue H, et al. Radiographic investigation of frequency and degree of canal curvatures in Chinese mandibular permanent incisors. Journal of endodontics. 2009;35:175-8.

10. Charles TJ, Charles JE. The 'balanced force' concept for instrumentation of curved canals revisited. Int Endod J. 1998;31:166-72.

11. Burklein S, Borjes L, Schafer E. Comparison of preparation of curved root canals with Hyflex CM and Revo-S rotary nickel-titanium instruments. International endodontic journal. 2014;47:470-6.

12. Hoppe CB, Bottcher DE, Justo AM, So MV, Grecca FS. Comparison of curved root canals preparation using reciprocating, continuous and an association of motions. Scanning. 2016.

13. de Chevigny C, Dao TT, Basrani BR, Marquis V, Farzaneh M, Abitbol S, et al. Treatment outcome in endodontics: the Toronto study--phases 3 and 4: orthograde retreatment. Journal of endodontics. 2008;34:131-7.

14. Shemesh H, Cristescu RC, Wesselink PR, Wu MK. The use of cone-beam computed tomography and digital periapical radiographs to diagnose root perforations. Journal of endodontics. 2011;37:513-6.

15. Burklein S, Hinschitza K, Dammaschke T, Schafer 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. International endodontic journal. 2012;45:449-61.

16. Del Fabbro M, Afrashtehfar KI, Corbella S, El-Kabbaney A, Perondi I, Taschieri S. In Vivo and In Vitro Effectiveness of Rotary Nickel-Titanium vs Manual Stainless Steel Instruments for Root Canal Therapy: Systematic Review and Meta-analysis. The journal of evidence-based dental practice. 2018;18:59-69.

17. Lopez FU, Fachin EV, Camargo Fontanella VR, Barletta FB, So MV, Grecca FS. Apical transportation: a comparative evaluation of three root canal instrumentation techniques with three different apical diameters. Journal of endodontics. 2008;34:1545-8.

18. Alovisi M, Cemenasco A, Mancini L, Paolino D, Scotti N, Bianchi CC, et al. Micro-CT evaluation of several glide path techniques and ProTaper Next shaping outcomes in maxillary first molar curved canals. International endodontic journal. 2017;50:387-97.

19. Berutti E, Cantatore G, Castellucci A, Chiandussi G, Pera F, Migliaretti G, et al. Use of nickel-titanium rotary PathFile to create the glide path: comparison with manual preflaring in simulated root canals. Journal of endodontics. 2009;35:408-12.

20. Dhingra A, Nagar N, Sapra V. Influence of the glide path on various parameters of root canal prepared with WaveOne reciprocating file using cone beam computed tomography. Dental research journal. 2015;12:534-40.

21. 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. Journal of endodontics. 2014;40:2053-6.

22. Gergi R, Rjeily JA, Sader J, Naaman A. 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. 2010;36:904-7.

23. West JD. The endodontic Glidepath: "Secret to rotary safety". Dentistry today. 2010;29:86, 8, 90-3.

24. Alovisi M, Cemenasco A, Mancini L, Paolino D, Scotti N, Bianchi CC, et al. Micro-CT evaluation of several glide path techniques and ProTaper Next shaping outcomes in maxillary first molar curved canals. International endodontic journal. 2017;50:387-97.

25. Alves O, Bueno CE, Cunha RS, Pinheiro SL, Fontana CE, de Martin AS. 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. 2012;38:117-20.

26. Amaral ROJF, Leonardi DP, Gabardo MCL, Coelho BS, Oliveira KVD, Baratto Filho F. Influence of cervical and apical enlargement associated with the wave one system on the transportation and centralization of endodontic preparations. Journal of endodontics. 2016;42:626-31.

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

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

29. Coelho MS, Fontana CE, Kato AS, de Martin AS, da Silveira Bueno CE. Effects of glide path on the centering ability and preparation time of two reciprocating instruments. Iranian endodontic journal. 2016;11:33-7.

30. D'Amario M, Baldi M, Petricca R, De Angelis F, El Abed R, Arcangelo C, et al. Evaluation of a new nickel-titanium system to create the glide path in root canal preparation of curved canals. Journal of endodontics. 2013;39:1581-4.

31. Dhingra A, Manchanda N. Modifications in canal anatomy of curved canals of mandibular first molars by two glide path instruments using CBCT. Journal of clinical and diagnostic research : JCDR. 2014;8:Zc13-7.

32. Dhingra A, Nagar N, Sapra V. Influence of the glide path on various parameters of root canal prepared with WaveOne reciprocating file using cone beam computed tomography. Dental research journal. 2015;12:534-40.

33. 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. Journal of endodontics. 2014;40:2053-6.

34. Gergi R, Rjeily JA, Sader J, Naaman A. 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. 2010;36:904-7.

35. Hasheminia SM, Farhadi N, Shokraneh A. Effect of patency file on transportation and curve straightening in canal preparation with Protaper system. ISRN Dentistry. 2013;2013.

36. Kirchhoff AL, Chu R, Mello I, Garzon AD, dos Santos M, Cunha RS. Glide path management with single- and multiple-instrument rotary systems in curved canals: a micro-computed tomographic study. Journal of endodontics. 2015;41:1880-3.

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

38. Ocampo A, Henao Bedoya A, Saavedra Amaya J, Fernanda Serpa M, Gutiérrez Barreto J. Transportación y centricidad en conductos curvos con ProTaper Next y PathFile. Universitas Odontologica. 2015;34:37-46.

39. Paleker F, van der Vyver PJ. 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. 2016;42:1105-9.

40. Rocha DGP, Alves VdO, De Martin AS, Fontana CE, Cunha RS, Bueno CEdS. Comparação entre os sistemas rotatórios Pathfile + Protaper Universal e Twisted Files quanto à preservação da morfologia e ao tempo de trabalho despendido na preparação de canais curvos. Rev odontol UNESP. 2013;42:99-103.

41. Turker SA, Uzunoglu E. Apical root canal transportation of different pathfinding systems and their effects on shaping ability of ProTaper Next. Journal of clinical and experimental dentistry. 2015;7:e392-5.

42. Uroz-Torres D, González-Rodríguez MP, Ferrer-Luque CM. Effectiveness of a manual glide path on the preparation of curved root canals by using Mtwo rotary instruments. Journal of endodontics. 2009;35:699-702.

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

44. American Association of Endodontists. Case difficulty assessment form and guidelines 2010 [14/03/2018]. Available from: https://www.aae.org/specialty/wp-content/uploads/sites/2/2017/06/2006casedifficultyassessmentformb_edited2010.pdf.

45. Canadian Academy of Endodontics. CAE standards of practice 2017 [14/03/2018]. Available from: https://www.caendo.org/wp-content/uploads/2017/10/Standards-of-Practice-2017-.pdf.

46. Falcon HC, Richardson P, Shaw MJ, Bulman JS, Smith BG. Developing an index of restorative dental treatment need. British Dental Journal. 2001;190:479-86.

47. Ree MH, Timmerman MF, Wesselink PR. An evaluation of the usefulness of two endodontic case assessment forms by general dentists. International endodontic journal. 2003;36:545-55.

48. Backman CA, Oswald RJ, Pitts DL. A radiographic comparison of two root canal instrumentation techniques. Journal of endodontics. 1992;18:19-24.

49. Berbert A, Nishiyama CK. Curvaturas radiculares: uma nova metologia para a mensuração e localização. Revista Gaúcha de Odontologia. 1994;42:356-8.

50. Cabrales RJS, Moura AAM, Yamazaki AK, Cardoso LN, Moura-Netto C, Kleine BM, et al. Análise comparativa entre dois métodos para determinação do grau de curvatura de canais radiculares. Journal of the Health Sciences Institute. 2006;24.

51. Choi MR, Moon YM, Seo MS. Prevalence and features of distolingual roots in mandibular molars analyzed by cone-beam computed tomography. Imaging Science in Dentistry. 2015;45:221-6.

52. Dannemann M, Kucher M, Kirsch J, Binkowski A, Modler N, Hannig C, et al. An approach for a mathematical description of human root canals by means of elementary parameters. Journal of endodontics. 2017;43:536-43.

53. Dobo-Nagy C, Keszthelyi G, Szabo J, Sulyok P, Ledeczky G, Szabo J. A computerized method for mathematical description of three-dimensional root canal axis. Journal of endodontics. 2000;26:639-43.

54. Dummer PM, Alodeh MH, Doller R. Shaping of simulated root canals in resin blocks using files activated by a sonic handpiece. International endodontic journal. 1989;22:211-5.

55. Eaton JA, Clement DJ, Lloyd A, Marchesan MA. Micro-computed tomographic evaluation of the influence of root canal system landmarks on access outline forms and canal curvatures in mandibular molars. Journal of endodontics. 2015;41:1888-91.

56. Estrela C, Bueno MR, Sousa-Neto MD, Pecora JD. Method for determination of root curvature radius using cone-beam computed tomography images. Brazilian Dental Journal. 2008;19:114-8.

57. Fuentes R, Arias A, Navarro P, Ottone N, Bucchi C. Morphometric study of mandibular premolars in panoramic digital radiographs; Analysis of root curvatures. International Journal of Morphology. 2015;33:476-82.

58. Fuentes R, Farfan C, Astete N, Navarro P, Arias A. Distal root curvatures in mandibular molars: analysis using digital panoramic X-rays. Folia Morphologica. 2018;77:131-7.

59. Gu Y, Lu Q, Wang P, Ni L. Root canal morphology of permanent three-rooted mandibular first molars: Part II - Measurement of root canal curvatures. Journal of endodontics. 2010;36:1341-6.

60. Günday M, Sazak H, Garip Y. A comparative study of three different root canal curvature measurement techniques and measuring the canal access angle in curved canals. Journal of endodontics. 2005;31:796-8.
61. Hankins PJ, ElDeeb ME. An evaluation of the Canal Master, balanced force, and step-back techniques. Journal of endodontics. 1996;22:123-30.
62. Harlan AL, Nicholls JI, Steiner JC. A comparison of curved canal instrumentation using nickel-titanium or stainless steel files with the balanced-force technique. Journal of endodontics. 1996;22:410-3.
63. Iqbal MK, Maggiore F, Suh B, Edwards KR, Kang J, Kim S. Comparison of apical transportation in four Ni-Ti rotary instrumentation techniques. Journal of endodontics. 2003;29:587-91.
64. Kyomen SM, Caputo AA, White SN. Critical analysis of the balanced force technique in endodontics. Journal of endodontics. 1994;20:332-7.
65. Lee J-K, Ha B-H, Choi J-H, Heo S-M, Perinpanayagam H. Quantitative three-dimensional analysis of root canal curvature in maxillary first molars using micro-computed tomography. Journal of endodontics. 2006;32:941-5.
66. Lopes HP, Elias CN, Estrela C, Siqueira JF, Jr. Assessment of the apical transportation of root canals using the method of the curvature radius. Brazilian Dental Journal. 1998;9:39-45.
67. López FU, Travessas JAC, Fachin E, Fontanella V, Grecca F. Apical transportation: Two assessment methods. Australian Endodontic Journal. 2009;35:85-8.
68. Luiten DJ, Morgan LA, Baugartner JC, Marshall JG. A comparison of four instrumentation techniques on apical canal transportation. Journal of endodontics. 1995;21:26-32.
69. Nagy CD, Szabo J, Szabo J. A mathematically based classification of root canal curvatures on natural human teeth. Journal of endodontics. 1995;21:557-60.
70. Pasqualini D, Alovisi M, Cemenasco A, Mancini L, Paolino DS, Bianchi CC, et al. Micro-Computed Tomography Evaluation of ProTaper Next and BioRace Shaping Outcomes in Maxillary First Molar Curved Canals. Journal of endodontics. 2015;41:1706-10.
71. Peters OA, Laib A, Rüegsegger P, Barbakow F. Three-dimensional analysis of root canal geometry by high-resolution computed tomography. Journal of Dental Research. 2000;79:1405-9.
72. Pettiette MT, Metzger Z, Phillips C, Trope M. Endodontic complications of root canal therapy performed by dental students with stainless-steel K-files and nickel-titanium hand files. Journal of endodontics. 1999;25:230-34.

73. Pruett JP, Clement DJ, Carnes DL, Jr. Cyclic fatigue testing of nickel-titanium endodontic instruments. Journal of endodontics. 1997;23:77-85.

74. Schäfer E, Diez C, Hoppe W, Tepel J. Roentgenographic investigation of frequency and degree of canal curvatures in human permanent teeth. Journal of endodontics. 2002;28:211-6.

75. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral surgery, oral medicine, and oral pathology. 1971;32:271-5.

76. Sonntag D, Stachniss-Carp S, Stachniss C, Stachniss V. Determination of root canal curvatures before and after canal preparation (part II): A method based on numeric calculus. Australian Endodontic Journal. 2006;32:16-25.

77. Southard DW, Oswald RJ, Natkin E. Instrumentation of curved molar root canals with the Roane technique. Journal of endodontics. 1987;13:479-89.

78. Thompson SA, Al-Omari MAO, Dummer PMH. Assessing the shape of root canals: an in vitro method using microradiography. International endodontic journal. 1995;28:61-7.

79. Weine FS. Endodontic therapy / Franklin S. Weine ; contributing authors, Marshall H. Smulson ... [et al.]. Saint Louis: Mosby; 1982.

80. Willershausen B, Tekyatan H, Kasaj A, Marroquín BB. Roentgenographic in vitro investigation of frequency and location of curvatures in human maxillary premolars. Journal of endodontics. 2006;32:307-11.

81. Zhang R, Hu T. Root canal curvature. International endodontic journal. 2010;43:616-8; discussion 8-21.

82. Gorni FG, Gagliani MM. The outcome of endodontic retreatment: a 2-yr follow-up. Journal of endodontics. 2004;30:1-4.

83. Lin LM, Rosenberg PA, Lin J. Do procedural errors cause endodontic treatment failure? Journal of the American Dental Association. 2005;136:187-93; quiz 231.

84. Gulabivala K, Ng YL. Non-surgical root-canal treatment. In: Gulabivala K, Ng Y-L, editors. Endodontics (4th Edition): Mosby; 2014. p. 174-236.

85. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. Journal of endodontics. 2004;30:559-67.

86. Bartols A, Robra BP, Walther W. The ability of Reciproc instruments to reach full working length without glide path preparation: a clinical retrospective study. PeerJ. 2017;5:e3583.

87. Zuolo ML, Carvalho MC, De-Deus G. Negotiability of Second Mesiobuccal Canals in Maxillary Molars Using a Reciprocating System. Journal of endodontics. 2015;41:1913-7.