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REVIEW

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

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Abstract

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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.

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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

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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),

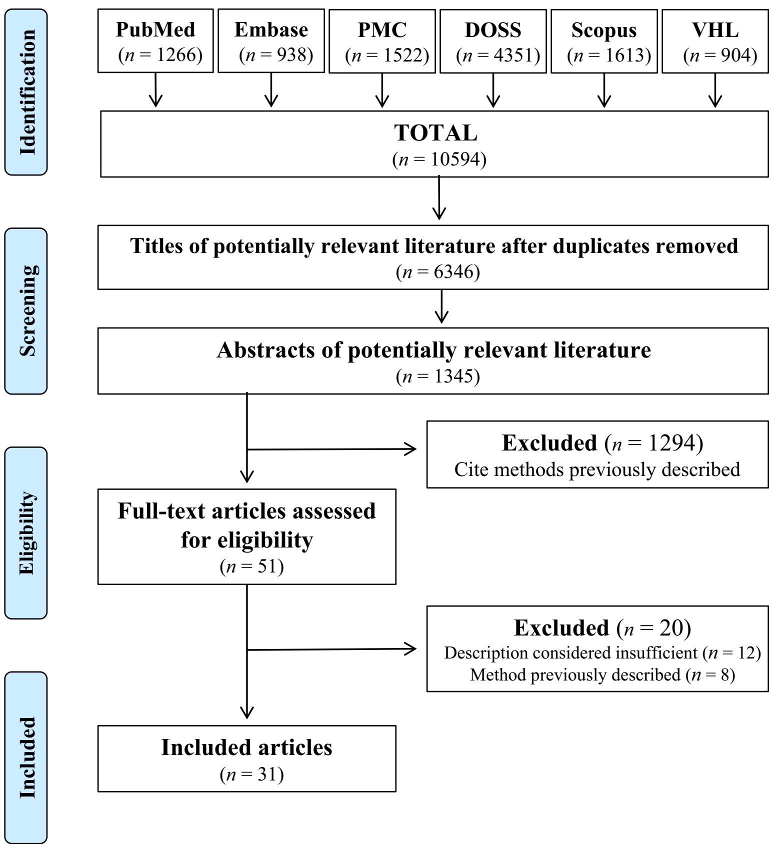

Figure 1 Flow chart of the search strategy.

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 determinate 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 determinate 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 determinate the radius
Pettiette et al.			1999	Different lines to determinate 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

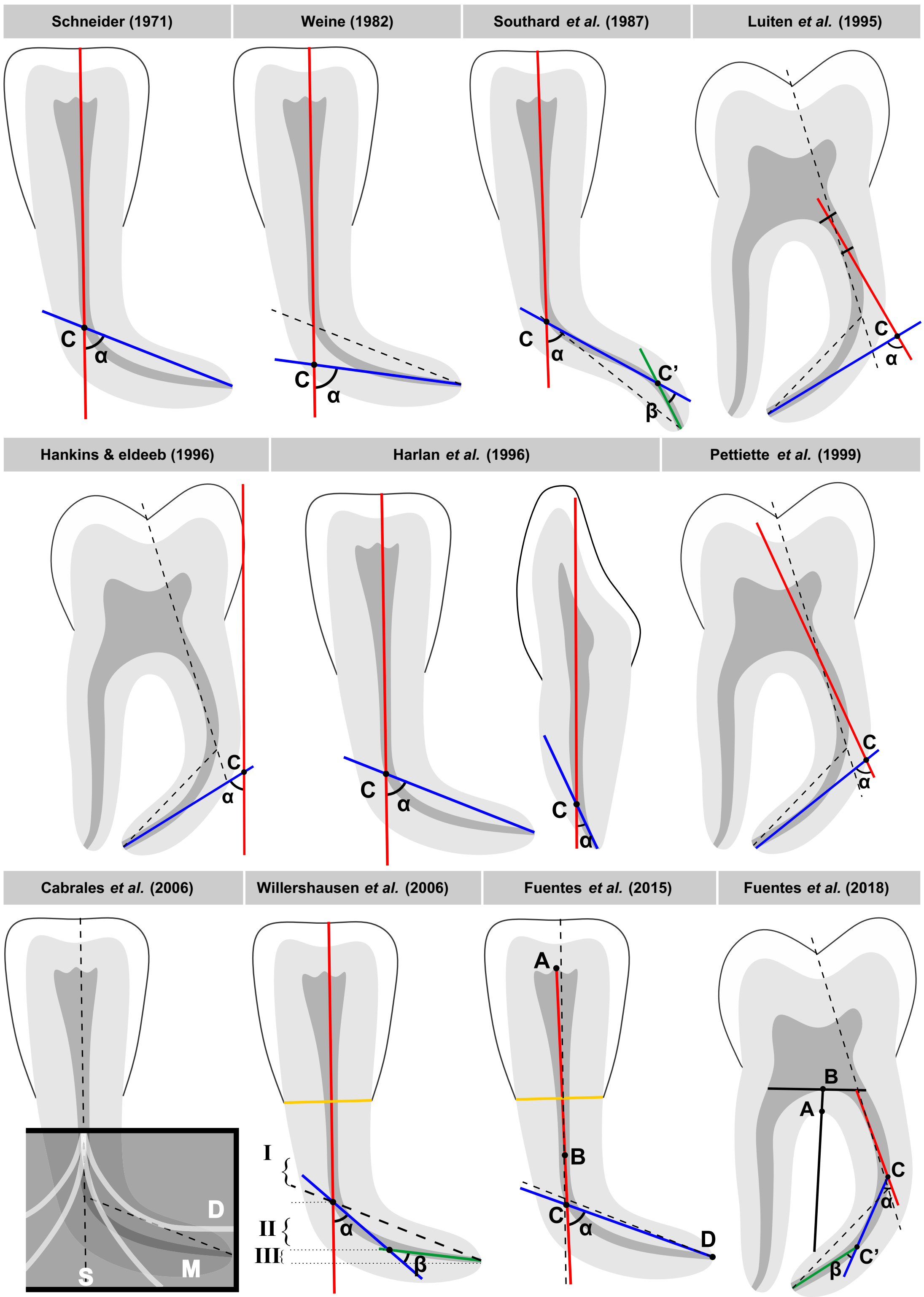

Figure 2 Diagrammatic representation of the methodologies proposed to measure angle of root canal curvature, from 2D imaging.

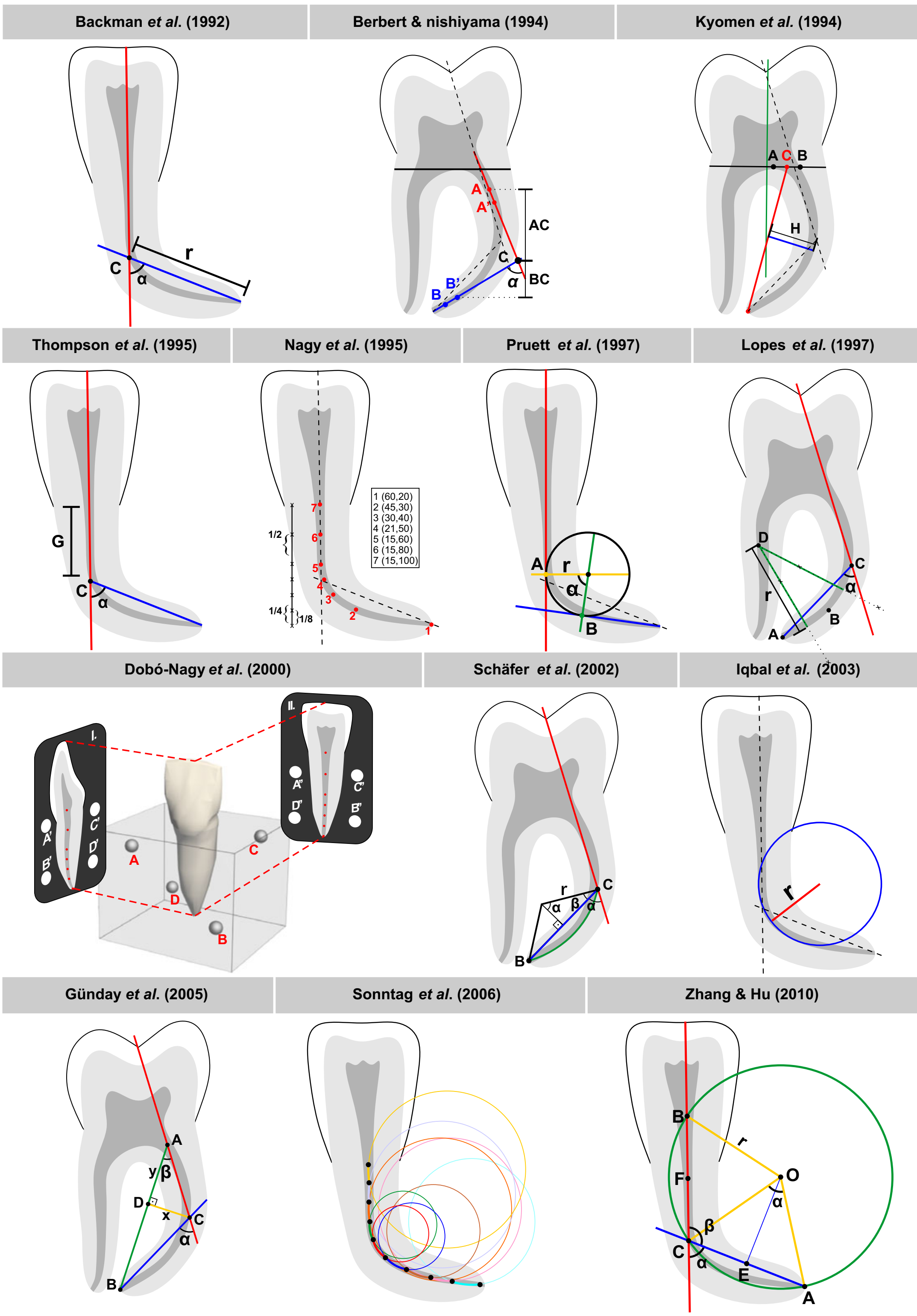

Figure 3 Diagrammatic representation of the methodologies proposed to measure angle of root canal curvature and other features, from 2D imaging.

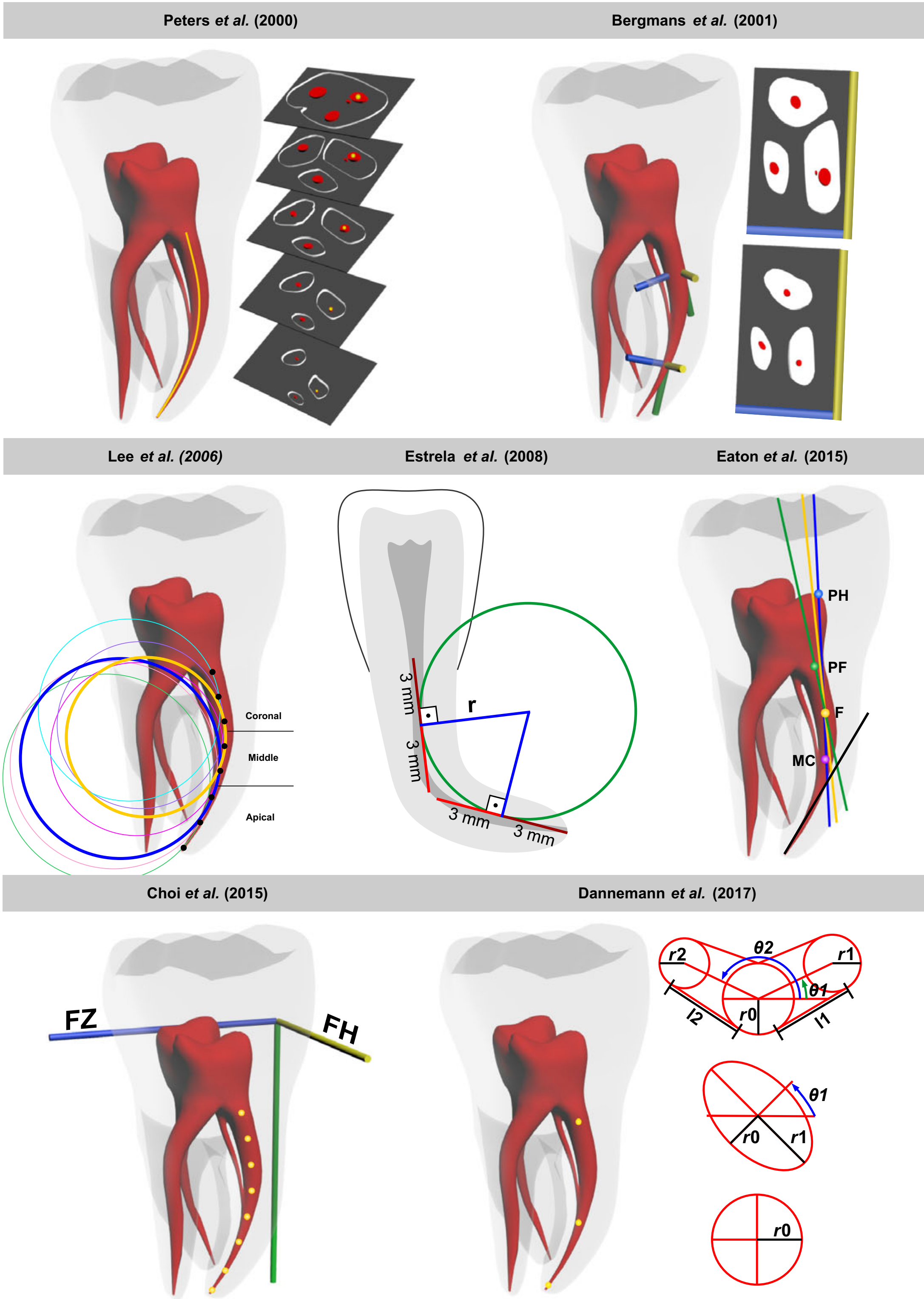

Figure 4 Diagrammatic representation of the methodologies proposed to measure angle of root canal curvature and other features, from 3D imaging.

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.

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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.