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REVIEW ARTICLE

The influence of kinematics of engine-driven nickel-titanium instruments on root canal shape assessed by micro-computed tomography: a systematic review

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ABSTRACT

Aim: To evaluate if the kinematics of engine-driven instruments affect the root canal shape.

Method: The systematic review was registered in PROSPERO (CRD 42017077043). A broad search was performed for articles published before 26 September 2018 in the electronic databases: pubmed, scopus, web of science and Lilacs using MeSH and free terms. Only in vitro studies with human teeth that evaluated root canal shape by volume, surface area and unprepared surface area using reciprocating and rotary system assessed by micro-computed tomography were included. A modified checklist for randomized controlled trials from the Joanna Briggs Institute was used to assess the risk of bias.

Results: Twenty-one articles were selected. According to quality assessment, all studies were considered 'moderate methodological quality'. Eighteen articles analysed volume increase, only four studies showed statistically significant difference, three indicating that the reciprocating movement obtained a greater increase in volume than the rotary system and one rotary system obtained a greater increase. Twelve studies analysed surface area, only three studies showed statistically significant difference, two presented a reciprocating system revealing greater amount of surface area and one showed a rotary system obtained a greater amount of surface area. Ten articles evaluated unprepared surface area, two studies that analysed total length, one study presented that the rotary system revealed lower unprepared surface area while another study showed reciprocating with less unprepared area. One study analysed middle and apical third, and observed that the rotary system presented lower unprepared surface area in the middle third.

Conclusions: Both the rotary and reciprocating kinematics produce changes in volume and surface area and leave unprepared areas in the root canal, however reciprocating system showed greater increase of volume and surface area, while the rotary system maintains less unprepared surface area.

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KEYWORDS
Rotary; reciprocating; micro-computed tomography; root canal shape

Introduction

Root canal cleaning and shaping are essential factors for a favourable prognosis in endodontics. In addition to the reduction of microorganisms and remaining pulp tissue [1], they determine the efficacy of the subsequent procedures [2].

Most of the difficulties occurring during endodontic therapy are the result of anatomical complexity, making it imperative to widen the canal, while maintaining the original anatomy to minimize damage to the dental structure [3]. A safe mechanical preparation technique is needed to enlarge root canals, including those that are curved, to minimize the risk of deviation [4]. Nickel-titanium (NiTi) instruments were introduced into the market to allow an efficient, fast and safe mechanical preparation, while maintaining the original canal shape [5]. With a lower modulus of elasticity, these instruments have greater flexibility compared to stainless steel instruments [6]. This gives them a characteristic of super elasticity, allowing a 'memory effect'. That is so these instruments, having great resistance, can return to their original form after they have been altered [7].

These technological advances facilitate the insertion of engine-driven instruments and enable faster and easier canal preparation. These advances drastically enhanced the quality of canal shaping with less iatrogenic damage. The extreme flexibility of these instruments allows their insertion into the root canal in a 360° continuous rotation movement, thus spreading the rotary kinematics between endodontists [8,9]. Over the years another concept for root canal cleaning and shaping was introduced, Yared described a mechanical preparation using reciprocating motion [10]. This movement is the action in the instrument cutting direction, rotating counterclockwise followed by a minor rotation in the clockwise release direction [11].

Several studies have compared the shaping ability of reciprocating and continuous rotational movements [11–13] and different methodologies have been used to assess this

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Table 1. Electronic database used and search strategy.

Database	Search strategy
PubMed	**#1** (X-Ray Microtomography [MeSH Terms]) OR Micro-CT [Title/Abstract]) OR Micro CT [Title/Abstract]) OR Micro-CT scanner [Title/Abstract]) OR Micro-computed tomography [Title/Abstract]) OR Micro-computed tomographic [Title/Abstract]) OR Microtomography [Title/Abstract] **#2** (Reciprocating [Title/Abstract]) OR Reciproc [Title/Abstract]) OR Reciprocating files [Title/Abstract]) OR Reciprocating instruments [Title/Abstract]) OR Reciprocating instrumentation [Title/Abstract]) OR Reciprocating Techniques [Title/Abstract]) OR Reciprocating root canal technique [Title/Abstract]) OR Reciprocating motion [Title/Abstract]) OR Reciprocating movement [Title/Abstract]) OR Rotatory [Title/Abstract]) OR Rotatory files [Title/Abstract]) OR Rotatory files system [Title/Abstract]) OR Rotatory instruments [Title/Abstract]) OR Rotatory instrumentation [Title/Abstract]) OR Rotatory techniques [Title/Abstract] OR Rotary Systems[Title/Abstract]) OR Continuous Rotary systems[Title/Abstract]) OR Rotary motion[Title/Abstract]) OR Rotary instruments[Title/Abstract]) OR rotary instrumentation[Title/Abstract] **#1 AND #2**
Scopus	**# 1** (TITLE-ABS-KEY (x-ray AND microtomography) OR TITLE-ABS-KEY (micro-ct) OR TITLE-ABS-KEY (micro AND ct) OR TITLE-ABS-KEY (micro-ct AND scanner) OR TITLE-ABS-KEY (micro-computed AND tomography) OR TITLE-ABS-KEY (micro-computed AND tomographic) OR TITLE-ABS-KEY (microtomography)) **#2** (TITLE-ABS-KEY (reciprocating) OR TITLE-ABS-KEY (reciproc) OR TITLE-ABS-KEY (reciprocating AND files) OR TITLE-ABS-KEY (reciprocating AND instruments) OR TITLE-ABS-KEY (reciprocating AND instrumentation) OR TITLE-ABS-KEY (reciprocating AND techniques) OR TITLE-ABS-KEY (reciprocating AND root AND canal AND technique) OR TITLE-ABS-KEY (reciprocating AND motion) OR TITLE-ABS-KEY (reciprocating AND movement) OR TITLE-ABS-KEY (rotatory) OR TITLE-ABS-KEY (rotatory AND files) OR TITLE-ABS-KEY (rotatory AND files AND system) OR TITLE-ABS-KEY (rotatory AND instruments) OR TITLE-ABS-KEY (rotatory AND instrumentation) OR TITLE-ABS-KEY (rotatory AND techniques) OR TITLE-ABS-KEY (rotary AND systems) OR TITLE-ABS-KEY (continuous AND rotary AND systems) OR TITLE-ABS-KEY (rotary AND motion) OR TITLE-ABS-KEY (rotary AND instruments) OR TITLE-ABS-KEY (rotary AND instrumentation)) **#1 AND #2**
Web of Science	**#1 Topic:** (X-Ray Microtomography) *OR* **Topic:** (Micro-CT) *OR* **Topic:** (Micro CT) *OR* **Topic:** (Micro-CT scanner) *OR* **Topic:** (Micro-computed tomography) *OR* **Topic:** (Micro-computed tomographic) *OR* **Topic:** (Microtomography) *Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan = All years* **#2 Topic:** (Reciprocating) *OR* **Topic:** (Reciproc) *OR* **Topic:** (Reciprocating files) *OR* **Topic:** (Reciprocating instruments) *OR* **Topic:** (Reciprocating instrumentation) *OR* **Topic:** (Reciprocating Techniques) *OR* **Topic:** (Reciprocating root canal technique) *OR* **Topic:** (Reciprocating motion) *OR* **Topic:** (Reciprocating movement) *OR* **Topic:** (Rotatory) *OR* **Topic:** (Rotatory files) *OR* **Topic:** (Rotatory files system) *OR* **Topic:** (Rotatory instruments) *OR* **Topic:** (Rotatory instrumentation) *OR* **Topic:** (Rotatory technique) *OR* **Topic:** (Rotary Systems) *OR* **Topic:** (Continuous rotary systems) *OR* **Topic:** (rotary motion) *OR* **Topic:** (rotary instruments) *OR* **Topic:** (rotary instrumentation) *Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI Timespan = All years* **#1 AND #2**
Lilacs	(tw:(x-ray microtomography OR micro-ct OR micro-computed tomography)) AND (tw:(reciprocating OR reciprocating instrumentation OR reciprocating movement)) OR (tw:(rotatory OR rotatory instrumentation OR rotary systems OR rotary instrumentantion)) AND (instance: 'regional') AND (db:('LILACS') AND jd:('ODONTOLOGIA'))

variable [14–16]. Micro-computed tomography allows non-destructive analyses of the effects of mechanical preparation and morphological changes on root canal walls [17].

Therefore, the purpose of this systematic review is to assess whether the kinematics of engine-driven instruments affects root canal shape assessed by Micro-computed Tomography.

Materials and methods

This systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guideline principles [18] and its protocol was registered in the PROSPERO (International Prospective Register of Systematic Review) database (registration number CRD 42017077043). The focused question was proposed by following the PICO (P: population, I: intervention, C: comparison, O: outcome) framework.

Focused question

This systematic review aims to answer a specific question: 'Do kinematics of engine-driven instruments affect the root canal shape assessed by Micro-computed Tomography?'

Strategy for identification and selection of the studies

An ample search for articles published before 26 September 2018 was performed and included no language restrictions. The following electronic databases were searched: Pubmed, Scopus, Web of Science and Virtual Health Library (LILACS). The grey literature was also consulted on Opensigle (http://www.opengrey.eu/). The search used keywords and a standardized vocabulary (e.g., MeSH). These terms were intended to represent the concepts of 'Micro-computed tomography' and 'Reciprocating' and 'Rotatory'. MeSH synonyms, related terms, and free terms were included. The terms were combined to refine the search results (the combination of the research descriptors is shown in Table 1).

Inclusion criteria outlines according to the population, inventions, comparisons and outcomes (PICOS)

Population (P): Human teeth

Interventions (I): Canal preparation with engine-driven instruments

Comparison (C): Reciprocating and rotatory system assessed by micro-computed tomography

Outcomes (O): Canal shape by volume, surface area and unprepared surface area

Study design (S): *In vitro* studies

Exclusion criteria

Duplicated studies, literature reviews, theses, guidelines, book chapters, studies with simulated roots, clinical study, low methodologic quality studies, studies did not analyse volume, surface area or unprepared area, studies which were not use micro-computed tomography were excluded.

Study selection

Initially, two independent examiners (SOT and CCG) evaluated the abstracts and titles. Only studies that matched inclusion criteria were accepted. In the event that doubt remained, the article was included in the full-text analysis. Subsequently, the potentially-eligible studies were reevaluated by two independent examiners (SOT and CCG). Disagreements between reviewers were solved by a third author (LSA). To measure the agreement between evaluators during the selection of articles the kappa coefficient of 0.90 was obtained.

Quality assessment

A modified checklist for Randomized Controlled Trials from the Joanna Briggs Institute was used to assess the risk of bias. Quality assessment was used to categorize the level of evidence in the included studies. Each domain received a score corresponding to the answer; 0 for 'No' or 'Unclear' and 1 for 'Yes'. A study was considered 'low methodological quality' when the sum results were 1, 2, 3 or 4 points; 'moderate methodological quality' 5, 6 or 7 points; and 'high methodological quality' 8, 9 or 10 points, as described in a previously published in vitro study [19].

Data extraction

Content analysis of included studies was performed by two independent examiners. The data were organized according to: 1 – the author and year of publication; 2 – country; 3 – sample, approaching the sample size and types of teeth; 4 – endodontic treatment, approaching irrigation, kinematics and instruments. Subsequently, the settings about micro-computed tomography scanner were extracted considering the following variables: 1 – author and year of publication; 2 – equipment, approaching the model and settings; 3 – software, approaching the software to reconstruction and software to analysis; 4 – analysed canal length.

Results

Data search and selection of articles

A total of 984 articles were found in electronic databases using our set of search queries: 144 articles from PubMed, 333 articles from Web of Science, 221 from Scopus, 286 from LILACS. The selection process is described in Figure 1. After disregarding duplicate studies, analysing titles and abstracts, and applying the inclusion and exclusion criteria, 42 articles were selected to be read in their entirety. After reading the full articles, 15 were excluded because they did not analyse volume, surface area or unprepared area, three articles were excluded for not analysing in micro-computed tomography and three for not comparing the different kinematics, rotary and reciprocating motion. Twenty-one were found to meet inclusion criteria and were included in the analysis.

Quality assessment of risk of bias

To assess the risk of internal bias, in accordance with the quality assessment guidelines, all studies were considered to have a 'moderate methodologic quality' (Table 2).

The analysis of selection bias demonstrated that one study did not include randomized samples [20]. All studies explained how the specimens were concealed from the allocator or whether samples that were withdrawn were described regarding their inclusion in the analysis. Two other studies showed blind results [3,20].

Parameters of studies

The results of the data extraction are shown in Tables 3 and 4. The size of the samples ranged from 26 teeth [21] to 80 teeth [22], and some studies counted the samples by the number of root canals [3,11,20,23–26,29,32–35]. Most of the authors used molars [3,11,20,22–35], but one study used contralateral premolars [21], one study used canine teeth [36] and two studies used incisor teeth [37,38].

All studies used sodium hypochlorite (NaOCl) as an irrigating substance [3,11,20–38] varying only the concentration, where 11 studies used NaOCl 2.5% [3,20–23,25–27,30,32,36–38], four used NaOCl 5.25% [11,24,29,35], two used NaOCl 3% [28,34], one used NaOCl 5% [31], and one study used NaOCl 1% [33].

For rotary systems, two studies used TRUShape (Dentsply/Tulsa Dental Specialities, Tulsa, OK) [21,38], two used Protaper Next (Dentsply Maillefer, Ballaigues, Switzerland) [27,31], three used Revo-S (Micro-Mega, Besancon Cedex, France) [22,26,28], two used One Shape (Micro-Mega, Besancon Cedex, France) [3,22], four used Twisted File (Sybroendo, Orange, CA) [23,25,29,32,33], one study used Hyflex CM system (Coltene-Whaledent, Altsatten, Switzerland) [25], three studies used Biorace (FGK Dentaire, La Chaux-de-Fonds, Switzerland) [24,30,38], three studies used Mtwo (VDW, Munich, Germany) [11,20,37], two studies used Protaper Universal system (Dentsply Maillefer, Ballaigues, Switzerland) [31,36], one study used Profile (Dentsply Maillefer, Ballaigues, Switzerland) [32], and two studies used Protaper (Dentsply Maillefer, Ballaigues, Switzerland) [33,35].

Regarding reciprocating instruments, 13 studies used the Reciproc System (VDW, Munich, Germany) [11,20–30,36–38], seven studies used the WaveOne System (Dentsply/Tulsa Dental Specialities, Tulsa, OK) [3,24,25,29,31,32,36], the Mtwo System (VDW, Munich, Germany) was used by one study [11], Protaper F2 (Dentsply Maillefer, Ballaigues, Switzerland) was used by two studies [33,34], one study used Protaper (Dentsply Maillefer, Ballaigues, Switzerland) [35] and one study used Unicone (Medin, Nove Mesto Morave, Czech Republic) [37]. Some of the studies used other systems to compare, such as the Self-Adjusting File (ReDent Nova Ra'anana, Israel) with an 'in and out' movement, and Manual K-File [27,38].

The results of the comparison between the kinematics are shown in Table 5. Of the studies that analysed the

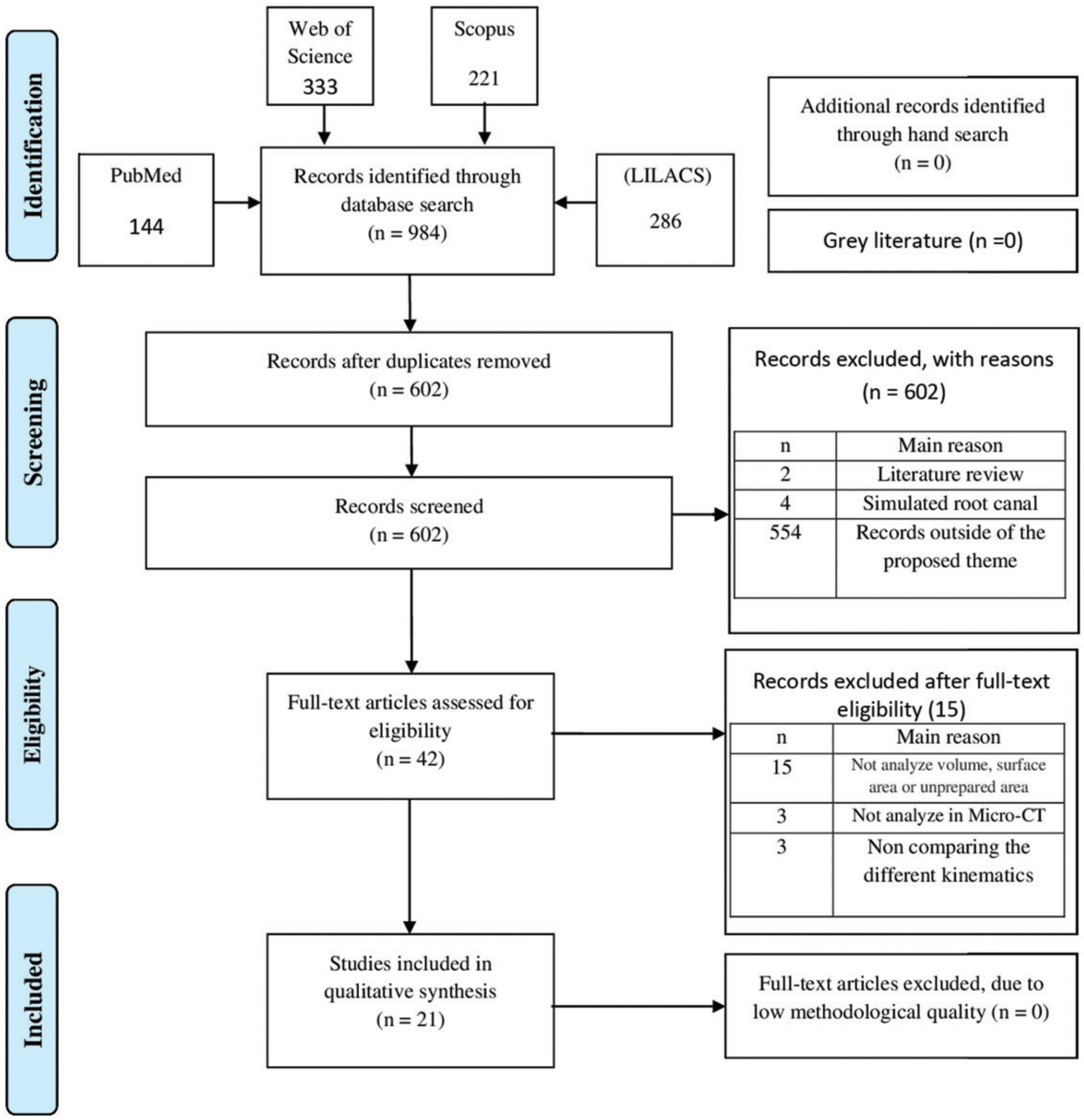

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: Prisma 2009 Flow Diagram (From: Moher et al. [18]. For more information, visit www.prisma-statement.org).

volumetric changes, the majority did not show statistically significant difference [3,11,20–23,25,27,28,31–35]. However, four studies showed statistically significant difference in their results evidencing the reciprocating movement obtained a greater increase in volume in total length [30,37], on apical third [22]. One study presented rotary system ProTaper and reciprocating system WaveOne did not show statistically significant difference, however comparing ProTaper with Reciproc, rotary system obtained statistically significant difference with a greater increase in volume, except in the cervical third where there was no statistically significant difference [36]. Only one study did not mention the significance of statistical analyses [26], and two studies did not evaluate volumetric changes [24,38].

In regard to surface area changes, eight of the studies did not show statistically significant difference [3,21,23,25,28,31,32,35], but three studies showed statistical significance in their analyses. Reciprocating movement obtained a greater increase in surface area using Reciproc reciprocating systems rather than the rotary system [29]. Another study showed the apical third having a greater increase in surface area with reciprocating rather than rotary systems [22]. One study presented rotary system ProTaper and reciprocating system WaveOne did not show statistically significant difference, however comparing ProTaper with Reciproc, rotary system obtained statistically significant difference with a greater increase in surface area, except in the cervical third where there was no statistically significant difference [36]. Only one study did not mention the significance of statistical analyses [26] and nine studies did not evaluate surface area changes [11,20,24,27,30,33,34,37,38].

In regard to unprepared surface area, ten studies were analysed. Seven of them showed no statistically significant difference [22–24,29,31,34,37], and three showed statistically significant difference. One study presented that the rotary system (TRUShape) revealed lower unprepared surface area than that of the reciprocating movement (Reciproc) in the middle third [21]. Another study showed the rotary system (BioRace) evidencing lower unprepared surface area than the reciprocating system (Reciproc) with the exception of the

Table 2. Quality of the included studies.

	Espir et al. [37]	Zuolo et al. [38]	Guimarães et al. [21]	Zanesco et al. [27]	Keles et al. [26]	Santa-Rosa et al. [3]	Marceliano-Alves et al. [25]	De Deus et al. [23]	Ahmetoglu et al. [28]	Gergi et al. [29]
1. Was the assignment to treatment groups truly random?	1	1	1	1	1	1	1	1	1	1
2. Were participants blinded to treatment allocation?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3. Was allocation to treatment groups concealed from the allocator?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4. Were the outcomes of people who withdrew described and included in the analysis?	0	0	0	0	0	0	0	0	0	0
5. Were those assessing the outcomes blind to the treatment allocation?	0	0	0	0	0	1	0	0	0	0
6. Were control and treatment groups comparable at entry?	1	1	1	1	1	1	1	1	1	1
7. Were groups treated identically other than for the named interventions?	1	1	1	1	1	1	1	1	1	1
8. Were outcomes measured in the same way for all groups?	1	1	1	1	1	1	1	1	1	1
9. Were outcomes measured in a reliable way?	1	1	1	1	1	1	1	1	1	1
10. Was appropriate statistical analysis used?	1	1	1	1	1	1	1	1	1	1
Total	6	6	6	6	6	7	6	6	6	6

	Busquim et al. [30]	Sant'anna Junior et al. [20]	Zeng et al. [22]	Zhao et al. [31]	Hwang et al. [11]	Baek et al. [32]	Siqueira et al. [23]	Versiani et al. [36]	Stern et al. [33]	Paque, Zehnder e De Deus [34]	You et al. [35]
1. Was the assignment to treatment groups truly random?	1	0	1	1	1	1	1	1	1	1	1
2. Were participants blinded to treatment allocation?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3. Was allocation to treatment groups concealed from the allocator?	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4. Were the outcomes of people who withdrew described and included in the analysis?	0	0	0	0	0	0	0	0	0	0	0
5. Were those assessing the outcomes blind to the treatment allocation?	0	0	0	1	0	0	0	0	0	0	0
6. Were control and treatment groups comparable at entry?	1	1	1	1	1	1	1	1	1	1	1
7. Were groups treated identically other than for the named interventions?	1	1	1	1	1	1	1	1	1	1	1
8. Were outcomes measured in the same way for all groups?	1	1	1	1	1	1	1	1	1	1	1
9. Were outcomes measured in a reliable way?	1	1	1	1	1	1	1	1	1	1	1
10. Was appropriate statistical analysis used?	1	1	1	1	1	1	1	1	1	1	1
Total	6	5	6	7	6	6	6	6	6	6	6

No and Unclair: 0 point. Yes: 1 point (low methodologic quality: 1-2-3-4 points; moderate methodologic quality: 5-6-7; high methodologic quality: 8-9-10 points). NA: not applied.

Table 3. Characteristics of studies that met inclusion criteria.

		Sample		Endodontic treatment		
Study (year)	Country	Sample size	Types of teeth	Irrigation	Kinematics	Instrument
Espir et al. [37]	Brazil	54	Mandibular incisors	6 mL 2.5% NaOCl	Reciprocating Reciprocating Rotary	Reciproc Unicone Mtwo
Zuolo et al. [38]	Brazil	40	Mandibular incisors	20 mL of 2,5% NaOCl 3 mL 17% EDTA	Rotary Reciprocating In-and-out movement Rotary	BioRace Reciproc SAF TRUShape
Guimarães et al. [21]	Brazil	26	Mandibular Premolars	20 mL of 2,5% NaOCl	Rotary Reciprocating	TRUShape Reciproc
Zanesco et al. [27]	Brazil	45	Maxillary first molar	2.5% NaOCl 17% EDTA	Manual Rotary Reciprocating	Manual K-File ProTaper Next Reciproc
Keles et al. [26]	Brazil	60 mesial roots	Mandibular Molars	20 mL of 2.5% NaOCl and 5mL 17% EDTA Bidistilled water	In-and-out movement Reciprocating Rotary	SAF Reciproc Revo-S
Santa-Rosa et al. [3]	Brazil	10 mesiobuccal roots	Maxillary Molars	10 mL of 2.5% NaOCl and 5mL 17% EDTA Deionized water	Reciprocating Rotary	Wave One One Shape
Marceliano-Alves et al. [25]	Brazil	64 mesial roots	Mandibular Molar	20 mL of 2.5% NaOCl and 5mL 17% EDTA Distilled water	Reciprocating Reciprocating Rotary Rotary	Reciproc Wave One Twisted File HyFlex CM
De Deus et al. [24]	Brazil	30 mesial roots	Mandibular 1° Molar	40 mL of 5,25% NaOCl and 5mL 17% EDTA Bidistilled water	Reciprocating Reciprocating Rotary	Reciproc Wave One BioRace
Ahmetoglu et al. [28]	Turkey	30	1° Maxillary Molars	20 mL of 3% NaOCl	In-and-out movement Reciprocating Rotary	SAF Reciproc Revo-S
Gergi et al. [29]	Lebanom	24 (48 mesial roots)	Mandibular Molar	9 mL of 5,25% NaOCl 1mL 17% EDTA	Reciprocating Reciprocating Rotary	Reciproc Wave One Twisted File Adaptative
Busquim et al. [30]	Republic of Korea	30	Mandibular Molar	23 mL of 2.5% NaOCl 5mL 17% EDTA	Reciprocating Rotary	Reciproc BioRace
Sant'anna Junior et al. [20]	Brazil	12 (24 mesial roots)	Mandibular First Molars	2.5% NaOCl 5 mL saline solution 3 mL 17% EDTA	Rotary Reciprocating	Mtwo Reciproc
Zeng et al. [22]	China	80	Molar	2 mL 2.5% NaOCl	Reciprocating Rotary Rotary Rotary	Reciproc OneShape Mtwo Revo S
Zhao et al. [31]	China	36	Mandibular first molar	5% NaOCl 17% EDTA	Reciprocating Rotary Rotary	Wave One ProTaper Universal ProTaper Next
Hwang et al. [11]	Republic of Korea	45 Mesiobuccal and Distobuccal roots	Maxillary Molars	RC-prep 5,25% NaOCl	Reciprocating Reciprocating Rotary	Reciproc Mtwo Mtwo
Baek et al. [32]	Republic of Korea	18 (36 Mesiobuccal and Mesiolingual roots)	Mandibular Molar	15 mL of 2.5% NaOCl 1mL 17% EDTA	Rotary Rotary Reciprocating	Profile Twisted File Wave One
Siqueira et al. [23]	Brazil	18 mesial roots	Mandibular Molars	14 mL of 2.5% NaOCl	In-and-out movement Reciprocating Rotary	SAF Reciproc Twisted File
Versiani et al. [36]	Brazil	72	Mandibular canine	20 mL of 2.5% NaOCl 2mL 17% EDTA 2 mL distilled water	In-and-out movement Reciprocating Reciprocating Rotary	SAF WaveOne Reciproc ProTaper Universal
Stern et al. [33]	United Kingdom	30 (60 Mesiobuccal and Mesiolingual roots)	Mandibular first and second molar	1% NaOCl	Rotary Reciprocating Rotary	Protaper Protaper F2 Twisted File
Paque, Zehnder e De Deus [34]	Switzerland	25 (50 Mesiobuccal and Mesiolingual roots)	Mandibular First Molars	3% NaOCl 5mL 17% EDTA Physiological saline solution	Rotary Reciprocating	Protaper Protaper F2
You et al. [35]	Republic of Korea	20 (40 Mesiobuccal and Distobuccal roots)_	Maxillary molars	RC-Prep 5.25% NaOCl	Rotary Reciprocating	ProTaper ProTaper

NaOCl: Sodium hypochlorite; EDTA: Ethylenediaminetetraacetic acid.

Table 4. Characteristics of micro-computed tomography.

	Equipment		Software		
Study (year)	Model	Settings	Software to reconstruction	Software to analysis	Canal length analysed
Espir et al. [37]	SkyScan 1176 (Bruker micro-CT, Kontich, Belgium)	70 kV 335 μA	NRecon v.1.6.3 software (Bruker micro-CT)	CTAn v.1.14.4 software (Bruker micro-CT)	Total length 1/3 coronal 1/3 middle 1/3 apical
Zuolo et al. [38]	SkyScan 1173 (Bruker microCT, Kontich, Belgium)	Isotropic resolution of 14.16 mm 70 kV 114 μA	NRecon v.1.6.10; Bruker micro-CT	Fiji v.1.47n; Fiji, Madison, WI, USA	Total length
Guimarães et al. [21]	SkyScan 1174.v2 (Bruker micro-CT, Kontich, Belgium)	Isotropic resolution of 19.9 μm 50 kV 800 μA	NRecon v.1.6.9 software (Bruker micro-CT)	CTAn v.1.14.4 software (Bruker micro-CT)	10 mm 4 mm
Zanesco et al. [27]	Skyscan 1172; SkyScan b.v.b.a, (Aartselaar, Belgium)	Isotropic resolution of 16 μm 100 kV 100 μA	–	–	1/3 coronal 1/3 middle 1/3 apical
Keles et al. [26]	SkyScan 1172 (Bruker-microCT, Kontich, Belgium)	Isotropic resolution of 12.5 μm 80 k 124 μA	NRecon v.1.6.9 software, (Bruker-microCT)	CTAn v.1.14.4 software (Bruker micro-CT)	Total length
Santa-Rosa et al. [3]	SkyScan 1174 v.2 (Bruker microCT, Kontich, Belgium)	Isotropic resolution of 19.9 μm 50 kV 800 μA	NRecon v1.6.4 (Bruke)	CTAn v1.11 software (CTAnalyser; Skyscan, Antwerp, Belgium)	Total length
Marceliano-Alves et al. [25]	SkyScan 1174v2 (Bruker micro-CT, Kontich, Belgium)	Isotropic resolution of 19.6 μm 50 kV 800 μA	NRecon v.1.6.9 software (Bruker micro-CT)	CTAn v.1.14.4 software (Bruker micro-CT)	Total length
De Deus et al. [24]	SkyScan 1173 (Bruker microCT, Kontich, Belgium)	Isotropic resolution of 14.16 mm 70 kV 114 μA.	NRecon v.1.6.9; Bruker micro-CT	Fiji v.1.47n; Fiji, Madison, WI, USA	Total length
Ahmetoglu et al. [28]	SkyScan 1172 (Bruker-microCT, Kontich, Belgium)	Isotropic resolution of 13.68 mm 85 kV 118 μA	NRecon v.1.6.3 software (Bruker-microCT)	CT An v.1.12 software (Bruker-microCT)	Total length
Gergi et al. [29]	VTome (Wunstorf, Germany)	Isotropic resolution of 20 μm 140 kV 200 μA	MicroView (GE Pre-clinical Imaging, General Electric, London, UK)	IPL V5.06B; Scanco Medical	Total length 1/3 apical
Busquim et al. [30]	SkyScan 1172 (Bruker-microCT, Bruker, Aartselaar, Belgium)	Isotropic resolution of 11.88 μm 100 kV 100 μA	NRecon v.1.6.6.0 (Bruker micro-CT)	CTAn v.1.12.0.0 software (Bruker micro-CT)	Total length 1/3 coronal 1/3 middle 1/3 apical
Sant'anna Junior et al. [20]	SkyScan 1174v2 (Bruker-microCT, Kontich, Belgium)	19 μm voxel size 50 kV 800 μA	NRecon v.1.6.3 (Bruker-microCT)	CTAn v.1.12 software (Bruker-microCT)	1/3 coronal 1/3 middle 1/3 apical
Zeng et al. [22]	KKS-MCT-Sharp Guangzhou Branch Sheng Kai Medical Technology Co., Ltd.	Resolution 20 μm 70 kV 40 W	MeVisLab software (MEVIS, Bremen, Alemanha)	–	1mm 2mm 3mm 5mm
Zhao et al. [31]	μCT -50 (Scanco Medical, Bassersdorf, Switzerland)	Resolution of 30 μm	ImageJ 1.41 software (National Institutes of Health, Bethesda, MD	VGStudio Max version 2.0.0 (Volume Graphics, Heidelberg, Germany)	Total length
Hwang et al. [11]	Skyscan 1172 (Skyscan b.v.b.a., Aartselaar, Belgium)	Isotropic resolution of 16 μm 100 kV 100 Ma	_	CTAn v 1.12 (Bruker micro-CT, Kontich, Belgium)	Total length
Baek et al. [32]	Skyscan 1172 (Skyscan, Aartselaar, Belgium)	Isotropic resolution of 19.7 μm 100 kV 100 μA	N-Recon (Skyscan)	CTan (Skyscan)	Total length
Siqueira et al. [23]	SkyScan 1174v2 (Bruker-microCT, Kontich, Belgium)	Isotropic resolution of 16.7 μm	NRecon v.1.6.3 (Bruker-microCT)	CTAn v.1.12 software (Bruker-microCT)	Total length
Versiani et al. [36]	SkyScan 1174v2 (Bruker-microCT, Kontich, Belgium)	50 kV 800 μA	NRecon v.1.6.3 (Bruker-microCT)	CTAn v.1.12 software (Bruker-microCT)	1/3 coronal 1/3 middle 1/3 apical Total length
Stern et al. [33]	GE Locus SP microCT scanner (GE Pre-clinical Imaging, London, ON, Canada)	80 kVp 80 μA	MicroView (GE Pre-clinical Imaging)	–	Total length

(continued)

Table 4. Continued.

	Equipment		Software		
Study (year)	Model	Settings	Software to reconstruction	Software to analysis	Canal length analysed
Paque, Zehnder e De Deus [34]	μCT 40 Scanco Medical (Brüttisellen, Switzerland)	Isotropic resolution of 20 μm 70 kV 114 μA	–	IPL (Scanco Medical)	Total length 1/3 apical
You et al. [35]	SkyScan 1172 (SkyScan b.v.b.a., Aartselaar, Belgium)	Isotropic resolution of 16 μm 100 kV 100 μA	–	–	Total length

apical third, where Reciproc showed less unprepared area [30]. Another showed reciprocating system evidencing lesser unprepared surface area than the rotary system [38]. Eleven studies did not evaluate unprepared surface area [3,11,20,25–28,32,33,35,36].

Discussion

Currently, several engine-driven NiTi systems have been launched in the market, with files having different designs and kinematics to improve canal shape. The premise of disinfection of the root canal is dependent on the removal of microorganisms and infected dentin through chemical-mechanical instrumentation [39]. Therefore, it is necessary to clean and enlarge the root canal, avoiding the maintenance of areas that the instrument does not touch, thus prohibiting the permeation of infected tissue [40]. Therefore, it is important to investigate shaping ability in order to understand how these technological changes in instrumentation systems affect performance [41]. Several interrelated parameters define the cutting ability of root canal instruments, including cross-sectional area and design, helical and rake angle, surface treatment, metallurgical properties and movement kinematics [14,41,42]. Although various studies compare reciprocating and rotary techniques in root canal instrumentation, it is not yet known which technique is most effective in regard to volume changes, increased surface area and fewer unprepared areas remaining. Based on this, the aim of this systematic review was to carry out a careful search of articles with greater scientific evidence in order to assess the kinematics of engine-driven instruments that affect root canal shape as assessed by micro-computed tomography.

To assess the risk of bias, according to the quality assessment, all studies obtaining between 5 and 7 points were considered to be of 'moderate methodological quality'. Regarding randomization in quality assessment, one article did not randomize samples [20] and four articles showed how the randomization was accomplished [24,25,27,36]. One of the studies used oval-shaped contralateral premolars, which were previously analysed in micro-computed tomography in order to certify the similarity of the samples. However, the pairs of samples (contralateral premolar) were randomized [21]. Randomization is important to ensure that the allocation to different groups was made in the same way for each sample, avoiding the risk of distribution affecting the outcome. Another important domain of quality assessment is the blindness of the study and the concealed allocation of treatment groups. These domains do not apply to all studies because the included studies are *in vitro* and performed by different engine-driven instrumentation systems. This makes it impossible for the operator not to know which system was used. Additionally, only two studies evaluated the results with blinding analysers [3,31] which reduced the risk of bias. Another domain in quality assessment is whether the groups were comparable upon entry. All of the included studies performed that analysis.

When selecting the tooth based on its internal anatomy, a better distribution of the samples between the groups is expected. This is indispensable to the variation of the root canal geometry, so the instrumentation does not affect the analysis of the results [25]. According to the quality assessment used, none of the included studies was considered to be of high methodological quality. An ideal study should follow specific parameters in order to have a representative sample: sample calculation, randomization of the samples, analysis and comparison of the samples before and after the procedures; uniformity of procedures outside of the comparison; a reproducible methodology; a statement that only one investigator performed the experiments or that investigators were calibrated; results measured in the same reducible manner; results read by a blind researcher; and performance of the correct statistical analysis.

The volumetric changes become a variable to evaluate the effect of root canal preparation. Canal instrumentation results in an increase of total volume due to the elimination of infected dentin [17]. This increase is determined in part by the diameter and taper of the endodontic instrument [27]. All included studies in this review sought to use the same final diameter of the instruments, though each system has different conicities. However, a previous study showed that taper size may not be a crucial factor for the amount of area touched during instrumentation [24].

Regarding the studies that analysed the volumetric changes, the majority did not show statistically significant difference. Among them, eight studies showed the reciprocating movement slightly better than the rotational movement [3,11,23,25,27,28,34,35], three showed a slightly better rotational movement [21,32,33]. These data show that both kinematics cause volume increase in the root canal. However, those studies showed statistically significant difference in one of its parameters analysed three showed that the reciprocating movement obtained a greater increase in volume using reciprocating systems [22,30,37]. This result is probably related to its high cutting efficiency due to its

Table 5. Morphometric data of micro-computed tomography.

	Volume (mm^3)				Surface area (mm^2)				Unprepared surface area (%)			
Study (year)	Cervical third	Middle third	Apical third	Total length	Cervical third	Middle third	Apical third	Total length	Cervical third	Middle third	Apical third	Total length
Espir et al. [37]	NS $RC_{21}>RO>RC_1$	NS/S* $RC_2>RO>RC_1$ *S between RC_1 to RC_2	NS $RC_2>RC_1>RO$	NS/S* $RC_2>RC_1>RO$ *S between RC_2 to/RC_1/RO	–	–	–	–	NS/S* $RC_1<RO<RC_2$ *S between RC_1 to RC_2	NS $RC_1<RO<RC_2$	NS $RC_1<RO<RC_2$	NS/S* $RC_1<RO<RC_2$ *S between RC_1 to RC_2
Zuolo et al. [38]	–	–	–	–	–	–	–	–	–	–	–	NS/S* $IO<RC<RO_1<RO_2$ *S between IO/RC/RO_1 to RO_2
Guimarães et al. [21]	–	NS RO > RC	NS RO > RC	–	–	NS RC > RO	NS RC > RO	–	–	S RO < RC	NS RO < RC	–
Zanesco et al. [27]	NS RC > RO > MN	NS MN > RC > RO	NS RC > MN > RO	NS RC > MN > RO	–	–	–	–	–	–	–	–
Keles et al. [26]	–	–	–	NM RC > RO > IO	–	–	–	NM IO > RC > RO	–	–	–	–
Santa-Rosa et al. [3]	–	–	–	NS RC > RO	–	–	–	NS RC > RO	–	–	–	–
Marceliano-Alves et al. [25]	–	–	–	NS $RC_1>RO_3>RC_3>RO_4$	–	–	–	NS $RC_1>RC_3>RO_4>RO_3$	–	–	–	–
De Deus et al. [24]	–	–	–	–	–	–	–	–	–	–	–	NS $RC_1<RO<RO_3$
Ahmetoglu et al. [28]	–	–	–	NS RC > IO > RO	–	–	–	NS RC > IO > RO	–	–	–	–
Gergi et al.[29]	–	–	–	–	–	–	S RC > RO	S RC > RO	–	–	NS RC < RO	NS RC < RO
Busquim et al. [30]	NS RC > RO	NS RO > RC	S RC > RO	S RC > RO	–	–	–	–	S RO < RC	S RO < RC	S RC < RO	S RO < RC
Sant'anna Junior et al. [20]	–	–	NS	–	–	–	–	–	–	–	–	–
Zeng et al. [22]	–	–	S RC > RO	NS	–	–	S RC > RO	NS	–	–	–	NS
Zhao et al. [31]	–	–	–	NS	–	–	–	NS	–	–	–	NS RO < RC
Hwang et al. [11]	–	–	–	NS RC > RO	–	–	–	–	–	–	–	–
Baek et al. [32]	–	–	–	NS RO > RC	–	–	–	NS RO > RC	–	–	–	–
Siqueira et al. [23]	–	–	–	NS RC > IO > RO	–	–	–	NS RC > RO > IO	–	–	–	NS RC < RO < IO
									–	–	–	–

(*continued*)

Table 5. Continued.

Study (year)	Volume (mm^3)				Surface area (mm^2)				Unprepared surface area (%)			
	Cervical third	Middle third	Apical third	Total length	Cervical third	Middle third	Apical third	Total length	Cervical third	Middle third	Apical third	Total length
Versiani et al. [36]	NS/S* RO > RC_3> RC_1>IO *– between RO/ RC_3/ RC_1 to IO	NS/S* RC_3>RO > RC_1>IO *S between RC_3/RO to RC to IO	NS/S* RC_3>RO > RC_1>IO *S between RC_3/RO to RC to IO	NS/S* RO > RC_3> RC_1>IO *S between RO/ RC_3 to RC_1 to IO	NS/S* RC_3>RO > RC_1>IO *S between RC_3/RO/ RC to IO	NS/S* RC_3>RO > RC_1>IO *S between RC_3/RO to RC to IO	NS/S* RC_3>RO > RC_1>IO *S between RC_3/RO to RC to IO	NS/S* RC_3>RO > RC_1>IO *S between RC_3/RO to RC to IO				
Stern et al. [33]	–	–	–	NS RO > RC	–	–	–	–	–	–	–	–
Paque, Zehnder e De Deus [34]	–	–	NS RC > RO	NS RC > RO	–	–	–	–	–	–	NS RC < RO	NS RC < RO
You et al. [35]	–	–	–	NS RC > RO	–	–	–	NS RC > RO	–	–	–	–

NS: Not-significant; S: Significant; NM: Not-mentioned; RC: Reciprocating; RO: Rotary; IO: In-and-out movement; MN: Manual; RC_1: Reciproc; RC_2 Unicone; RC_3: WaveOne; RO_1: TRUShape; RO_2: BioRace; RO_3: Twisted File; RO_4 Hyflex CM.

S-shaped cross-section and positive cutting angle, which was proven in a previous study [43]. Volumetric changes are important in view of a previous study which showed that the bacteria can penetrate the dentin tubules up to 150 μm [44]. The enlargement of the root canal allows a greater penetration of the irrigant, particularly in the apical area [45], allowing reflux of the solution and debris. If the reflux does not occur correctly the dentin residues are accumulated and compacted in the apical area [46], which compromises cleaning.

Surface area increase is also linked to dentin removal during instrumentation. Eight studies did not show statistically significant difference. While four of the studies reveal the reciprocating movement as slightly more effective than the rotary one [3,21,23,35], one study showed the slightly better rotational movement [25]. Those studies showed statistically significant difference in one of the analysed parameters. One study revealed that the reciprocating movement obtained greater increase in surface area using Reciproc [29]; however, one study showed rotary system obtained statistically significant difference with a greater increase in surface area, except in the cervical third where there was no statistically significant difference [36]. In short, both kinematics caused changes on the surface area. Over-instrumentation of the root canal could result in excessive wear of the root [29] leading to the formation of dentinal micro-cracks which could lead to root fractures [47]. However, the increase of the surface area, as well as in the increase of volume, to obtain a larger area of contact with the irrigant substance facilitates more effective cleaning [45]. This greater contact of the irrigant with the inner surface of the root canal achieves greater penetration into the dentinal tubules. This fact is important because bacteria can form biofilm and colonize the unprepared areas. They can also remain in the dentinal tubules and produce a persistent infection and apical periodontitis [48].

The search for instruments to clean the full length of root canals is important because tissue remnants can affect the quality of canal filling and can serve as a substrate for bacterial growth in case of secondary infection in unprepared areas [38,49]. In this review only four studies showed statistically significant difference in one of its parameters analysed. In one of these studies, the TRUShape rotary system revealed a lesser amount of unprepared surface area than reciprocating movement using Reciproc [21]. The TRUShape files have an innovative three-dimensional design which, according to the manufacturer, can produce a line/curve when operated in the root canal, allowing greater contact of the instrument with the walls [50].

Another study evidenced a lesser amount of unprepared surface area with the rotary system BioRaCe than reciprocating system Reciproc, unless in the apical third where BioRaCe showed a greater amount of unprepared area [30]. The anatomical complexity of the root canals, such as extremely curved or oval cross-section canals, is a challenge for root instrumentation, with a tendency to maintain unprepared areas. Adaptations in the use of engine-driven systems can be made to reach these areas, such as a slight brushing movement in the surrounding walls [21]; however, this extension of the preparation can lead to perforations or 'zips' in the apical danger zone [51].

One of the limitations of this review is that it includes laboratory-based studies with *in vitro* samples. This carries an important confounding factor, which is the anatomy of the root canal system under investigation. This can generate results showing the diversity of original canal anatomy instead of the variable of interest [52]. However, *in vitro,* well-controlled studies with extracted human teeth are highly indicated for simulation and analysis of clinical efficacy in the morphological changes by the different kinematics [3,36]. Studies comparing the effect of instrumentation use several methods such as cone-beam computed tomography [14] or a double-digital standardized radiographic technique [16]. Thus, the micro-computed tomography scan was performed to analyse the changes within the root canal. Its accuracy and reproducibility were previously verified [17] and this tool has been widely used in laboratory-based studies in endodontics [29,33]. It also allows a three-dimensional analysis before and after instrumentation without destroying the sample.

Of the included studies, 12 analysed the entire length of the root canals [3,11,23–26,28,31–33,35,38]. Another three analysed the combined length of each third (apical, middle and cervical) [30,36,37], and yet another two studies evaluated each third separately [20,27], while another two evaluated the entire extension of the canal and the apical third. Another two of the studies evaluated specific thirds measured in *mm* [21,22]. A meta-analysis was impossible in this review because non-standardization of methodologies was found with analysis of distinct parameters in different areas of the root canal of different sample selections. To avoid the possibility of not finding potentially eligible studies, the search was carried out carefully, in reliable databases, in the grey literature and manually in the list of references of the selected studies. The keywords and MESH terms, or synonyms searched were based on articles in the area of study. Parameters were followed to decrease the possibility of bias in this review.

The majority of the included studies did not show a significant difference in the assessments of volume increase, surface area increase and unprepared area. According to the data from included studies in this systematic review, both the rotational and reciprocating kinematics provide changes in volume and surface area and leave unprepared areas in the root canal.

Disclosure statement

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

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